Semi-Analytical approach to Coulomb breakup reactions

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Introduction

Coulomb dissociation of exotic nuclei has been investigated by several authors with different theoretical approaches and approximations. However a consistent fully quantum mechanical approach with three charged particles in the final state is still under investigation. The application of such a theory to radiative capture reactions (proton, neutron or alpha capture), as an indirect method in astrophysics will be a welcome step.

In this context we present a theoretical model to describe the pure Coulomb breakup of one neutron and proton exotic nuclei within the framework of the finite range distorted-wave approximation (FRDWBA). This method is based on plane-wave expansion [1, 2] of the distorted waves, which allow a separation of coordinates and, in essence, replaces integrals with sums over plane-wave state.

We present our first test results on the breakup of ^{11}Be on Au at 41 MeV/nucleon.

Formalism

We consider the elastic breakup of a two body composite projectile a in the Coulomb field of target t. Projectile a breaks up into fragments b (charged) and c (charged/uncharged). $a + t \rightarrow b + c + t$

The triple differential cross section for the reaction is given by

$$\frac{d^3\sigma}{dE_b d\Omega_b d\Omega_c} = \frac{2\pi}{\hbar v_a}\rho(E_b, \Omega_b, \Omega_c)\sum_{lm}|\beta_{lm}|^2, \quad (1)$$

where v_a is the a-t relative velocity in the entrance channel and $\rho(E_b, \Omega_b, \Omega_c)$ the phase space factor appropriate to the three-body final state. β_{lm} is the reduced amplitude in post form of finite range distorted wave Born approximation, given by

$$\hat{l}\beta_{lm}(\mathbf{q}_b, \mathbf{q}_c; \mathbf{q}_a) = \iint d\mathbf{r}_1 d\mathbf{r}_i \chi_b^{(-)*}(\mathbf{q}_b, \mathbf{r}) \chi_c^{(-)*}(\mathbf{q}_c, \mathbf{r}_c) V_{bc}(\mathbf{r}_1)\phi_a^{lm}(\mathbf{r}_1)\chi_a^{(+)*}(\mathbf{q}_a, \mathbf{r}_i) \quad (2)$$

where, $\mathbf{q}_b$, $\mathbf{q}_c$ and $\mathbf{q}_a$ are the wave vectors of b, c, and a corresponding to Jacobi vectors $\mathbf{r}$, $\mathbf{r}_c$ and $\mathbf{r}_1$, respectively. V_{bc} is the interaction between b and c. $\phi_a^{lm}(\mathbf{r}_1)$ is the ground state wave function of the projectile with relative orbital angular momentum state l and projection m. $\chi^{(-)}$'s are the distorted waves for relative motions of b and c with respect to t and the center of mass(c.m.) of the b-t system, respectively, with ingoing wave boundary condition. $\chi^{(+)}(q_a, r_i)$ is the distorted wave for the scattering of the c.m. of projectile a with respect to the target with outgoing wave boundary condition.

To solve β_{lm} we use the plane wave expansion [1, 2] of the distorted wave $\chi^{(-)*}(\mathbf{q}_b, \mathbf{r})$. The plane wave expansion is equivalent to an expansion in spherical Bessel function for each partial wave. This allow a separation of co-ordinates and, in effect, replaces integrals with sums over plane wave states. Preliminary calculations in this method reveal that the breakup transition amplitude can still be broken into two parts– the structure part and dynamics part. Furthermore the dynamics part can be done analytically which will go a long way in preserving the analyticity of our method.

In case the breakup fragment c is uncharged; making the local momentum approximation (LMA) [3], can be avoided.

In Eq.(2) we use a Coulomb distorted wave for χ_a^+, a plane wave for χ_c^+ (for the neutron)

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and expand χ_b^+ (for the charged core) in plane waves. The reduced amplitude then becomes,

$$\beta_{lm} = \frac{1}{(2l+1)} e^{(-\frac{\pi\eta_a}{2})}\Gamma(1+i\eta_a)\sum_L (\frac{2L+1}{4\pi}) \times \sum_n a_n^{(L)} \int d\hat{\mathbf{k_n}} P_L(-\hat{\mathbf{q_b}}.\hat{\mathbf{k_n}}) I_d I_f (3)$$

Here I_d is Bremsstrahlung Integral [3] and contains the information about the dynamics of reaction. I_f is the structure part. $a_n^{(L)}$s are the expansion coefficients which depend upon number of partial waves L, used in the expansion.

$$a_n^{(L)} = \sum_m M_{nm}^{(L)} b_m^{(L)}; \quad M^L = (O^L)^{-1} \quad (4)$$

$$O_{mn}^{(L)} = \int_0^{rmax} r^2 dr j_L(k_m r) j_L(k_n r) \quad (5)$$

$$b_m^{(L)} = k^{-1}\int_0^{rmax} r dr j_L(k_m r)\chi_L(q_b, r) \quad (6)$$

In case of proton exotic nuclei the valence particle c is charged. To solve β_{lm} we use Coulomb distorted waves for χ_a^+, χ_b^+ and expand χ_c^+ in plane waves.

$$\beta_{lm} = \frac{1}{(2l+1)} e^{-\frac{\pi(\eta_a+\eta_b)}{2}}\Gamma(1+i\eta_a)\Gamma(1+i\eta_b) \times \sum_L (\frac{2L+1}{4\pi}) \sum_n a_n^{(L)} \int d\hat{\mathbf{k_n}} P_L(-\hat{\mathbf{q_c}}.\hat{\mathbf{k_n}}) I_D I_F (7)$$

Here I_D and I_F are the dynamics and structure part of the reaction. The dynamics part I_D can be evaluated analytically.

Result and discussion

Preliminary triple differential cross sections from our calculation for the Coulomb breakup of ^{11}Be on Au at beam energy 41 MeV/nucleon are presented in Fig. 1. These calculations are done by taking L=20.

In Fig. 1, the solid and dotted lines are calculations without and with the LMA, respectively. The peak position and the magnitude of the peak seems to be similar in both calculations. However a larger width of the curve for the case where we have been able to avoid the LMA, suggests that the total cross section may be a larger than the LMA case, a feature we will be testing in our future calculations.

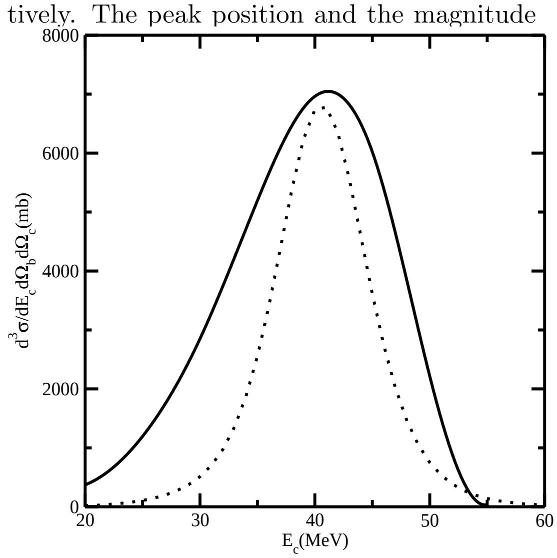

FIG. 1: Triple differential cross section for the breakup of ^{11}Be on Au target at beam energy 41 MeV/nucleon calculated (a) using plane wave expansion (solid line) and (b) using Local momentum approximation (dotted line).

Acknowledgments

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References

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