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Journal Article

How to cite:

Keeley, N.; Mackintosh, R. S. and Beck, C. (2010). Breakup coupling effects on near-barrier $^6\text{Li}$, $^7\text{Be}$ and $^8\text{B}$ + $^{58}\text{Ni}$ elastic scattering compared. Nuclear Physics A, 834(1-4) 792c-795c.
Breakup Coupling Effects on Near-Barrier $^6$Li, $^7$Be and $^8$B + $^{58}$Ni Elastic Scattering Compared

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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, 1n- and 2n-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 $^6\text{Li}$, $^7\text{Be}$ 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 $E_{\text{c.m.}} - V_B$ 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 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

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig1.png}
\caption{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.}
\end{figure}
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

![Graph showing 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.

**REFERENCES**