MICROSCOPIC ANALYSIS OF ^{11}LI ELASTIC SCATTERING ON PROTONS

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1. Introduction

In a series of experiments on light nuclei it was established that the nucleus ^{11}Li has abnormally large rms radius. This is due to its neutron halo consists of two valence neutrons extended well beyond the ^{9}Li core, and the corresponding two-neutron separation energy is extremely small (0.247 MeV). In the present work we are aimed to calculate the elastic scattering cross section for ^{11}Li+p at three incident energies using the hybrid model of the microscopic optical potential (OP) [1] which has been applied successfully before [2–4] for ^{6,8}He+p and ^{6}He+^{12}C elastic scattering. Its real part is calculated by a single-folding procedure [5] using the large-scale shell model (LSSM) density of ^{11}Li, [6,7] while its imaginary part is derived basing on the high-energy approximation (HEA) theory. Besides, in the second part of this study we estimate the reaction mechanism such as the ^{11}Li breakup cross section with a help of the two-cluster model of ^{11}Li consisting of di-neutron and ^{9}Li core, and then we also calculate the fragment momentum distributions from the ^{11}Li+p breakup reaction.

2. Elastic scattering cross section

The optical potential used in our calculations has the form

$$U_{opt}(r) = N_R V^F + iN_I W^H + 2\lambda_\pi^2 \left\{ \frac{N_R^{SO}}{r}\frac{dV_0^F}{dr} + i\frac{N_I^{SO}}{r}\frac{dW_0^H}{dr} \right\} (\mathbf{l}.\mathbf{s}). \quad (1)$$

The real part V^F is a single folding of the ^{11}Li density ρ(r) and of the effective NN potential, and involves the direct and exchange parts [5].

The imaginary part W^H was derived [1] by comparison of the eikonal phase with the corresponding HEA phase of the Glauber theory to get:

$$W^H = -\frac{\hbar v}{(2\pi)^2}\bar{\sigma}_{NN}\int_0^\infty dq q^2 j_0(qr)\rho(q)f_{NN}(q). \quad (2)$$

Here σ_{NN} is the isospin averaged NN total cross section, and f_{NN} is the form factor of the NN amplitude of scattering. The calculated potentials are shown in Fig.1.

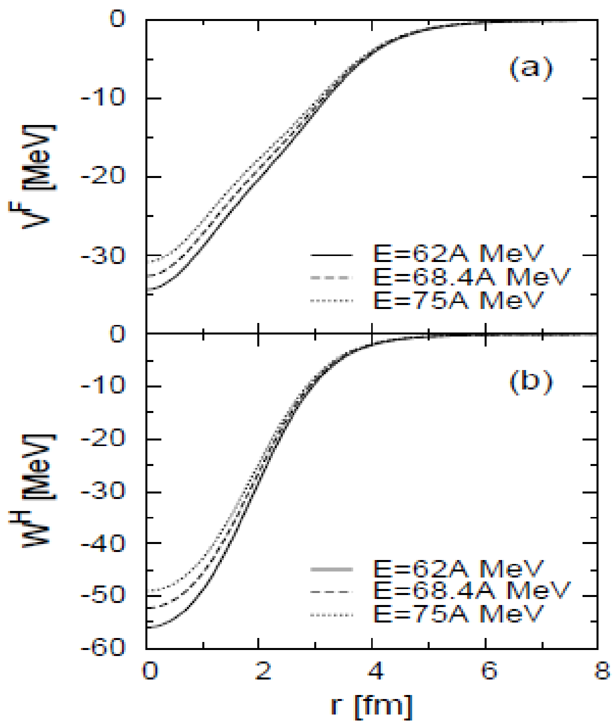

Figure 1. Microscopic OPs calculated using the LSSM proton and neutron densities of ^{11}Li at E = 62 (solid), 68.4 (dashed) and 75 MeV/nucleon (dotted lines)..

The spin-orbit (SO) contribution is shown in Fig.2 to be negligibly small. We fit the depths of V^F and W^F by introducing the parameters N_I , N_R, N_I^{SO}, N_R^{SO}. To resolve the problem of their ambiguity we additionally compare [3,4] the data with the known behavior of the volume integrals of OP as functions of energy.

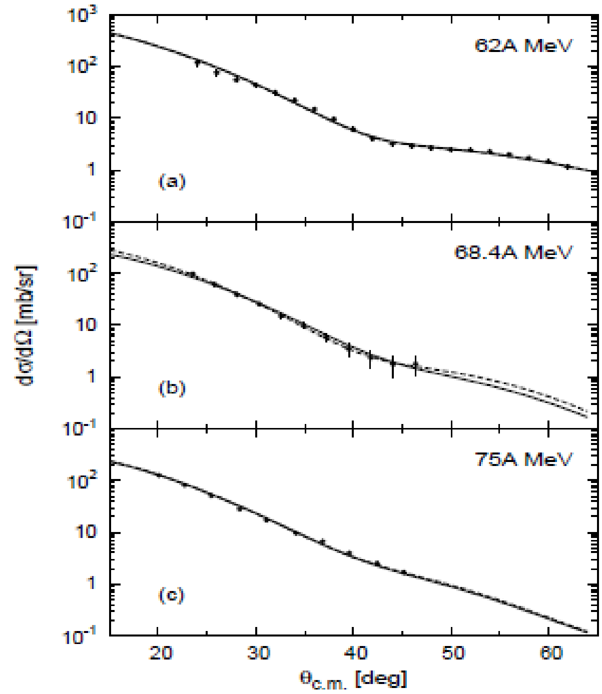

Figure 2. The ^{11}Li+p elastic scattering cross section at E = 62, 68.4, and 75 MeV/nucleon. Solid line: without SO term; dashed line: with SO term.

As a result the best sets of parameters were obtained and are shown below:

E	N_R	N_I	N_R^{SO}	N_I^{SO}	J_V	J_W	χ^2	σ_R
62	0.871	0.953			342.474	332.015	1.415	456.97
	0.851	0.974	0.028	0.000	334.610	339.332	1.468	461.21
68.4	0.625	0.186			232.210	60.489	1.328	153.44
	0.543	0.140	0.201	0.000	201.744	45.530	0.316	122.25
75	0.679	0.370			238.048	112.913		232.62
	0.660	0.369	0.045	0.000	231.387	112.607		232.62

3. Breakup cross section

It has been demonstrated [8] that the HEA method can estimate the total breakup cross sections. Here we consider ^{11}Li consisting of two clusters: the ^{9}Li core and the correlated pair of neutrons h = 2n [9]. The ”breakup”

V^F and W^H potentials were calculated, too. The corresponding elastic scattering cross section is shown in Fig.3, and the respective N's parameters together with the total absorption σ_{abs}^{tot}, breakup σ_{bu}^{tot} and reaction σ_R^{tot} cross sections are shown below (in mb):

$U^{(b)}$	N_R	N_I	σ_{abs}^{tot}	σ_{bu}^{tot}	σ_R^{tot}
V^F	1.407	1.195	79.0	431.8	510.8
W^H	1.381	1.306	78.6	405.3	483.9

4. Momentum distributions of fragments

In the case of the stripping reaction when the h - cluster leaves the elastic channel, the cross section takes the form:

$$\left(\frac{d\sigma}{dk_L}\right)_{str} = \frac{1}{2\pi^2}\int_0^\infty b_h db_h d\varphi_h \left[1-|S_h(b_h)|^2\right] \times$$
$$\times \int \rho d\rho d\varphi_\rho |S_c(b_c)|^2 \left[\int_0^\infty dz \cos(k_L z)\phi_0\left(\sqrt{\rho^2+z^2}\right)\right]^2 \qquad (3)$$

Here $\Phi_{00}(s) = \Phi_0(s) \times 1/(4\Pi)^{1/2}$ is the s-state wave function of the relative motion of two clusters. As is seen from Fig.4 the width of the peak of this cross section in reaction on the proton target is about 100 MeV/c, which is twice larger than those obtained in the experiments for reactions on nuclei ^{9}Be, ^{93}Nb and ^{181}Ta. One can estimate that if one considers the rms radius of ^{11}Li like that obtained by Tanihata (~ 3.1 fm), it is impossible to get value of ~50 MeV/c of the width. This problem remains open and requires further analysis.

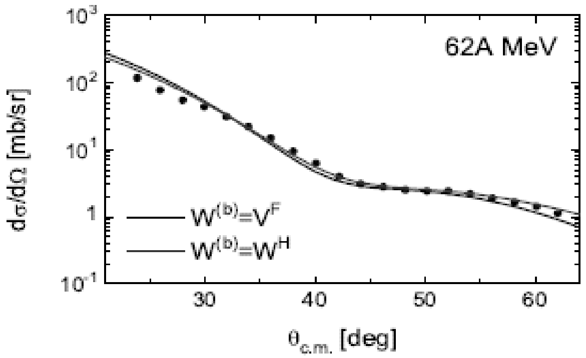

Figure 3. Elastic scattering cross section of ^{11}Li+p at E = 62 MeV/nucleon using ^{9}Li+2n model.

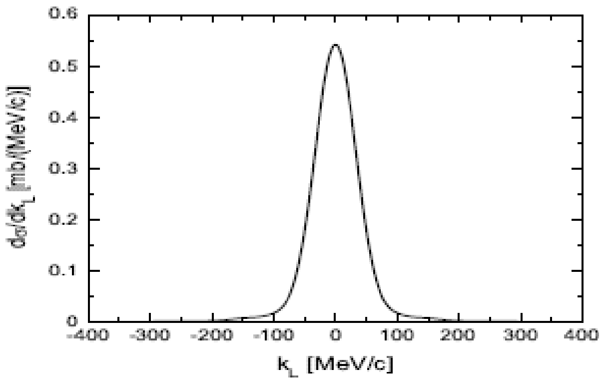

Figure 4. Cross section of stripping in ^{11}Li+p reaction at E = 62 MeV/nucleon

5. Conclusions

The microscopic OP and elastic cross sections of ^{11}Li+p scattering were calculated and successfully compared to the available experimental data. The SO term was included in the OP, but didn't contribute significantly. The problem of selecting N's parameters from many sets was solved using information on behavior of the volume integrals. We have also used another folding approach where ^{11}Li is considered as two-cluster system. This model predicts the breakup cross section σ_{bu}^{tot} that exceeds 80% from σ_R^{tot}. As for the longitudinal momentum distributions of ^{9}Li fragments produced in the breakup reaction on protons, its estimated width occurs twice larger than those measured in experiments on nuclear targets. We emphasize the necessity of experiments on stripping and diffraction reactions of ^{11}Li on proton targets at energy E < 100 MeV/nucleon.

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