Does the $\alpha$ cluster structure in light nuclei persist through the fusion process?

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- Fusion involves the amalgamation of two nuclei into a compound nucleus which no longer retains the memory of the identity or structure of the colliding nuclei (Bohr independence hypothesis)

- At low excitation, the compound nucleus de-excites by statistical emission of light particles ($n,p,\alpha$)

- Limited information exists on the de-excitation of light compound nuclei formed at low excitation

- Measurement of the energy spectra, angular distributions, and cross-sections of fusion products provide a test for statistical model calculations

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The Reaction and its Products

$^{18}O + ^{12}C \rightarrow ^{30}Si^* \rightarrow ^{28}Si + 2n$  
$^{28}Al + p + n$  
$^{25}Mg + \alpha + n$

$E^* = 30 - 38 \text{ MeV}$

- Excited compound nucleus decays by emitting protons, neutrons, and particles
- The resulting heavy nucleus is known as an evaporation residue
- Emission of these light particles impart transverse momentum on the residue, kicking them off zero degrees and allowing for direct measurement of the residues and light particles

\[ E = \frac{1}{2}mv^2 \quad m \propto Et^2 \]
$^{18}\text{O} + ^{12}\text{C} \rightarrow ^{30}\text{Si}^*$

at Florida State University

- $E_{\text{lab}} = 16.25 - 36 \text{ MeV}$
- Intensity $\sim 10^5 \text{ p/s}$
- Reaction products distinguished by energy and time-of-flight
- Energy measured in segmented annular silicon detectors (T2, T3)
- Fusion product time-of-flight measured between target MCP and silicon detectors

Residue Angular Distributions

- Residue angular distributions are bimodal

- Recoil considerations suggest that the residues measured at large angles are associated with α emission, and small angle residues are associated with nucleon emission

- Small angle component is reasonably well described by statistical model calculations, but the large angle component is significantly underpredicted

Direct Measurement of $\alpha$ Particles

- Experimental $\alpha$ angular and energy distributions are reasonably described by EVAPOR statistical model calculations.

- As $E_{\text{c.m.}}$ increases:
  - $\alpha$ emission becomes an increasingly important channel in the de-excitation process.
  - The measured $\sigma_\alpha$ increasingly deviates from statistical model predictions.
  - $\sigma_\alpha$ exhibits the same $E_{\text{c.m.}}$ dependence as $\sigma_{\text{fusion}}$.
  - $\sigma_\alpha = P_{\alpha} \sigma_{\text{fusion}}$

Alpha Emission Probability, $P_\alpha = \frac{\sigma_\alpha}{\sigma_{fusion}}$

- $P_\alpha$ increases with increasing $E_{c.m.}$ and is enhanced in the data relative to EVAPOR.
- Same features evident in other O + C systems.
- Larger enhancement of $^{18}\text{O} + ^{12}\text{C}$ for higher $E_{c.m.}$ suggests neutron emission is overemphasized by the statistical model.
- Enhancement could be attributed to the failure of the statistical model to correctly account for $\alpha$ cluster structure of the projectile/target.

Conclusions/Outlook

Does $\alpha$ cluster structure persist through the fusion process?

• Statistical model codes underpredict the large angle component of the residue angular distributions, suggesting $\alpha$ emission channels are underemphasized

• Direct measurement of $\sigma_\alpha$ is larger than statistical model predictions, confirming that $\alpha$ emission is enhanced

• This enhancement is also observed for similar systems with well known $\alpha$ cluster structure

• These observations suggest that $\alpha$ cluster structure present in the projectile and target nuclei persist through the fusion process

Future Measurements

• $^{39,47}\text{K} + ^{28}\text{Si}$ at NSCL (ReA3, Exp. 15214, Fall 2016)

• $^{20,21}\text{O} + ^{12}\text{C}$ at GANIL (PAC proposal submitted)

• $^{18,19}\text{O} + ^{18}\text{O}$ at FSU
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Additional Material
Alpha Cluster Structure

- $N = Z$ even-even nuclei represent the most stable isotopes for low to mid mass nuclei ($A<40$)
- $^4\text{He}$ in particular is more strongly bound than other light nuclei
- Deformation of these nuclei can lead to nuclear molecular states comprised of $\alpha$ particles
- Clustering phenomena have also been observed for neutron-rich isotopes such as $^{18}\text{O}$

Further investigation is required to determine if the $\alpha$ cluster structure is responsible for the enhanced $\alpha$ cross-section
• Experimental angular and energy distributions are reasonably described by EVAPOR statistical model calculations.

Residue energy distributions have two components:

- Coincident measurement of evaporation residues and $\alpha$ particles demonstrates that the low energy component is associated with $\alpha$ channels.