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A Dynamical Origin of Momentum-Dependent Tensor Potentials in Elastic Scattering*

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As is well known[1], three types of tensor potentials, T_R, T_L and T_P, are allowed kinematically in elastic scattering of a projectile with spin one, in addition to central and spin-orbit potentials. Such a consideration is also relevant to ^{7}Li elastic scattering from 0^+ nuclei, and a rank-3 tensor potential, T_3, is possible in this scattering. It has been shown that the T_R potential can be derived in folding procedures for both deuteron and ^{7}Li elastic scatterings, while the T_L and the T_P potentials have not been established by a simple folding model calculation and are still being investigated by several authors [2].

Coupled channel calculations including excited states of the projectile have made it clear that peculiar features of analyzing powers in ^{7}Li elastic scattering are induced mainly by projectile excitation process[3), 4)], thus generating dynamical optical potentials. Thereby, it may be possible to find momentum dependent tensor potentials.

In this note we show that the T_P and other potentials can arise from a dynamical effect of a projectile-virtual-excitation process if we include spin-orbit interactions in transitions between the excited state and the ground state. With this model we estimate the magnitudes of T_L, T_P and T_3 tensor potentials for ^{58}Ni(^{7}Li,^{7}Li)^{58}Ni.

We postulate that ^{7}Li is well described by α + t cluster model.

For present aim we need to evaluate the second-order matrix element for projectile virtual excitation, that is the dynamical optical potential

$$V^{(dy)} = (0 \,|\, vGv \,|\, 0), \tag{1}$$

where 0 means the ground state channel, G a Green's function in the excited state of ^{7}Li, and v the sum of the α - ^{58}Ni interaction and the t - ^{58}Ni central and spin-orbit interactions, denoted by $v^{(c)}(\mathbf{r},\boldsymbol{\rho})$, and $v_t^{(c)}(\mathbf{r},\boldsymbol{\rho})$ and $v_t^{(LS)}(\mathbf{r},\boldsymbol{\rho})\mathbf{L}_t\cdot\mathbf{s}_t$, respectively. Further

$$\mathbf{L}_t\cdot\mathbf{s}_t = \frac{\hbar}{i}(\,\mathbf{r} + \alpha\boldsymbol{\rho}\,) \times (\beta\nabla_{\mathbf{r}} + \nabla_{\boldsymbol{\rho}}\,)\cdot\mathbf{s}_t, \tag{2}$$

as defined in Ref.(3).

To simplify descriptions, we define an operator $\mathcal{O}^{(K)}$ which relates to the matrix element of v as

$$(L',(\ell's)I';JM\,|\,v\,|\,L,(\ell s)I;JM) = \sum_K (-1)^{I'+J+K}\begin{Bmatrix} L' & I' & J \\ I & L & K\end{Bmatrix}(L'\|\mathcal{O}^{(K)}\|L), \tag{3}$$

where ℓ (ℓ') is an inner angular momentum which couples with triton spin s to total spin I=3/2(I'=1/2) in the ground(excited) state, L(L') is orbital angular momentum, and J total angular momentum in scattering. Inserting eq.(3) into eq.(1), and extracting the potential depth $V^{(K)}(r)$ of rank K by applying a sum rule on 6-j symbol, one can get the following formula for the rank-K potential $V^{(K)}(r)([\mathbf{I}]^{(K)}\cdot\mathbf{R}^{(K)})$,

$$V^{(K)}(r) = -\frac{1}{\varepsilon}\hat{K}\sum_{k_1k_2} W(k_1k_2II:KI')\,\frac{(L'\|[\mathcal{O}^{(k_1)}\times\mathcal{O}^{(k_2)}]\|L)}{(L'\|\mathbf{R}^{(K)}\|L)\,(I'\,[\mathbf{I}]^{(K)}\|\,I)}, \tag{4}$$

where $\mathbf{R}^{(K)}$ denotes a radial operator of rank K, $\mathbf{R}^{(2)} = [\,\mathbf{L}\times\mathbf{L}\,]^{(2)}$ for T_L potential, $\mathbf{R}^{(2)} = [\,\mathbf{P}\times\mathbf{P}\,]^{(2)}$ for T_P, and $\mathbf{R}^{(3)} = [\,\mathbf{r}\times\mathbf{r}\times\mathbf{L}\,]^{(3)}$ for T_3 tensor potential.

For ^{7}Li scattering, we show the operator $\mathcal{O}^{(K)}$ explicitly.

$$\mathcal{O}^{(1)} = g_1^{(LS)}(r)\,\mathbf{L}, \tag{5}$$

$$\mathcal{O}^{(2)} = g_2^{(LS)}(r)\,[\,\mathbf{C}_1\times\nabla_r\,]^{(2)} + g_3^{(LS)}(r)\,[\,\mathbf{C}_3\times\nabla_r\,]^{(2)} + f^{(c)}(r)\mathbf{C}_2\,, \tag{6}$$

where $g^{(Ls)}(r)$ ($f^{(c)}(r)$) represents the integrated term of multipole j of the spin-orbit(central) interaction $v_j^{(Ls)}(\mathbf{r},\rho)$ ($v_j^{(c)}(\mathbf{r},\rho)$) with the inner wave functions.

In the derivation of eq.(4) the adiabatic approximation was used for simplicity,

$$G_{L'}(r,r') = -\frac{1}{\varepsilon}\delta(r-r'), \tag{7}$$

ε is the excitation energy of $I'=1/2$ state in ^{7}Li.

Now we can calculate the magnitude of each kind of the dynamical potential. As an example, we show the explicit expression for the strength of T_P potential;

$$V_{T_P}(r) = \frac{1}{1000}\left(\frac{3}{7}\right)^2 \frac{r^2}{\varepsilon}[-48\left\langle\frac{\alpha\rho}{r}v_1^{(Ls)} - v_2^{(Ls)}\right\rangle^2 + 10\left\langle -v_2^{(Ls)} + \frac{\alpha\rho}{r} \times v_3^{(Ls)}\right\rangle^2 + 5\left\langle\frac{\alpha\rho}{r}v_1^{(Ls)} - v_2^{(Ls)}\right\rangle\left\langle -v_2^{(Ls)} + \frac{\alpha\rho}{r}v_3^{(Ls)}\right\rangle], \tag{8}$$

where α is 4/7 and $v_j^{(Ls)}$ denotes multipole term of j in the spin-orbit interaction, and $\langle v\rangle = \int u_f v\, u_i\, d\rho$.

Fig. 1 displays the resultant momentum-dependent tensor potentials V_{T_P}, V_{T_L} and V_{T_3} calculated by the parameter set of the triton- and the alpha- ^{58}Ni potential, same as in Ref.(3).

One can see that the 3rd-rank tensor potential is relatively larger than the other two. The reason is that the T_P and T_L potentials are generated only from the spin-orbit force, while the T_3 potential arises from both the central and the spin-orbit forces in the present model. The dynamical T_3 potential may affect polarization observables, especially third-rank tensor analyzing powers, of ^{7}Li elastic scattering

The details will be published elsewhere.

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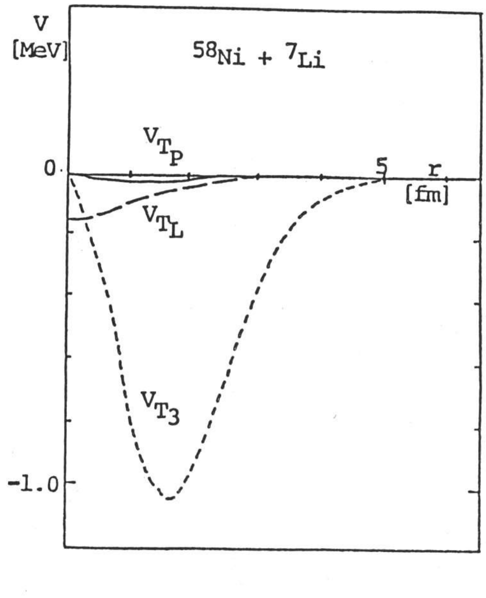

Fig. 1. The strength of dynamical optical potentials of ^{7}Li from virtual excitation process including spin-orbit transition interaction.