PIONIC FUSION

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Recent experiments [1,2] have opened a new domain for the study of subthreshold pion production ($A+A\to\pi+X$), that is the absolute threshold, where all the initial energy is transformed into the pionic mode. The resulting nucleus is left in either it's ground state or one of the low-lying excited states. As the energy is initially spread amongst $2A$ nucleons, the transfer of the energy into one mode represents a challenging theoretical issue. Here, we present results of a simple model, where the fusion is calculated through the overlap of the initial single-particle states with the states of the final nucleus, via the one-step process of the $NN\pi$ three-point interaction. The advantage of this approach is that energy, momentum, angular momentum, charge and isospin are precisely conserved. The principal disadvantage is that the distortion of incoming nuclei do to the interaction of their mutual mean fields is neglected.

We calculate the cross section in the Born approximation,

$$d\sigma=\frac{\omega km}{2p_n(2\pi)^2}|\langle F|H|I\rangle|^2V^2d\Omega, \tag{1}$$

where ω and k are the energy and momentum of the pion, m is the nucleon mass and p_n is the momentum per nucleon in the initial state as measured in the center of mass.

The interaction is the p-wave type,

$$\mathcal{H}=g_{\pi NN}\overline{\Psi}\gamma_5\vec{\tau}\cdot\pi\Psi. \tag{2}$$

The nuclei of the initial and final states are considered to be many-body eigenstates of a harmonic oscillator centered at $\mathbf{R}$, $|\Psi,\mathbf{R}>$ which are then convoluted over $\mathbf{R}$ such that they become eigenstates of momentum,

$$|\Psi,\mathbf{p}>=\int d\mathbf{R}e^{i\mathbf{p}\cdot\mathbf{R}}|\Psi,\mathbf{R}>. \tag{3}$$

Analytic expressions can be found for the matrix elements when the nuclei are considered to be in the Cartesian basis. It is then tractable to calculate for angular momentum eigenstates by projecting Cartesian matrix elements onto the appropriate basis.

In Figure 1, we show cross sections for the case where two identical nuclei with filled shells fuse along with the production of a low-momentum pion. One can see that the cross section falls rapidly with increasing momentum. An important lesson from our calculations is that the result is extremely sensitive to the oscillator parameter.

Results were compared to experimental results for $^3He+^3He\to^6Li+\pi$ [3] and $^{12}C+^{12}C\to^{24}Mg+\pi_0$. In both cases the calculations were within a factor of two of the measurement. Given the crude nature of the approximations and the sensitivity to the details of the wave function, such an agreement is remarkable. This suggests that the most important aspects of the A dependence of pionic fusion are realized in this approach, even though it is easy to imagine a plethora of improvements.

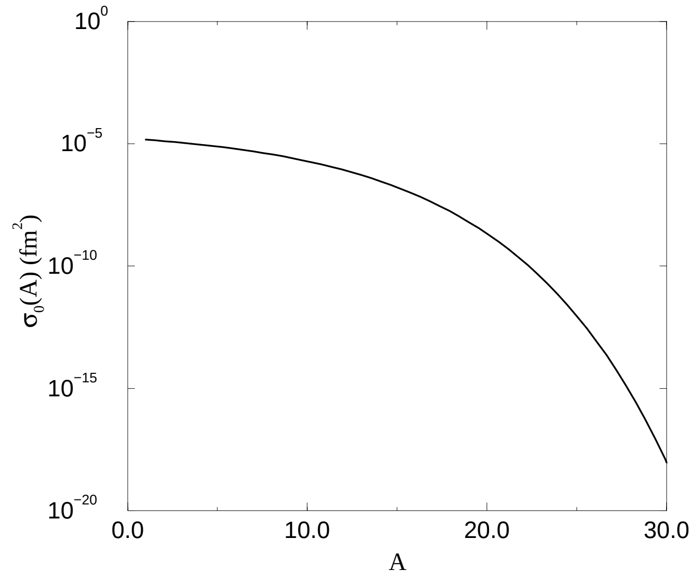

Figure 1: The general behavior of the pionic fusion cross section $A + A \rightarrow 2A + \pi$ is shown for reactions where the incoming nuclei had filled oscillator shells. The displayed value, σ_0 is related to the true cross section through the factor, $\sigma = \sigma_0 |\mathbf{k}|^3/m_\pi^3$.

References

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2. M. Waters et al., Nucl. Phys. A**564**, 595 (1993).
3. Y. LeBornec et al., Phys. Rev. Lett. **47**, 1870 (1981).