Longitudinal momentum distribution analyses close to the neutron drip line, near N = 8 and N = 20

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Introduction

During the past few decades, structures of exotic nuclei have been extensively studied through a number of experiments using radioactive beams. Apart from the interesting phenomenon of 'halo formation' in light drip line nuclei, one has seen evidences of breakdown of 'magic numbers' away from the valley of stability, in some cases.

Another interesting observation in recent times is the interpretation of a large interaction cross section for ^{31}Ne and the Coulomb breakup of ^{31}Ne in terms of deformation [1]. This is all the more interesting because there seems to be indications that ^{31}Ne, which has a low one-neutron separation energy (S_{-n}) [2], is speculated to be a one-neutron halo nucleus.

This is a very new and exciting development which has expanded the field of light exotic nuclei to the deformed medium mass region. Naturally, rigorous theoretical investigation of this area is of great importance currently and in the near future.

In this contribution we will study the effect of 'magicity', near neutron number N = 8 (Be region) and N = 20 (Al region) as one approaches the neutron drip-line, *within the same theory*. The specific reaction observable that we will choose will be the Longitudinal momentum distribution (LMD) of the charged fragment, in the Coulomb dissociation of the projectile in the field of a heavy target. Indeed it has been well known that the full width at half maxima (FWHM) of the LMD for the breakup of well known halo nuclei like ^{11}Be and ^{19}C is around 44 MeV/c, while that for stabler isotopes it is around over 140 MeV/c. Our contention is that for the case of magic numbers a larger FWHM should be seen than the neighbouring isotopes.

Formalism

Our fully quantum mechanical Coulomb dissociation theory [3] is formulated within the post-form finite range distorted wave Born approximation. Only the full ground state wave function of the projectile enters in this theory as input, which is calculated using the Lagrange-mesh method [4]. This is an approximate variational calculation method, with the simplicity of a mesh calculation because of the use of a consistent Gauss quadrature.

In this method a variational approximation of the wave function is given by an expansion in the Lagrange basis,

$$\psi(x) = \sum_{i=1}^{N} c_i f_i(x) \tag{1}$$

The coefficients c_i have a simple physical interpretation, $c_i = \lambda_i^{1/2}\psi(x_i)$, where the mesh points x_i and weights λ_i define an approximate quadrature rule of the Gauss type.

Using Eq.(1), the one dimensional Schrödinger equation reduces to a matrix equation:

$$\sum_{j=1}^{N}(T_{ij} + V_{ij})c_j = Ec_i, \tag{2}$$

where T_{ij} and $V_{i,j}$ are matrix elements of kinetic and potential energy respectively. Essentially, one solves the eigenvalue equation, above, and gets the eigenenergies for a given potential (an Woods-Saxon in our case). The corresponding eigenfunctions are found by plugging the coefficients c_j in Eq. (1), given

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that the expansion basis, $f_i(x)$ (Lagrange-Laguerre) is known. Of course, to obtain a realistic ground state wave function of the projectile, the depth of the Woods-Saxon is adjusted to reproduce the binding energy. The radius and diffuseness parameters are taken as $r_0 = 1.15$ fm and $a_0 = 0.5$ fm, respectively. To the best of our knowledge, the application of the Lagrange mesh technique wave function to finite range DWBA is being done for the first time.

Results and discussions

We have calculated LMD of the core in the Coulomb breakup of ^{10,11,12,13}Be and ^{33,34,35}Al on Au target at beam energy of 100 MeV/u.

For the case of Be isotopes the FWHM of the LMD is small ($\approx$ 44 MeV/c) for ^{12}Be and ^{10}Be (see Table I), which are obtained from the breakup of ^{13}Be and ^{11}Be respectively. It is interesting to note that the maximum width is obtained for N = 6 and not for N = 8 (the usual magic number). This is indeed a comment on the breakdown of magicity for N = 8 near the drip-line.

Our results for ^{13}Be are also important, as only two energy levels are known ($1/2^-$ and $5/2^+$) [5], which are resonance states with some uncertainity in their positions. So it is not surprising that it has a small FWHM (given a small S_{-n}) which seems to mimic the halo case of ^{11}Be.

TABLE I: LMD in the Coulomb breakup of Be isotopes on Au at 100 MeV/u beam energy.

Projectile	N	single particle state	S_{-n} (MeV)	FWHM (MeV/c)
^{13}Be	9	^{12}Be$(1/2^-)\otimes 0p_{1/2}\nu$	0.510	44.85
^{12}Be	8	^{11}Be$(1/2^+)\otimes 1s_{1/2}\nu$	3.169	93.99
^{11}Be	7	^{10}Be$(0^+)\otimes 1s_{1/2}\nu$	0.501	44.41
^{10}Be	6	^{9}Be$(3/2^-)\otimes 0p_{3/2}\nu$	6.812	130.28

For the case of Al isotopes (Table II), we consider the different possible single particle configuration given in Ref. [6], where LMD is calculated at 900 MeV/u beam energy. Our calculations, on the other hand are at 100 MeV/u to keep it in conjunction with the Be isotopes; where higher energy data are not available. The FWHM calculated for LMD of ^{32}Al, ^{33}Al and ^{34}Al is large ($>$ 80 MeV/c) for all the different configuration considered in each case (see Table II). Interestingly we do not see any sharp rise in FWHM for N = 20 as compared to N = 21, 22.

TABLE II: LMD in the Coulomb breakup of Al isotopes on Au at 100 MeV/u beam energy.

Projectile	N	single particle state	S_{-n} (MeV)	FWHM (MeV/c)
^{33}Al	20	^{32}Al$(1^+)\otimes 0d_{5/2}\nu$	5.54	111.67
		^{32}Al$(2^+)\otimes 1s_{1/2}\nu$	6.27	103.90
^{34}Al	21	^{33}Al$(5/2^+)\otimes 1p_{3/2}\nu$	2.47	79.33
		^{33}Al$(7/2^-)\otimes 1s_{1/2}\nu$	6.18	101.74
		^{33}Al$(7/2^-)\otimes 0d_{5/2}\nu$	6.18	112.09
		^{33}Al$(5/2^+)\otimes 0f_{7/2}\nu$	2.47	88.52
^{35}Al	22	^{34}Al$(4^-)\otimes 1p_{3/2}\nu$	5.27	96.07
		^{34}Al$(2^+)\otimes 1s_{1/2}\nu$	6.07	104.62
		^{34}Al$(1^+)\otimes 0d_{5/2}\nu$	5.47	112.66
		^{34}Al$(4^-)\otimes 0f_{7/2}\nu$	5.27	113.24

However, to have more confirmed results, we also intend to repeat our calculations with a 'deformed Woods-Saxon' potential and therefore will be able to study the effect of 'deformation' on the widths of the LMD in the breakup of Al isotopes and also possibly on ^{31}Ne. These calculations are in progress.

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References

[1] T. Nakamura *et al.*, Phys. Rev. Lett. **103**, 262501 (2009); Y. Urata, K. Hagino and H. Sagawa arXiv: 1205.2962[nucl-th].
[2] M. Takechi *et al.*, Phys. Lett. B **707**, 357 (2012).
[3] R. Chatterjee, P. Banerjee and R. Shyam, Nucl. Phys. A **675**, 477, (2000).
[4] Daniel Baye, phys. stat. sol. (b) **243**, No. 5, 1095 (2006).
[5] Yoshiko Kanada-En'yo, Phys. Rev. C **85**, 044320 (2012); *nndc.bnl.gov/nudat2.*
[6] C. Nociforo *et al.*, Phys. Rev. C **85**, 044312 (2012).