Analysis of (^{3}He, t) charge exchange reactions at 140AMeV

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The spin-isospin response in nuclei has been studied widely through (^{3}He, t) and (t, ^{3}He) charge-exchange reactions wherein a proton (neutron) transforms into a neutron (proton), which in turn changes the isospin, ΔT=1, of the nuclei participating in the reaction, either with or without spin transfer [1, 2]. The Gamow-Teller transitions are used to obtain the weak transition strength in the excitation- energy regions inaccessible through β-decay. The strengths deduced using charge exchange experiments provide stringent tests for nuclear structure calculations and serve as inputs for variety of applications in which weak transition strengths play a role [3, 4]. In this context, we explore here the (^{3}He,t) charge-exchange reaction at 140 MeV/u on ^{18}O, ^{26}Mg, ^{58,60,62,64}Ni, ^{90}Zr, ^{118,120}Sn and ^{208}Pb targets, within the theoretical framework of distorted wave impulse approximation.

In this approximation, the transition amplitude for inelastic charge exchange reaction A(a, b)B is written as

$$T = \left\langle \chi_b^{(-)*} Bb \left| V(\vec{r}) \right| Aa\, \chi_a^{(+)} \right\rangle \quad (1)$$

Here, V represents the interaction potential which is taken as the sum of effective nucleon-nucleon potential and, within the impulse approximation, can be expressed as

$$V = \int dx_1\, dx_2\, dx_1'\, dx_2'\, \hat{\rho}_T(x_1, x_1')\, \hat{\rho}_P(x_2, x_2') \times v_{12}(x_1' x_2', x_1\, x_2) \quad (2)$$

In the above, the abbreviated argument is $x_i \equiv (\vec{r}_i, \sigma_i, \tau_i)$ $[(i=1,2)$ and x_i' represents x_i following the charge exchange] stands for the space, spin and isospin coordinates of the i^{th} nucleon. Moreover, $\hat{\rho}_T(x_1, x_1')$ and $\hat{\rho}_P(x_2, x_2')$ represent the non-local density operators for the target and projectile system respectively and can be expressed in terms of the nucleon field creation, $\hat{\psi}^+(x_1)$, and annihilation $\hat{\psi}(x_1')$ operators as

$$\hat{\rho}_T(x_1, x_1') = \hat{\psi}_T^+(x_1)\, \hat{\psi}_T(x_1')$$

and

$$\hat{\rho}_P(x_2, x_2') = \hat{\psi}_P^+(x_2)\, \hat{\psi}_P(x_2').$$

Now the interaction potential, $v_{12}(x_1' x_2', x_1\, x_2)$, that appeared in equation (2), may also be written as the sum of direct and exchange part of the Love and Franey type effective-interaction [5], i.e. as $v_{12}(x_1' x_2', x_1\, x_2) = \left\langle x_1' x_2' \left| V^D \right| x_1 x_2 \right\rangle + (-)^l P^r \left\langle x_1' x_2' \left| V^E \right| x_1 x_2 \right\rangle$, where P^r is the exchange operator for the spatial coordinates.

In light of the above discussion, one can modify equation (1) for the transition amplitude T and express that amplitude as a sum of direct T_D and exchange T_E terms [6]:

$$T = T_D + T_E \quad (3)$$

$$T_D = \iiint dr_a\, dx_1\, dx_2\, \chi_b^{(-)*}(\vec{k}_b, \vec{r}_b) \times \left\langle Bb \left| V^D(\vec{r})\, \hat{\rho}_T(x_1, x_1)\, \hat{\rho}_P(x_2, x_2) \right| Aa \right\rangle \chi_a^+(\vec{k}_a, \vec{r}_a) \quad (3a)$$

$$T_E = \iiint dr_a\, dx_1\, dx_2\, \chi_b^{(-)*}(\vec{k}_b, \vec{r}_b) \times \left\langle Bb \left| V^E(\vec{r})\, \hat{\rho}_T(x_1, x_1')\, \hat{\rho}_P(x_2, x_2') \right| Aa \right\rangle \chi_a^+(\vec{k}_a, \vec{r}_a) \quad (3b)$$

Here, $|Aa\rangle$ and $|Bb\rangle$ represent the initial and final nuclear states of the projectile-target and residue-ejectile systems, respectively. Moreover, the distorted wave functions $\chi_a^+(\vec{k}_a, \vec{r}_a)$ and $\chi_b^{(-)*}(\vec{k}_b, \vec{r}_b)$ represent the relative states in the incident and exit channels, respectively. Now the insertion of field operator's expansion, in terms of an appropriate set of single-particle wave functions, along with the use of matrix element for the projectile and target density operators and the carrying out of the summation over the spin-isospin variables, lead to new expressions for the direct and exchange amplitudes, cf. Eqs. (3a) and (3b),

$$T_D^{t_1 s_1 l_1 k l_t m_{l_t}} = \int d\vec{r}_a\, \chi_b^{(-)*}(\vec{k}_b, \vec{r}_a)\, f_D^{t_1 s_1 l_1 k l_t m_{l_t}}(\vec{r}_a)\, \chi_a^+(\vec{k}_a, \vec{r}_a)$$

$$T_E^{t_1 s_1 l_1 k l_t m_{l_t}} = \iint d\vec{r}_a\, d\vec{r}_b\, \chi_b^{(-)*}(\vec{k}_b, \vec{r}_b)\, f_E^{t_1 s_1 l_1 k l_t m_{l_t}}(\vec{r}_b, \vec{r}_a)\, \chi_a^+(\vec{k}_a, \vec{r}_a)$$

Here, $f_D^{t_1 s_1 l_1 k l_t m_{l_t}}(\vec{r}_a)$ and $f_E^{t_1 s_1 l_1 k l_t m_{l_t}}(\vec{r}_b, \vec{r}_a)$ are the direct and exchange form factors. Combining the above contributions, the differential cross section may be obtained from the expression [6]

$$\frac{d\sigma}{d\Omega} = \frac{\mu_a \mu_b}{(2\pi\hbar^2)^2} \frac{k_b}{k_a} \left| \sum_{i=D,E} \sum_{k, l_t t_1} \alpha_{j_t s_t v_1}^{t_1 s_1 l_1 k l_t}\, T_i^{t_1 s_1 l_1 k l_t m_{l_t}} \right|^2 .$$

Here μ_a, μ_b, k_a, k_b are the reduced masses and wave numbers in the incident and exit channels, respectively. The coefficient, $\alpha^{t_1 s_1 l_1 k l_t}_{j_t s_t v_1}$, contains the Racah coefficient describing the recoupling of various angular momenta and the usual spectroscopic amplitude for projectile spin-isospin wave function.

Results and Discussion

The present conference contribution focuses on the Gamow-Teller and Fermi transitions, for which proportionality relations between the differential cross section at zero momentum transfer and the corresponding transition strength exist:

$$\frac{d\sigma}{d\Omega}(q=0) = \hat{\sigma}_{GT}\, B(GT),$$

for Gamow-Teller transitions and

$$\frac{d\sigma}{d\Omega}(q=0) = \hat{\sigma}_{F}\, B(F)$$

for Fermi, respectively. The current objective is to investigate the quality of the new reaction calculations which eventually should enable a more systematic exploitation of the charge-exchange reactions data, obtained with composite particles including transitions having ΔL > 0. Here, in contrast to most previous calculations, the exchange contributions to the reaction are treated exactly. The preliminary results obtained using the code DCP2, for the GT and Fermi unit cross sections, are presented in Figs. 1 and 2. Fig. 1 specifically depicts the calculated Gamow–Teller unit cross sections for (^{3}He, t) charge exchange reaction on ^{18}O, ^{26}Mg, ^{58,62,64}Ni and ^{118,120}Sn targets. The unit cross sections are calculated either without the exchange contribution (squares in the figures) and with that contribution (circles). These results are further compared with the empirical function (line) fitted to the experimental results [7], $\hat{\sigma}_{GT,fit} = 109/A^{0.65}$.

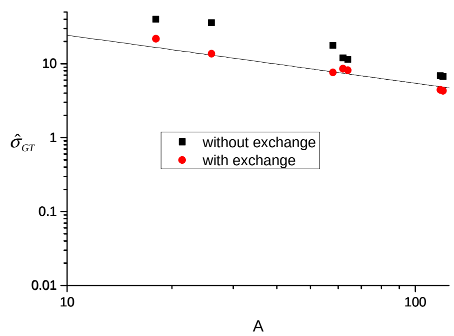

Fig. 1(color online). Mass dependence of unit cross section obtained from (^{3}He, t) at 140MeV for Gamow-Teller transitions. The solid line represents a power fit to the experimental results. The squares represents the unit cross sections calculated without the exchange contribution while circles represent complete results.

Figure 1 rather clearly demonstrates that the inclusion of exchange contributions in the calculations reduces the unit cross section bringing it down towards the empirical line, thus generally improving the match with experiment. A similar observation can be made for Fig. 2 which shows the Fermi unit cross section on ^{18}O, ^{26}Mg, ^{58,60}Ni, ^{90}Zr, ^{120}Sn and ^{208}Pb targets. Again, the cross section calculated with (circles) and without (squares) the exchange terms is compared there to the empirical function fitted to the data [7], $\hat{\sigma}_{F,fit} = 72/A^{1.06}$.

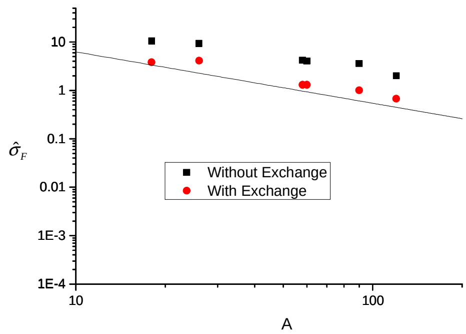

Fig. 2 (color online). Analogous to figure 1 but for Fermi transition.

In conclusion, within the present calculations the exchange effects have been incorporated exactly for charge exchange reactions, (^{3}He, t). Our calculations carried out for a wide range of target mass demonstrate the quantitative importance of including correctly calculated exchange terms in establishing the correspondence between theory and data.

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