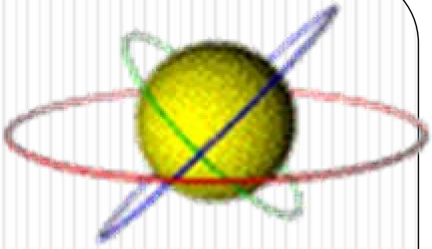

Orientation effects on evaporation residue cross sections in ^{48}Ca-induced hot fusion reactions

祝龙，李成，张凡，张东红，张丰收

北京师范大学

2014.10

简 介

1．超重核理论和实验的研究进展

2．理论模型（双核系统模型）介绍

3．对^{48}Ca引起的热熔合的研究

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3.2 ^{48}Ca引起的热熔合反应产生Z = 113   118的同位素的蒸发剩余截面计算

3.3 对超重核Z=119和120的预言

4．总结与展望

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实验进展:

冷熔合:

基于^{208}Pb 和 ^{209}Bi 靶

S. Hofmann *et al*., Eur. Phys. J. A **14**, 147 (2002). **Z=111,112** **GSI**

K. Morita *et al*., J. Phys. Soc. Jpn. **81**, 103201 (2012). **Z=113** **RIKEN**

热熔合:

Dubna

^{48}Ca引起

Yu. Ts. Oganessian *et al*., Phys. Rev. C **70**, 064609 (2004) **Z=112**

Yu. Ts. Oganessian *et al*., Phys. Rev. C **76**, 011601(R) (2007) **Z=113**

Yu. Ts. Oganessian *et al*., *Nature* **400** (1999)242; *PRC* **62** (2000)041604(R) ; **69** (2004)054607; **70** (2004)064609; *NPA* **734**(2004)109 **Z=114**

Yu. Ts. Oganessian *et al*., Phys. Rev. C **69**, 021601(R) (2004) **Z=115**

Yu. Ts. Oganessian *et al*., Phys. Rev. C **63**, 011301(R) **Z=116**

Yu. Ts. Oganessian *et al*., Phys. Rev. Lett. **104**, 142502 (2010) **Z=117**

Yu. Ts. Oganessian *et al*., Phys. Rev. C **74**, 044602 (2006) **Z=118**

Yu. Ts. Oganessian *et al*., Phys. Rev. C **79**, 024603 (2009).

通过反应^{58}**Fe+**^{244}**Pu**尝试合成**120**号元素

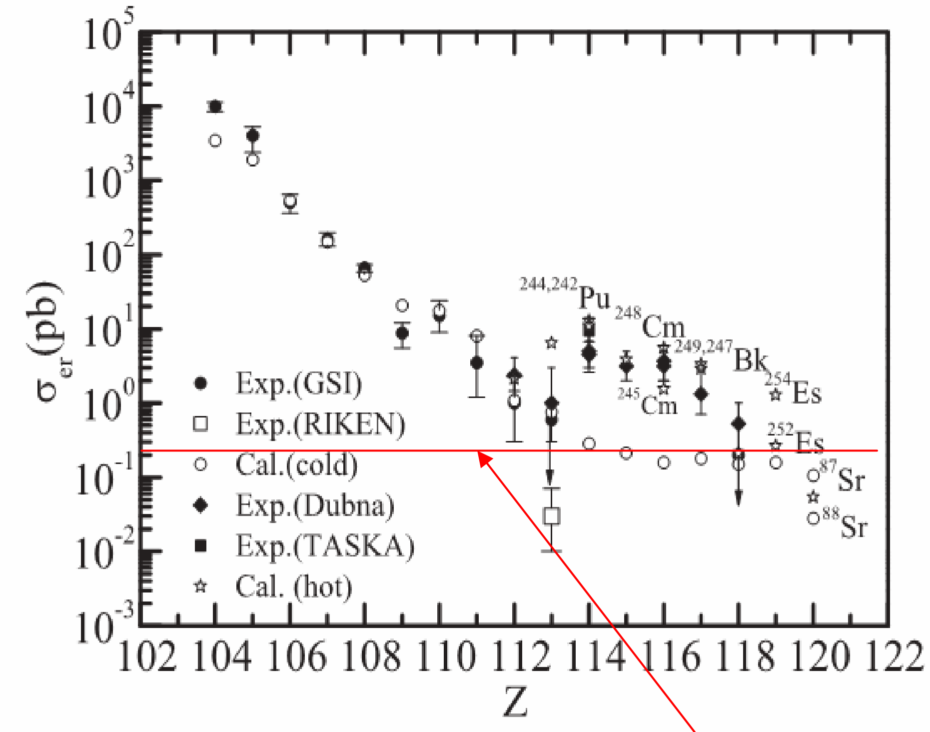
No decay chains consistent with fusion-evaporation reaction products were Observed. A more mass-asymmetry reaction would be preferable.

Introduction

热熔和

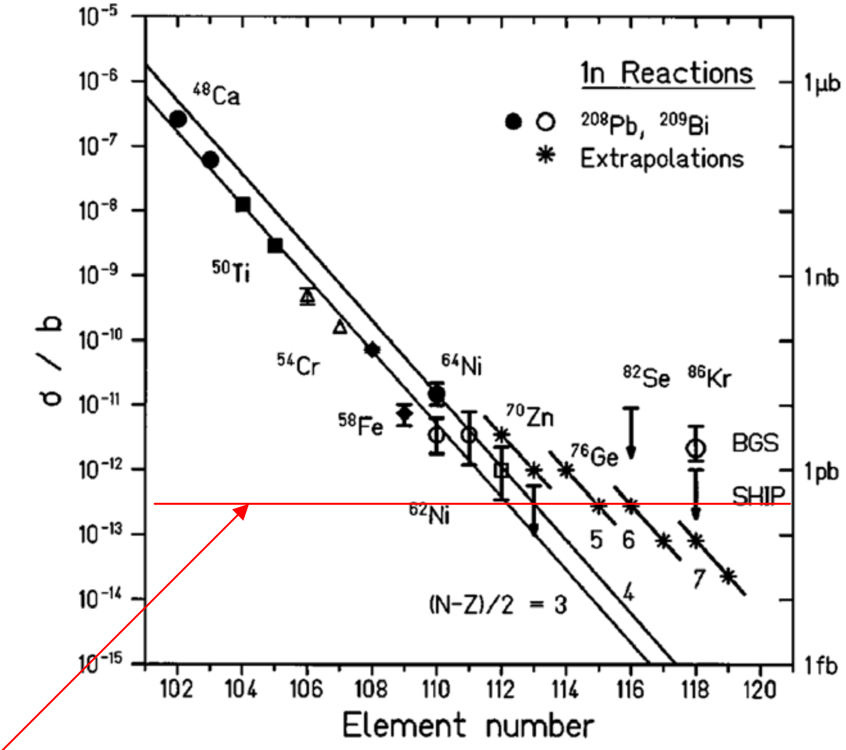
M. H. Huang *et al.*, *Phys. Rev. C* 82, 044614 (2010).

P. Armbruster, *Ann. Rev. Nucl. Part. Sci.*, 2000, **50**: 411



冷熔合

S. Hofmann *et al.*, *Rev. Mod. Phys.*, 2000, **72**: 733



现在实验能探测的极限

1. 提高实验设备的探测灵敏度.
2. 找到更适合的反应体系或方法.

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理论进展:

有很多模型和方法来研究超重核的合成机制:

DNS model：

G. G. Adamian, N. V. Antonenko, W. Scheid, and V. V. Volkov, Nucl. Phys. A 627, 361 (1997).
Zhao-qing Feng, Gen-ming Jin, Jun-qing Li, Nucl. Phys. A 836, 82 (2010).

Coupled Langevin-type equations:

V. Zagrebaev and W. Greiner J. Phys. G: Nucl. Part. Phys. 31(2005) 825–844

Fusion by diffusion model (FBD model): Smoluchowski diffusion equation

K. Siwek-Wilczynska, T. Cap, M. Kowal, *et al*., Phys. Rev. C 87, 034616 (2013).
Zu-Hua Liu and Jing-Dong Bao, Phys. Rev. C 87, 034616 (2013).

Phenomenological approaches:

Ning Wang, Junlong Tian, and Werner Scheid, Phys. Rev. C 84, 061601(R) (2011).
L. Zhu, W. J. Xie, and F. S . Zhang, Phys. Rev. C 89 , 024615 (2014).
R. Smolanczuk, Phys. Rev. C 81, 067602 (2010).

Nucleon collectivization mechanism：

V. I. Zagrebaev, Phys. Rev. C 64, 034606 (2001).

Two step model：

C. W. Shen, Y. Abe, D. Boilley, G. Kosenko, and E. G. Zhao, Int. J. Mod. Phys. E 17, 66 (2008).

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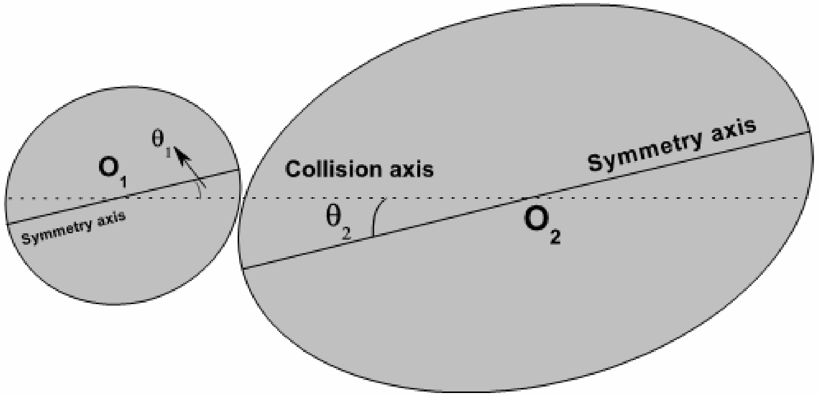
Theoretical model

ER cross section：

$$\sigma_{\mathrm{ER}}(E_{\mathrm{c.m.}}) = \frac{\pi\hbar^2}{2\mu E_{\mathrm{c.m.}}} \int_0^{\pi/2} \sin\theta_1 d\theta_1 \int_0^{\pi/2} \sum_J (2J+1) T(E_{\mathrm{c.m.}}, J, \theta_1, \theta_2) \times P_{\mathrm{CN}}(E_{\mathrm{c.m.}}, J, \theta_1, \theta_2) W_{\mathrm{sur}}(E_{\mathrm{c.m.}}, J) \sin\theta_2 d\theta_2$$

Capture cross section：

$$\sigma_{\mathrm{cap}}(E_{\mathrm{c.m.}}) = \frac{\pi\hbar^2}{2\mu E_{\mathrm{c.m.}}} \sum_J (2J+1) \times \int_0^{\pi/2} \int_0^{\pi/2} T(E_{\mathrm{c.m.}}, \theta_1, \theta_2, J) \sin\theta_1 \sin\theta_2 d\theta_1 d\theta_2$$



L. Zhu, Z.Q. Feng, C. Li, and F.S. Zhang, Phys. Rev. C 90, 014612 (2014).

俘获过程：

The transmission probability can be written as

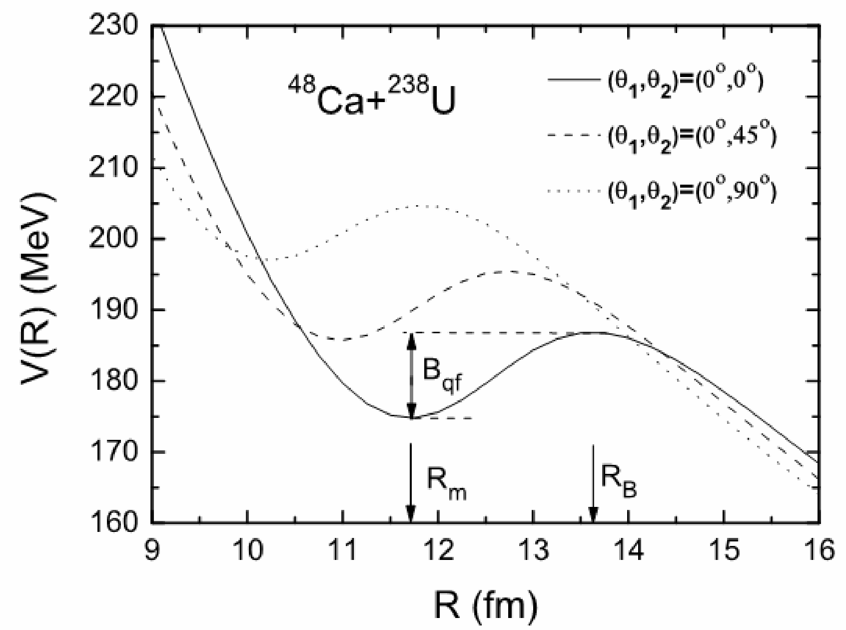
$$T(E_{\mathrm{c.m.}},\theta_1,\theta_2,J)=\frac{1}{1+\exp\{-\frac{2\pi}{\hbar\omega(\theta_1,\theta_2,J)}[E_{\mathrm{c.m.}}-B(\theta_1,\theta_2)-\frac{\hbar^2}{2\mu R_{\mathrm{B}}^2(\theta_1,\theta_2,J)}]\}}$$

The nucleus-nucleus interaction potential

$$V(r,\theta_1,\theta_2)=V_{\mathrm{N}}(r,\theta_1,\theta_2)+V_{\mathrm{C}}(r,\theta_1,\theta_2)$$

$$V_{\mathrm{C}}(r,\theta_1,\theta_2)=\frac{Z_1Z_2e^2}{r}$$
$$+(\frac{9}{20\pi})^{1/2}(\frac{Z_1Z_2e^2}{r^3})\sum_{i=1}^{2}R_i^2\beta_2^{(i)}P_2(\cos\theta_i)$$
$$+(\frac{3}{7\pi})(\frac{Z_1Z_2e^2}{r^3})\sum_{i=1}^{2}R_i^2[\beta_2^{(i)}P_2(\cos\theta_i)]^2.$$

$$V_{\mathrm{N}}(r,\theta_1,\theta_2)=-V_0\times$$
$$\{1+\exp[(r-\sum_{i=1}^{2}R_i[1+(5/4\pi)^{1/2}\beta_2^{(i)}P_2(\cos\theta_i)])a^{-1}]\}^{-1}$$



C. Y. Wong, Phys. Rev. Lett. 31, 766 (1973).

Theoretical model

熔合概率：(DNS 模型)

$$P_{CN}(E_{\text{c.m.}},J,\theta_1,\theta_2)=\sum_{A_1=1}^{A_{BG}}P(A_1,E_{\text{c.m.}},J,\theta_1,\theta_2)$$

$$\begin{aligned}
&\frac{dP(Z_1,N_1,E_1,\theta_1,\theta_2,t)}{dt}\\
&=\sum_{Z_1'}W_{Z_1,N_1;Z_1',N_1}(t)[d_{Z_1,N_1}P(Z_1',N_1,E_1',\theta_1,\theta_2,t)\\
&-d_{Z_1',N_1}P(Z_1,N_1,E_1,\theta_1,\theta_2,t)]\\
&+\sum_{N_1'}W_{Z_1,N_1;Z_1,N_1'}(t)[d_{Z_1,N_1}P(Z_1,N_1',E_1',\theta_1,\theta_2,\\
&-d_{Z_1,N_1'}P(Z_1,N_1,E_1,\theta_1,\theta_2,t)]\\
&-[\Lambda_{\text{qf}}(\Theta(t),\theta_1,\theta_2)+\Lambda_{\text{fis}}(\Theta(t))]P(Z_1,N_1,E_1,\theta_1,\theta_2,t)
\end{aligned}$$

$$\begin{aligned}
\Lambda_{\text{qf}}(\Theta(t),\theta_1,\theta_2)=&\frac{\omega}{2\pi\omega^{B_{\text{qf}}}}[\sqrt{(\frac{\Gamma}{2\hbar})^2+(\omega^{B_{\text{qf}}})^2}-\frac{\Gamma}{2\hbar}]\\
&\times\exp[-\frac{B_{\text{qf}}(Z_1,N_1,\theta_1,\theta_2)}{\Theta(t)}].
\end{aligned}$$

存活几率:

$$\begin{aligned}
W_{\text{sur}}(E_{\text{CN}}^*,x,J)=&P(E_{\text{CN}}^*,x,J)\times\\
&\prod_i^x[\frac{\Gamma_n(E_i^*,J)}{\Gamma_n(E_i^*,J)+\Gamma_f(E_i^*,J)}]
\end{aligned}$$

G. G. Adamian, N. V. Antonenko, W. Scheid, and V. V. Volkov, Nucl. Phys. A 627, 361 (1997).

Zhao-qing Feng, Gen-ming Jin, Jun-qing Li, Nucl. Phys. A 836, 82 (2010).

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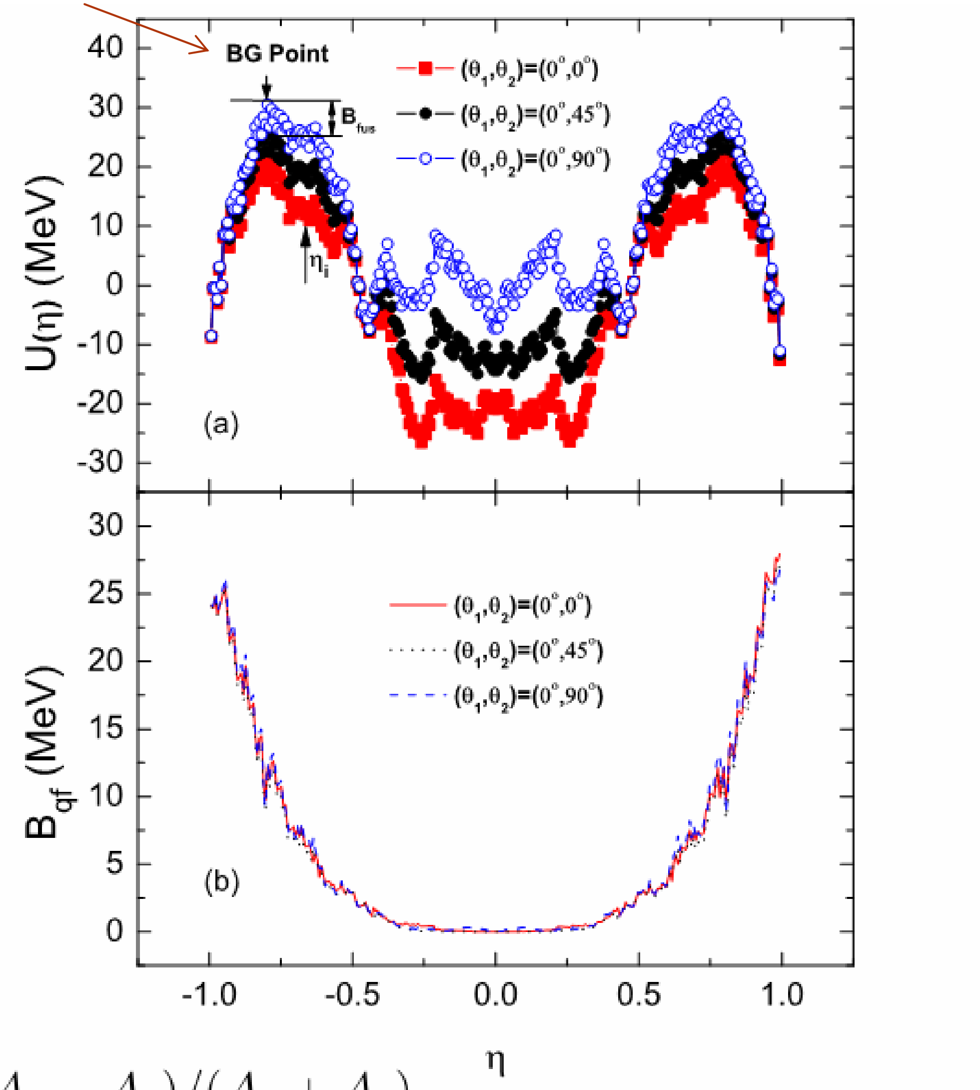
^{48}Ca+^{238}U

Businaro-Gallone point

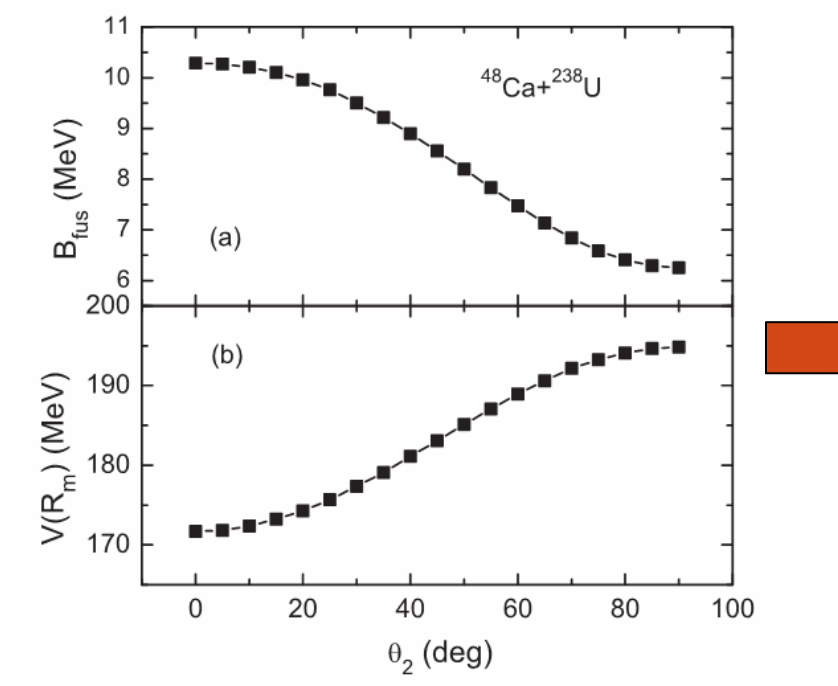


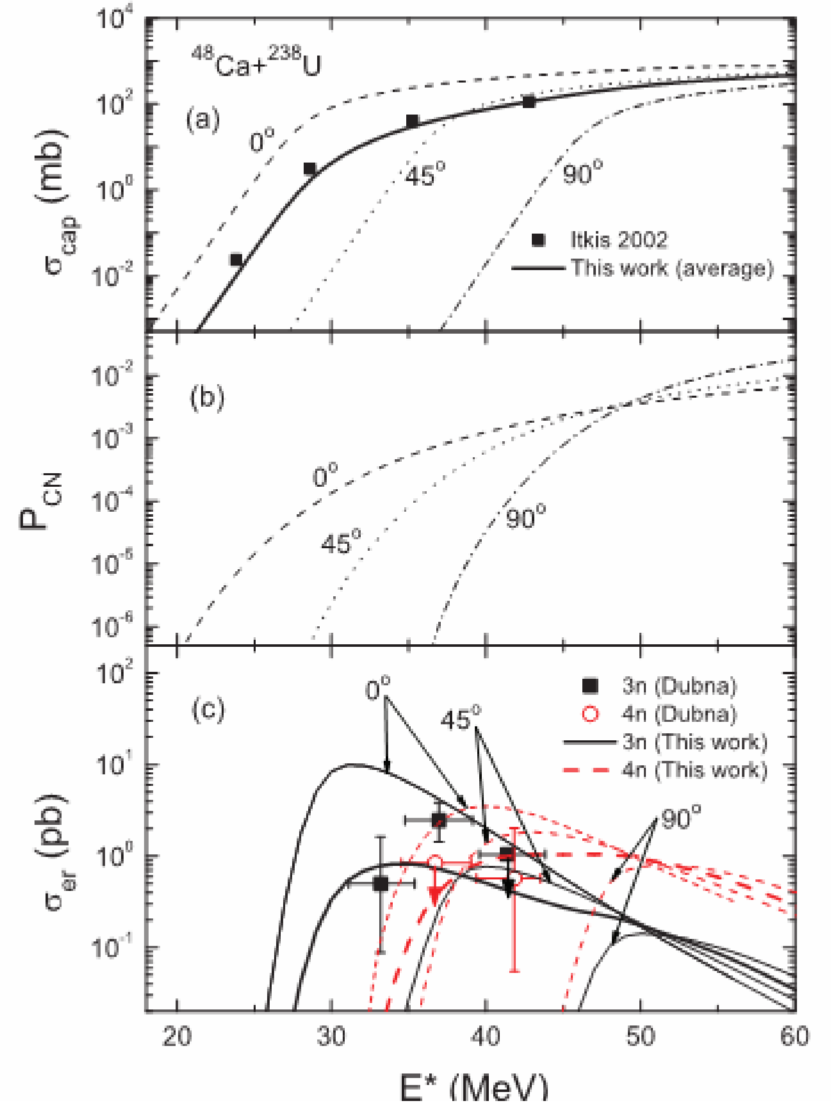
驱动势：

$$U(A_1, A_2, R, \beta_1, \beta_2, \theta_1, \theta_2, J) = U_{\mathrm{LD}}(A_1) + U_{\mathrm{LD}}(A_2) - U_{\mathrm{LD}}(A) + V_{\mathrm{CN}}(A_1, A_2, R, \beta_1, \beta_2, \theta_1, \theta_2, J)$$

$$\eta = (A_1 - A_2)/(A_1 + A_2)$$

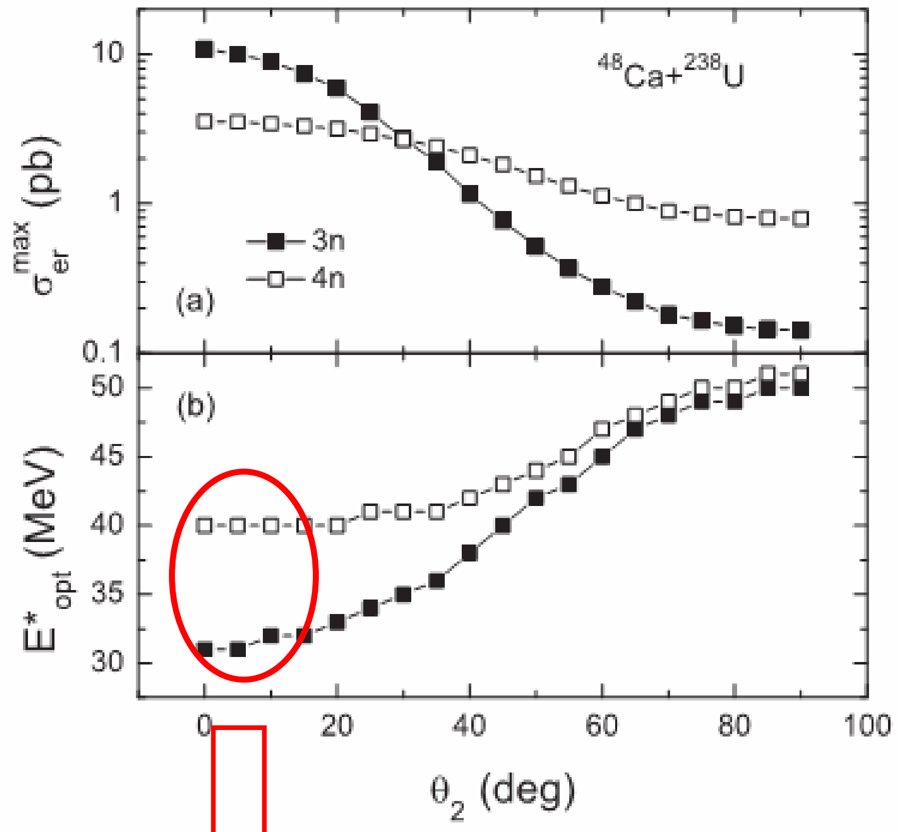
熔合反应 ^{48}Ca+^{238}U的蒸发剩余截面的方向效应研究





熔合概率的方向效应是内部熔合位垒B_{fus}和接触时的相互作用势$V(R_m)$相互竞争的结果。

Study of ^{48}Ca-induced hot fusion reactions



Decrease with the increasing value of theta2

The discrepancy is large.

The maximal ER cross sections decrease with the increasing theta2 for both the 3n and 4n channel. The optimal excitation energies are increase by increasing theta2.

Study of ^{48}Ca-induced hot fusion reactions

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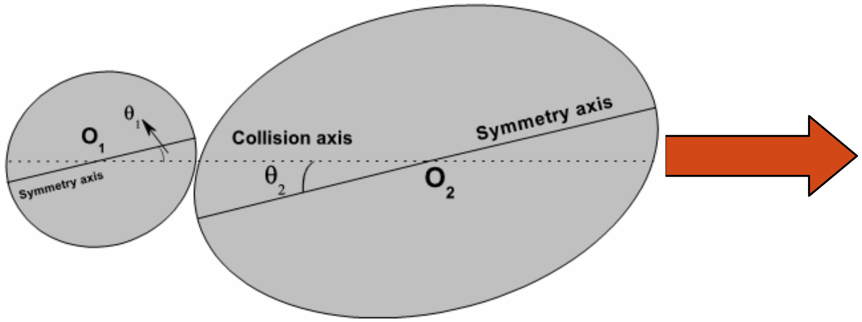
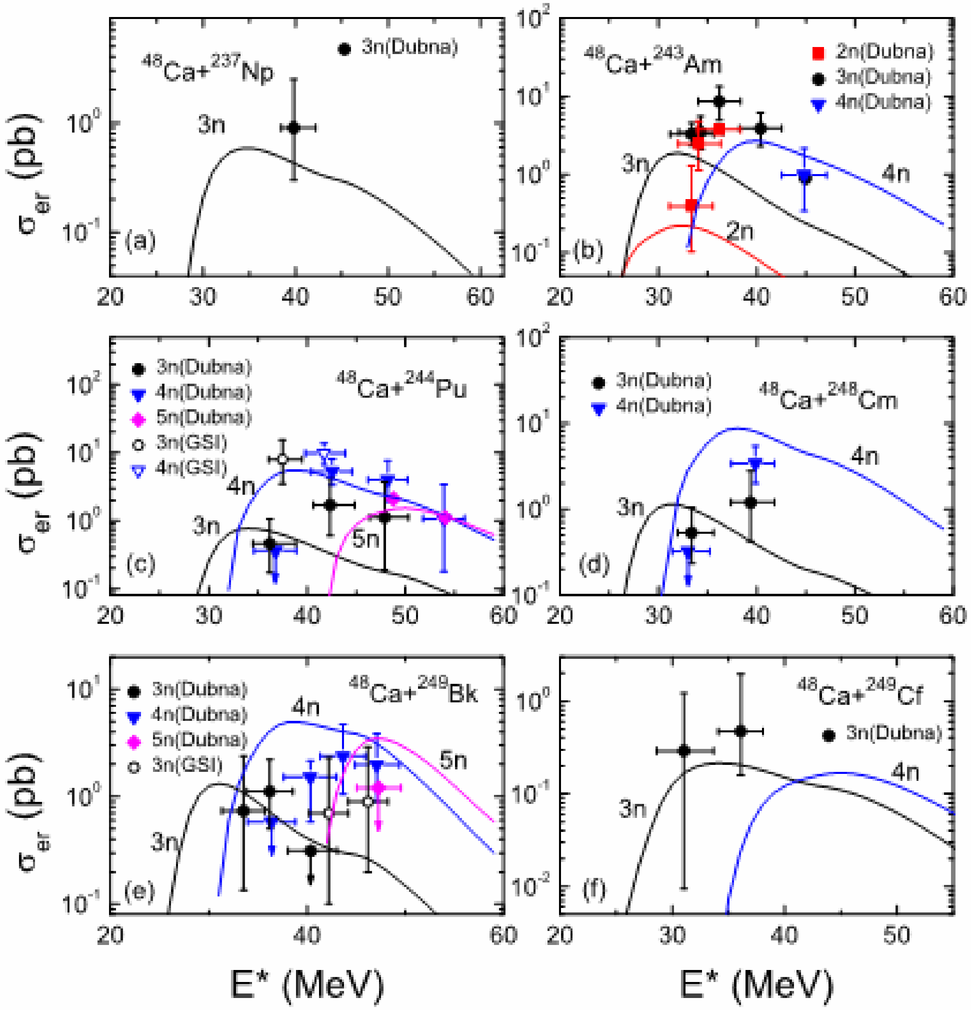
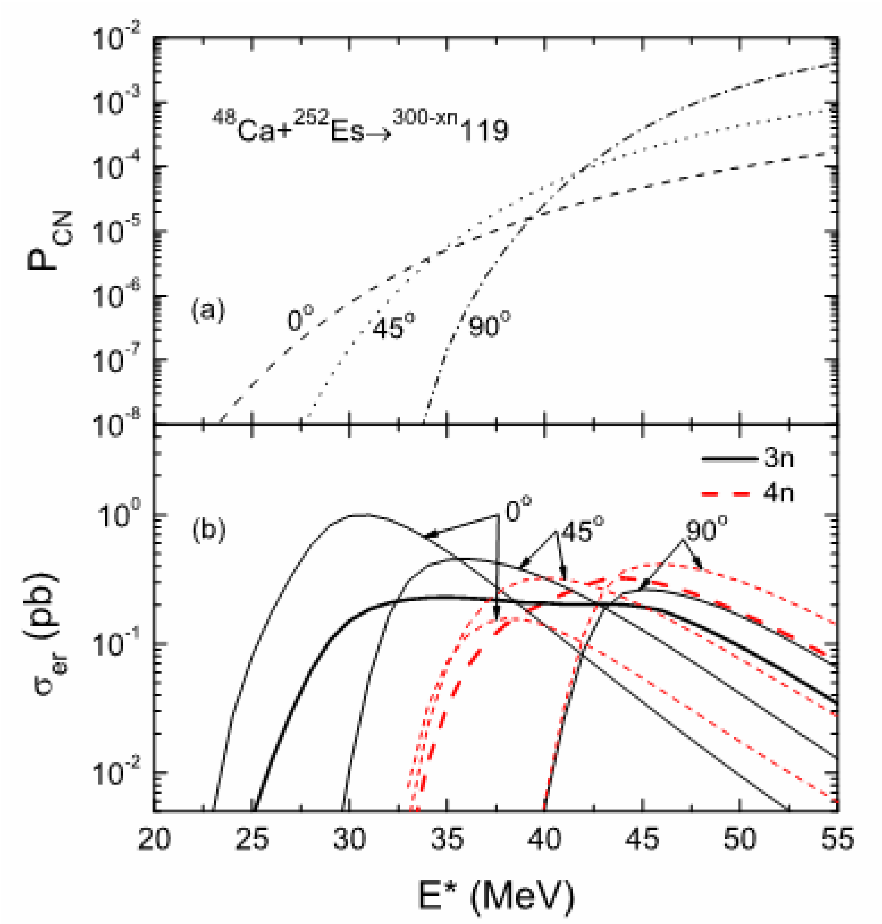


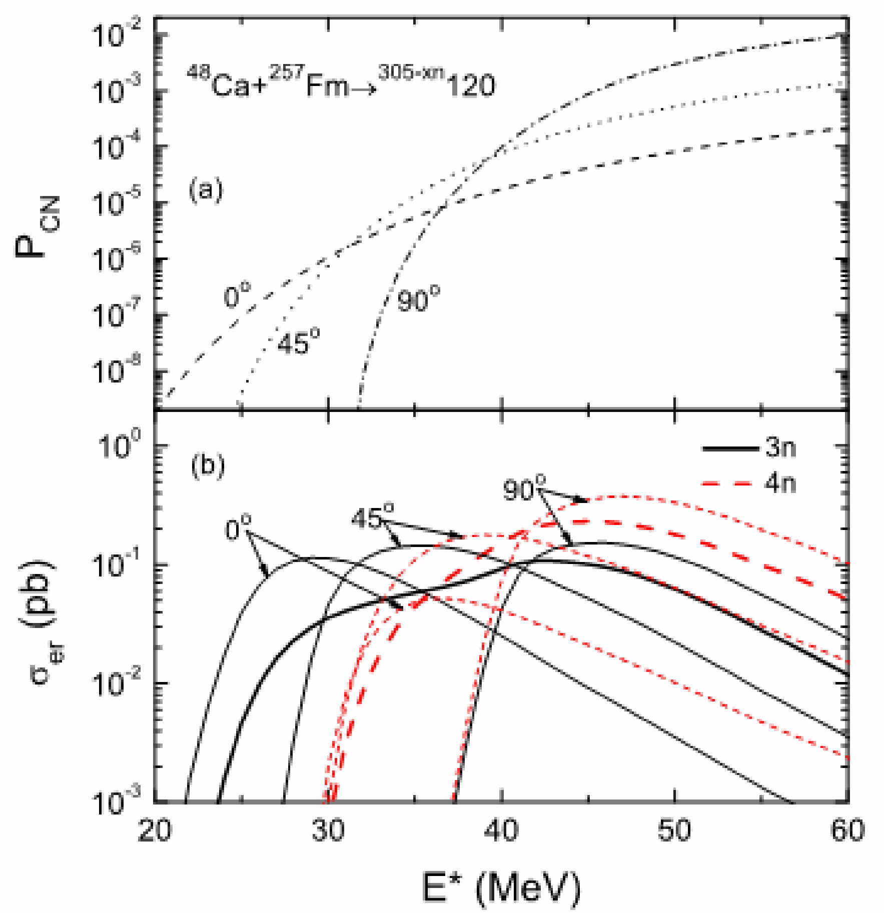


不同方向的平均结果

对超重核Z=119和120的预言



0.32 pb in the 4n channel



0.23 pb in the 4n channel

In the future, if it will be possible to prepare targets of ^{252}Es and ^{257}Fm, then the superheavy elements Z=119 and 120 probably can be synthesized.

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Conclusions

- The orientation of the colliding nuclei plays a significant role in fusion reactions.

- The capture cross sections for theta2=90^o are obviously suppressed, especially at sub-barrier energies. According to the DNS concept, the fusion probability strongly depend on the inner fusion barrier, the QF barrier, and the excitation energy of the DNS.

- It is found that fusion probability for theta2=0^o are much higher than those for Theta2=90^o at lower incident energies, while the opposite behavior can be seen in the high incident region.

- The production cross sections of Z =119 and 120 through the reactions ^{48}Ca+^{252}Es and ^{48}Ca+^{257}Fm are predicted. The maximal production cross sections of Z =119 and 120 are 0.32 and 0.23 pb, respectively, in the 4n emission channel.

Thanks !