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Breakup Coupling Effects on Near-Barrier $^6$Li, $^7$Be and $^8$B + $^{58}$Ni Elastic Scattering Compared

N. Keeley$^a$, R.S. Mackintosh$^b$ and C. Beck$^c$

$^a$Department of Nuclear Reactions, The Andrzej Sołtan Institute for Nuclear Studies, ul. Hoża 69, 00-681 Warsaw, Poland

$^b$Department of Physics and Astronomy, The Open University, Milton Keynes, MK7 6AA, United Kingdom

$^c$Institut Pluridisciplinaire Hubert Curien et Université Louis Pasteur, Boîte Postale 28, F-67037 Strasbourg Cedex 2, France

New data for near-barrier $^6$Li, $^7$Be and $^8$B + $^{58}$Ni elastic scattering enable a comparison of breakup coupling effects for these loosely-bound projectiles. Coupled Discretised Continuum Channels (CDCC) calculations suggest that the large total reaction cross sections for $^8$B + $^{58}$Ni are dominated by breakup at near-barrier energies, unlike $^6$Li and $^7$Be where breakup makes a small contribution. In spite of this, the CDCC calculations show a small coupling influence due to breakup for $^8$B, in contrast to the situation for $^6$Li and $^7$Be. An examination of the S matrices gives a clue to this counter-intuitive behaviour.

1. INTRODUCTION

Recent data [1] for near-barrier $^6$Li, $^7$Be and $^8$B + $^{58}$Ni elastic scattering allow some interesting comparisons for these weakly-bound nuclei. Optical model fits find much larger total reaction cross sections ($\sigma_R$) for $^8$B than for $^6$Li or $^7$Be, even when “reduced” [2]; while the reduced $\sigma_R$ for other weakly-bound projectiles lie on a universal curve, those for $^8$B and $^6$He are significantly larger [1]. The low $^8$B $\rightarrow$ $^7$Be + p breakup threshold (0.1375 MeV) suggests a dominant contribution to the direct part of $\sigma_R$. This is not automatic: for $^6$He with an $\alpha + 2n$ breakup threshold of 0.973 MeV, 1$n$- and 2$n$-stripping are the main contributors to $\sigma_R$ at near-barrier energies. However, the weakly-bound proton in $^8$B experiences Coulomb barrier and charge polarisation effects tending to suppress transfer.

CDCC calculations [3] find that breakup does dominate the direct component of $\sigma_R$ for $^8$B: as the cross sections are large — of the order of 100 mb or more — one might expect an equally important coupling effect on the elastic scattering angular distribution. However, this is not the case [3]. We thus have an apparent paradox: $^6$Li, with a relatively small breakup cross section, exhibits an important breakup coupling effect on the elastic scattering (see e.g. [4]) whereas $^8$B, with a large breakup cross section, shows only a modest coupling effect. A comparison of S matrices obtained from CDCC calculations for $^6$Li, $^7$Be and $^8$B + $^{58}$Ni provides a clue to this behaviour. Preliminary dynamic polarisation potentials (DPPs) are also presented.
2. CALCULATIONS

Calculations were performed with the code FRESCO [5]: only a brief outline is given here. The $^6$Li, $^7$Be and $^8$B nuclei were modelled as $\alpha + d$, $\alpha + ^3$He and $^7$Be + $p$ clusters, respectively. The $^7$Be core was treated as inert but its non-zero spin was retained. Interaction potentials were obtained by Watanabe-type folding of global optical potentials, with a $^6$Li potential as surrogate for $^7$Be, the well-depths being adjusted to give the best fit to the data. The $^6$Li and $^7$Be calculations were similar to those in [4] and [6], but with finer continuum binning for $^7$Be. The $^8$B calculations included couplings to the $L = 0$, 1, 2 and 3 continuum and the 0.774 MeV $1^+$ and 2.32 MeV $3^+$ resonances. Good fits to all the data were obtained. Due to lack of space we show only results for the same values of $E_{c.m.} - V_B$ for each system, where $V_B$ is the nominal Coulomb barrier, taking as our “benchmark” the $^8$B data at $E_{lab} = 29.26$ MeV. This procedure yields values of $E_{lab} = 19.04$ and 24.12 MeV for $^6$Li and $^7$Be + $^{58}$Ni, respectively. In this way effects due to differences in projectile charge should be minimised.

Results are presented in Fig. 1: the coupling effect is much stronger for $^6$Li and $^7$Be, with $^6$Li $\rightarrow$ $\alpha + d$ and $^7$Be $\rightarrow$ $\alpha + ^3$He breakup thresholds of 1.47 and 1.59 MeV, respectively, an order of magnitude larger than the $^8$B $\rightarrow$ $^7$Be + $p$ threshold. The $^6$Li $\rightarrow$ $\alpha + d$ process has the additional peculiarity that it cannot proceed via dipole breakup. If we include population of the bound 1/2$^-$ state in $^7$Be (considering breakup as an inelastic excitation) the total breakup cross sections for both $^6$Li and $^7$Be are about a factor of three smaller than for $^8$B. To obtain a clue to this apparent paradox, we show in Fig. 2 the modulus and argument of the $J$-weighted S matrices [7] obtained from full and no-coupling calculations. The coupling effect on $|S|$ is almost negligible for $^8$B and largest for $^6$Li, but qualitatively

Figure 1. CDCC calculations for $^8$B, $^7$Be and $^6$Li + $^{58}$Ni at $E_{lab} = 29.26$, 24.12 and 19.04 MeV. Solid and dashed curves denote full and no-coupling results, respectively.
Figure 2. $|S|$ and $\arg(S)$ from CDCC calculations for $^8$B, $^7$Be and $^6$Li + $^{58}$Ni at $E_{\text{lab}} = 29.26$, 24.12 and 19.04 MeV. Solid and dashed curves denote full and no-coupling results, respectively.

similar for all three nuclei: a decrease of $|S|$ at small $L$ and an increase at large $L$. By contrast, for $\arg(S)$ the coupling effect is greatest for $^8$B, smallest for $^7$Be and intermediate for $^6$Li.

3. DISCUSSION

For protons and other light particles, changes in $|S|$ correspond to changes in the imaginary part of the potential, while changes in $\arg(S)$ correspond to changes in the real part. While this simple picture is not so clear-cut in the presence of strong absorption (as here) it provides a useful guide. Thus, the coupling effect on $|S|$ suggests reduced absorption at small $L$, switching to increased absorption at large $L$. The effect on $\arg(S)$ suggests repulsion at small $L$ and attraction at large $L$. These effects are qualitatively similar for all three nuclei. The fact that the coupling effect on both the elastic scattering and $|S|$ is so small for $^8$B suggests that, paradoxical as it may seem for a coupling producing such a large cross section, its effective imaginary potential is small.

DPPs may be obtained by inversion of the $S$ matrix, see e.g. [8]. In Fig. 3 we show the results of such a procedure for $^8$B and $^7$Be. Those for $^7$Be are preliminary; we expect the final DPPs to be somewhat smoother. While the DPPs are qualitatively similar,
short-range repulsion and long-range attraction combined with surface absorption (this behaviour seems to be universal, see e.g. [9]), the details are very different. The small

Figure 3. DPPs from CDCC calculations for $^{8}$B (solid curves) and $^{7}$Be (dotted curves).

imaginary DPP for $^{8}$B is particularly striking, confirming the conclusions inferred from the S matrices. The surface repulsion for $^{8}$B is also much smaller than for $^{7}$Be, although for radii larger than about 9 fm it is significantly larger than for $^{7}$Be, having a longer, more repulsive tail. Our results show that a large cross section is no guarantee of a large coupling effect. The S matrices and DPPs shed some light on this, but it remains to be explained at a more fundamental level.

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