Finite Range Distorted Wave Analysis of 101.3 MeV $^{16}O(p, pd)^{14}N^*$ Reaction

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Experimental and theoretical studies of cluster knockout reactions have been progressing for the past several decades. This is to study the cluster structure as well as to yield the cluster spectroscopic factor in the light-medium mass nuclei using quasi-free $(p, p\alpha)$, $(\alpha, 2\alpha)$, (p, pd), $(\alpha, \alpha d)$ type of reactions[1]. The spectroscopic factors deduced from the $(\alpha, 2\alpha)$ reactions are found be almost 100 times larger than expected from the conventional shell model estimates[2]. These values were deduced by comparing the experimental data with the predictions of the conventional Zero Range-Distorted Wave Impulse Approximation (ZR-DWIA) calculations. When different projectiles were used to obtain the same spectroscopic information the discrepancy in the absolute spectroscopic factor was very striking and remained unresolved till today. The large discrepancy in absolute spectroscopic factors with the $(\alpha, 2\alpha)$ reactions has been resolved recently using a Finite Range-Distorted Wave Impulse Approximation (FR-DWIA) formalism[3]. Similar calculations have been performed for the carbon knockout reactions using carbon beam [4]. The absolute spectroscopic factors obtained from the FR-DWIA calculations were found to be consistent with the structure estimates.

Only recently the FR-DWIA analyses have been performed for co-planar symmetric configurations only[5, 6]. However in the present case 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 [1].

The transition amplitude, T_{fi} for the knockout reaction A(p, pd)B in the FR-DWIA formalism from the initial state, i to the final state, f can be written [7–9],

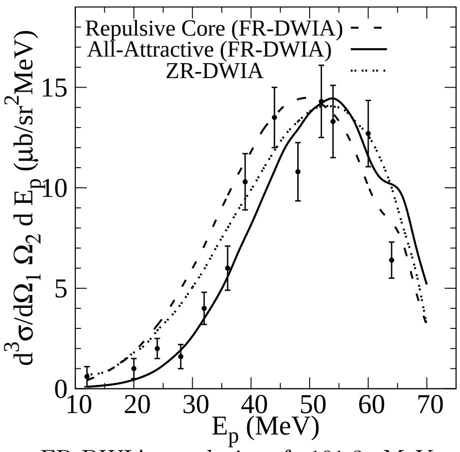

FIG. 1: FR-DWIA analysis of 101.3 MeV $^{16}O(p, pd)^{14}N$ reaction. Dotted line is ZR-DWIA calculations. Dashed line used p-d optical potential having an attractive plus repulsive core (R+A) of $\sim$ 2.5 fm while the solid line represents results for an all-through attractive(A) p-d potential.

$$\frac{d^3\sigma^{L,J}}{d\Omega_1 d\Omega_2 dE_1} = F_{kin} \cdot S_x^{LJ} \cdot \sum_{\wedge} |T_{fi}^{xL\wedge}(\vec{k}_f, \vec{k}_i)|^2 \quad (1)$$

where J and L ($\wedge$) are the total and orbital (its azimuthal component) angular momenta of the bound cluster-particle x in the target nucleus, F_{kin} is a kinematic factor and S_x^{LJ} is the cluster spectroscopic factor to be evaluated. The conventional transition matrix element for the knockout reaction, $T_{fi}^{xL\wedge}(\vec{k}_f, \vec{k}_i)$ using the finite range p-d t-matrix effective interaction $t_{12}(\vec{r}_{12})$ is given by[7–9]:

$$T_{fi}^{xL\wedge}(\vec{k}_f, \vec{k}_i) = \int \chi_1^{(-)*}(\vec{k}_{1B}, \vec{r}_{1B}) \chi_2^{(-)*}(\vec{k}_{2B}, \vec{R}_{2B}) \\ t_{12}(\vec{r}_{12}) \chi_0^{(+)}(\vec{k}_{1A}, \vec{r}_{1A}) \varphi_{L\wedge}^x(\vec{R}_{2B}) d\vec{r}_{12} d\vec{R}_{2B} \quad (2)$$

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Here the $t_{12}(\vec{r}_{12})$, evaluated at the final state relative energy E_f, and is given by[5, 10]:

$$t^{+}_{12}(E,\vec{r}) = e^{-ikz}V(\vec{r})\Psi^{+}_{12}(\vec{r}) \equiv \sum_{L=0,1,2...} t_L(E,r)P_L(\hat{r}) \quad (3)$$

where,

$$\Psi^{+}_{12}(\vec{r}) = \sum_{\ell=0,1,2,...} i^{\ell}(2\ell+1)\frac{u_\ell(kr)}{kr}e^{i\sigma_\ell}P_\ell(\hat{r}). \quad (4)$$

As discussed in Ref.[5], the L^{th} multipole component of the $t^{+}_{12}(E,\vec{r})$ can be written as:

$$t_L(E,r) = \frac{2L+1}{2}\sum_{\ell,n} V_\ell(r) i^\ell (2\ell+1)\frac{u_\ell(kr)}{kr} \jmath_n(kr)(-i)^n(2n+1)e^{i\sigma_\ell} \int_{-1}^{+1} P^*_L(\cos\theta)P_\ell(\cos\theta)P_n(\cos\theta)d(\cos\theta). \quad (5)$$

The distorted waves χ_0, χ_1 and χ_2 of Eq.(2) are evaluated using p-^{16}O, p-^{14}N and d-^{14}N optical potentials. The final state optical potentials for the distorted wave χ_1 (χ_2) were taken for relative energy between outgoing proton, deuteron with the recoiling ^{14}N [1]. The incident p and struck d interaction is taken care of by the $t_{p\text{-}d}(\vec{r})$ effective interaction. The half off-shell $t_{p\text{-}d}(\vec{r})$ effective interaction is evaluated using a p-d all-through attractive potential[11], as also a long range attractive plus a short range repulsive p-d potential generated by keeping $2.5fm$ repulsive core radius and varying other potential parameters to yield the same phase shifts as that by the all-through attractive potential.

Analysis using the FR-DWIA formalism has been performed for the 101.3 MeV $^{16}O(p,pd)^{14}N^*$ quasi-free reaction using all-through attractive(A) and an L-dependent attractive plus repulsive core(A+R) (of $2.5fm$) between the p and d potential. In Fig.1 the theoretically obtained spectra peaks are normalized to the experimental peak value at $E_p \sim 52$ MeV. The spectroscopic factors, obtained by the FR-DWIA calculations are 0.117 and 0.474 for the repulsive core(R+A) and the all-through attractive(A) p-d optical potentials respectively, are seen not to be very different in comparison to the two orders of magnitude anomaly observed in the $^{16}O(\alpha,\alpha d)^{14}N^*$ reaction. From the shape however one can say that the all-through attractive(A) p-d optical potential fits the data decisively better than the one using the repulsive core(R+A). This result is indicative of an attractive p-d potential explaining the 101.3 MeV $^{16}O(p,pd)^{14}N^*$ reaction data. Hence the finite range (FR-DWIA) effects are not as dramatic as in the other cluster knockout reactions where there is a repulsive core. Hence the anomaly produced by the zero range (ZR-DWIA) formalism in the case of $^{16}O(\alpha,\alpha d)^{14}N^*$ reaction is not present in the present case of $^{16}O(p,pd)^{14}N^*$ reaction.

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