Microscopic Calculation of Fusion Cross Sections

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In the high density environment of the crust of a neutron star it is expected that electron capture dominates nuclear processes, driving nucleosynthesis towards the neutron drip line [1]. At sufficiently high densities and low temperatures pycnonuclear reactions are favoured to occur. The determination of fusion cross sections at extremely low energies is a critical issue for calculating reaction rates of astrophysical interest.

Our aim is to provide fully microscopic calculations of the fusion cross sections for some selected nuclei (^{16}O, ^{22}O and ^{24}O) that can be used to test the simpler models used in astrophysical network calculations. We perform these calculations in the framework of the Fermionic Molecular Dynamics (FMD) model. We use an effective interaction that is derived from realistic nucleon-nucleon forces by explicitly introducing short-range central and tensor correlations in the Unitary Correlation Operator Method (UCOM) [2].

The FMD ground states are obtained by minimizing the energy with respect to the parameters of all the nucleons. In the case at hand they are identical to spherical closed shell configurations. The FMD basis allows us to easily shift and boost the wave functions. We can therefore use our wave functions and interaction in the spirit of the microscopic cluster model to calculate nucleus-nucleus potentials. The system of two nuclei at a distance R is described by a Slater determinant built with the two ground state wave functions projected on angular momentum

$$\left|\,\Psi^{\ell}(R)\,\right\rangle = P^{\ell}_{00}\mathcal{A}\left\{\left|\,\psi(-R\vec{e_z}/2), \psi(R\vec{e_z}/2)\,\right\rangle\right\} . \qquad (1)$$

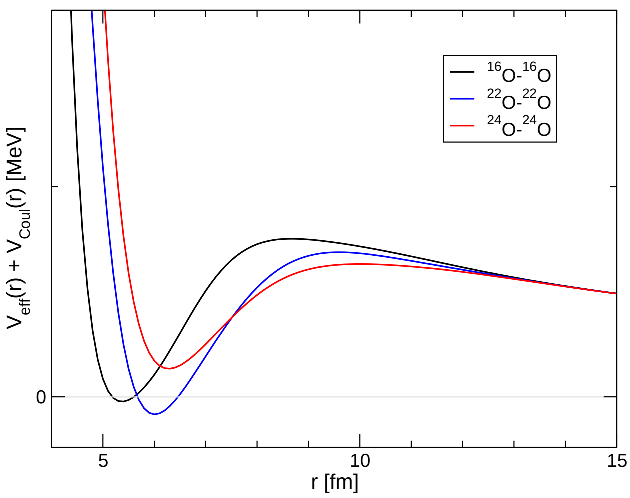

Figure 1: Effective Nucleus-Nucleus Potentials ($\ell = 0$) derived from the FMD energy surfaces. The barrier gets lower and shallower with increased neutron number.

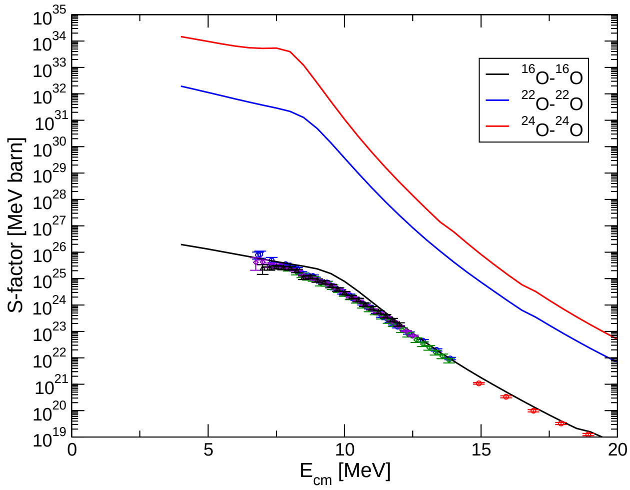

Figure 2: S-factor for the fusion of oxygen isotopes. Experimental data for ^{16}O are included.

The Slater determinants still contain the center of mass motion. In the case of equal widths for the Gaussians the center of mass wave function factorizes and we can define the corresponding RGM wave function [3]. The RGM wave function can not yet be identified with a wave function of two point-like nuclei as the basis states are non orthogonal because of the antisymmetrization. Therefore in a following step the RGM norm kernel is diagonalized numerically. Using these eigenstates we could now define a non-local potential for two point-like nuclei. Alternatively we can try to fit a local equivalent potential $V_{\mathit{eff}}(r) + \frac{\ell(\ell+1)}{2\mu r^2}$ to the matrix elements. This works remarkably well giving the same fit for the different partial waves. The potentials derived in this way are depicted in Fig. 1. These potentials are finally used to solve the Schrödinger equation with incoming wave boundary conditions. Here we assume that the two nuclei will fuse if they reach the minimum behind the Coulomb barrier. The penetration probabilities for all possible partial waves are finally summed up to get the total fusion cross section shown in Fig. 2. A remarkable agreement with the data for ^{16}O can be observed. For the neutron rich isotopes we find much enlarged cross sections.

References

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