Microscopic Analysis of Elastic Scattering and Transfer Reaction in the ^{7}Li+^{10}B Collision at Energy 58 MeV

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The aim

- We analyse, within the microscopic model of OP, the differential cross sections of the ^{7}Li+^{10}B elastic scattering and the transfer reaction ^{7}Li+^{10}B$\rightarrow$^{6}Li+^{11}B at the beam energy $E_{LAB} = 58$ MeV.
- The OP is obtained by a corresponding double folding procedure and depends on the nucleon density distributions of interacting nuclei. The only free parameters are the depths of the real and imaginary parts of the OPs determined by fitting the experimental data (including the surface terms if needed).
- The cross sections are calculated using this OP and the DWUCK4 code (where the DWBA approach is implemented)
- The calculated differential cross sections are compared with the experimental data on the elastic scattering channel and the nucleon transfer reactions obtained in 2023 at the U-400 cyclotron (FLNR JINR).

MicroOP: DF (1/2)

$$V_{DF}(r) = V_D(r) + V_{EX}(r)$$

Both direct V_D and exchange V_{EX} potentials are composed of the isoscalar and isovector terms.

Isoscalar term:

$$V_D(r) = \int d^3r_p d^3r_t \rho_p(\mathrm{r}_p)\rho_t(\mathrm{r}_t) v^D_{NN}(s)$$

$$V_{EX}(r) = \int d^3r_p d^3r_t \rho_p(\mathrm{r}_p, \mathrm{r}_p + \mathrm{s})\rho_t(\mathrm{r}_t, \mathrm{r}_t + \mathrm{s}) \times v^{EX}_{NN}(s) \exp\left[\frac{i\mathrm{K}(r)\cdot s}{M}\right]$$

$\rho_{p,t}$ – projectile and target densities, $\mathrm{K}(r)$ – local momentum of nucleus-nucleus relative motion, $v^{D,EX}_{NN}$ – effective NN potentials (with known parametrization).

Isovector part: $(\mathrm{r}_{p,t} + \mathrm{s})$ is replaced by $(\mathrm{r}_{p,t} - \mathrm{s})$; other parameters in expressions of $v^{D,EX}_{NN}$.

MicroOP: DF (2/2)

The effective nucleoun-nucleon potential v_{NN} is taken in the Paris CDM3Y6 form:

$$v_{NN}(E,\rho,s) = g(E)\,F(\rho)\,v(s), \quad v(s) = \sum_{i=1,2,3} N_i \frac{\exp(-\mu_i s)}{\mu_i s},$$

where the energy and density dependencies are given as

$$g(E) = 1{-}0.003E/A_p, \;\; F(\rho) = C\Big[1{+}\alpha\exp(-\beta\rho){-}\gamma\rho\Big], \;\; \rho = \rho_p{+}\rho_t,$$

where $C = 0.2658$, $\alpha = 3.8033$, $\gamma = 4.0$, and the parameters N_i and μ_i are done in D.T.Khoa & G.R.Satchler, Nucl. Phys. A 668 (2000) 3.

The local nucleus-nucleus momentum:

$$\mathrm{K}(r) = \{2Mm/\hbar^2[E - V_{DF}(r) - V_C(r)]\}^{1/2}$$

$M = A_p A_t/(A_p + A_t)$, m is the nucleon mass, V_C – Coulomb potential.

MicroOP: HEA

Within the optical limit of the Glauber theory, the microOP takes the form (V.Lukyanov at al, Phys. At. Nucl. 69 (2006) 240)

$$U^H_{opt}(r) = -\frac{E}{k}\bar{\sigma}_N(i+\bar{\alpha}_N)\frac{1}{(2\pi)^3}\int e^{-i\mathbf{qr}}\rho_p(q)\rho_t(q)f_N(q)d^3q$$

So, for the imaginary potential, we obtain:

$$W^H(r) = -\frac{1}{2\pi^2}\frac{E}{k}\bar{\sigma}_N\int_0^\infty j_0(qr)\rho_p(q)\rho_t(q)f_N(q)q^2dq.$$

$\bar{\sigma}_N$ – the isospin averaged NN total cross section, $\bar{\alpha}_N$ – the ratio of the real to imaginary part of the *NN* scattering amplitude at forward angles, $f_N(q) = \exp(-\beta_N \cdot q^2/2)$ is the form factor of *NN* amplitude.

OP: general form

$$U(r) = [N_R \cdot V(r) + N_{Rsf} \cdot V_{sf}(r)] + i[N_I \cdot W(r) + N_{Isf} \cdot W_{sf}(r)]$$

Relativistic energies:

$$V = V_H; \quad W = W_H$$

Intermediate energies:

$$V = V_{DF}; \quad W = W_H$$

Low energies:

$$V = V_{DF}; \quad W = W_{DF} = V_{DF}$$

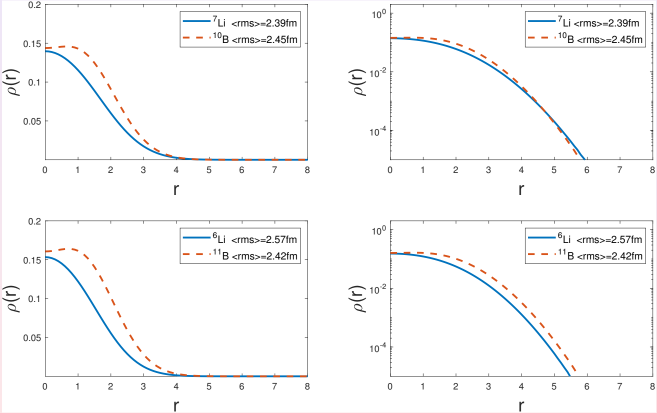
The surface term:

$$(1) \quad W_{sf} = -\frac{dW}{dr}; \qquad (2) \quad W_{sf} = -r \cdot \frac{dW}{dr}$$

Cross sections are calculated via the wave functions of corresponding Schrödinger equation using standard code DWUCK4; Coulomb potential and SO potential (if needed) are included.

Densities of interacting nuclei

Densities of ^{6,7}Li, ^{10,11}B are taken from Patterson & Peterson, Nucl. Phys. A. 717 (2003) 235 in the MHO form

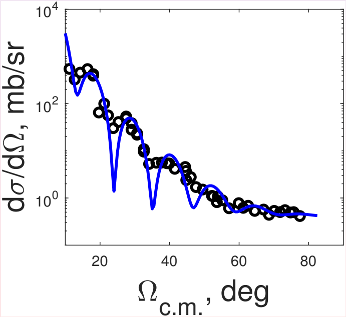


Elastic scattering ^{7}Li+^{10}B at 58 MeV (Var. 1)

Following K.Lukyanov et al, Bull. RAS: Physics, 72, No.3 (2008) 356, we used the OP in the form:

$$U(r) = [N_R \cdot V_{DF}(r) - N_{Rsf} \cdot r \frac{dV_{DF}}{dr}] + i[N_I \cdot W_{DF}(r) - N_{Isf} \cdot r \frac{dW_{DF}}{dr}]$$

where $N_R = 0.4$, $N_{Rsf} = 0.01$, $N_I = 0.01$, $N_{Isf} = 0.07$.



The ^{7}Li+^{10}B elastic scattering E_{lab}=39 MeV

We follow A.Etchegoyen et al. Phys. Rev. C38 (1988) 2124 where the ^{7}Li+^{10}B elastic scattering at 39 MeV was analysed neglecting the volume imaginary OP. The experimental data we reproduced using real volume WS OP and the imaginary surface WS-based OP. We could provide a reasonable agreement with experimental data usind our microOP.

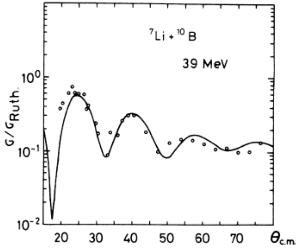
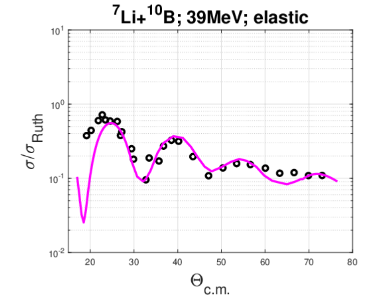


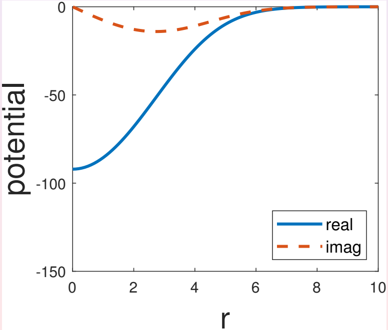
FIG. 3. Optical model fit to the ^{7}Li+^{10}B elastic reaction at 39 MeV.

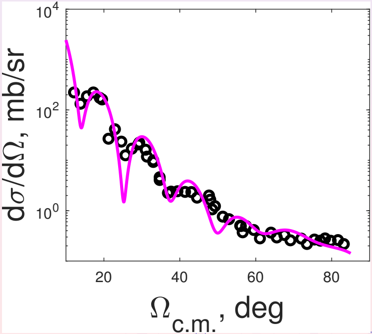


Elastic scattering of ^{7}Li+^{10}B at 58 MeV (Var. 2)

We use the same combination of real and imaginary terms in the E=58 MeV calculation:

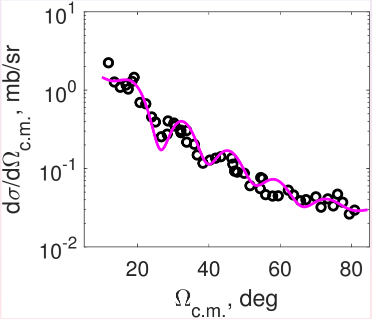
$$U(r) = N_R \cdot V_{DF}(r) - iN_{Isf} \cdot \frac{dW_{DF}}{dr}, \quad N_R = 0.65, N_{Isf} = 0.39$$



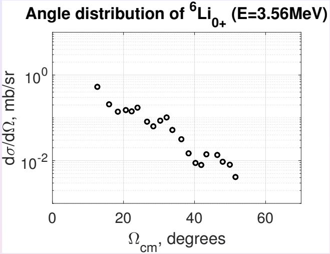


Transfer reaction ^{7}Li+^{10}B$\rightarrow$^{6}Li$_{g.s.}$+^{11}B

- ^{7}Li+^{10}B: the same OP as for elastic scattering case.
- ^{6}Li+^{11}B: $N_R = 0.9$, $N_{Rsf} = 0.05$, $N_I = 0.033$, $N_{Isf} = 0.63$.
- bound state of ^{11}B=n+^{10}B: parameters of WS potential were chosen to reproduce the binding energy



Transfer reaction $^{7}Li + ^{10}B \rightarrow ^{6}Li_{0+} + ^{11}B$

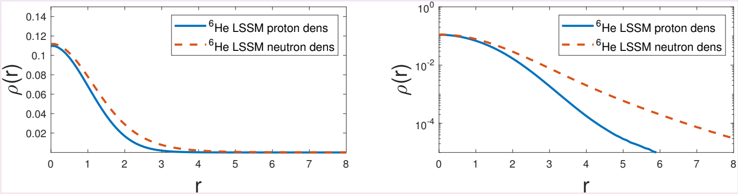


Excited nucleus $^{6}Li_{0+}$ is known as the isobar-analog state (IAS) of the neutron rich nucleus ^{6}He with 2n-halo. In the recent work A.Demyanova et al, Phys. Part. Nucl. 55 (2024) 375, the rms-radii of $^{6}Li_{0+}$ and ^{6}He are estimated to be close, the halo structure of $^{6}Li_{0+}$ has been assumed.

Open question – how to construct the density?

Structure of the $^{6}He_{g.s.}$ (IAS of $^{6}Li_{0+}$)

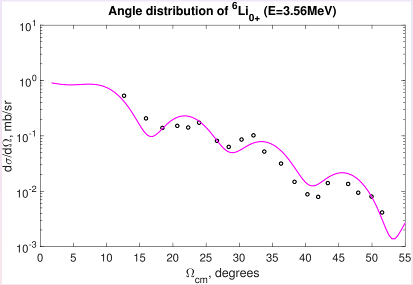
The LSSM model of the ^{6}He nuclear density distribution accounts for the halo structure of this nuclei which is considered as a cluster of ^{4}He and 2n-halo, S.Karataglidis et al,Phys. Rev. C 61 (2000) 024319 (rms-radius 2.586 fm).



$^{6}Li_{0+} \rightarrow {}^{4}He + pn$?

Is the $^{6}Li_{0+}$ structure (and density) close to the ^{6}He one?

Very preliminary



Summary

- The theoretical approach based on the microscopic double folding OP and on the DWBA method is appropriate to explain experimental data on ^{7}Li+^{10}B elastic scattering and the transfer reaction ^{7}Li+^{10}B→^{6}Li$_{g.s.}$+^{11}B at the beam energy $E_{LAB} = 58$ MeV.
- Confirmed that the absorption in this reaction plays a role only on the periferal region of nucleus.
- The results can be serve a framework for the further study on analysis of another experimental data, including the transfer reaction ^{7}Li+^{10}B→^{6}Li$_{0+}$+^{11}B.

Next steps

- Another models of nuclear density and OPs?
- Density of the excited nucleus ^{6}Li$_{0+}$ (E=3.56 MeV)?

Thank you for your attention!