Polarization potential for elastic scattering of ^{6,7}Li + ^{28}Si at near-barrier energies

Athena Pakou*
Department of Physics, The University of Ioannina, GR-45110 Ioannina, Greece
(Received 21 August 2008; published 2 December 2008)

The polarization potential for the elastic scattering of ^{6,7}Li + ^{28}Si at near barrier energies has been investigated in the context of an optical model framework. The effect on the elastic scattering was found to be strong, energy dependent, and compatible with the transfer channel.

DOI: 10.1103/PhysRevC.78.067601 PACS number(s): 25.70.Bc, 24.10.Ht, 24.50.+g

In recent decades, the effect of projectile breakup processes on elastic scattering, with respect to weakly bound nuclei, has attracted considerable attention. It has been found that for ^{6,7}Li projectiles a normalization factor must be applied in the effective M3Y(NN) interaction of a double folding model, which should be close to $N_R = 0.5$–0.6. This reduction of the normalization factor is necessary for the description of elastic scattering data and has been attributed to breakup [1].

Moreover, a comprehensive investigation into a microscopic framework was undertaken by Sakuragi [2] with ^{6,7}Li projectiles at various energies well above the Coulomb barrier. Breakup channels were taken into account by Continuum-Discretized Coupled Channels (CDCC) calculations. The work seems also to favor a picture where breakup can describe the loss of flux from the elastic channel. Other works [3,4], also in a polarization potential framework for stable or unstable weakly bound projectiles, treated breakup as the coupled channel which absorbs flux from the elastic one, while others considered inelastic scattering as the major absorber channel [5].

In recent research, however, it becomes more and more evident that transfer channels, especially at near barrier energies, are strong [6–12] and may be responsible for coupled channel effects appearing as a potential anomaly or fusion increase and/or reduction.

In principle, to calculate the interaction potential, one should include all possible virtual couplings between the ground and higher excited states or couplings to continuum states or to other reaction processes, like breakup and transfer. The effect on the elastic scattering of coupling to inelastic channels or to breakup can be represented in the optical potential by the addition of a polarization potential (DPP) [2,13].

In recent work, the elastic scattering for ^{6,7}Li + ^{28}Si at near barrier energies [14,15] has been successfully represented through a BDM3Y1 interaction with a normalization factor reduced by ∼35% for ^{6}Li and ∼45% for ^{7}Li. Using an alternative approach in this work, we seek a polarization potential that removes flux from elastic scattering and our aim is to identify the possible candidate channel compatible with this process. We have chosen these systems because they have been thoroughly investigated in the past from the point of view of both elastic scattering [14,15] and reaction mechanisms at near barrier energies [6,9,10,16].

Let us describe this polarization potential as

$$U_{\rm pol}(r) = V_{\rm pol}(r) + i\,W_{\rm pol}(r), \tag{1}$$

and according to the prescription in Ref. [3], let us represent it for reasons of simplicity by a Woods-Saxon derivative, centered at $r = 0$.

$$\begin{aligned} U_{\rm pol}(r) &= -(V_{\rm pol}(r) + i\,W_{\rm pol}(r))e^{r/\alpha}/(e^{r/\alpha}+1)^2 \\ &\rightarrow -(V_{\rm pol} + i\,W_{\rm pol})e^{-r/\alpha} \text{ for } r \rightarrow \infty. \end{aligned} \tag{2}$$

The adoption of a large diffusivity, α, and of the appropriate depths, $V_{\rm pol}$ and $W_{\rm pol}$, will give the necessary strength at the surface.

Subsequently let us add this potential to a "bare" potential like the one adopted in Refs. [14] and [15]. In that case the real part of the bare potential is calculated within the double folding model [17] by using the BDM3Y1 interaction developed by Khoa *et al.* [18]. The densities involved are obtained from electron scattering data, adopting a three parameter Fermi model, for ^{28}Si [19]; Hartree Fock calculations obtained by Trache *et al.* [20] for ^{7}Li; and the phenomenological relation adopted by Bray *et al.* [21] for ^{6}Li. The imaginary potential is assumed to be of the same radial shape as the real one and the same folded potential is adopted. For both potentials the normalization factor is set equal to 1.

Subsequently, by using the code ECIS [22] with a full potential, $U(r) = U_{\rm bare}(r) + U_{\rm pol}(r)$, the parameters $V_{\rm pol}$ and $W_{\rm pol}$ are adjusted for various values of $\alpha_{\rm pol}$ to best fit the elastic scattering data at three near barrier energies. Good fits are obtained with $\alpha_{\rm pol}$'s in the range of 1.3 to 1.6 fm, while the best values are obtained for $\alpha_{\rm pol} = 1.6$ fm and are shown as a function of energy in Fig. 1 and tabulated in Table I. As an example, the angular distributions of elastic scattering cross sections calculated with the full potential (bare + polarization) are compared with data measured at 13 MeV for both projectiles and show very good agreement (Fig. 2). Results of the calculation with the bare potential are also shown. Total reaction cross sections with the "bare" and full potentials are listed in Table II. In the same Table, the loss of flux described by the polarization potential is expressed via reaction cross sections, $\sigma_{\rm lost}$, obtained as the difference between reaction cross sections extracted with the bare and the full potentials. These cross sections should in principle account for all channels absorbing flux from the elastic scattering

*apakou@cc.uoi.gr

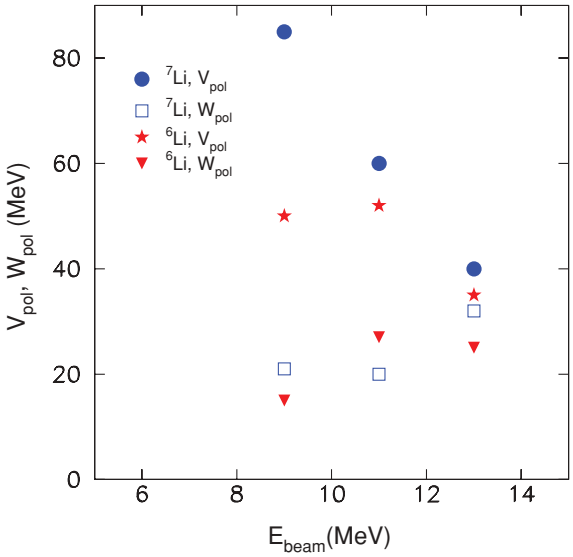

FIG. 1. (Color online) The real (V_{pol}) and imaginary (W_{pol}) parts of the polarization potential extracted from elastic scattering data for ^{6,7}Li + ^{28}Si are presented as a function of projectile energy. The assigned error is of the order of 20%.

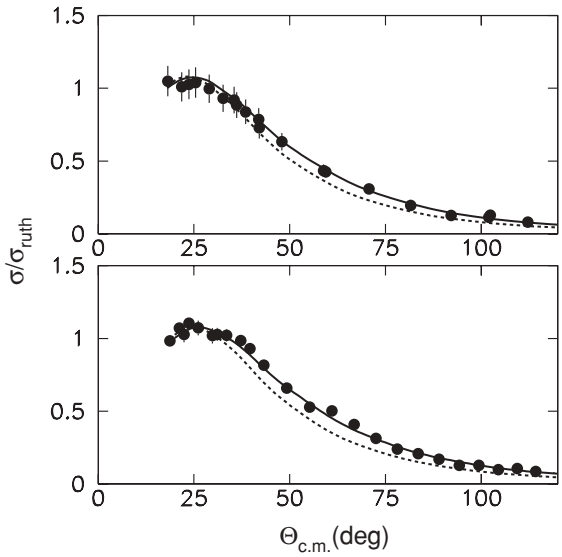

FIG. 2. Elastic scattering angular distribution data for ^{6}Li + ^{28}Si (top) and ^{7}Li + ^{28}Si (bottom) are compared with calculations with the bare potential (dashed line) and with the full potential (bare + polarization potential, solid line).

channel, that is, inelastic scattering, breakup, and transfer. At this point, we should underline that the above results are liable to the following assumptions: (a) The bare potential generates a reaction cross section, which almost equals fusion (the direct cross sections is zero or minimal). (b) The change of the barrier height, which occurs by changing the real part of the potential in the fit, is small and does not appreciably affect the fusion cross section from the stage of using the bare potential to the stage of using the full potential.

Comparing in Table II the cross sections due to the loss of flux, σ_{lost}, with previously measured transfer cross sections, $\sigma^{tr.}_{meas.}$, and breakup cross sections, $\sigma^{br.}_{meas.}$, for energies where such data exist [10,16,23], we note that the mechanism of transfer exhausts the cross section appearing due to the polarization potential. Of course more comprehensive research in a full CDCC and Coupled Reaction Channels (CRC) framework is necessary to draw firm conclusions for the suitability of breakup versus transfer for describing coupled channel effects at barrier energies. While extensive CDCC and CRC calculations are necessary to fully understand the origin of the real and imaginary part of the polarization potential and therefore to interpret its obtained energy dependence, in the present work we can speculate the following. Despite the large errors attributed to the parameters of the polarization potential to the extent of 20%, the energy dependence of both the real part and the imaginary part indicate (a) a difference between ^{6}Li and ^{7}Li with respect to the effect of the direct mechanism in the loss of flux and (b) an energy dependence, which is stronger for the last one and is well represented by the measured transfer cross sections (Table II: at higher energies the transfer cross sections are higher in accordance with the lower strength of the real potential depth parameters).

In summary, we have obtained a polarization potential that describes well elastic scattering data for ^{6,7}Li + ^{28}Si at near barrier energies in an optical potential framework. The effect of this polarization potential on elastic scattering is strong, energy dependent, and capable of producing "loss of flux" cross sections that are compatible with previously measured transfer cross sections. This fact indicates that transfer can

TABLE I. The real and imaginary part of the polarization potential as described by a Woods Saxon derivative for α = 1.6 fm.

Projectile	E (MeV)	V_{pol} (MeV)	W_{pol} (MeV)
^{6}Li	13	35	25
	11	58	20
	9	50	15
^{7}Li	13	40	32
	11	45	20
	9	85	21

TABLE II. Reaction cross sections in mb with the bare potential, $\sigma^{reac.}_{bare}$, and the full potential, $\sigma^{reac.}_{full}$. Reaction cross sections due to the loss of flux from the elastic channel described with the polarization potential, σ_{lost} ($\sigma_{lost} = \sigma^{reac.}_{bare} - \sigma^{reac.}_{full} = \sigma^{elastic}_{full} - \sigma^{elastic}_{bare}$), are compared with transfer, $\sigma^{tr.}_{meas.}$, and breakup, $\sigma^{br.}_{meas.}$, cross sections measured previously [10,16,23].

Projectile	E (MeV)	$\sigma^{reac.}_{bare}$	$\sigma^{reac.}_{full}$	σ_{lost}	$\sigma^{tr}_{meas.}$	$\sigma^{br}_{meas.}$
^{6}Li	13	1057	879	178	191	21
	11	808	603	176		
	9	453	298	128	128	
^{7}Li	13	1051	824	227	273	
	11	787	617	170		
	9	416	239	177		

play a dominant role in coupled channel effects at near barrier energies for weakly bound projectiles.

We warmly acknowledge enlightening discussions with Nicola Alamanos, Krzysztof Rusek, and Nick Keeley.

[1] G. R. Satchler and W. G. Love, Phys. Lett. **B76**, 23 (1978).
[2] Y. Sakuragi, Phys. Rev. C **35**, 2161 (1987).
[3] M. S. Hussein and G. R. Satchler, Nucl. Phys. **A567**, 165 (1994).
[4] V. Lapoux *et al*., Phys. Lett. **B658**, 198 (2008).
[5] J. Gomez-Camacho, M. Lozano, and M. A. Nagarayan, Phys. Lett. **B161**, 39 (1985).
[6] A. Pakou *et al*., Phys. Rev. Lett. **90**, 202701 (2003).
[7] A. Raabe *et al*., Nature (London) **431**, 823 (2004).
[8] A. Navin *et al*., Phys. Rev. C **70**, 044601 (2004).
[9] A. Pakou *et al*., Phys. Rev. C **71**, 064602 (2005).
[10] A. Pakou *et al*., Phys. Rev. C **76**, 054601 (2007).
[11] J. J. Kolata, Phys. Rev. C **71**, 067603 (2005); E. F. Aguilera *et al*., *ibid*. **63**, 061603(R) (2001).
[12] N. Keeley, R. Raabe, N. Alamanos, and J. L. Sida, Prog. Part. Nucl. Phys. **59**, 579 (2007).
[13] M. E. Brandam and G. R. Satchler, Phys. Rep. **285**, 143 (1997).
[14] A. Pakou *et al*., Phys. Lett. **B556**, 21 (2003).
[15] A. Pakou *et al*., Phys. Rev. C **69**, 054602 (2004).
[16] A. Pakou *et al*., Phys. Lett. **B633**, 691 (2006).
[17] G. R. Satchler and W. G. Love, Phys. Rep. **55**, 183 (1979).
[18] D. T. Khoa and W. von Oertzen, Phys. Lett. **B342**, 6 (1995).
[19] H. D. De Vries, C. W. Jager, and C. De Vries, At. Data Nucl. Data Tables **14**, 479 (1974).
[20] L. Trache *et al*., Phys. Rev. C **61**, 024612 (2000) (private communication).
[21] K. H. Bray *et al*., Nucl. Phys. **89**, 35 (1972).
[22] Jacques Raynal, Phys. Rev. C **23**, 2571 (1981).
[23] A. Pakou *et al*. (submitted for publication to PRC).