The 140 MeV $^{16}O(\alpha, \alpha d)^{14}N^{*}$ Deuteron Knockout Reaction and the E-Dependent α-^{14}N Repulsive Core Potential

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The d-knockout reaction, $^{16}O(\alpha, \alpha d)^{14}N^{*}$ [1]has been analyzed using Finite Range-Distorted Wave Impulse Approximation (FR-DWIA) formalism. Compared to the fully attractive α-d interaction for the knockout vertex the repulsive core knockout vertex α-d interaction with 1.5 fm repulsive core provided better shape and improved agreement with the structure theory. Therefore we will be mainly discussing the repulsive core results.

In the FR-DWIA formalism [2] the $\frac{d^3\sigma}{d\Omega_1 d\Omega_2 dE_1}$ for a knockout reaction $A(a_o, a_1 b_2)B$ expressed in terms of a FR transition amplitude, T_{FR}, a kinematic factor, F_{kin} and a spectroscopic factor, S_b^L is:

$$\frac{d^3\sigma}{d\Omega_1 d\Omega_2 dE_1} = F_{kin} \cdot S_b^L \cdot \sum_{\wedge} |T^{L\wedge}_{FR}(\vec{k}_f, \vec{k}_i)|^2.$$

Here the finite range t-matrix effective interaction, $T^{L\wedge}_{FR}(\vec{k}_f, \vec{k}_i)$ is evaluated using the α-d knockout interaction a the final state prescription value. For the initial state distorted waves $\chi_0(r_{aA})$, we have used the entrance channel single folding method. For the evaluation of the final state scattering state wave functions $\chi_1(r_{aB})$ and $\chi_2(r_{bB})$ appropriate optical potentials are taken from the literature at energies close to the required values.

In Fig.1 the FR-DWIA calculations (normalized at $\sim$ peak) with attractive α-d interaction(A) are compared with the experiment as well as with the ZR-DWIA calculations. This FR-DWIA distribution, with attractive α-d interaction, does not seem to match with the experimental shape, and disagrees even with the ZR-DWIA shape. Thus the finite range character is seen to have a profound impact on the shape. The $S_d^{L=0}$ obtained from the FR-DWIA with the attractive α-d is ~ 0.173, almost ten times smaller than

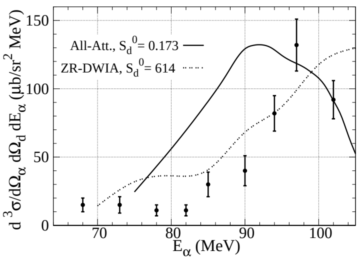

FIG. 1: FR-DWIA results (normalized to the peak experimental value), solid line(_______), with attractive (A) α-d knockout interaction, compared with the 139.2 MeV $^{16}O(\alpha, \alpha d)^{14}N^{*}_{(3.95)}$ experiment and ZR-DWIA results dashed line(- - -).

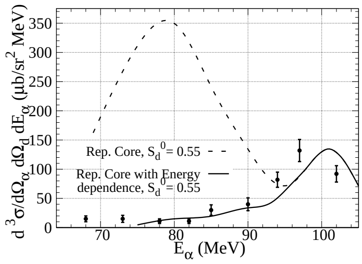

FIG. 2: FR-DWIA calculations (normalized) solid line, with 1.5 fm repulsive core knockout vertex α-d interaction compared with the experimental data. The dashed line(- - -) represent same FR-DWIA calculations without modification of the α-^{14}N distorting optical potentials for $E_\alpha \lesssim 96$ MeV while the solid line for $E_\alpha \lesssim 96$ MeV correspond to repulsive core and enhanced absorpton of the α-^{14}N interaction, increasing with decreasing $E_{\alpha\text{-}^{14}N}$ of Figs. 3 and 4.

structure theory estimate.

In Fig.2 the (normalized) FR-DWIA-results for the $(\alpha, \alpha d)$ reaction with a 1.5 fm repulsive core (R+A) in the α-d interaction are shown. The results with the dashed line below $E_\alpha \sim 95$ MeV and solid line beyond $E_\alpha \sim$ 95 MeV correspond to this repulsive core of $r_{\alpha\text{-}d}$=1.5 fm range. It is seen that although the peak shape is almost reproduced, the cross

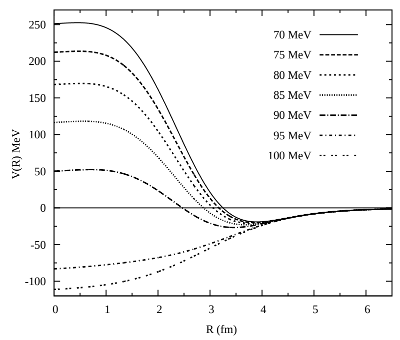

FIG. 3: Enhanced repulsion in the $V_{\alpha\text{-}^{14}N}(r)$ with decreasing $E_{\alpha\text{-}^{14}N}$ used to fit the 139.2 MeV $(\alpha, \alpha d)$ reaction data for $E_\alpha \leq 95$ MeV.

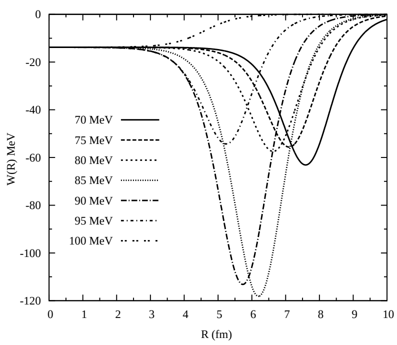

FIG. 4: Same as for Fig.3 but enhanced surface absorption $W_{\alpha\text{-}^{14}N}(r)$.

section at lower E_α is enhanced instead of declining steadily. This is also seen in the FR-DWIA (R+A) study of $(\alpha, 2\alpha)$ reactions[2], where a similar inexplicable awkward behavior was witnessed.

Varying the α-d interaction parameters as well d-^{14}N optical potentials did not result in any significant improvement in the FR-DWIA(R+A) results below the peak region. However the results were found to be very sensitive to the α-^{14}N-optical potentials. Increasing the surface absorption with the reducing $E_{\alpha\text{-}^{14}N}$ resulted in the solid line, fitting the experimental data. This fitting of the lower energy spectrum by increasing the surface absorption with reducing $E_{\alpha\text{-}^{14}N}$, finds an explanation in the application of the Pauli principle. In a p-α system with $E_{p\text{-}\alpha}$ of < 20.5 MeV (the lowest single particle excited state of ^4He), when the $E_{p\text{-}\alpha} \lesssim 20.5$ MeV the proton will be expelled out of the α volume. Hence any nucleon entering the α-volume should have $E_p > (5/4)E_{p\text{-}\alpha}$ or >25.5 MeV, which gives E_α ~4x25.5 MeV ~102 MeV for the nucleon to enter the α-volume. From a detailed optical model analysis of 104 MeV α-elastic scattering, Hauser *et al*[3] concluded that for light nuclei ($A \leq 16$), the inner region of the interaction potential contributes to the scattering, and a repulsive core for small interaction distances explains the observed cross sections. In Fig.3 of Pang *et al* [4] it is seen that the α-^{12}C reaction cross section drastically increases from ~ 800 *mb* to ~ 960 *mb* for E_α varying from 116 MeV to 86 MeV respectively. Alexander *et al* [5] have shown in their Fig.1(top) that the nucleon-α potentials have a repulsive core and show a change of short range repulsion at $E_n \sim 20$ MeV to attraction at $E_n \sim 23.7$ MeV.

These findings support the short range repulsion and enhanced absorption in the α-^{14}N interactions with decreasing $E_{\alpha\text{-}^{14}N}$. Thus a nucleon of ^{14}N in contact with an α of $\lesssim$102 MeV will experience a large force to move it away from the α-volume and simultaneously the moving α will displace more and more nucleons of the ^{14}N nucleus and hence excite the ^{14}N nucleus to higher excitations corresponding to larger absorption in the α-^{14}N potential as the energy E_α is reduced. Although at lower energies the α will bloat temporarily in the interior of the nucleus only to reemerge at the target surface.

Thus the Pauli blocking explains the 139.2 MeV $^{16}O(\alpha, \alpha d)^{14}N^*_{(3.95\text{MeV})}$ data as well as the awkward lower E_α behavior of the 140 MeV FR-DWIA $(\alpha, 2\alpha)$ results[2].

References

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