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

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New data for near-barrier ${}^6\text{Li}$, ${}^7\text{Be}$ and ${}^8\text{B} + {}^{58}\text{Ni}$ 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 ${}^8\text{B} + {}^{58}\text{Ni}$ are dominated by breakup at near-barrier energies, unlike ${}^6\text{Li}$ and ${}^7\text{Be}$ where breakup makes a small contribution. In spite of this, the CDCC calculations show a small coupling influence due to breakup for ${}^8\text{B}$, in contrast to the situation for ${}^6\text{Li}$ and ${}^7\text{Be}$. An examination of the S matrices gives a clue to this counter-intuitive behaviour.

1. INTRODUCTION

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

CDCC calculations [3] find that breakup does dominate the direct component of σ_R for ${}^8\text{B}$: 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: ${}^6\text{Li}$, with a relatively small breakup cross section, exhibits an important breakup coupling effect on the elastic scattering (see e.g. [4]) whereas ${}^8\text{B}$, with a large breakup cross section, shows only a modest coupling effect. A comparison of S matrices obtained from CDCC calculations for ${}^6\text{Li}$, ${}^7\text{Be}$ and ${}^8\text{B} + {}^{58}\text{Ni}$ provides a clue to this behaviour. Preliminary dynamic polarisation potentials (DPPs) are also presented.

2. CALCULATIONS

Calculations were performed with the code FRESKO [5]: only a brief outline is given here. The ${}^6\text{Li}$, ${}^7\text{Be}$ and ${}^8\text{B}$ nuclei were modelled as $\alpha + d$, $\alpha + {}^3\text{He}$ and ${}^7\text{Be} + p$ clusters, respectively. The ${}^7\text{Be}$ 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 ${}^6\text{Li}$ potential as surrogate for ${}^7\text{Be}$, the well-depths being adjusted to give the best fit to the data. The ${}^6\text{Li}$ and ${}^7\text{Be}$ calculations were similar to those in [4] and [6], but with finer continuum binning for ${}^7\text{Be}$. The ${}^8\text{B}$ 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 $E_{\text{c.m.}} - V_{\text{B}}$ for each system, where V_{B} is the nominal Coulomb barrier, taking as our ‘‘benchmark’’ the ${}^8\text{B}$ data at $E_{\text{lab}} = 29.26$ MeV. This procedure yields values of $E_{\text{lab}} = 19.04$ and 24.12 MeV for ${}^6\text{Li}$ and ${}^7\text{Be} + {}^{58}\text{Ni}$, 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 ${}^6\text{Li}$ and ${}^7\text{Be}$, with ${}^6\text{Li} \rightarrow \alpha + d$ and ${}^7\text{Be} \rightarrow \alpha + {}^3\text{He}$ breakup thresholds of 1.47 and 1.59 MeV, respectively, an order of magnitude larger than the ${}^8\text{B} \rightarrow {}^7\text{Be} + p$ threshold. The ${}^6\text{Li} \rightarrow \alpha + d$ process

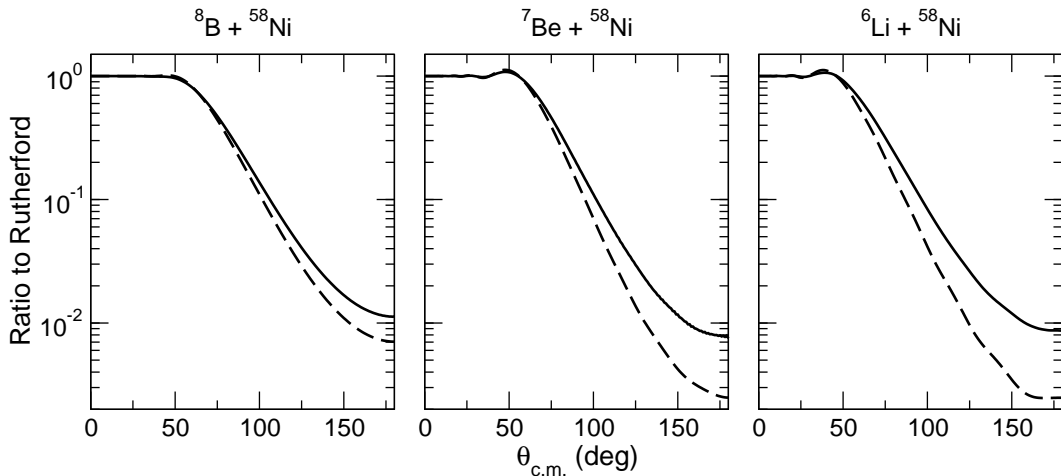


Figure 1. CDCC calculations for ${}^8\text{B}$, ${}^7\text{Be}$ and ${}^6\text{Li} + {}^{58}\text{Ni}$ at $E_{\text{lab}} = 29.26, 24.12$ and 19.04 MeV. Solid and dashed curves denote full and no-coupling results, respectively.

has the additional peculiarity that it cannot proceed via dipole breakup. If we include population of the bound $1/2^-$ state in ${}^7\text{Be}$ (considering breakup as an inelastic excitation) the total breakup cross sections for both ${}^6\text{Li}$ and ${}^7\text{Be}$ are about a factor of three smaller than for ${}^8\text{B}$. 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 ${}^8\text{B}$ and largest for ${}^6\text{Li}$, but qualitatively

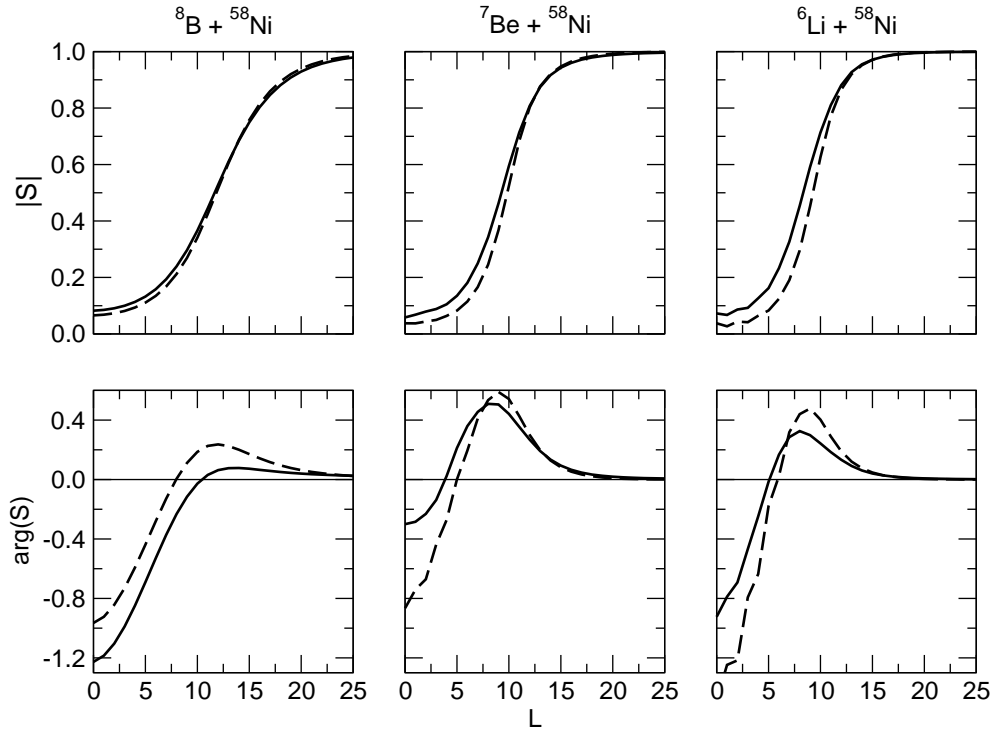


Figure 2. $|S|$ and $\arg(S)$ from CDCC calculations for ${}^8\text{B}$, ${}^7\text{Be}$ and ${}^6\text{Li} + {}^{58}\text{Ni}$ at $E_{\text{lab}} = 29.26, 24.12$ and 19.04 MeV. Solid and dashed curves denote full and no-coupling results, respectively.

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 ${}^8\text{B}$, smallest for ${}^7\text{Be}$ and intermediate for ${}^6\text{Li}$.

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 ${}^8\text{B}$ 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 ${}^8\text{B}$ and ${}^7\text{Be}$. Those for ${}^7\text{Be}$ 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

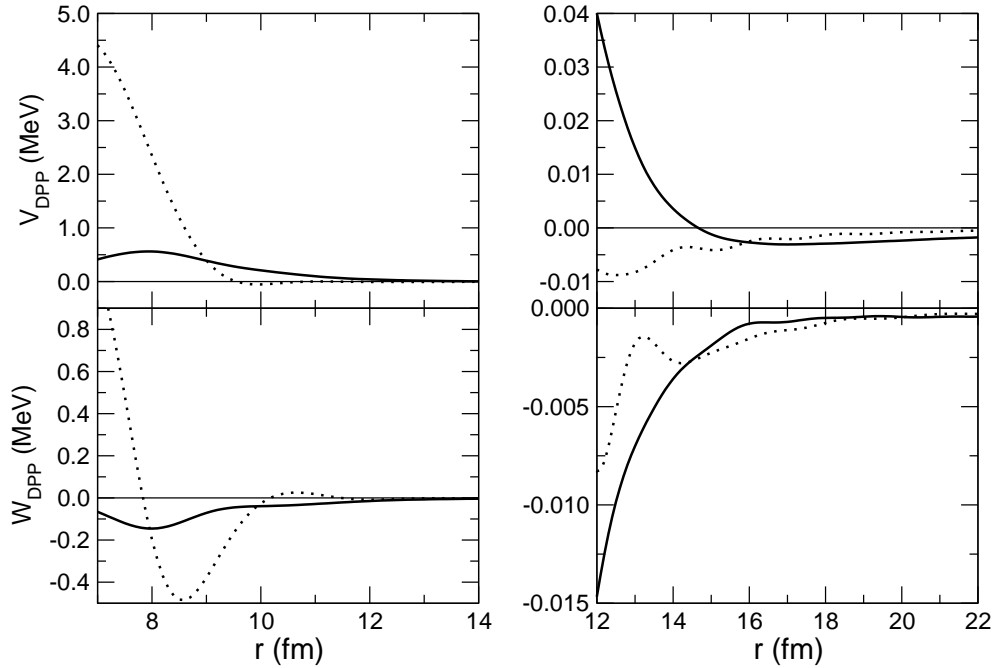


Figure 3. DPPs from CDCC calculations for ${}^8\text{B}$ (solid curves) and ${}^7\text{Be}$ (dotted curves).

imaginary DPP for ${}^8\text{B}$ is particularly striking, confirming the conclusions inferred from the S matrices. The surface repulsion for ${}^8\text{B}$ is also much smaller than for ${}^7\text{Be}$, although for radii larger than about 9 fm it is significantly larger than for ${}^7\text{Be}$, 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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