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1.92 Microscopic Derivation of the Spin-Orbit Potentials of ^{3}He and t

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It has been reported that the scattering data of ^{3}He and t require the spin-orbit (l·s) potentials of these projectiles to be a few times stronger than are expected by the folding model[1]. It is therefore important to derive and study microscopically the l·s potential of 3N particles where 3N particle means ^{3}He or t.

We have used the resonating group method (RGM) for the systems, 3N+^{16}O and 3N+^{40}Ca. The RGM equation of motion is written as

$$\int h(\vec{r},\vec{r}')\chi(\vec{r}')\, d\vec{r}' = E\chi(\vec{r}),$$

$$h(\vec{r},\vec{r}') = \left\{-\frac{\hbar^2}{2\mu}\left(\frac{\partial}{\partial r}\right)^2 + V_D(\vec{r})\right\}\delta(\vec{r}-\vec{r}')$$
$$+ G_I(\vec{r},\vec{r}') + G_{II}(\vec{r},\vec{r}')\frac{\hbar}{i}(\vec{r}\times\vec{r}')\cdot\vec{s} \quad . \tag{1}$$

The non-local interaction $G_{II}(\vec{r},\vec{r}')(\hbar/i)(\vec{r}\times\vec{r}')\cdot\vec{s}$ comes from the two-nucleon spin-orbit force v_{LS}^{NN} and gives rise to the l·s potential of 3N. By applying the WKB approximation[2] to Eq.(1), we obtain the Hamilton-Jacobi equation

$$\frac{1}{2\mu}(\vec{p}(\vec{r}))^2 + V_D(r) + G_I^W(\vec{r},\vec{p}(\vec{r}))$$
$$-\left(\hbar^3\frac{\partial G_{II}^W(\vec{r},\vec{p}(\vec{r}))}{\partial p^2(r)}\right)\times\left\{j(j+1)-\ell(\ell+1)-\frac{3}{4}\right\} = E \quad . \tag{2}$$

from which we determine the local momentum $\vec{p}(\vec{r})$ under the condition $|\vec{r}\times\vec{p}(\vec{r})| = \hbar(l+\frac{1}{2})$. In Eq.(2), $G_I^W(\vec{r},\vec{p})$ and $G_{II}^W(\vec{r},\vec{p})$ are Wigner transforms of $G_I(\vec{r},\vec{r}')$ and $G_{II}(\vec{r},\vec{r}')$, respectively, and l and j are orbital and total angular momenta, respectively.

For each of $j=l+\frac{1}{2}$ and $j=l-\frac{1}{2}$ we calculate the local momentum $\vec{p}_j(\vec{r})$ and then define the equivalent local potential $V_j^{eq}(r)$ by

$$V_j^{eq}(r) = E - (1/2\mu)(\vec{p}_j(\vec{r}))^2 \quad . \tag{3}$$

Then the central potential $V_c(r)$ and the l·s potential $V_{ls}(r)$ of 3N particle are obtained to be

$$V_c(r) = ((\ell+1)V^{eq}_{\ell+\frac{1}{2}}(r) + \ell\cdot V^{eq}_{\ell-\frac{1}{2}}(r))/(2\ell+1) \ ,$$
$$V_{ls}(r) = ((V^{eq}_{\ell+\frac{1}{2}}(r) - V^{eq}_{\ell-\frac{1}{2}}(r))/(\ell+\tfrac{1}{2}) \ . \tag{4}$$

There are two origins of $V_{ls}(r)$: One is of course the direct contribution of v_{LS}^{NN}, which constitutes the main part of $V_{ls}(r)$. The other is the renormalization from the non-local central interaction; namely since $\vec{p}_{l+\frac{1}{2}}(\vec{r})$ is not equal to $\vec{p}_{l-\frac{1}{2}}(\vec{r})$, the equivalent local potential coming from the non-local central potential takes different values for different j values, and this difference of the central potential should be accounted for as the l·s potential.

As for the main part of $V_{ls}(r)$ due to the direct contribution of v_{LS}^{NN}, it can be divided into three components: Since three nucleons of 3N particle are accommodated in the valence orbits around the core nucleus (^{16}O or ^{40}Ca), the l·s potential of the 3N particle comes from three terms, the Hartree and Fock potentials of the valence nucleons and the mutual interaction among the valence nucleons. The last term is found to be negligibly small, which is due to the weak ^{3}E component of v_{LS}^{NN} and the extreme short-range nature of v_{LS}^{NN}. The contribution from the Fock potential is comparable in magnitude with that from the Hartree potential, due to the extreme short-range nature of v_{LS}^{NN}.

The calculated results of $V_{ls}(r)$ are shown in Fig.1 in the case of ^{3}He+^{40}Ca for two incident energies 5 MeV/u and 10 MeV/u. The oscillator parameter ν is 0.14 fm^{-2}, the effective central two-nucleon force is Volkov No.1[3] with m=0.623 and v_{LS}^{NN} is taken from Ref.4. In Fig.1 we compare $V_{ls}(r)$ with the double-folding l·s potential $V_{ls}^{D}(r)$ without exchange effects. We see that in the surface region $V_{ls}(r)$ is larger than $V_{ls}^{D}(r)$ by more than two times.

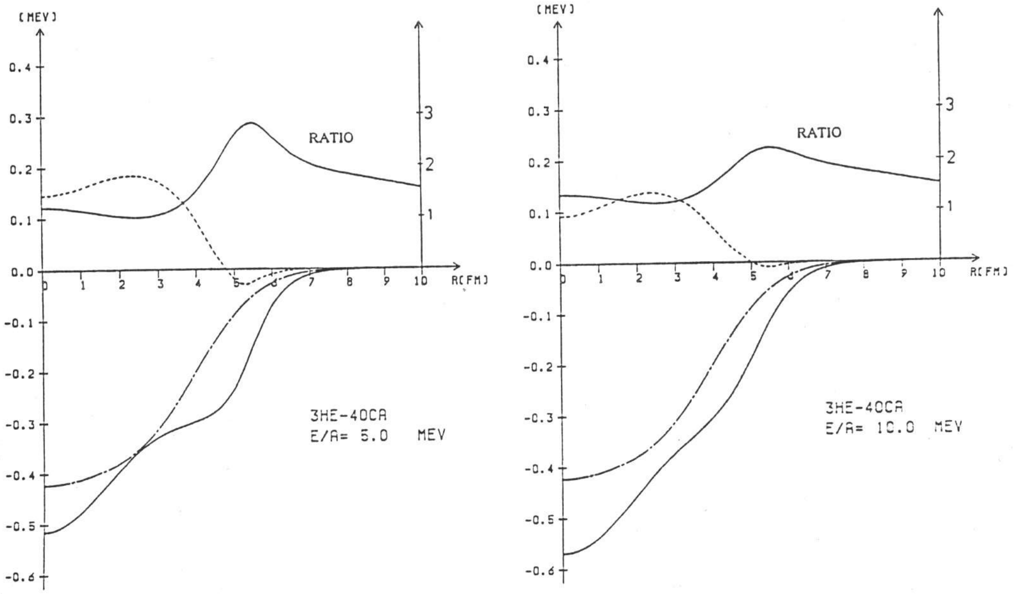

Fig.1 The total l·s potential $V_{ls}(r)$ (solid line), the double-folding l·s potential $V_{ls}^{D}(r)$ (dash-dotted line) and the renormalization l·s potential $V_{ls}^{Ren}(r)$ from the central potential (dotted line) are shown for ^{3}He+^{40}Ca. Here also the ratio RATIO = $V_{ls}(r)/V_{ls}^{D}(r)$ (solid line) is displayed, for which the scale is given by the right-hand-side ordinate.

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