Computational Nuclear Physics

Heavy element synthesis in giant stars

There are about 100 elements in the universe, but how have they been synthesized? *Alpha reaction* is one of the important nuclear reactions to synthesize new elements by fusion of alpha particles. Relevant nuclear reactions involve quantum mechanical motion of many protons and neutrons. For microscopic study, we have developed a method which selects the relevant reaction path from many degrees of freedom (Fig. 1). We re-quantize the Hamiltonian on the reaction path, and succeed to calculate the fusion cross section of quantum tunneling (Fig.2).

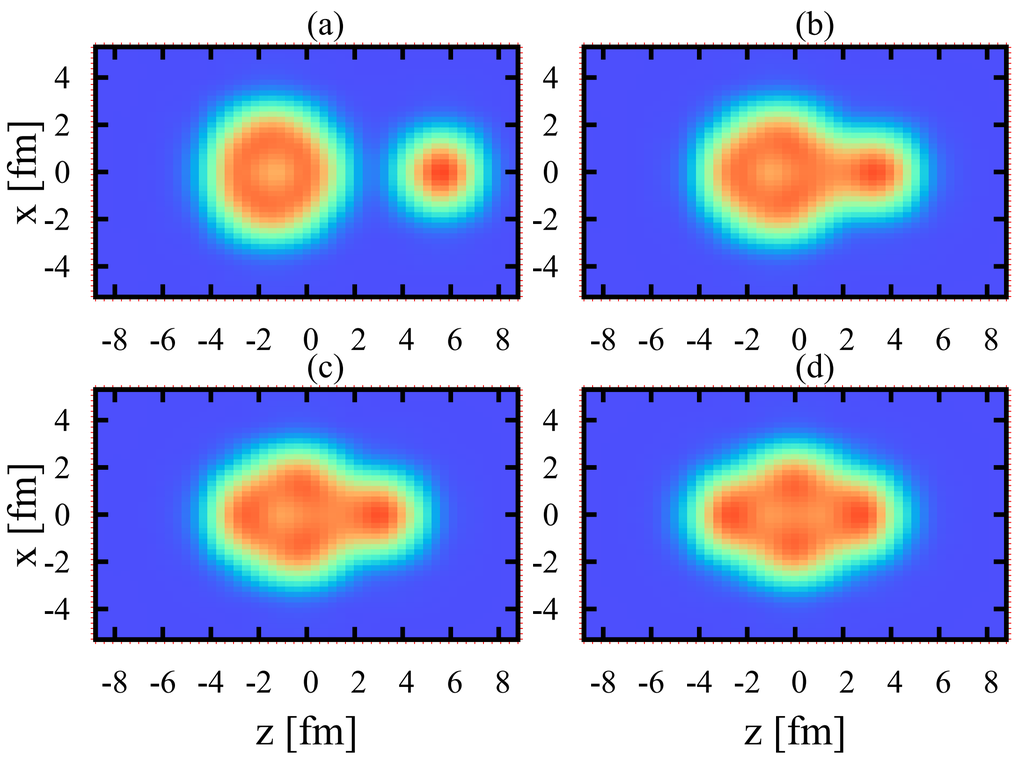

Fig. 1: Density plots along the reaction path determined self-consistently, which connects two separated nuclei (a), ^{16}O+α, to the single neon nucleus (d).

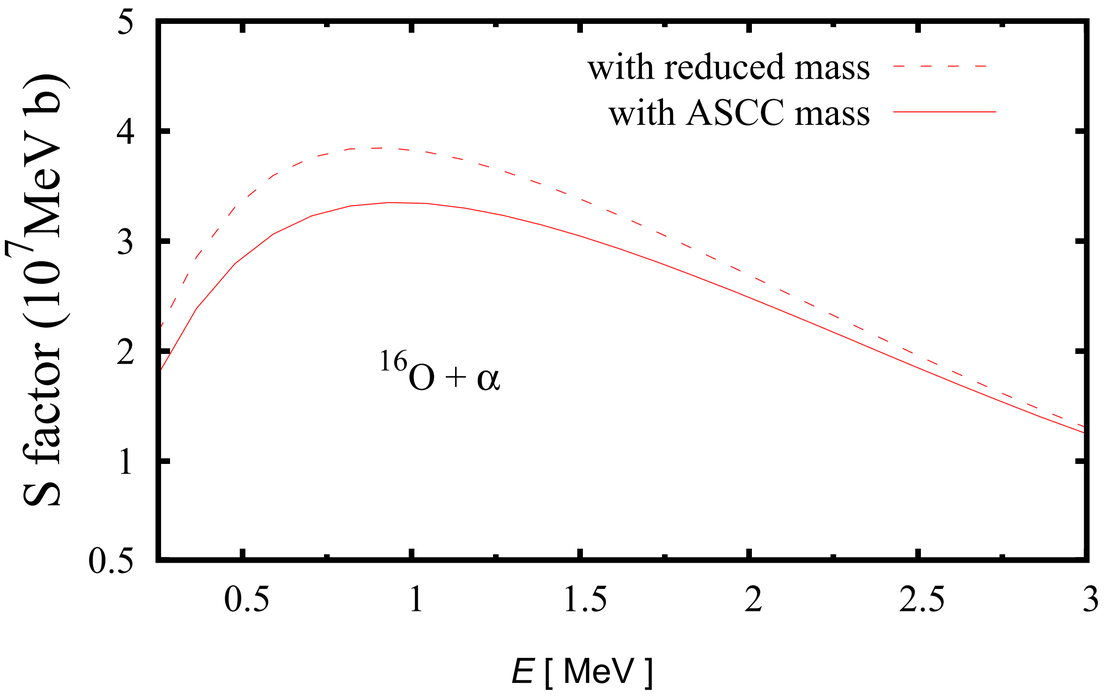

Fig. 2: Calculated fusion cross section (astrophysical S-factor) for ^{16}O+α. The dotted line shows results of a conventional approach without dynamical effect.

Quark masses visible in heavy atomic nuclei

Imagine you wanted to distinguish between white and black seeds inside a watermelon without actually breaking it. To distinguish up and down quarks inside an atomic nucleus seems to be even more outlandish task. Here we show that this can be done by looking at the simplest characteristics of heavy nuclei – their masses. We know that the up quark is about twice lighter than the down quark, which leads to interactions between pairs of neutrons being slightly stronger than those between pairs of protons. The question is “Can we see a prominent signature of this asymmetry in heavier nuclei?” We calculate masses of heavy nuclei and thus, by comparing results with measured masses, to quantify strengths of the symmetry-breaking effects (Fig. 3). We showed some of former experimental data were far away from the calculation (open symbols in Fig. 3). These nuclear masses are revisited experimentally in the world, and the new data support our predictions.

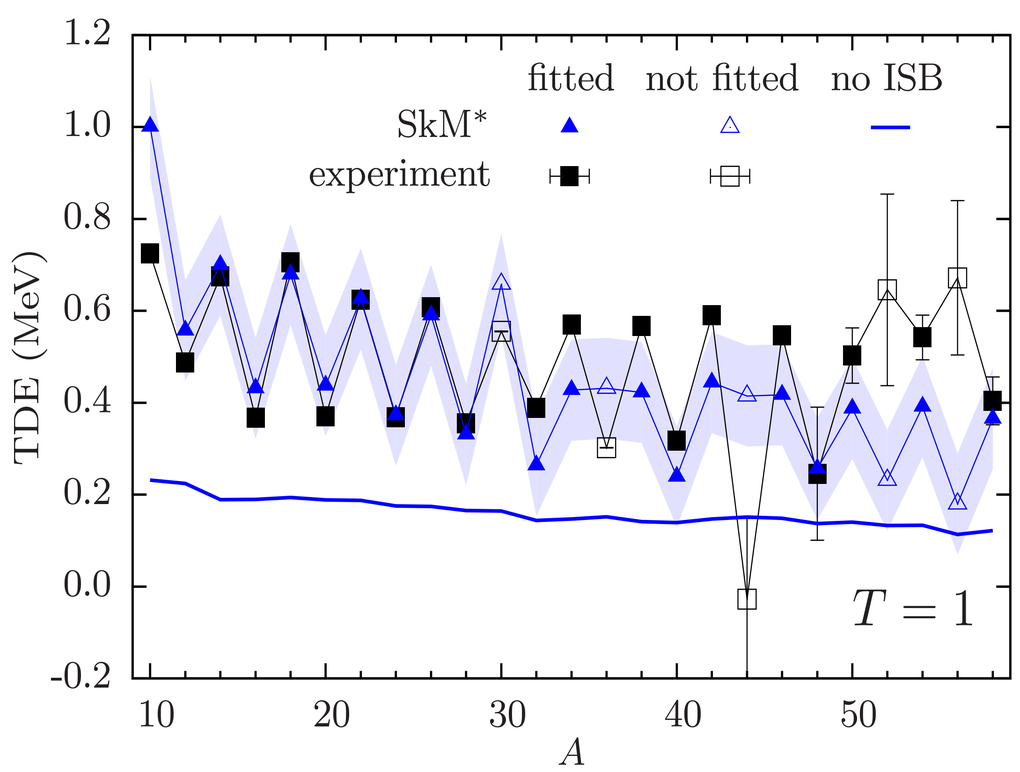

Fig. 3: The nuclear mass difference among the isospin triplets (triangles), called triple displacement energy (TDE). The conventional theory predicts the solid line, which is very different from experimental data (squares).

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