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A $^{5}He{+}\alpha$ CLUSTER MODEL OF ^{9}Be*

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Using a simple ^{5}He+α cluster model of ^{9}Be we are able to obtain good agreement with the measured values of the ground-state quadrupole moment and B (E2; $3/2^- \to 5/2^-$) and B (E2; $3/2^- \to 7/2^-$). We use this simple model to fit elastic scattering data in 3-channel coupled-channels calculations and produce predictions for the angular distribution of the breakup of ^{9}Be via the $5/2^-$ resonant state at 2.43 MeV.

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1. Introduction

The ^{9}Be nucleus is of particular interest as not only does it have a low breakup threshold, thus providing an interesting comparison with the other weakly bound nuclei ^{6}Li and ^{7}Li, but it is also "Borromean" like the halo nuclei ^{6}He and ^{11}Li, *i.e.* it has no stable binary breakup channel but must be considered as a three-body system. From the experimental point of view, as ^{9}Be is stable, unlike the other three-body systems of interest, it is much easier to obtain accurate scattering data. It is also possible to obtain data at energies near the Coulomb barrier, where we hope to see interesting effects (based on experience with ^{6}Li and ^{7}Li), at present impossible for radioactive beams.

However, at present there is no way of treating a 3-body projectile in a reaction calculation at energies near the Coulomb barrier, current theoretical models being limited to high incident energies due to the approximations necessary for a practicable calculation. Therefore, we have considered the possibility of using a simple two-body cluster picture of ^{9}Be for near-barrier scattering.

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2. The model

There are several possible ways of dividing ^{9}Be into a two-body cluster, but the two most likely systems are ^{8}Be+n and ^{5}He+α, both decaying to 2α+n. Of the two, ^{8}Be+n has the lowest breakup threshold (1.67 MeV) and was investigated first. However, we were unable to obtain agreement with the measured values of the ground-state quadrupole moment, Q, or the B(E2) for excitation of the $5/2^-$ and $7/2^-$ resonant states at 2.43 and 6.76 MeV respectively (these two resonances were found to be most important by Hirabayashi *et al.* [1]). Thus, we discarded this model and turned to a ^{5}He+α cluster picture.

The ^{5}He+α cluster model was much more sucessfull; we were able to obtain excellent agreement with the measured values of Q and $B(\mathrm{E2}; 3/2^- \rightarrow 5/2^-)$ and slightly worse agreement for $B(\mathrm{E2}; 3/2^- \rightarrow 7/2^-)$. The measured values are as follows: $Q = 5.3 \pm 0.3$ e fm^2 [2], $B(\mathrm{E2}; 3/2^- \rightarrow 5/2^-) = 34.8$ [3] or 27.7 [4] e^{2}fm^4 and $B(\mathrm{E2}; 3/2^- \rightarrow 7/2^-) = 12.8$ [3] or 9.6 e^{2}fm^4, while our model gives 5.4 e fm^2, 37.2 e^{2}fm^4 and 18.3 e^{2}fm^4, respectively.

The calculations were carried out within the framework of the cluster-folding model, using the code FRESCO [5], version FRXP. The breakup threshold for ^{5}He+α is 2.47 MeV [2], thus the $5/2^-$ resonance is bound with respect to this threshold and was treated as such. The $7/2^-$ resonance was treated as an unbound bin of width $\Delta E = 3$ MeV (the measured FWHM is 1.54 ± 0.2 MeV [2]). The ^{5}He+α clusters were bound in Woods–Saxon wells, the depths being adjusted to give the appropriate binding energies. The geometry parameters were adjusted to give optimum agreement with the measured Q and B (E2) values in the case of the ground and $5/2^-$ states, and the correct resonance energy for the $7/2^-$ state. The ground-state was considered to be $L = 1$ while the $5/2^-$ and $7/2^-$ states were treated as $L = 3$, where L is the angular momentum of relative motion of the clusters.

Our calculations do not consider the effect of any "^{5}He+α" continuum, as tests showed that its inclusion has little effect on the elastic scattering and the measurements of MacDonald *et al.* [6] suggest that the continuum is mainly ^{8}Be+n.

The ^{5}He-target and α-target potentials were both taken from the global α potential of Avrigeanu *et al.* [7]. The real and imaginary depths were considered as parameters in the calculations, being re-normalised to give optimum agreement with the elastic scattering.

3. Results

Figure 1 compares 3-channel (*i.e.* including couplings to the $5/2^-$ and $7/2^-$ states plus ground-state reorientation) calculations with optical model fits [8, 9] to elastic scattering data for three different targets at near-barrier energies. The optical model fits are indicated by the dots; the dashed curves indicate the results with un-re-normalised ^{5}He-target and α-target optical potentials and the full curves denote the results where V and W have been re-normalised to obtain optimum agreement with the optical model fits.

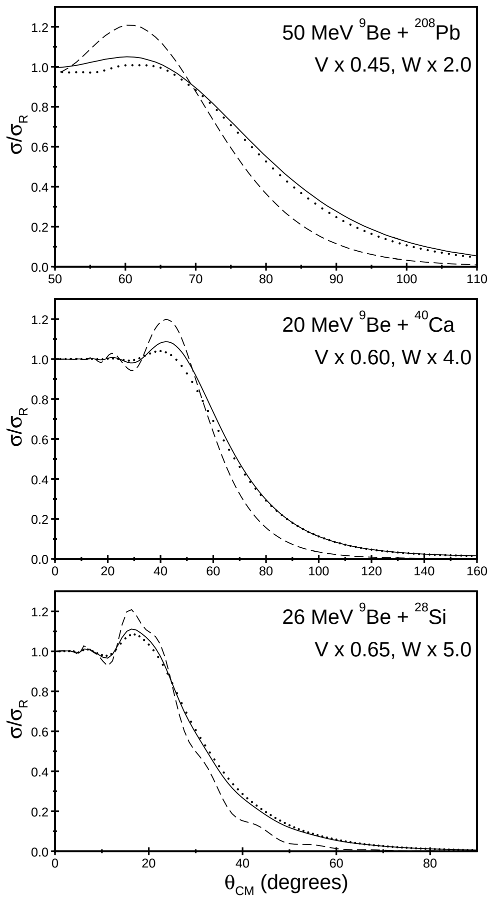

Fig. 1. Comparison of the results of 3-channel coupled-channels calculations with un-re-normalised (dashed curves) and re-normalised (full curves) optical potentials with optical model fits to elastic scattering data (dots). The re-normalisations used are indicated in the figure.

Predicted angular distributions using the re-normalised potentials for breakup of ^{9}Be via the $5/2^-$ state are shown in figure 2. The full curves show the results of the full calculations, the dashed curves show the results of calculations using only the Coulomb form-factor and the dotted curves those using just nuclear excitation.

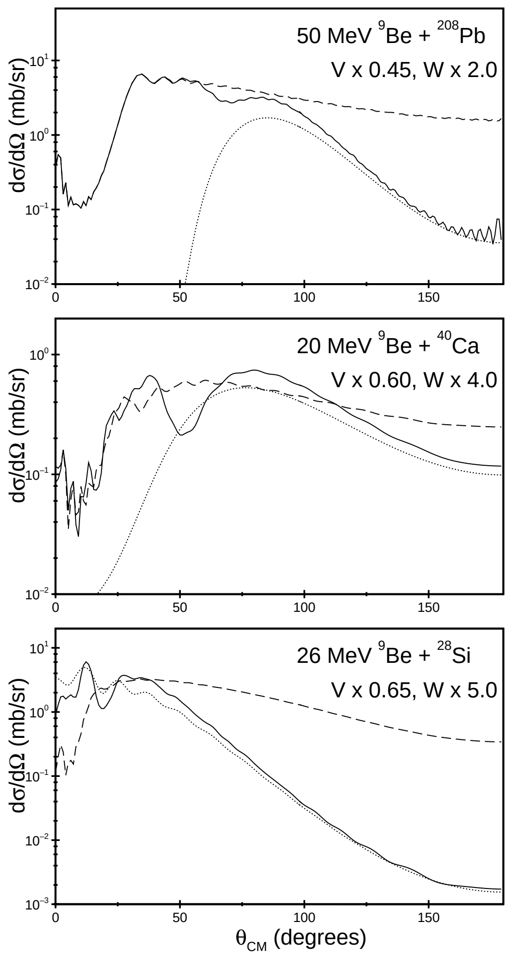

Fig. 2. Predictions of angular distributions for breakup of ^{9}Be via the $5/2^{-}$ resonance at 2.43 MeV using the re-normalised optical potentials. The dashed curves indicate the use of the Coulomb form-factor only, the dotted curves that of the nuclear form-factor only and the full curves denote the full calculations using both form-factors.

4. Conclusions

Using a simple two-body ^{5}He+α cluster model of ^{9}Be we are able to reproduce the measured values of the ground-state Q and $B(\mathrm{E2};\, 3/2^{-} \to 5/2^{-})$ very well. We obtain slightly less good agreement for $B(\mathrm{E2};\, 3/2^{-} \to 7/2^{-})$, our calculated value being about 1.4 times the measured one. This suggests that while the ground-state and $5/2^{-}$ state at 2.43 MeV are largely of ^{5}He+α cluster character, the $7/2^{-}$ state at 6.76 MeV is less well described in this way. This is supported to some extent by the three-body structure calculations of Okabe and Abe [10]. Their calculated decay widths show substantial branches to the ^{5}He ground state for both the $5/2^-$ and $7/2^-$ states, but with a significant fraction also decaying to ^{8}Be for the $7/2^-$. It should, however, be noted that their calculated total widths are not always in good agreement with the measured values.

We are able to obtain good agreement with optical model fits to elastic scattering data using our model, provided that the real and imaginary depths of the ^{5}He-target and α-target optical potentials are regarded as parameters. The large ($\sim$ 50-60 %) re-normalisations of the real parts of the potentials are probably partly due to the omission of any continuum coupling, which we expect to produce a positive real polarization potential similar to those for ^{6}Li and ^{7}Li, as well as to ambiguities in the choice of potential parameters.

The angular distribution predictions for breakup via the $5/2^-$ resonance indicate that Coulomb breakup completely dominates at forward angles near the barrier, thus providing a good regime for studies of astrophysical interest. As the energy increases, however, it appears that nuclear breakup rapidly dominates.

Thus, we believe that our simple two-body cluster model provides a useful basis for near-barrier reaction studies with ^{9}Be, providing a good description of the ground and main resonant states. Accurate data for breakup of ^{9}Be via the $5/2^-$ and $7/2^-$ resonances is highly desirable to provide a more rigorous test of the model.

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