Article title: The puzzle of complete fusion suppression in weakly-bound exotic nuclei: a Trojan Horse effect?

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Purpose

They are trying to determine the origin of complete fusion (CF) suppression in light weakly-bound nuclei. They propose a new, quantum-mechanical model to compute cross sections and explain the suppression using the projectile binding energy.

Context

The complete fusion cross section (defined as the capture of all projectile charge) is suppressed by ∼20-30% 'compared to the case of tightly bound nuclei' (I don't fully understand the suppression, but they have refs 1-7 listed with this claim). So far this suppression has been explained by break up of the light projectile followed by capture of a charged fragment, but classical dynamical model calculations indicate that this can only account for part of the suppression. The other problem is that for exotic nuclei, the main breakup mode is via neutron separation (no loss of charge), yet a large (∼30%) fusion suppression has been observed.

Approach

They use two features in their evauation of the cross section for complete fusion: 1. strong clustering in the projectile to decompose non-elastic processes into those undergone by the clusters and 2. CF + non-el gives total reaction cross section. The central idea of their method is that the total reaction cross section can be broken down into further components (they name inelastic scattering, elastic breakup and nonelastic breakup and provide a good diagram) which can individually be reliably calculated using existing models and calculation codes. They provide great detail on the models used for each component.

Contribution

The authors have chosen the test case of 6,7Li+209Bi to test their methods (I know there are a lot of experimental papers studying breakup with this reaction). They first provide evidence for the suppression compared to the barrier-penetration model (which I know is a simplified model because it accounts for tunneling but not coupling to channels other than the ground state). On the same plots, they show a plot for each component of the total reaction cross section to show the contribution. They also have a calculation of the total reaction cross section on the same plot.

The resulting deduced CF cross section agrees 'remarkably' well with the experimental data, which I think is very interesting because they do not tune any of the parameters of their models to this data. The component calculations have been fit to other data sets, like elastic scattering.

They go on to recognise that the small contribution of the elastic breakup mechanism is the reason why previous calculations of breakup before fusion can only account for a small amount of suppression.

As the degree of suppression has been shown to be correlated with separation energy, the authors then systematically study the cross section of each component as a function of (artificial) separation energy for both reactions. They verify that for stronger binding, fusion is not suppressed in their model.

Finally they note that the highest cross sections come from reactione of d or t with the target. This is unexpected because 'the average deutron and triton energies in the incident ... projectiles are of the order, or even smaller, than their respective Coulomb barrier energies'. That is, the energy of the system can be thought of as shared between the two clusters, weighted by their masses (e.g. a triton would have 3/7ths of the energy). This phenomenon can be explained with a "Trojan Horse Mechanism", where the d/t is brought inside its Coulomb barrier by being part of the system containing the heavier alpha particle. This is evidenced in the plots of figure 4, where we see that near the barrier, the two-body cross section is minimal, but the cross section of the three-body process is large.

Relevance

My project is also related to experimentally observing fusion suppression. While I am looking at systems with heavier projectiles, and the mechanism for suppression is not expected to be attributed to clustering or breakup, I wanted to understand the suppression problem with lighter projectiles. I don't think I need any more understanding than I have so far.

The other reason I am interested in this paper is because breakup of Li with Bi targets has been experimentally examined by my group, and I have participated in experiments to measure breakup before, so I wanted to understand more about the progress in this field so I can contribute to experiments in the future.

Quality I found the writing in this paper really good. They have a conceptual thread which is easy to follow for a first read but have also included the details of their calculations which I can come back to if I want to. The presentation of their results is clear because they have a limited number of plots which strongly illustrate their point.

The assumptions in this paper seem clear and logical to me. They have benchmarked the calculation of the component cross sections against independent data, and I believe that individually the calculations have all been performed before with good results.

I am not a theoretical physicist, and have not performed many of these types of calculations myself, so I am unsure about commenting on the many models and calculations, but because they have included the details of these models I know I can go back to them if I needed them for my project, and reassess their significance.

In conclusion, I think the authors have made a significant step towards understanding fusion suppression in these nuclei. They bring together many separate experimental observations and ideas about the mechanisms underlying suppression, and use them to build and then justify their model.

Questions/Directions

- Can we use this method of breaking down the reaction cross section into its components for my project? As I am using heavy ions rather than light ones, the number of reaction outcomes is far greater, so there may be problems with applying this concept in a practical sense, but perhaps we could start with a simplified picture? Talk to supervisors about this.
- There are a number of different codes mentioned here, I would like to look into them and see if any are applicable to the reactions I am studying.
- There are other weakly-bound, clustered nuclei our group can examine experimentally. This could be an opportunity to collaborate with these authors by providing another test of their model with a nucleus like 12C, or the nearby 9Be, 8Li, 6Li...