Light and Heavy Cluster Knockout Reactions

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Knockout reactions are direct reactions where the reaction time is small enough such that there is hardly any time for rearrangement, except for the rearrangement caused by the incident projectile. In knockout reactions simple kinematic energy momentum conservation considerations, along with the assumption that the struck portion of the target behaves as if it were free, lead to the extraction of the momentum distribution of the knocked out cluster from the target before it was knocked out. Conventional analysis of the knockout of α-cluster by proton and α projectiles with the distorted wave impulse approximation using zero range interaction (ZR-DWIA) has resulted in large inconsistencies. While the absolute cross section predictions for the (p, pα) reactions are close to the experimental data the corresponding comparison for the (α,2α) reactions lead to almost two orders of magnitude lower predictions. Exceptions to these observations however, were seen for the (α,2α) reactions on ^9Be and ^{12}C. Similar inconsistencies were detected in the case of (p, pα), (p, pd),(α, αd), (α, α ^3He), (α, α ^3H) etc. on light and medium mass nuclei.

The small predictions of absolute cross sections and hence large α-cluster spectroscopic factors from (α, 2α) reactions up to 140 MeV were ascribed to induced α-clustering, simulated by using the large bound state potential radius or in terms of reduced optical distortion effects. These adhoc prescriptions can not however account for the 200 MeV data. In the conventional ZR-DWIA treatment of the knockout transition matrix element, the factorization of the knockout vertex contribution is built in. The factorization can arise either from the zero range nature of the knockout vertex transition operator or from the optical distortion free scattering states.

In order to remove these inconsistencies in conventional ZR-DWIA reactions the Finite Range Distorted Wave Impulse Approximation (FR-DWIA) theory have been formulated. The FR-DWIA theory incorporates L-dependent t-matrix effective interaction. Large anomalies observed in zero range (ZR)-distorted wave impulse approximation (DWIA) analysis of these reactions may be understood in terms of the finite size of the α-α knockout vertex. This study indicated a large sensitivity of the cluster knockout reaction especially to the short distance behaviour of the knockout vertex. Huge differences were noticed between the Finite Range (FR)-DWIA results from the fully attractive α-α interaction and the α-α effective interaction with a short-medium range repulsive core.

Based on this finding, a heavy cluster knockout reaction, $^{16}O(^{12}C, 2^{12}C)^4He$ has been conceptualized and executed for the first time so as to reveal the true short distance behaviour of the ^{12}C-^{12}C knockout vertex. The $^{16}O(^{12}C, 2^{12}C)^4He$ reaction was performed at Pelletron LINAC facility, Mumbai at 118.8 MeV. A conventional ZR-DWIA estimate of the present reaction was performed using the final state prescription for the off-shell effects. Corresponding to the experimental peak cross section value of $\sim$ 125 $\pm$50 $\mu b/Sr^2$ MeV, the conventional ZR-DWIA prescriptions provided a spectroscopic factor value of 268. The FR-DWIA calculation were performed for the (C, 2C) reactions using the totally attractive and attractive plus repulsive core of 3.65 fm C-C vertex resulting in a spectroscopic factor of 10 and 0.9 respectively. Reasonably consistent value of 0.9 confirm that the C-C interaction vertex potential has a repulsive core. It was found impossible to discriminate between these two kinds of ^{12}C-^{12}C interactions from

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the analysis of the ^{12}C-^{12}C elastic scattering alone,

After successfully describing the cluster structure of ^{16}O and ^{12}C, it was proposed to experimentally verify the the heavy cluster structure of light-medium mass nuclei such as ^{24}Mg in its ground state. For this the key feature of the theoretical heavy cluster models is that the nucleus is described in terms of two sub nuclei. For example the ^{24}Mg has been described in terms of ^{12}C+^{12}C and ^{16}O+^{8}Be structures. The heavy cluster structures of these nuclei is studied for their high lying excited states by inelastic scattering and transfer reactions as tools. On the other hand the α -cluster structure in ground state of ^{24}Mg has been studied with the knockout reactions using proton as well as the α beams.

The $^{24}Mg(^{12}C, 2^{12}C)^{12}C$ and $Mg(^{16}O, 2^{16}O)^{8}Be$ knockout reaction experiments were performed at the Pelletron LINAC facility at Mumbai at energies from 104 MeV to 127 MeV. Our aim is to extract the most probable intrinsic clustering in terms of $^{12}C_{(g.s.)}$ -$^{12}C_{(g.s.)}$ and $^{16}O_{(g.s.)}$ +$^{8}Be_{(g.s.)}$ in the ground state of $^{24}Mg_{(g.s.)}$ nucleus exclusively. Finite Range Distorted Wave Impulse Approximation (FR-DWIA) formalism is used for the analysis of these cluster knockout data. The FR-DWIA analyses were found to reproduce the absolute cross section observations well in contrast to the orders of magnitude small cross section on predictions from the prevalent and conventional Zero range calculations

The heavy cluster knockout experiments investigate the heavy cluster structure of $^{24}Mg_{(g.s.)}$ for the first time. We observed that $^{12}C_{(g.s.)}$ -$^{12}C_{(g.s.)}$ clustering to be negligible (Spectroscopic factor of 0.024) while witnessing $^{8}Be_{(g.s.)}$ - $^{16}O_{(g.s.)}$ clustering to be large in $^{24}Mg_{(g.s.)}$ (Spectroscopic factor of 0.4). These findings of the heavy cluster probabilities provide only partial support to the Harvey prescription, which was used to predict the behaviour of many of the sd-shell nuclei, which indicated the possibility of both the $^{12}C_{(g.s.)}$ -$^{12}C_{(g.s.)}$ and $^{8}Be_{(g.s.)}$ -$^{16}O_{(g.s.)}$ clustering to be present in $^{24}Mg_{(g.s.)}$. Our $^{8}Be_{(g.s.)}$ -$^{16}O_{(g.s.)}$ findings do not support even the alpha cluster model (ACM) which predicted that both $^{12}C_{(g.s.)}$ -$^{12}C_{(g.s.)}$ as well as $^{8}Be_{(g.s.)}$ -$^{16}O_{(g.s.)}$ clustering should not be present in the ground state of ^{24}Mg. The disagreement of our findings with most of the theoretical models may be sought in terms of different regions of sensitivity of our experiments, seen to be peaking in the surface regions. The present results in conjunction with the results of the fairly sharp energy dependence in α-α optical potentials observed in the FR-DWIA analyses of (α, 2α)knockout reactions calls for some scrutiny in the working of the double folding model.

So far the FR-DWIA analyses have been performed for co-planar symmetric configurations only like the $(\alpha, 2\alpha)$ $(C, 2C)$, $(O, 2O)$ reactions. However the FR-DWIA analysis of the co-planar non-symmetric reaction has been performed with different combination of projectile and struck particle for the first time, such as $^{16}O(p, pd)^{14}N^{*}$ at 101.3 MeV and $^{16}O(\alpha, \alpha d)^{14}N$ at 139.2 MeV quasi-free reaction using all through attractive(A) and an L-dependent attractive plus repulsive core(A+R) knockout vertex interaction. The spectroscopic factors obtained by the FR-DWIA calculations for the $^{16}O(\alpha, \alpha d)^{14}N$ reaction are 0.22 and 30.5 for the repulsive core(R+A) and the all-through attractive(A) α-d optical potentials respectively. The spectroscopic factors obtained by the FR-DWIA calculations for the $^{16}O(p, pd)^{14}N^{*}$ are 0.117 and 0.474 for the repulsive core(R+A) and the all-through attractive(A) p-d optical potentials respectively. These indicate a repulsive core even in the α-d interaction while p-d interaction does not show any such preference.

Our FR-DWIA prescription has enlarged the boundaries of the investigation to heavy cluster structure of light-medium mass nuclei and provided significant results. It is a tool to verify many heavy cluster models.