Semi-analytical approaches in the Coulomb breakup of loosely bound nuclei

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Coulomb breakup reactions have been an important tool in unraveling the structure of the exotic systems. This thesis concerns the application of the theory of elastic Coulomb breakup of a projectile in the field of a target nucleus under the framework of finite range distorted wave Born approximation [1], to problems related to the structure and reactions of nuclei away from the line of stability. The theory includes the electromagnetic interaction between the fragments and the target to all orders. Furthermore the breakup contribution from the entire non-resonant continuum (corresponding to all multipoles and relative orbital angular momentum between the fragments) are also accounted for. The uncertainties associated with multipole strength distributions in many other formalisms are also avoided as one needs only the ground state wave function of the projectile as an input. The analytic nature of this theory stems from the fact that pure Coulomb wave functions are used in the calculation and that the dynamics can be analytically evaluated.

This thesis is divided into two parts. In the first part, we studied the breakdown of $N = 8$ magic number near the neutron drip line by calculating the PMD of the charged fragment in the Coulomb breakup of various Be isotopes ($N = 5, 6, 7, 8, 9$) on Au target at 100 MeV/u, using the post form finite range DWBA theory and the Adiabatic method. Indeed it has been well known that the full width at half maxima (FWHM) of the PMD for the breakup of well known halo nuclei like ^{11}Be and ^{19}C is around 44 MeV/c, while that for the stable 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 neighboring isotopes. However, among the Be isotopes ($N = 5, 6, 7, 8, 9$), ^{12}Be ($N = 8$) does not have the largest FWHM, thereby confirming the breakdown of ($N = 8$) magic number, near the neutron drip line.

We also extended our elastic Coulomb breakup theory to include 'deformation' effects in the structure part [2] and hence the application of our fully finite range quantum mechanical theory of Coulomb breakup to medium mass nuclei. We applied our theory to the pure Coulomb breakup of ^{31}Ne on heavy targets and computed several reaction observables. We calculated the one-neutron removal cross section as a function of the one-neutron separation energy (S_n) and also as a function of the quadrupole deformation parameter (β_2) in the breakup of ^{31}Ne on Pb target at 234 MeV/u beam energy, for both the reported ground state spin parities of ^{31}Ne ($J^\pi = 3/2^-, 1/2^+$). On comparison with the available data [3], we are able to bring down the uncertainties in the reported separation energies of ^{31}Ne and also put a limit on β_2.

We calculated the relative energy spectra in the pure Coulomb breakup of ^{31}Ne on a Pb target at 234 MeV/u beam energy and simultaneously as a function of β_2, for the ^{30}Ne$(0^+) \otimes 2p_{3/2}\nu$ configuration of ^{31}Ne with $S_n = 0.29$ MeV. The peak position is seen to be sensitive to the projectile configuration and the peak height depends on the quadrupole deformation parameter. The PMD of the charged ^{30}Ne fragment in the Coulomb breakup of ^{31}Ne on Au target at 234 MeV/u beam was also calculated. It is interesting to note that the effects of deformation would be pronounced near the peaks, which corresponds to the beam velocity momentum. Finally, we calculated the neutron

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energy-angular distribution and the neutron angular distribution for the Coulomb breakup of ^{31}Ne on Au target at 234 MeV/u beam energy. The results seem to indicate that the effect of deformation would be visible essentially at small scattering angles.

Apart from studying the breakup of exotic drip line nuclei, another interesting application of breakup theory is in nuclear astrophysics, especially in using Coulomb dissociation as an indirect method in astrophysics. The Coulomb dissociation cross section can be related to the photodisintegration cross section of projectile, which in turn, can be directly related to the radiative capture cross section by the principle of detailed balance. Thus by measuring the Coulomb dissociation cross section, which can be done at higher energies and has larger cross section, one can relate it to the relevant radiative capture cross section, which is of astrophysical interest. We have calculated the ^{14}C$(n, \gamma)^{15}$C radiative capture cross section and the associated reaction rate by studying the Coulomb dissociation of ^{15}C on Pb at 68 MeV/u [4]. We calculated the relative energy spectra in the breakup of ^{15}C on Pb at 68 MeV/u and discussed it in comparison with the available data [5].

The neutron capture cross section is then calculated from the photodisintegration cross section of ^{15}C. Comparison with available data from both the direct [6] and indirect [5] measurements is done for a wide energy range. While our calculation is in good agreement with both data, nevertheless we wish to point out that at $E_{c.m} = 0.5$ MeV, there are some disagreements between the direct measurements and those extracted from the Coulomb dissociation data. Since this is the region where the capture cross section is expected to be maximum, it would be useful to experimentally investigate this region in more details.

We also calculated the ^{14}C$(n, \gamma)^{15}$C reaction rate per mole as a function of temperature. They are in good agreement with that evaluated from a direct measurement of the capture cross section especially for $T_9 < 1$. Our results also show that ^{14}C$(n, \gamma)^{15}$C reaction will dominate over ^{14}C$(p, \gamma)^{15}$N for temperature $T_9 < 1.4$.

Finally in second part of the thesis, we have studied the problem of Coulomb breakup with three charged particles in the final channel [7], in a post form reaction theory within the framework of the finite range distorted wave Born approximation using the plane wave expansion of Coulomb distorted waves. Our calculations reveal that the breakup amplitude can be factorized into two parts - a structure part and a dynamics part, which in turn can be expressed as a sum of a series of Bremsstrahlung integrals. Given the analyticity of the method, applications of this theory to radiative capture reactions (especially involving charged particles, like proton and alpha capture) as an indirect method in astrophysics can be considered. It can also serve as a benchmark test for theories of breakup reactions involving charged halo nuclei.

We have also calculated the breakup amplitude with two charged particles in the final channel, using our theory, and have shown that it can be put on a firmer theoretical basis without invoking the local momentum approximation [1].

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