Finite Range Distorted Wave analysis of 139.2 MeV $^{16}O(\alpha,\alpha d)^{14}N$ Reaction

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Experimental and theoretical studies of cluster knockout reactions has been done for the past several decades to study the cluster structure as well as to yield the cluster spectroscopic factor in light to medium mass nuclei. Using quasi-free $(p,p\alpha)$, $(\alpha,2\alpha)$, (p,pd), $(\alpha,\alpha d)$ type of reactions[1] the spectroscopic factors were deduced but the $(\alpha,2\alpha)$ reactions are found to predict almost 100 times larger spectroscopic factors than expected from the conventional shell model estimates[2]. These values were deduced by the conventional Zero Range-Distorted Wave Impulse Approximation (ZR-DWIA) calculations. When different projectile were used to obtain the same spectroscopic information the discrepancy in 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.

Until now the FR-DWIA analysis has 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 for a different combination of projectile and struck particle for the first time.

The transition amplitude, T_{fi} for the knockout reaction A$(\alpha,\alpha x)$B in the FR-DWIA formalism from the initial state, i to the final state, f can be written [7, 8, 9],

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

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. The conventional transition matrix element for the knockout reaction, $T_{fi}^{xL\wedge}(\vec{k}_f,\vec{k}_i)$ using the finite range α-x t-matrix effective interaction $t_{12}(\vec{r}_{12})$ is given by[7, 8, 9]:

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

Here the $t_{12}(\vec{r}_{12})$, evaluated at the final state relative energy E_f, 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 of the $t_{12}^+(E,\vec{r})$ can be written:

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

The distorted waves χ_0, χ_1 and χ_2 of Eq.(2) are evaluated using α-^{14}N, α-^{14}N and d-^{14}N optical potential. The final state optical potentials for the distorted wave χ_1 (and χ_2) were taken for relative energy between outgoing α particle (and deuteron) with recoiling ^{14}N [11, 12]. The incident optical potential for

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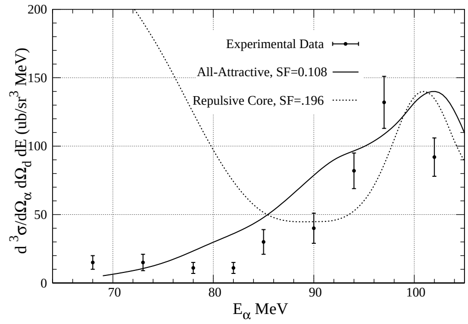

FIG. 1: FR-DWIA analysis of 139.2 MeV $^{16}O(\alpha,\alpha d)^{14}N$ reaction. Dotted line uses d-α optical potential having an attractive plus repulsive core (R+A) of $\sim 1.5\ fm$ and solid line represents an all-through attractive(A) potential.

the distorted wave χ_0 is evaluated by a folding procedure [6] by taking α-^{14}N potential and folding this with the square of the bound d-^{14}N wave function to evaluate the effective α-^{16}O incident channel potential since the incident α and struck x interaction is taken care of by the $t_{\alpha\text{-}x}(r)$ effective interaction. The half off-shell $t_{\alpha\text{-}x}(r)$ effective interaction is evaluated using a x-α all-through attractive optical model potential[13], as also a long range attractive plus a short range repulsive x-α potential generated by keeping $1.5fm$ repulsive core radius and varying other potential parameters to yield the same phase shifts as that by the all-through attractive potential.

An analysis using the FR-DWIA formalism has been performed for the 139.2 MeV $^{16}O(\alpha,\alpha d)^{14}N$ quasi-free reaction using all-through attractive(A) and an L-dependent attractive plus repulsive core(A+R) (of $1.5fm$) between the d and α potential. In Fig.1 the theoretically obtained spectra peaks are normalized to the experimental peak value at $E_\alpha = 97$ MeV. The spectroscopic factors, obtained by the FR-DWIA calculations are 0.196 and 0.108 for the repulsive core(R+A) and the all-through attractive(A) α-d optical potentials respectively, are not very different. From the shape however one can say that the all-through attractive(A) α-d optical potential fits the data decisively better than the one using the repulsive core(R+A). It is also to be remarked that α-d relative energy is 46.4 MeV in the prior form while it is only ~ 22 MeV in the post form. In the RGM formalism the prior form energy satisfies the Pauli principle for the two-nucleons of the deuteron to lie inside the α-particle in the $p_{3/2}$ orbitals, indicative of an attractive α-d potential. On the other hand the ~ 22 MeV post form α-d relative energy can accommodate only one nucleon in the $p_{3/2}$ orbital leading to a repulsive core for the α-d potential.Therefore theoretical predictions for the 139.2 MeV $^{16}O(\alpha,\alpha d)^{14}N$ reaction lie between the post and prior form values because of the high Q-value. Hence the finite range (FR-DWIA) effects not only correct the anomaly produced by the zero range (ZR-DWIA) formalism but also produces spectroscopic factor in the correct range.

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