Double-folding model potentials for ^{6}Li elastic scattering at 99 MeV

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Double-folding model potentials generated from a realistic nucleon-nucleon interaction and densities that are consistent with electron scattering are used to generate angular distributions for ^{6}Li elastic scattering at 99 MeV. When used to calculate observed angular distributions it is found that the double-folding model potential is roughly twice the potential required to generate a fit to the data. This is consistent with observations at both lower and higher ^{6}Li energies.

[NUCLEAR REACTIONS ^{12}C, ^{28}Si, ^{40}Ca, ^{58}Ni, ^{90}Zr, ^{208}Pb(^{6}Li,^{6}Li), $E=99$ MeV; calculated $\sigma(\theta)$ with double-folding model potentials.]

Optical model potentials generated by double folding a realistic G matrix interaction with projectile and target density distributions have been generally successful in reproducing elastic scattering angular distributions for light heavy ions.[1,2] For projectile energies in the range from a few to tens of MeV per nucleon, the only projectiles whose scattering have been found not to be reproduced are Be and Li. Elastic scattering of ^{6,7}Li from several targets has been analyzed at ~35 MeV (Refs. 1 and 2) and at 152 MeV.[3] At both energies the potential generated by the double-folding model was found to be too strong to reproduce the data. If, however, the double-folding model potential was multiplied by approximately one half, the data could be reproduced. Here we apply the double-folding model to data for elastic scattering of ^{6}Li at 99 MeV from seven targets.[4]

Double-folding model potentials were obtained by evaluating

$$U(R)=\int d^3r_t d^3r_p \rho_p(r_p)\rho_t(r_t) g(|\vec{r}_p-\vec{r}_t+\vec{R}|) \qquad (1)$$

using standard momentum-space techniques.[5] The nucleon-nucleon interaction $g(|\vec{r}_p-\vec{r}_t+\vec{R}|)$ was taken to be the Reid-even, Elliott-odd central components of the G matrix of Bertsch *et al.*[6] modified to account for single-nucleon knockout exchange.[7] The Bertsch *et al.* G-matrix interaction includes a spin-orbit term which leads to a nucleus-nucleus spin-orbit potential[8]; however, none of the systems considered here were found to be sensitive to including this term except ^{12}C. With the exception of ^{12}C, which is discussed separately, only the central terms have been included in the calculations. The ^{6}Li point matter density $\rho_p(r_p)$ was taken to be the form given by Bray *et al.*[9]

$$\rho_p(r_p)=0.203e^{-(0.575r)^2}+[-0.0131+0.0087(0.398r)^2]e^{-(0.398r)^2}, \qquad (2)$$

which has been constructed from a phenomenological electron scattering proton charge distribution[10] with the assumption that the ^{6}Li proton and neutron densities are equal since $N=Z$. This density distribution has $\langle r^2\rangle = 5.73$ fm^2. Proton parts of the target densities were taken from electron scattering.[10] The neutron parts of the target densities were obtained by assuming a neutron skin as predicted by the droplet model.[11] The target density parameters are given in Table I. The proton size[12] was deconvoluted from the target densities during the evaluation of the integral in Eq. (1).

Imaginary optical potentials were assumed to have the same shape as the real potentials. The quality of agreement with the data was not improved by allowing a different imaginary potential shape for any of the systems considered with the exception of ^{12}C. Elastic scattering angular distributions were generated from optical potentials given by

$$U^{\rm opt}(R)=(N_R+iN_I)U(R), \qquad (3)$$

where $U(R)$ is given by Eq. (1) and N_R and N_I were varied until the data were reproduced.

The angular distributions which best reproduce the data are shown in Fig. 1. The values of N_R and N_I used to obtain these angular distributions are given in the last two columns in Table I. The values of N_R given in the table are consistent with those found at other scattering energies.[1-3] At-

TABLE I. Target densities and optical potential normalization factors for ^{6}Li elastic scattering calculations. The densities have the form $\rho_t(r_t) = p_p/(1+e^{(r-c_p)/a}) + p_n/(1+e^{(r-c_n)/a})$.

Target	p_p(fm^{-3})	c_p(fm)	$\langle r^2\rangle_p$(fm^2) [a]	p_n(fm^{-3})	c_n(fm)	$\langle r^2\rangle_n$(fm^2) [a]	a(fm)	N_R [b]	N_I [b]
^{28}Si	0.0964	2.94	9.00	0.0971	2.93	8.97	0.569	0.554	0.623
^{40}Ca	0.0876	3.52	11.2	0.0884	3.51	11.1	0.563	0.576	0.661
^{58}Ni	0.0798	4.14	14.0	0.0839	4.17	14.1	0.561	0.532	0.543
^{90}Zr	0.0751	4.83	17.6	0.0870	4.97	18.3	0.550	0.509	0.567
^{208}Pb	0.0631	6.62	29.9	0.0853	6.92	32.3	0.550	0.527	0.548

[a] The values of $\langle r^2\rangle$ listed are after deconvolution of proton size from density distributions given.

[b] Normalization factors for optical potentials defined by Eq. (3).

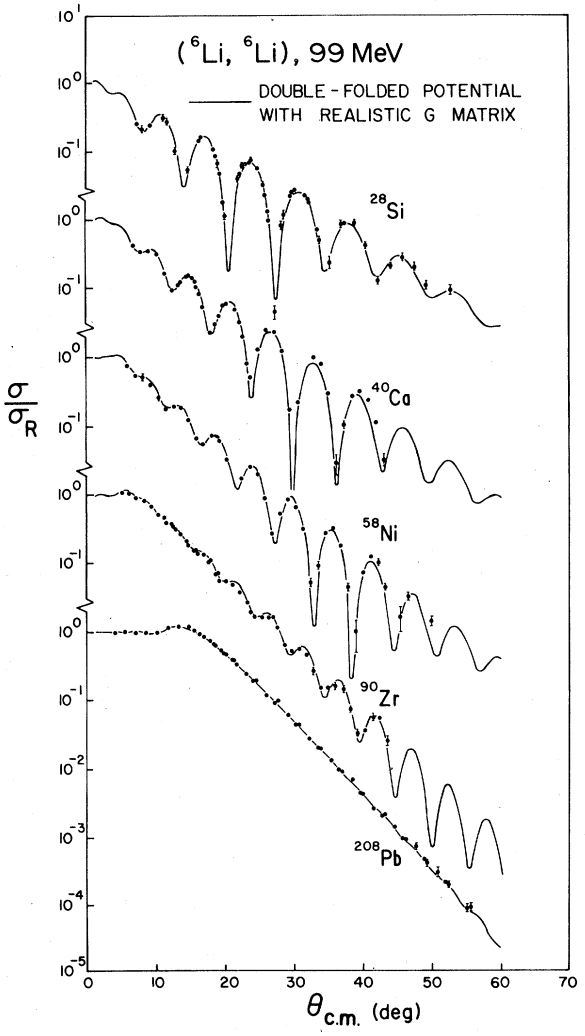

FIG. 1. Double-folding model fits to the experimental data for elastic scattering of ^{6}Li from several targets at 99 MeV. The solid lines were calculated from potentials of the form of Eq. (3) with the normalization constants given in Table I. The data are from Ref. 4.

tempts to reproduce the angular distributions with real normalizations different from those given in the table indicated that when N_R was varied by more than ~15%, the quality of agreement with the data rapidly degenerated even if the imaginary potential was allowed to have a shape different from the real potential.

We discuss ^{6}Li + ^{12}C scattering separately from the other systems because this system is slightly dependent upon including a spin-orbit potential and the imaginary potential must be different in shape from the real potential if the data are to be reproduced. The ^{12}C density was assumed to have equal neutron and proton parts. The proton density was taken from electron scattering[10] and assumed equal to the neutron density. Specifically the matter density has the form

$$\rho_t(r_t) = 0.173(1.0 + 0.375r^2)e^{-0.351r^2}, \tag{4}$$

which has $\langle r^2\rangle = 5.39$ fm^2 after deconvolution of the proton size.[12] The real potential was generated in the same manner as for other targets. To allow a different shape for the imaginary potential, Eq. (1) was evaluated with g replaced by

$$g_I(|\vec{r}_p - \vec{r}_t + \vec{R}|) = \frac{G_I e^{-m_I|\vec{r}_p - \vec{r}_t + \vec{R}|}}{m_I|\vec{r}_p - \vec{r}_t + \vec{R}|}. \tag{5}$$

The resulting potential $U_I(R, G_I, m_I)$ was then used for the imaginary potential. That is, Eq. (3) was replaced by

$$U^{\rm opt}(R) = N_R U(R) - iU_I(R, G_I, m_I). \tag{6}$$

The parameters N_R, G_I, and m_I were then varied until the data could be reproduced. This result is shown by the solid line in Fig. 2. The parameters have the values $N_R = 0.636$, $G_I = 6.98$ MeV, and $m_I = 0.8$ fm^{-1}.

A double-folding model spin-orbit potential calculated from the interaction of Bertsch *et al.*[6] was found to give a good description of analyzing powers for ^{6}Li scattering.[8] The construction of the spin-orbit potential for ^{6}Li + ^{12}C is fully discussed in Ref. 8. When the spin-orbit term is added to

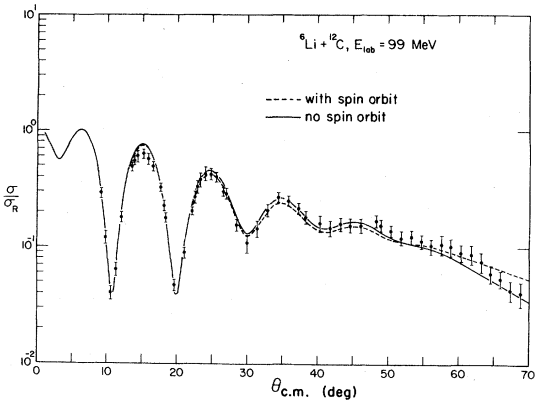

FIG. 2. Double-folding model fit to the experimental data for elastic scattering of ^{6}Li from ^{12}C at 99 MeV. The spin-orbit potential of Ref. 8 has been neglected in obtaining the solid curve and included in obtaining the dashed curve. Again the data are from Ref. 4.

the central optical potential for ^{6}Li + ^{12}C determined above, there is a noticeable effect upon the angular distribution. Because of this an additional search has been performed including this spin-orbit potential. The result is shown by the dashed line in Fig. 2. The parameters obtained were $N_R = 0.626$, $G_I = 6.99$ MeV, and $m_I = 0.8$ fm^{-1}. These are almost the same values obtained without the spin-orbit potential.

With these results, ^{6}Li elastic scattering over the range from a few to a few tens of MeV per nucleon has been fairly completely investigated with double-folding model potentials. At all energies the double-folding model overpredicts the real part of the optical potential needed to reproduce the observed angular distribution by approximately a factor of 2. In these calculations the disagreement between the double-folding model and what is required to reproduce experiment, which is measured by the deviation of the value of N_R from unity, does not appear to have any obvious energy dependence. The target densities used here along with the interaction of Bertsch *et al.*[6] have been able to reproduce elastic scattering of other light heavy ion projectiles with $N_R \approx 1$.[1,2] The reason that Li scattering is anomalous in the double-folding model is still outstanding; however, a recent low energy study[13] of ^{7}Li elastic scattering suggests that it may be due to the fact that the cross sections are more sensitive to the optical potential interior than other systems. The assumptions made in the double-folding model are not valid in the interior region.[1,2] It would be interesting to extend the study of Ref. 13 to the higher energy data of the present work and that of Ref. 3.

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