# Enhancement of $^{16}$O + $^{18}$O sub-barrier fusion cross sections by distortion of valence neutrons in $^{18}$O

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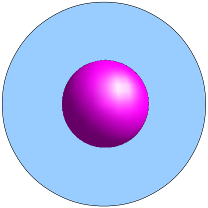
Oct. 3, 2011
YITP, Kyoto University

# Properties of valence neutrons



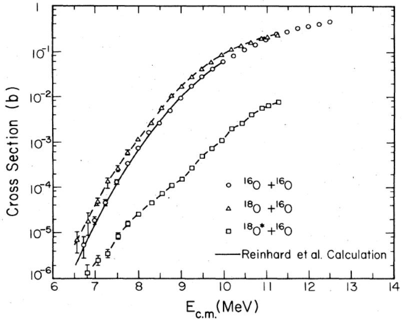
- Skin structures
- Halo structures

Dynamical properties?

$^{16}$O + $^{16,18}$O sub-barrier fusion

$^{18}$O: $^{16}$O + $2n$

# $^{16}$O + $^{16,18}$O sub-barrier fusion cross sections




[J. Thomas et al, PRC 31, 1980 (1985)]

- $^{16}$O + $^{18}$O sub-barrier fusion cross section is larger than $^{16}$O + $^{16}$O.
- $^{16}$O + $^{18}$O internuclear potential is deeper than $^{16}$O + $^{16}$O.

Aims are

- to calculate adiabatic inter-nuclear potentials microscopically.
- to clarify roles of distortion of valence neutrons in $^{18}$O for $^{16}$O + $^{16,18}$O sub-barrier nuclear fusion.

# Effective inter-nuclear potential

Effective inter-nuclear potential operator:

$$\hat{V}_{\text{eff}} \equiv \hat{T} + \hat{V} - 2\hat{T}_{\text{G}} - E_{1\text{gs}} - E_{2\text{gs}},$$

$\hat{V}$: Modified Volkov No. 1 whose contact 3-body term is replaced with a density dependent term + $LS$ term in the Gogny D1S.

$\hat{T}_{\text{G}}$: energy of center-of-mass motion

$E_{n\text{gs}}$: energy of ground state in nucleus $n$

Effective inter-nuclear potential:

$$V_{\text{eff}}(R) = \langle \Phi_1 \Phi_2; R | \, \hat{V}_{\text{eff}} \, | \Phi_1 \Phi_2; R \rangle \,,$$

$$|\Phi_1 \Phi_2; R\rangle = \hat{\mathcal{A}} \left| \Phi_1 \left( -\frac{A_2}{A} \mathbf{R} \right) \otimes \Phi_2 \left( \frac{A_1}{A} \mathbf{R} \right) \right\rangle \quad \text{(AMD)}$$

# Adiabatic and sudden potentials

Adiabatic potentials $V_{\rm ad}(R)$:

Wave functions of nuclei 1 and 2 are obtained by variational calculations with constraints on inter-nuclear distances.

$$V_{\rm ad}(R) = \min \langle \Phi_1 \Phi_2; R | \hat{V}_{\rm eff} | \Phi_1 \Phi_2; R \rangle \, .$$

Sudden potentials $V_{\rm sud}(R)$:

Nuclei 1 and 2 are their ground states.

$$V_{\rm sud}(R) = \langle \Phi_{1\rm gs} \Phi_{2\rm gs}; R | \hat{V}_{\rm eff} | \Phi_{1\rm gs} \Phi_{2\rm gs}; R \rangle \, .$$

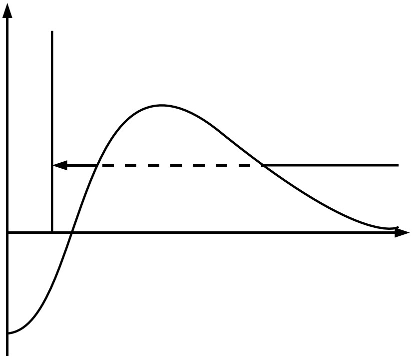
Orientation of $^{18}$O is averaged.

# Fusion Cross Section

## Fusion cross section

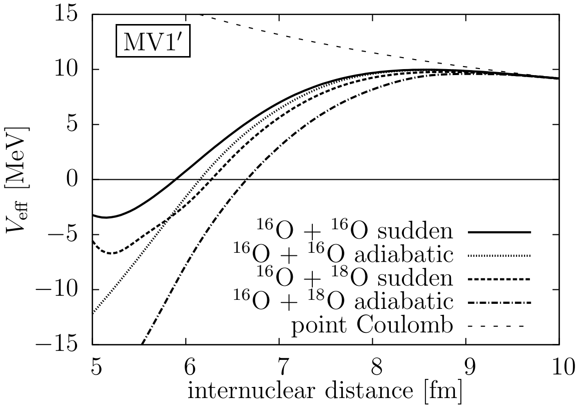
Potential model version provided by K. Hagino et al,
http://www.nucl.phys.tohoku.ac.jp/˜hagino/ccfull.html

- Strong absorption



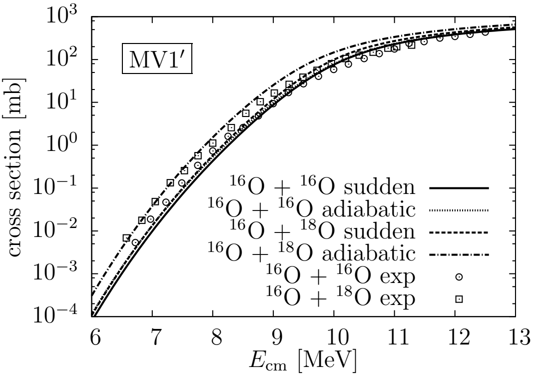
touching point = 6 fm

# $^{16}$O + $^{16,18}$O potentials



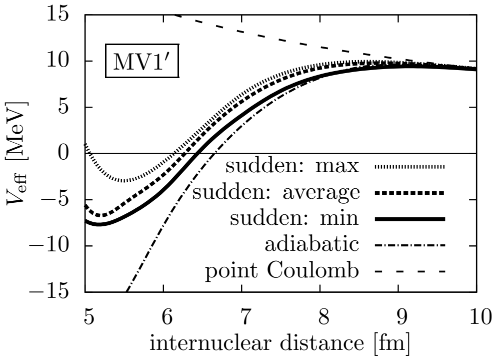

- Adiabatic and sudden $^{16}$O + $^{16}$O potentials and a sudden $^{16}$O + $^{18}$O potential are similar.
- An adiabatic $^{16}$O + $^{18}$O potential is deeper than them.

# $^{16}$O + $^{16,18}$O Fusion Cross Sections



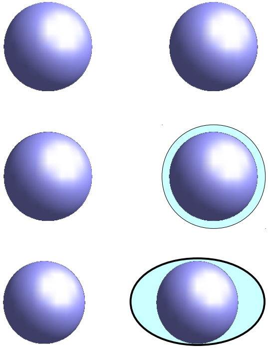

- Fusion cross sections obtained by the $V_{\rm ad}$($^{16}$O + $^{18}$O) is larger than those obtained by the $V_{\rm sud}$($^{16}$O + $^{16}$O), $V_{\rm ad}$($^{16}$O + $^{16}$O), and $V_{\rm sud}$($^{16}$O + $^{18}$O) potentials.
- Adiabatic potentials account for $^{16}$O + $^{16,18}$O sub-barrier fusion cross sections.

# Alignment of $^{18}$O: $^{16}$O + $^{18}$O potentials




- Minimum values (min) of $^{16}$O + $^{18}$O potential for orientation of $^{18}$O, in which $^{16}$O and $^{18}$O are frozen, is similar to sudden potential (averaged).
- Alignment of $^{18}$O gains internuclear potential and enhances sub-barrier fusion cross sections.

# Enhancement of $^{16}$O + $^{18}$O sub-barrier fusion cross section by distortion of valence neutrons



$\sigma(^{16}\mathrm{O} + ^{16}\mathrm{O}; \mathrm{ad}) \sim \sigma(^{16}\mathrm{O} + ^{16}\mathrm{O}; \mathrm{sud})$

Distortion of $^{16}$O cores: negligible

$\sigma(^{16}\mathrm{O} + ^{18}\mathrm{O}; \mathrm{sud}) \sim \sigma(^{16}\mathrm{O} + ^{16}\mathrm{O}; \mathrm{sud})$

Larger radius of $^{18}$O: negligible

$\sigma(^{16}\mathrm{O} + ^{18}\mathrm{O}; \mathrm{ad}) > \sigma(^{16}\mathrm{O} + ^{18}\mathrm{O}; \mathrm{sud})$

Alignment of valence neutrons: dominant

Alignment of valence neutrons
enhances sub-barrier fusion cross sections.

# Conclusions

- Effects of distortion of valence neutrons in $^{18}$O for $^{16}$O + $^{16,18}$O sub-barrier fusion cross sections have been studied using adiabatic potentials a potential model.
- Adiabatic potentials account for $^{16}$O + $^{16,18}$O sub-barrier fusion cross sections.
- Alignment of valence neutrons in $^{18}$O enhances sub-barrier fusion cross sections.
- It is important for understanding low-energy nuclear reactions to analyze structural changes of colliding nuclei in details.