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FUSION MECHANISM OF MASSIVE NUCLEI

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Content

- Motivation of theoretical study of the fusion mechanism.
- Advance and of the cold and hot fusion reactions used in the synthesis of superheavy elements.
- Comparison of the 4 reactions leading to formation ^{220}Th to study the role of the nuclear shell effects and impact parameter of collision in formation of the observed evaporation residues.
- Conclusions

Motivation of study

An unambiguous estimation of the fusion cross section is difficult task for the experimental and theoretical point view.

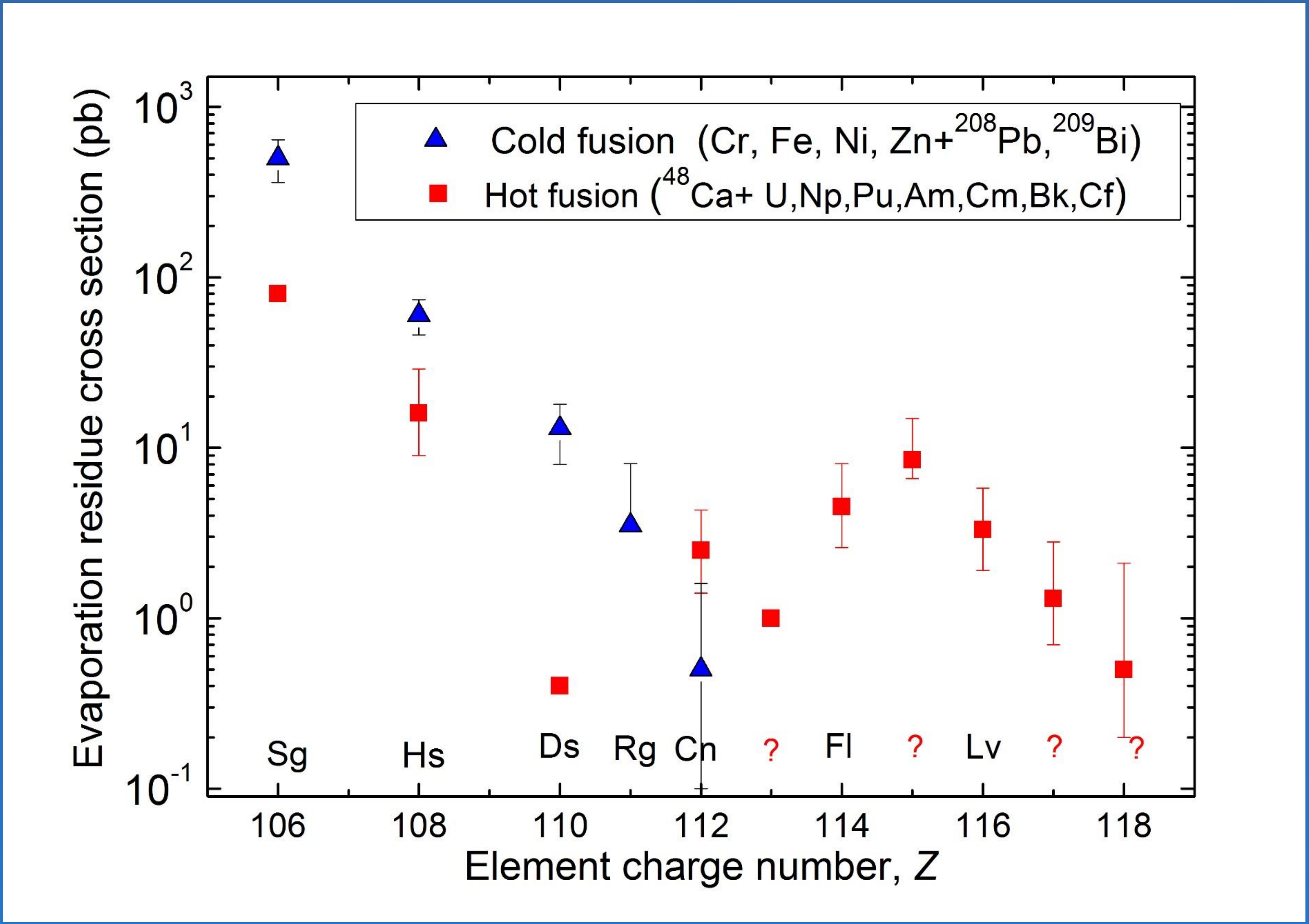
1) overlap of the characteristics of the reaction products formed in different channels causes ambiguity in reconstruction of the realistic mechanism of the given reaction channel;

2) Theoretical model to calculate the cross section of processes in heavy ion collisions can be developed on the base of the realistic concept about reaction mechanism.

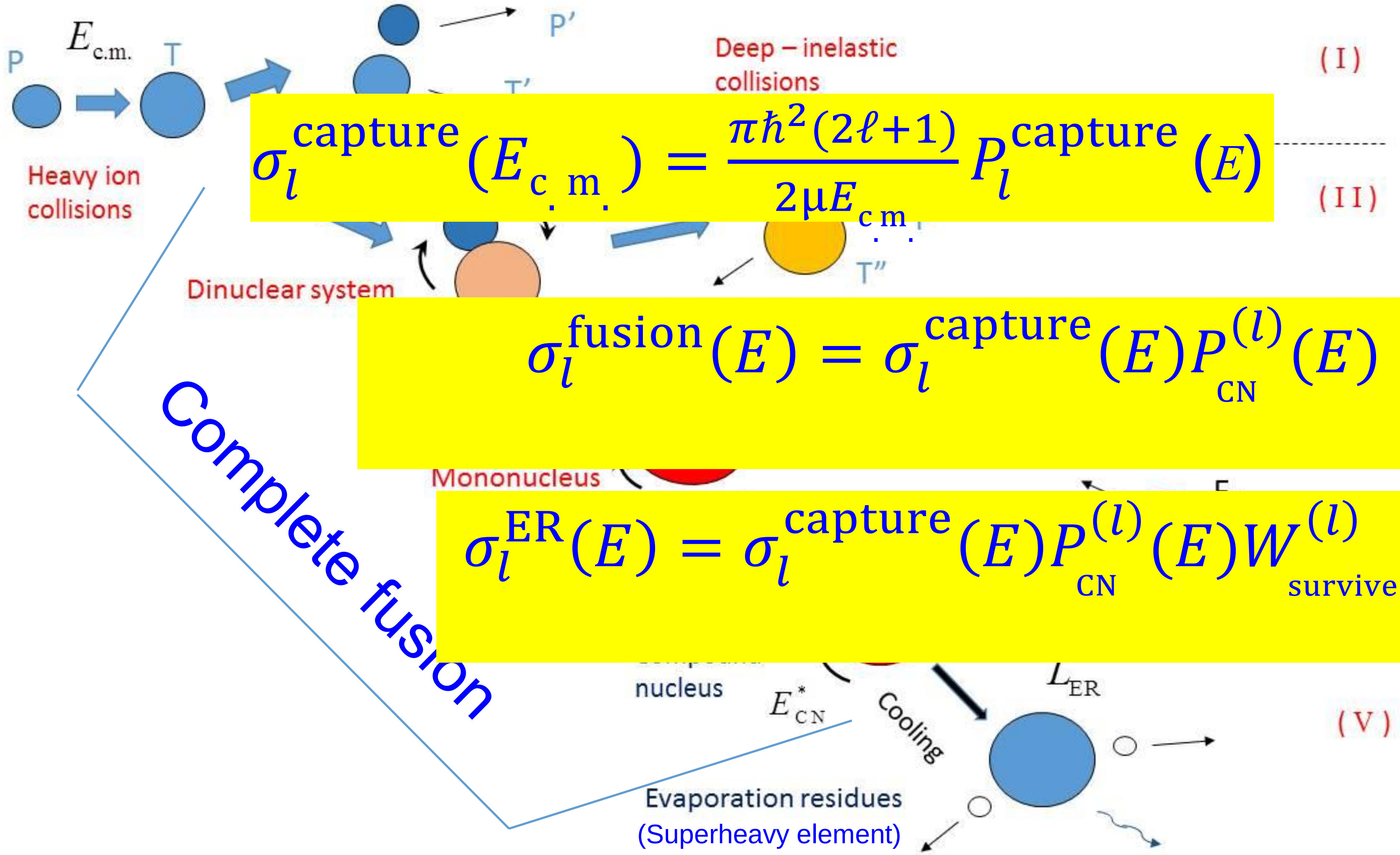
Mendeleev periodic table of the elements (2015)

IB
IIB
29
30
Zn
65,39
Zinc
31 Ga 69,723 Gallium
32 Ge 72,61 Germanium
33 As 74,92159 Arsenic
34 Se 78,96 Selenium
35 Br 79,904 Bromine
45
46 Pd 106,42 Palladium
47 Ag 107,8682 Silver
48 Cd 112,411 Cadmium
49 In 114,818 Indium
50 Sn 118,710 Tin
51 Sb 121,757 Antimony
52 Te 127,60 Tellurium
53 I 126,90447 Iodine
54 Xe 131,29 Xenon
77
78 Pt 195,08 Platinum
79 Au 196,96654
80 Hg 200,59 Mercury
81 Tl 204,3833 Thallium
82 Pb 207,2 Lead
83 Bi 208,98037 Bismuth
84 Po [209] Polonium
85 At [210] Astatine
86 Rn [222] Radon
110 Ds [269] Darmstadtium
111 Rg [272] Roentgenium
Cn [277] Copernicium
113
114 Flerovium Fl 288
115
116 Livermorium Lv 292
117
118
66
67 Ho 164,93032 Holmium
68 Er 167,26 Erbium
69 Tm 168,93421 Thulium
70 Yb 173,04 Ytterbium
71 Lu 174,967 Lutetium
1 H 1,00794 Hydrogen

Synthesis of superheavy elements in the cold and hot fusion reactions.



Reaction channels in heavy ion collisions at low energies

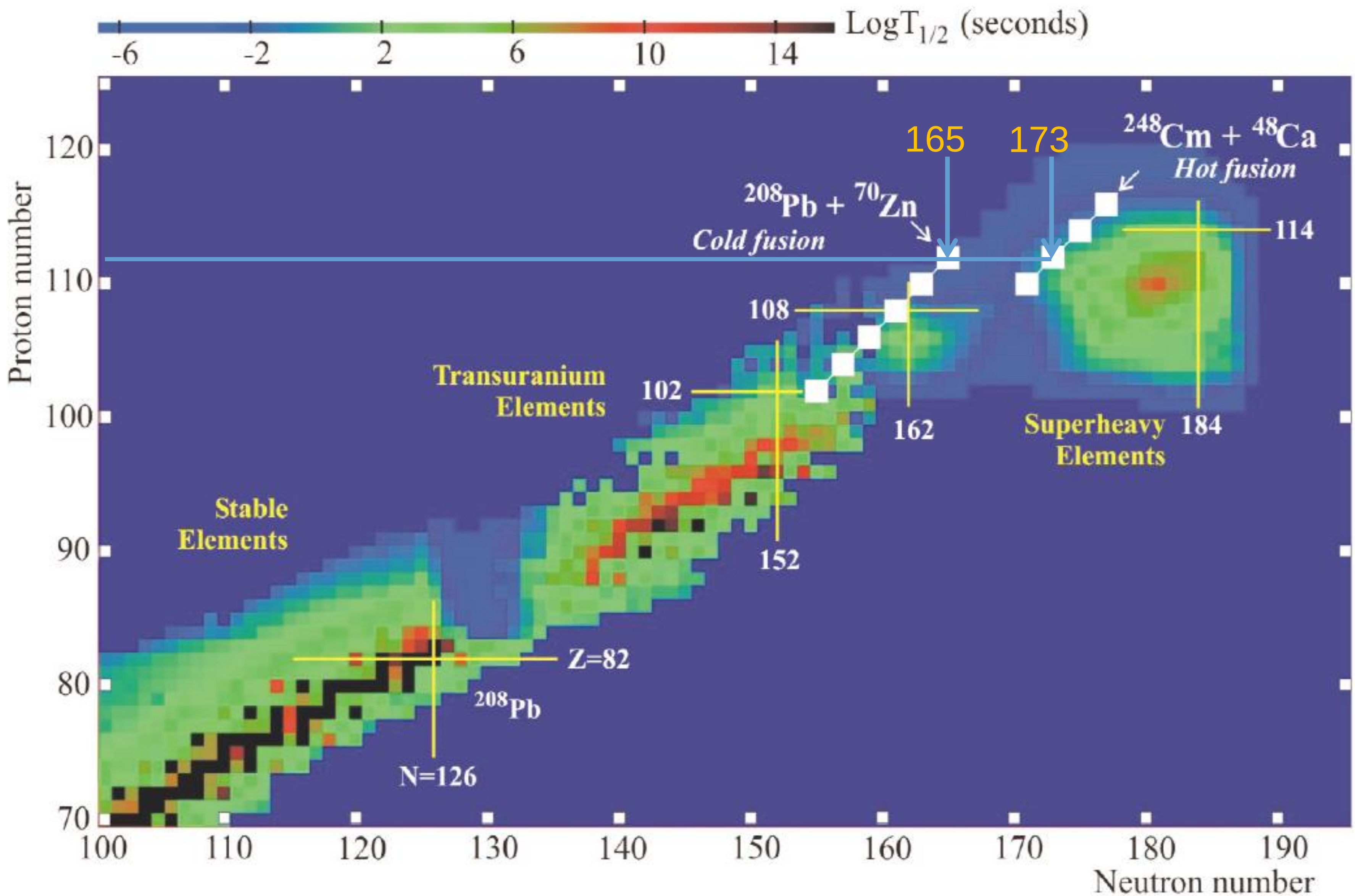


$$\sigma_l^{\text{capture}}(E_{\text{c.m.}}) = \frac{\pi\hbar^2(2\ell+1)}{2\mu E_{\text{c.m.}}} P_l^{\text{capture}}(E)$$

$$\sigma_l^{\text{fusion}}(E) = \sigma_l^{\text{capture}}(E) P_{\text{CN}}^{(l)}(E)$$

$$\sigma_l^{\text{ER}}(E) = \sigma_l^{\text{capture}}(E) P_{\text{CN}}^{(l)}(E) W_{\text{survive}}^{(l)}(E)$$

Map of superheavy elements region



From paper Yuri Oganessian, Pure Appl. Chem., Vol. 78, No. 5, pp. 889–904, 2006

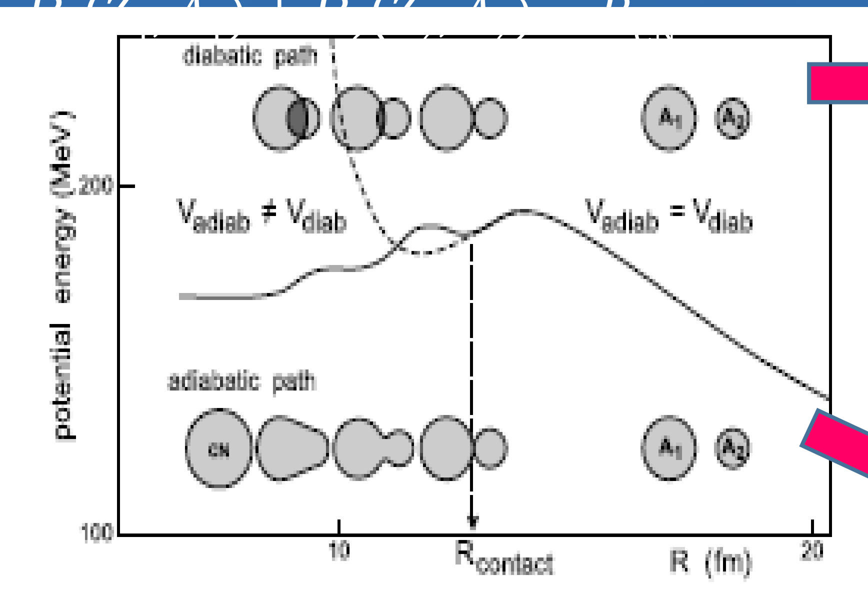
Transition of the advantage from the “cold" fusion reaction to the hot fusion reactions.

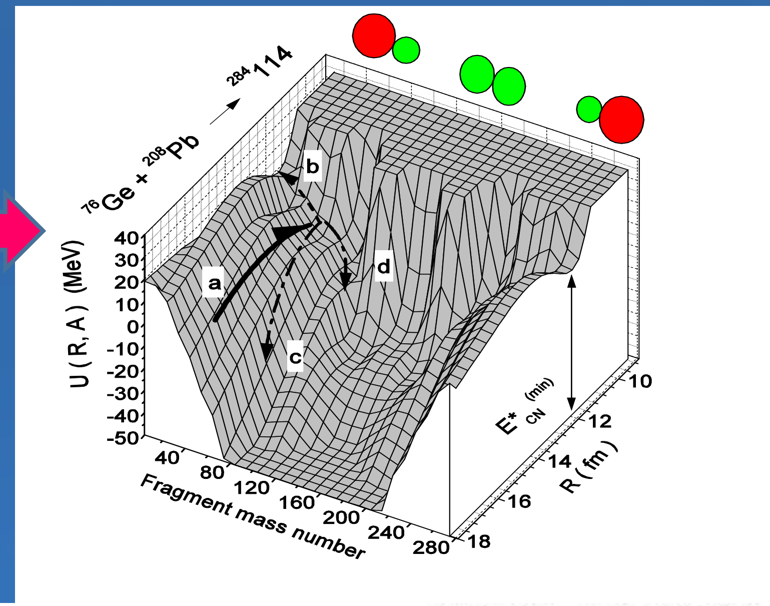
Cold fusion	Z_{CN}	N	B_f (MeV)	σ_{ER} (pb)	Hot fusion	N	B_f (MeV)	σ_{ER} (pb)
$^{54}Cr + ^{208}Pb$ [1]	106	156	6.05	500±140	$^{22}Ne+^{248}Cm$ [3]	160	5.37	≈80
$^{58}Fe+^{208}Pb$ [1]	108	156	5.47	60±14	$^{26}Mg+^{248}Cm$ [4]	161	6.15	7^{+3}_{-3}
-	108		-	-	$^{48}Ca+^{226}Ra$ [5]	162	6.42	16^{+13}_{-7}
$^{64}Ni+^{208}Pb$ [1]	110	162	5.83	13±5	$^{34}S+^{244}Pu$ [6]	163	5.52	≈0.4
$^{64}Ni+^{209}Bi$ [1]	111	162	5.52	$3.5^{+4.6}_{-3.5}$	-		-	-
$^{70}Zn+^{208}Pb$ [1]	112	165	4.29	$0.5^{+1.1}_{-0.4}$	$^{48}Ca+^{238}U$ [7]	171	4.01	$2.5^{+1.8}_{-1.1}$
$^{70}Zn+^{209}Bi$ [2]	113	165	4.53	$0.022^{+0.020}_{-0.013}$	$^{48}Ca+^{237}Np$ [8]	169	3.93	1.0
	114		-	-	$^{48}Ca+^{244}Pu$ [7]	174	5.53	$4.5^{+3.6}_{-1.9}$
	115				$^{48}Ca+^{243}Am$ [9]	173	5.40	$8.5^{+6.4}_{-3.7}$
	116				$^{48}Ca+^{248}Cm$ [7]	176	6.22	$3.3^{+2.5}_{-1.4}$
	117				$^{48}Ca+^{249}Bk$ [10]	176	6.11	$3.6^{+6.1}_{-2.5}$
	118				$^{48}Ca+^{249}Cf$ [10]	176	5.99	$0.5^{+1.6}_{-0.3}$

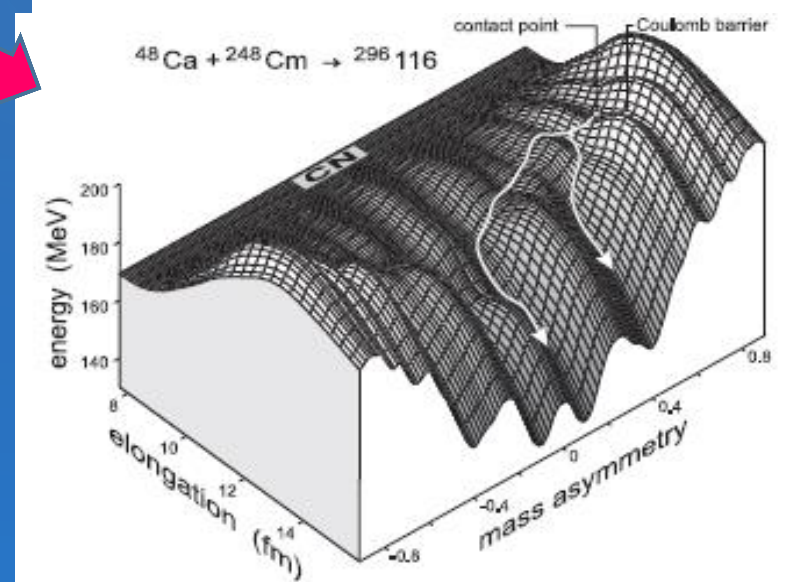
1. S. Hofmann, Rev. of Mod. Phys. 2000. V.72. P.733.
2. K. Morita et al., J. Phys. Soc. of Jap, 81, (2012) 103201 .
3. Yu. A. Lazarev,Phys. Rev. Lett. 1994. V.73. P. 624.
4. J. Dvorak Phys. Rev. Lett. 2008. V.100. P.132503.
5. Yu. Ts. Oganessian Phys. Rev. C. 2013. V.87. P.034605.
6. Yu. A. Lazarev Phys. Rev. .C. 1996. V.54. P.620.
7. Yu. Ts. Oganessian PRC 70, 2004. P.064609.
8. Yu. Ts. Oganessian, PRC 76. 2007, P.011601.
9. Yu. Ts. Oganessian PRC 69, 2004, P.021601(R) , PRC 87, 2013, P.014302.
10. Yu. Ts. Oganessian PRL 109, 2012, P.162501.

Two main concepts forcomplete fusion of massive nuclei

$U(Z_1, A_1, Z_2, A_2, R, Qgg)=$
$V_{int}(Z_1, A_1, Z_2, A_2, R)$







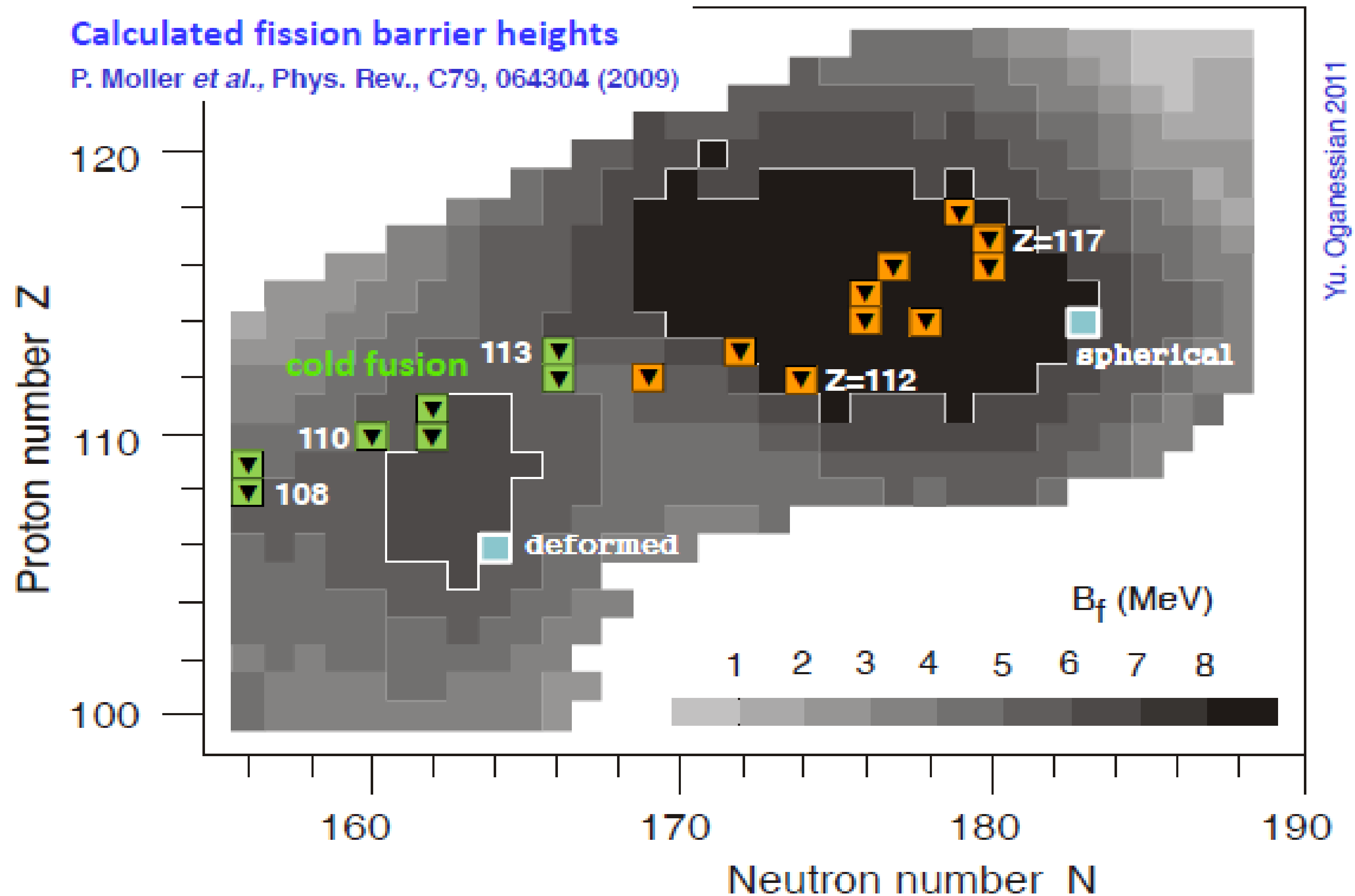
$$V = V_{\mathrm{diab}}[1 - f(t)] + V_{\mathrm{adiab}} f(t)$$

$\tau_{\mathrm{relax}} \sim 10^{-21}$ s (see, e.g., [24]),

$$f(t = 0) = 0, \; f(t \gg \tau_{\mathrm{relax}}) = 1.$$

[24] Bertsch G F 1978 *Z. Phys.* A **289** 103
Cassing W and Nörenberg W 1983 *Nucl. Phys.* A **401** 467

Role of fission barrier in synthesis of the superheavy elements



Yu. Oganessian "Nuclei from Island of Stability of SHE" M-Lakes Conference Sept. 11-18, 2011, Poland

Fission barriers calculated by macroscopic-microscopic model:

M. Kowal, P. Jachimowicz, and A. Sobiczewski, Phys. Rev. C **82, 014303 (2010)**

$$B_{\text{fis}}(J,T) = cB_{\text{fis}}^{LD}(J) - h(T)q(J)\delta W,$$

$$h(T) = \frac{1}{1+\exp[(T-T_0)/d]}$$

T_0=1.16 MeV, d=0.3 MeV

$$q(J) = \frac{1}{1+\exp[(J-J_{1/2})/\Delta J]}$$

$J_{1/2}=20\hbar$, $\Delta J=3\hbar$,

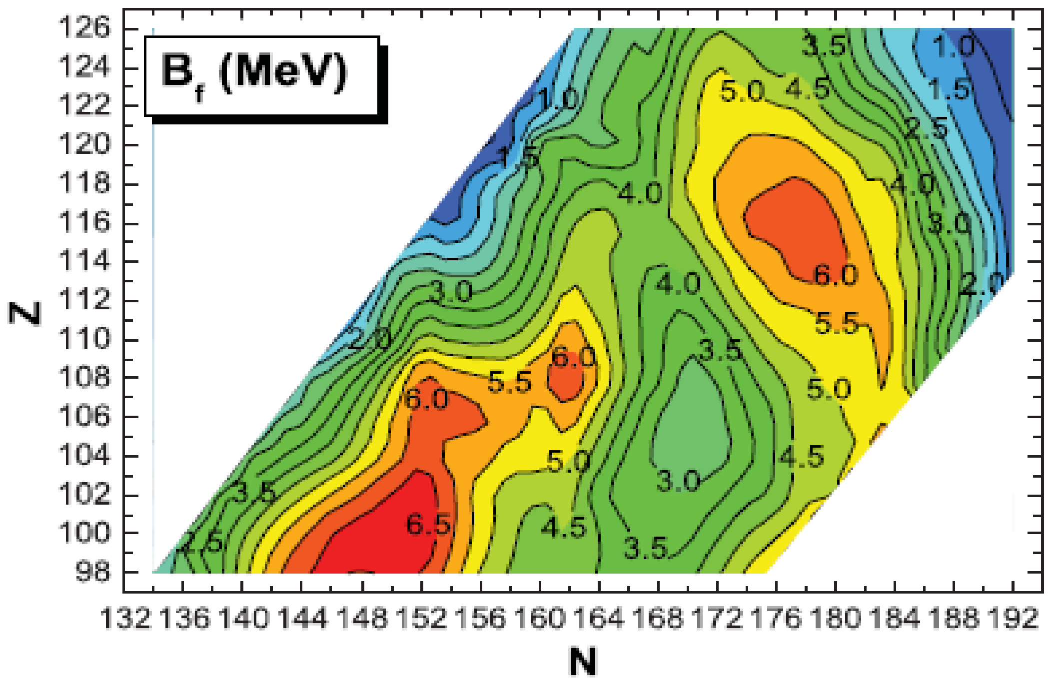
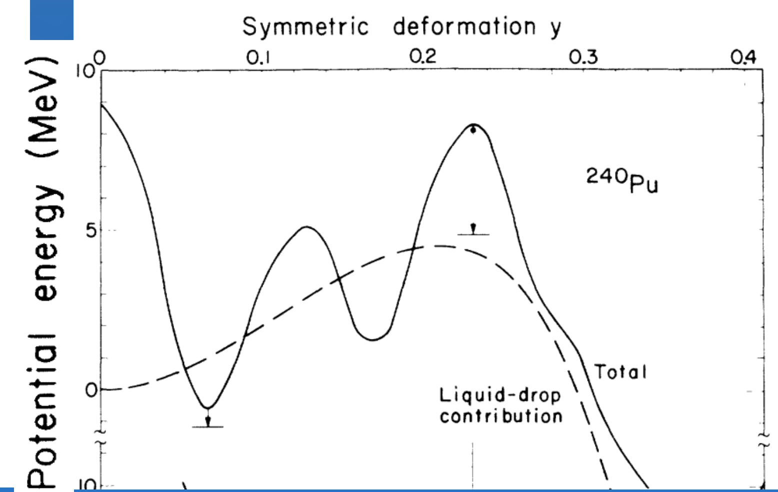
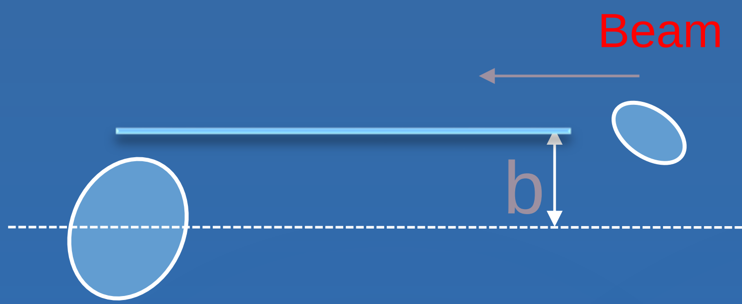


FIG. 6. (Color online) Contour map of calculated fission barrier heights B_f for even-even superheavy nuclei.



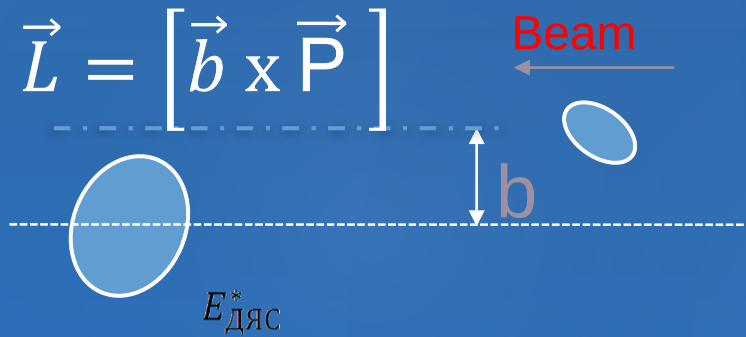


I. Deep inelastic collisions:

1) Partial momentum transfer;
2) There is not equilibrium of energy distribution and mass distribution;
3) Anisotropic angular distribution

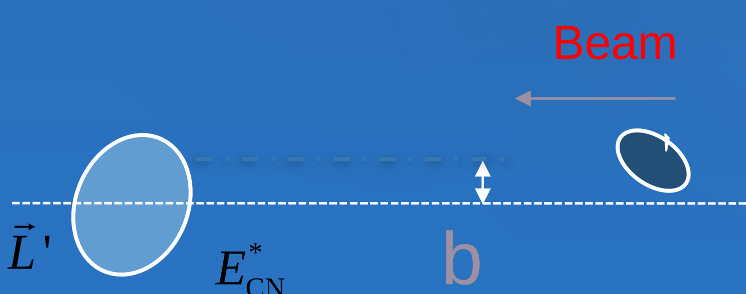
Formation of the dinuclear system (Capture reactions)

$$\vec{L} = \left[\vec{b} \times \vec{P}\right]$$



II. Quasifission:

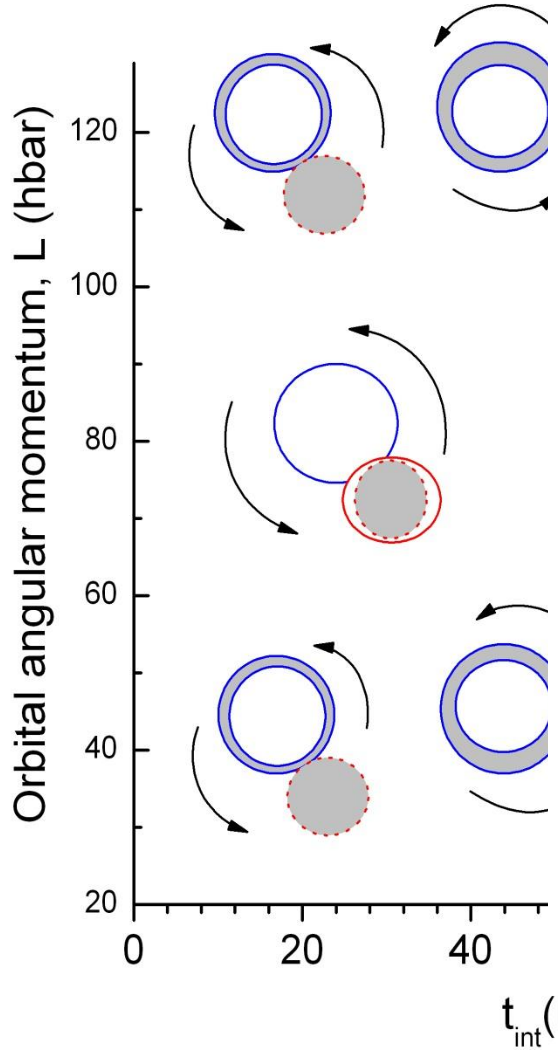
1) Full momentum transfer;
2) Equilibrium of energy distribution and mass distribution;
3) Anisotropic and isotropic angular distributions.



III. Compound nucleus formation:

1) Full momentum transfer;
2) Equilibrium of energy distribution and mass distribution;
3) Isotropic angular distributions.

Mechanisms of the reaction following after capture (capture means formation of dinuclear system): Fusion-fission, quasifission and fast-fission.



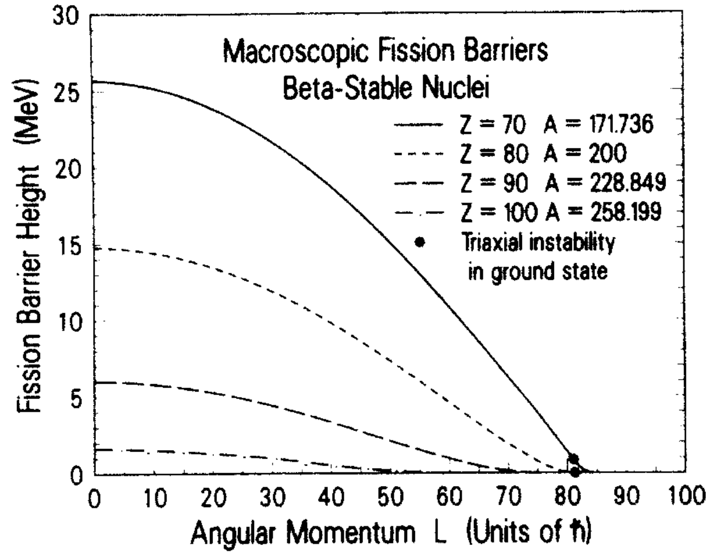


FIG. 10. Same as Fig. 9 for $Z=70$ to 100. There are no solid points for $Z=90$ and $Z=100$ since no triaxial ground states exist for these nuclei.

The methods of calculation of the capture and Fusion cross section in the dinuclear system approach.

Main assumptions:

1) the shell effects does not allow to fuse nuclei immediately;
2) The hindrance to fusion is determined by the intrinsic fusion barrier B^*_{fus} which is determined from the landscape of the potential energy surface of dinuclear system;
3) the interacting nuclei can be deformed and nucleon exchange between them takes place allowing dinuclear system to be transformed into compound nucleus or to populate shapes corresponding minimal values of the potential energy surface;
4) The lifetime of dinuclear system is determined by its excitation energy E^*_{DNS} and quasifission barrier B_{qf}.

Theoretical calculation of evaporation residue cross section (synthesis of superheavy element).

$$\sigma_{ER} = \sum_{l=0}^{l_d} (2l+1)\sigma_l^{fus}(E,l)W_{\mathrm{surv}}(\mathrm{E,l})$$

$$\sigma_l^{fus}(E,l) = \sigma_l^{capture}(E,l)P_{\mathrm{CN}}(E,l)$$

$P_{\mathrm{CN}}(E,l)$ is fusion probability which calculated by diffusion-dissipative method, Y. Aritomo, Phys.Rev.C65, 014607 (2001)

or G.G. Adamian, N.V. Antonenko, and W. Scheid,

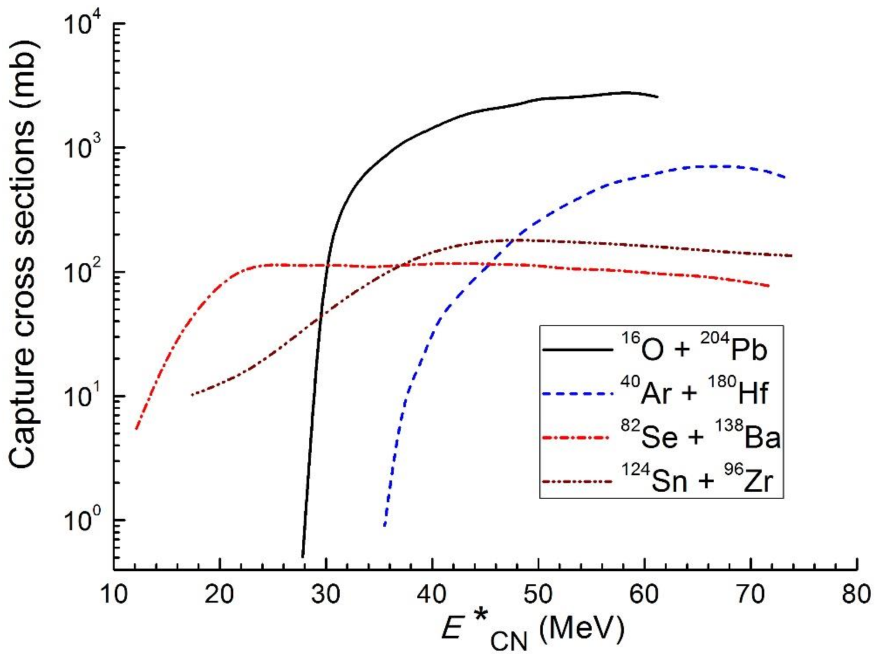
Eur. Phys. J. A 41, 235 (2009);.

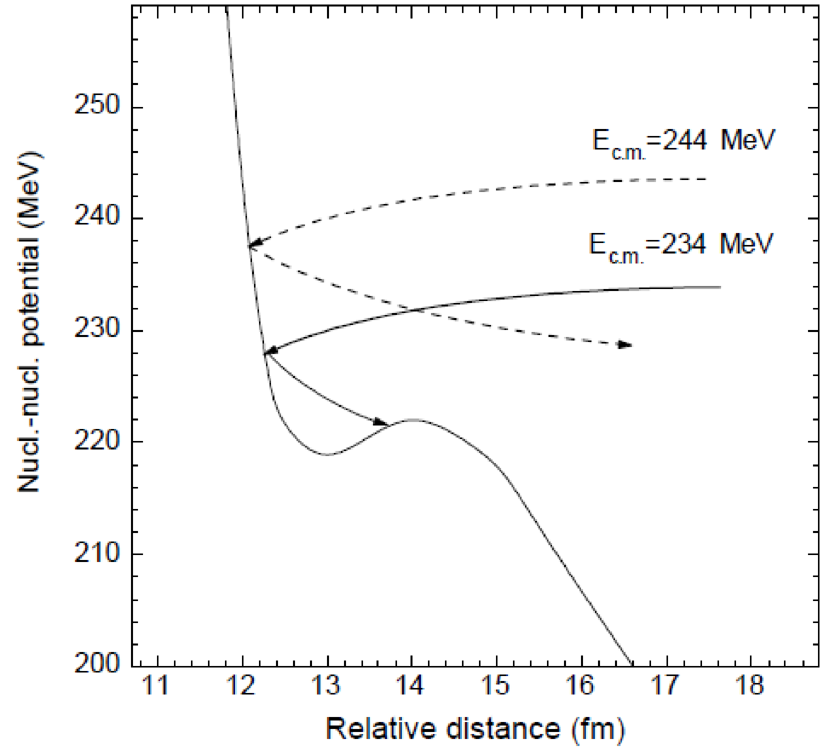
A. K. Nasirov, G. Giardina, S.Hofmann, et al.

Phys. Rev. C **79**, 024606 (2009).

$\sigma_l^{capture}$ is capture probability, which calculated in different theoretical models by different way.

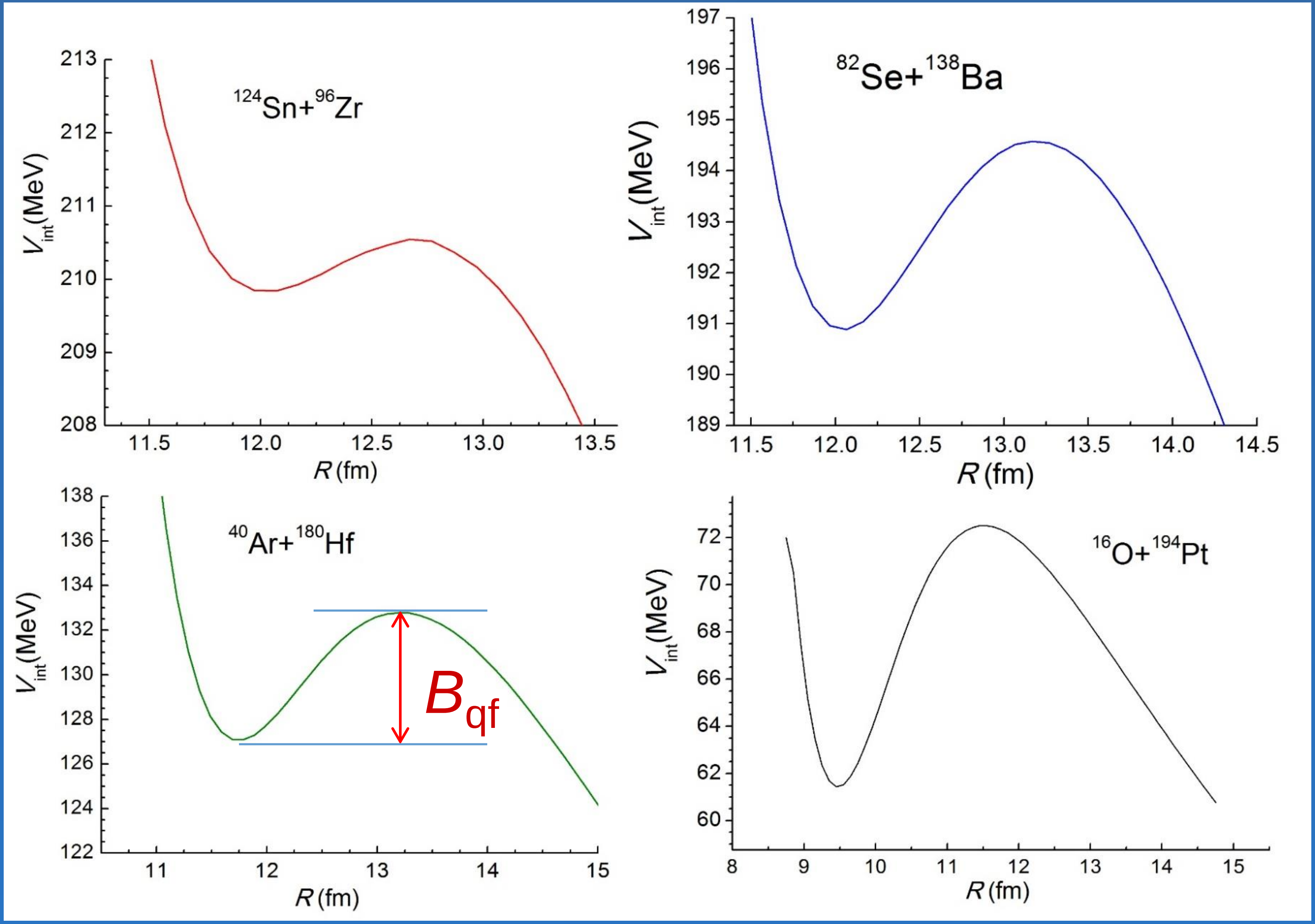
Comparison of the capture cross sections of the reactions leading to ^{220}Th





$$\mu(R)\ddot{R}+\gamma_R(R)\dot{R}(t)=-\frac{\partial V(R)}{\partial R}-\dot{R}^2\frac{\partial \mu(R)}{\partial R}$$

Comparison of the potential wells of the nucleus-nucleus interaction for reactions leading to formation of ^{220}Th.



Equations of motion used to find the capture of projectile by target-nucleus

$$\mu(R)\ddot{R}+\gamma_R(R)\dot{R}(t)=-\frac{\partial V(R)}{\partial R}-\dot{R}^2\frac{\partial \mu(R)}{\partial R}$$

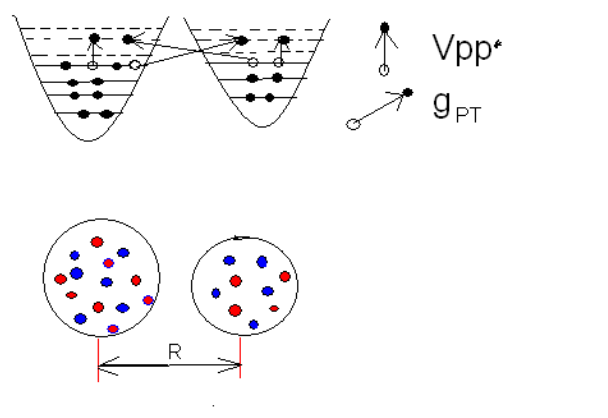
$$\mu(R)=\delta\mu(R)+m_0A_{\mathrm{T}}A_{\mathrm{P}}/A_{\mathrm{tot}}$$
$$\times\left(1-\frac{2}{A_{\mathrm{tot}}}\int\frac{\rho_1^{(0)}(\mathbf{r}-\mathbf{r}_1)\rho_2^{(0)}(\mathbf{r}-\mathbf{r}_2)}{\rho_1^{(0)}(\mathbf{r}-\mathbf{r}_1)+\rho_2^{(0)}(\mathbf{r}-\mathbf{r}_2)}\mathrm{d}^3\mathbf{r}\right),$$

$$\frac{dL}{dt}=\gamma_\theta(R)R(t)\left[\dot{\theta}R(t)-\dot{\theta}_1R_{1eff}-\dot{\theta}_2R_{2eff}\right]$$

$$L_0=J_R\dot{\theta}+J_1\dot{\theta}_1+J_2\dot{\theta}_2\,,$$

$$E_{rot}=\frac{J_R\theta^2}{2}+\frac{J_1\theta_1^{\,2}}{2}+\frac{J_2\theta_2^{\,2}}{2}$$

Hamiltonian for calculation of the transport coefficients of collective motion



$$H = H_{coll}(Z_1, A_1, Z_2, A_2, R, \alpha_1, \alpha_2, \beta_1, \beta_2)$$
$$+H_{micr}\left(\left\{\varepsilon_{i_1}, n_{i_1}\right\}, \left\{\varepsilon_{i_2}, n_{i_2}\right\}\right) + \delta V \qquad (1)$$

where

$$H_{coll} = \frac{P^2}{2\mu} + U(Z_1, A_1, Z_2, A_2, R, \alpha_1, \alpha_2, \beta_1, \beta_2)$$ - for the relative motion of nuclei; (2)

$$H_{micr} = \sum_{i_P} \varepsilon_{i_P} \hat{a}^+_{i_P} \hat{a}_{i_P} + \sum_{i_T} \varepsilon_{i_T} \hat{a}^+_{i_T} \hat{a}_{i_T} \ - \textit{for nucleons of nuclei;} \qquad (3)$$

$$\delta V = \sum_{i_P, j_T} g_{i_P j_T}(R)(\hat{a}^+_{i_P} \hat{a}_{j_T} + \hat{a}^+_{j_T} \hat{a}_{i_P}) + \sum_{i_P, j_T} \kappa_{i_P j_T}(R)(\hat{a}^+_{i_P} \hat{a}_{j_T} + \hat{a}^+_{j_T} \hat{a}_{i_P})$$
$$+\sum_{i_P, j_P} \Lambda^{(T)}_{i_P j_P}(R) \hat{a}^+_{i_P} \hat{a}_{j_P} + \sum_{i_P, j_P} \Lambda^{(P)}_{i_T j_T}(R) \hat{a}^+_{i_T} \hat{a}_{j_T}$$ – –nucleon exchange between nuclei and particle – hole excitations in nuclei; (4)

$g_{i_P j_T}$, $\kappa_{i_P j_T}$ and $\Lambda^{(P)}_{i_T j_T}$ – matrix elements of nucleon exchange between nuclei and particle – hole excitations in them caused by meanfield of partner nucleus.

G.G. Adamian, et al. Phys. Rev. C**56** No.2, (1997) p.373-380
A.K. Nasirov, Thesis of the Doctor of Science, 2004, INP, Tashkent

Nucleus-nucleus interaction potential

$$V_C(R,\alpha_1,\alpha_2) = \frac{Z_1 Z_2}{R} e^2$$

$$+ \frac{Z_1 Z_2}{R^3} e^2 \left\{ \left(\frac{9}{20\pi} \right)^{1/2} \sum_{i=1}^{2} R_{0i}^2 \beta_2^{(i)} P_2(\cos\alpha_i) + \frac{3}{7\pi} \sum_{i=1}^{2} R_{0i}^2 \left[\beta_2^{(i)} P_2(\cos\alpha_i) \right]^2 \right\}$$

$$V_{nucl}(R,\alpha_1,\alpha_2) = \int \rho_1^{(0)}(\vec{r} - \vec{R})\, f_{eff} \left[\rho_1^{(0)} + \rho_2^{(0)} \right] \rho_2^{(0)}(\vec{r}) d^3\vec{r}$$

$$\rho_i^{(0)}(\vec{r}, \vec{R}_i, \alpha_i, \theta_i, \beta_2^{(i)}) = \left\{ 1 + \exp\left[\frac{\left| \vec{r} - \vec{R}_i(t) \right| - R_{oi}(1 + \beta_2^{(i)} Y_{20}(\theta_i, \alpha_i))}{a} \right] \right\}^{-1}.$$

$$V_{rot} = \hbar^2 \frac{l(l+1)}{2\mu [R(\alpha_1, \alpha_2)]^2 + J_1 + J_2}$$

Density dependent effective nucleon-nucleon forces

$$f_{eff}(r) = C_0\left(f + f'\vec{\tau}_1\vec{\tau}_2 + (g + g'\vec{\tau}_1\vec{\tau}_2)\vec{\sigma}_1\vec{\sigma}_2 \right)$$

$$f(r) = f^{ex} + (f^{in} - f^{ex})\frac{\rho(r)}{\rho(0)}$$

Constants	Versions	
	I	II
1	2	
f_{in}	−0,09	+0,09
f_{ex}	−2,23	−2,59
f'_{in}	0,89	0,42
f'_{ex}	0,06	0,54
g	0,7	0,7
g'	0,83	0,83

$C_0 = 300$ MeV fm^{-3}

The values of the constants of the effective nucleon-nucleon forces from the textbook A.B. Migdal, "*Theory of the Finite Fermi-Systems and properties of Atomic Nuclei*", Moscow, Nauka, 1983. The constants of version II were used in our calculations.

Expressions for the friction coefficients

$$\gamma_R(R(t)) = \sum_{i,i'} \left| \frac{\partial V_{ii'}(R(t))}{\partial R} \right|^2 B_{ii'}^{(1)}(t), \tag{B.1}$$

$$\gamma_\theta(R(t)) = \frac{1}{R^2} \sum_{i,i'} \left| \frac{\partial V_{ii'}(R(t))}{\partial \theta} \right|^2 B_{ii'}^{(1)}(t), \tag{B.2}$$

and the dynamic contribution to the nucleus-nucleus potential

$$\delta V(R(t)) = \sum_{i,i'} \left| \frac{\partial V_{ii'}(R(t))}{\partial R} \right|^2 B_{ii'}^{(0)}(t), \tag{B.3}$$

$$B_{ik}^{(n)}(t) = \frac{2}{\hbar} \int_0^t \mathrm{d}t'(t-t')^n \exp\left(\frac{t'-t}{\tau_{ik}}\right) \times \sin\left[\omega_{ik}\left(\mathbf{R}(t')\right)(t-t')\right]\left[\tilde{n}_k(t') - \tilde{n}_i(t')\right], \tag{B.4}$$

$$\hbar\omega_{ik} = \epsilon_i + \Lambda_{ii} - \epsilon_k - \Lambda_{kk}\,. \tag{B.5}$$

Calculation of the competition between complete fusion and quasifission: $P_{cn}(E_{DNS},L)$

$$P_{CN}(E^*_{DNS},\ell)=\sum_{Z_{sym}}^{Z_{max}} Y_Z(E^*_{DNS},\ell)P^{(Z)}_{CN}(E^*_{DNS},\ell)$$

where

$$P^{(Z)}_{CN}(E^*_{DNS},\ell)=\frac{\rho(E^*_{DNS}(Z)-B^*_{fus}(Z),\ell)}{\rho(E^*_{DNS}(Z)-B^*_{fus}(Z),\ell)+\rho(E^*_{DNS}(Z)-B^*_{qf}(Z),\ell)+\rho(E^*_{DNS}(Z)-B^*_{sym}(Z),\ell)}$$

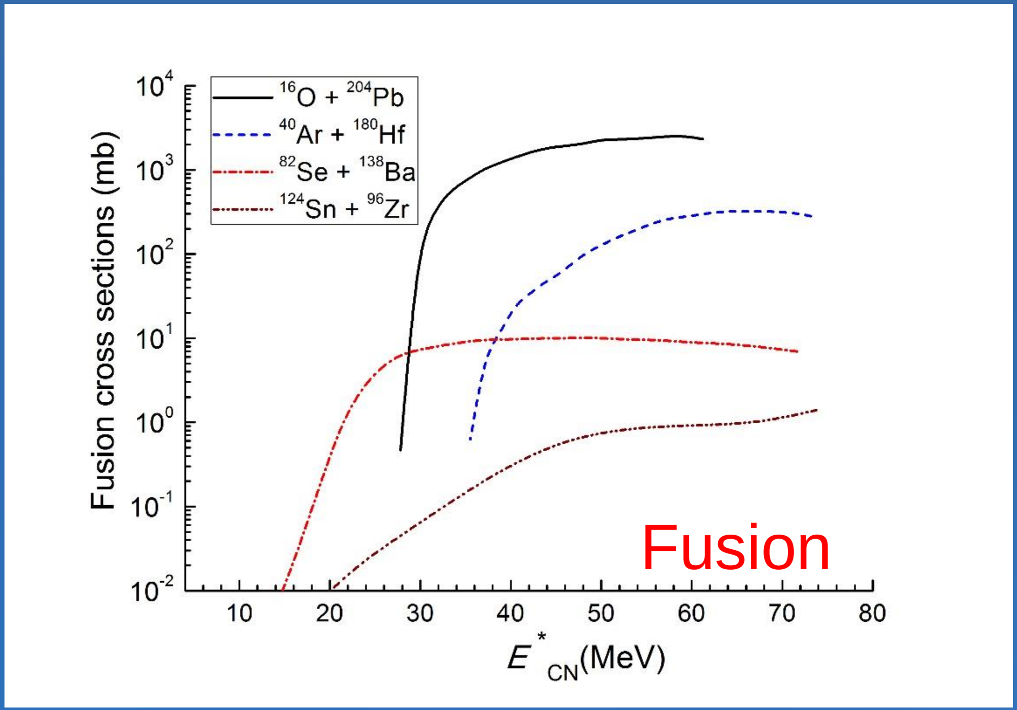
$$\frac{\partial}{\partial t}Y_Z(E^*_Z,\ell,t)=\Delta^{(-)}_{Z+1}Y_{Z+1}(E^*_Z,\ell,t)+\Delta^{(+)}_{Z-1}Y_{Z-1}(E^*_Z,\ell,t)$$
$$-(\Delta^{(-)}_Z+\Delta^{(+)}_Z+\Lambda^{qf}_Z)Y_Z(E^*_Z,\ell,t)$$

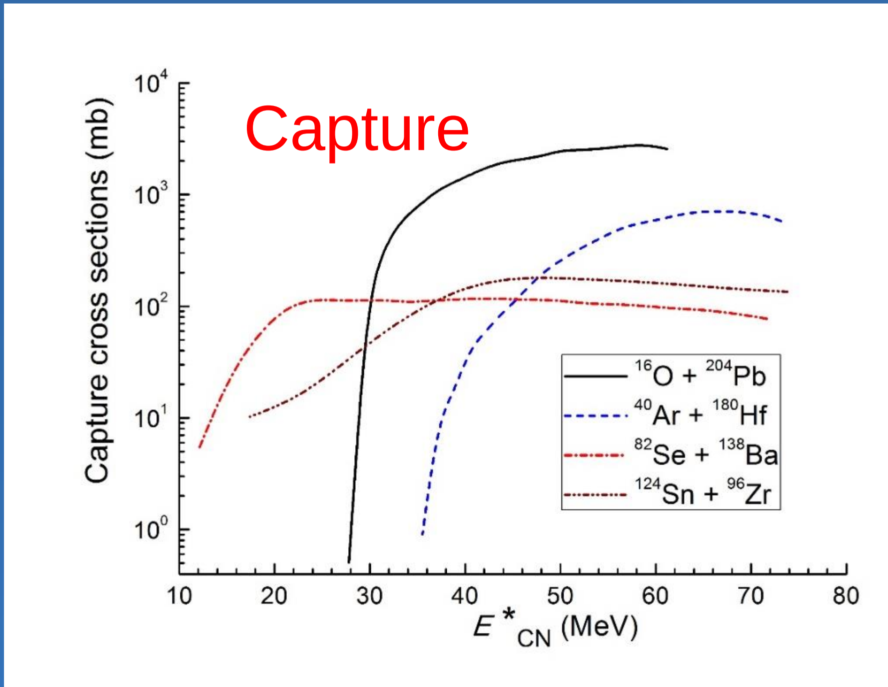
for $\mathrm{Z}=2,3,\ldots,\mathrm{Z}_{\mathrm{tot}}-2$

Nasirov A.K. et al. Nuclear Physics A 759 (2005) 342–369

Fazio G. et al, Modern Phys. Lett. A 20 (2005) p.391

Comparison of the complete fusion cross sections of the 4 reactions

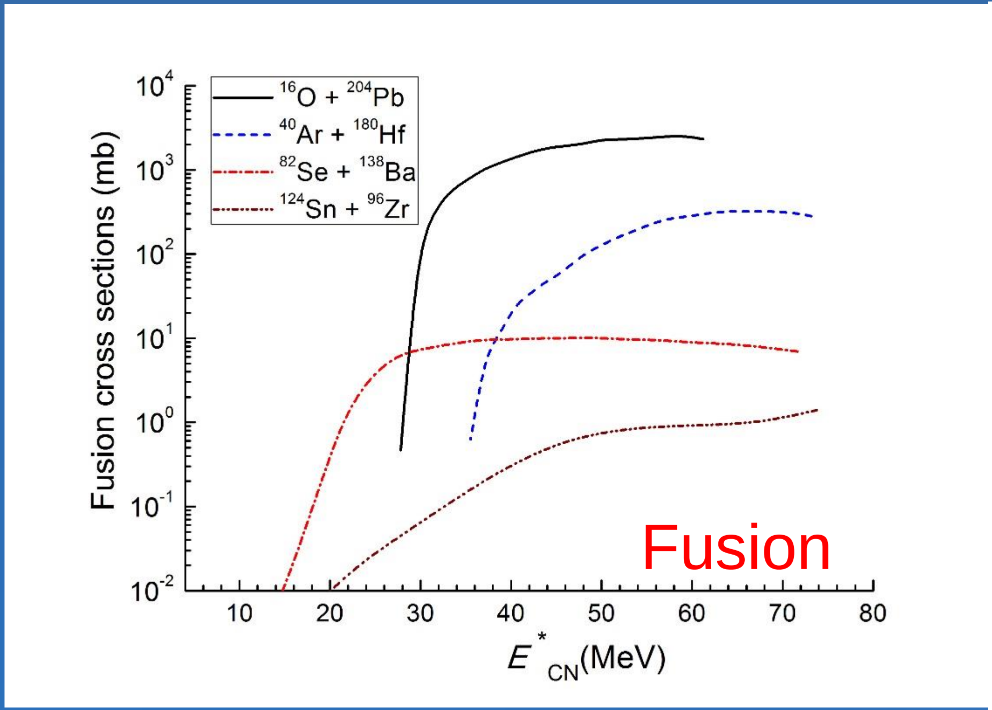


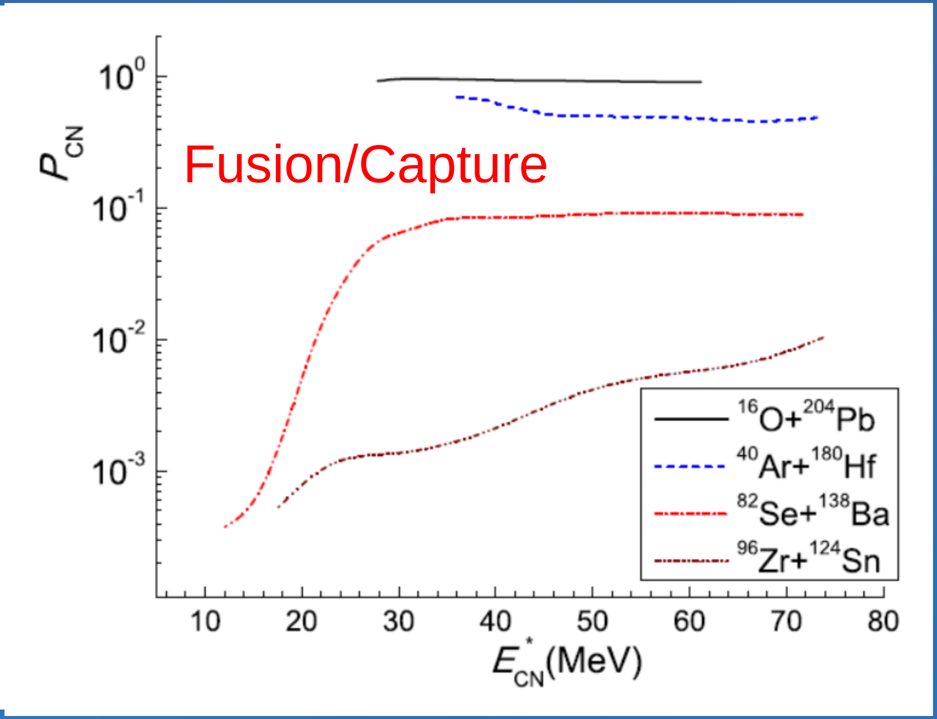


$$\sigma_l^{fus}(E,l) = \sigma_l^{capture}(E,l) P_{\mathrm{CN}}(E,l)$$

K.Kim et al, Phys. Rev. C 91, 064608 (2015)

Comparison of the complete fusion cross sections of the 4 reactions



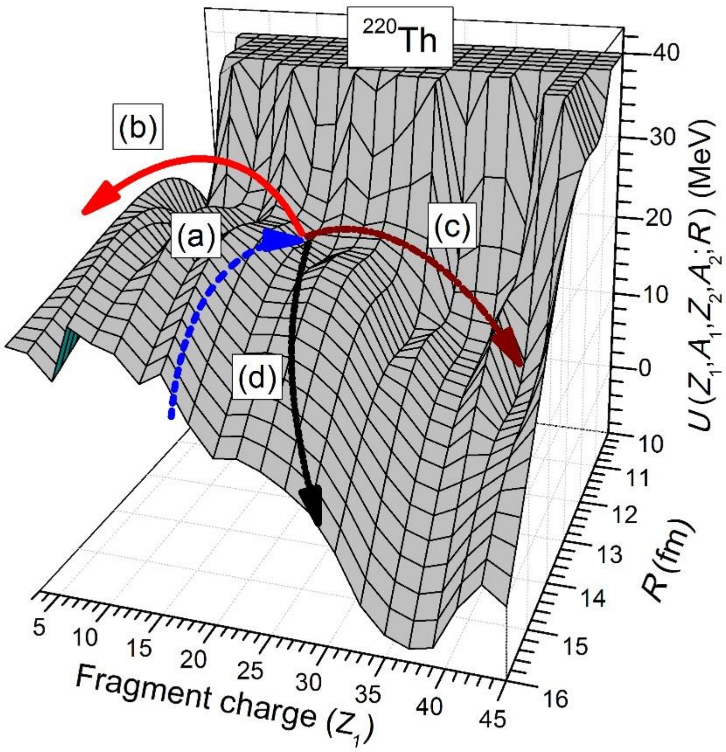


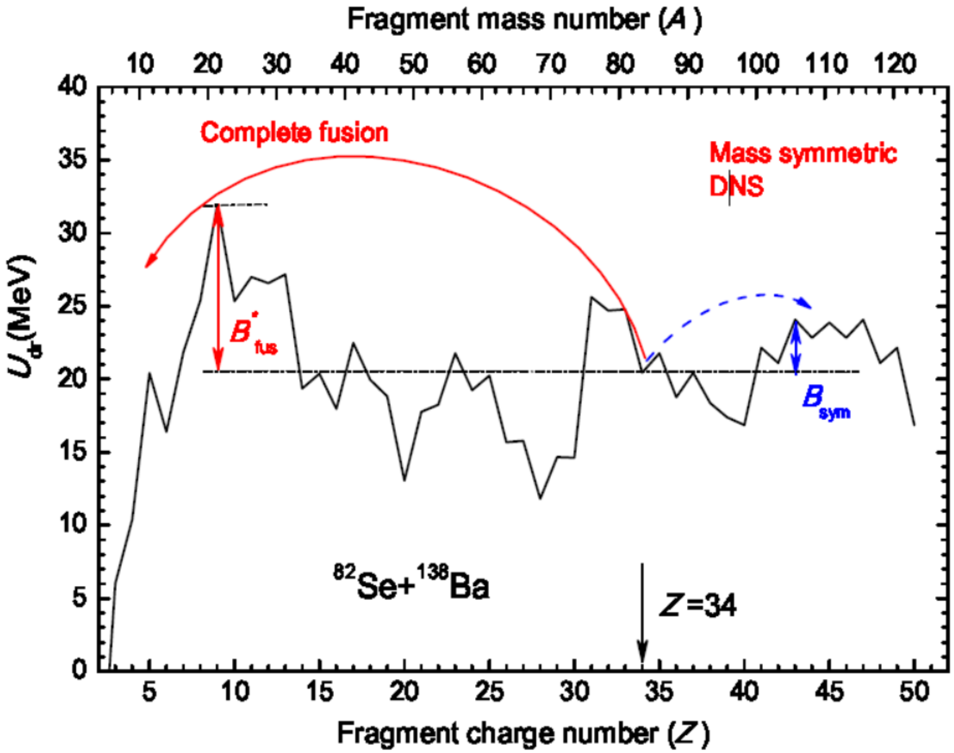
$$\sigma_l^{fus}(E,l) = \sigma_l^{capture}(E,l)P_{\rm CN}(E,l)$$

Potential energy surface

$$U(Z_1, A_1, Z_2, A_2, R, Qgg)= B_1(Z_1, A_1) + B_2(Z_2, A_2) - B_{CN} + V_{int}(Z_1, A_1, Z_2, A_2, R)$$

K.Kim et al, Phys. Rev. C 91, 064608 (2015)

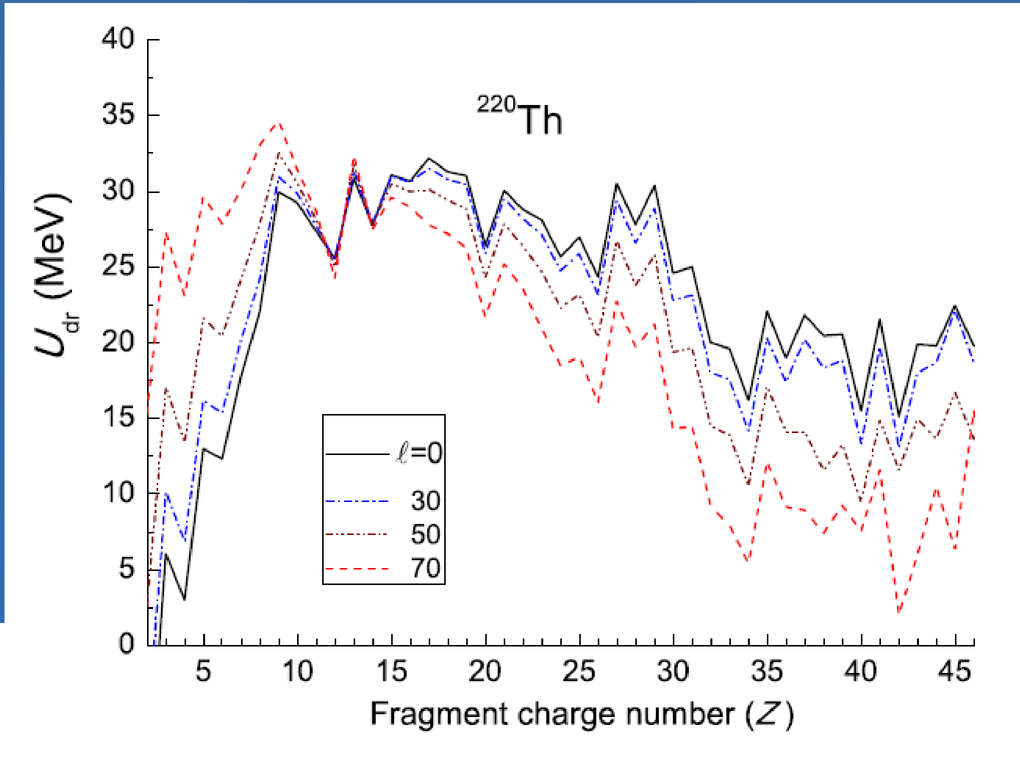


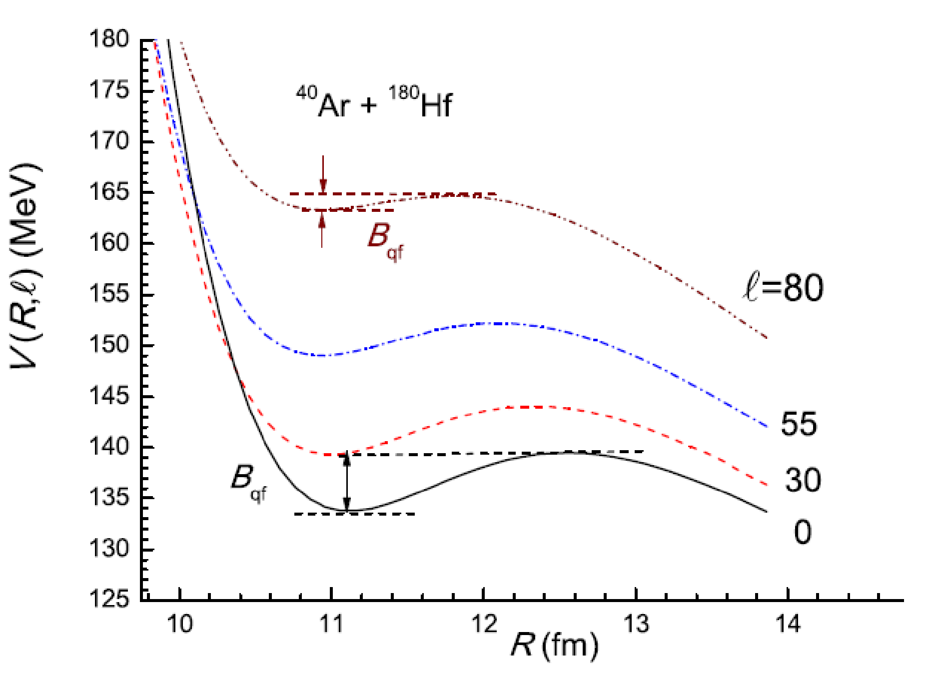


Driving potential

$$U_{dr}(Z_1, A_1, Z_2, A_2, Rm, Qgg)= B_1(Z_1, A_1) + B_2(Z_2, A_2) - B_{CN} + V_{int}(Z_1, A_1, Z_2, A_2, Rm)$$

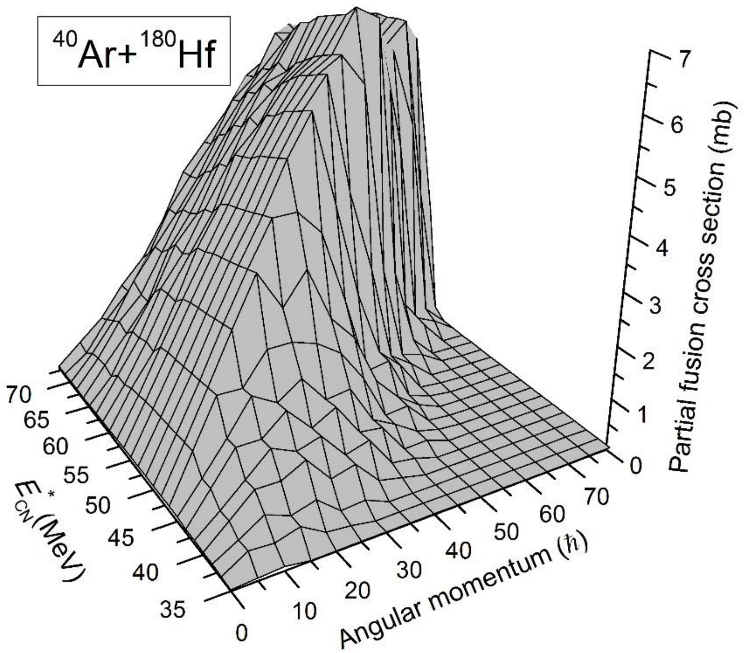
Dependence of the driving potential on the angular momentum

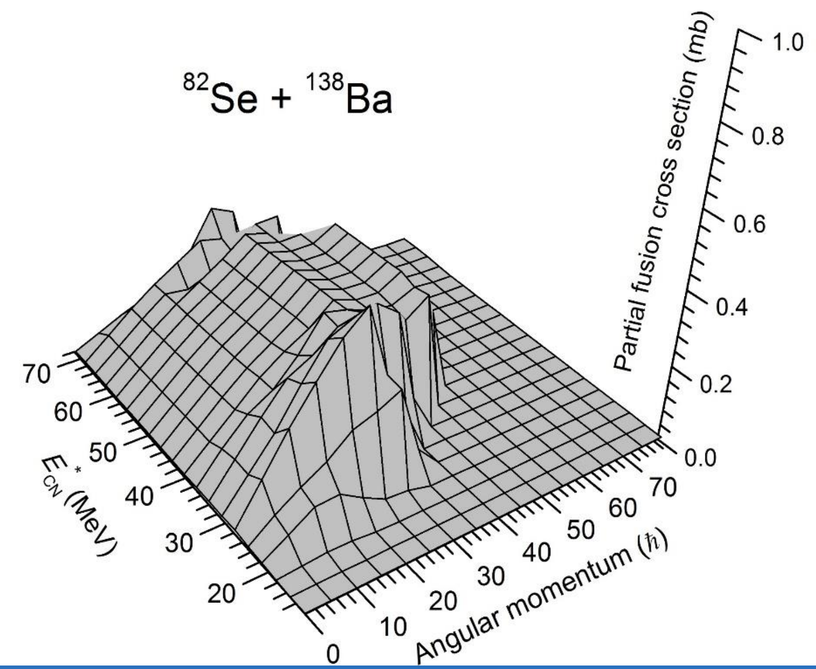




Dependence of the quasifission barrier on the angular momentum

Partial fusion cross section of the $^{40}Ar+^{180}Hf$ and $^{82}Se+^{138}Ba$ reactions





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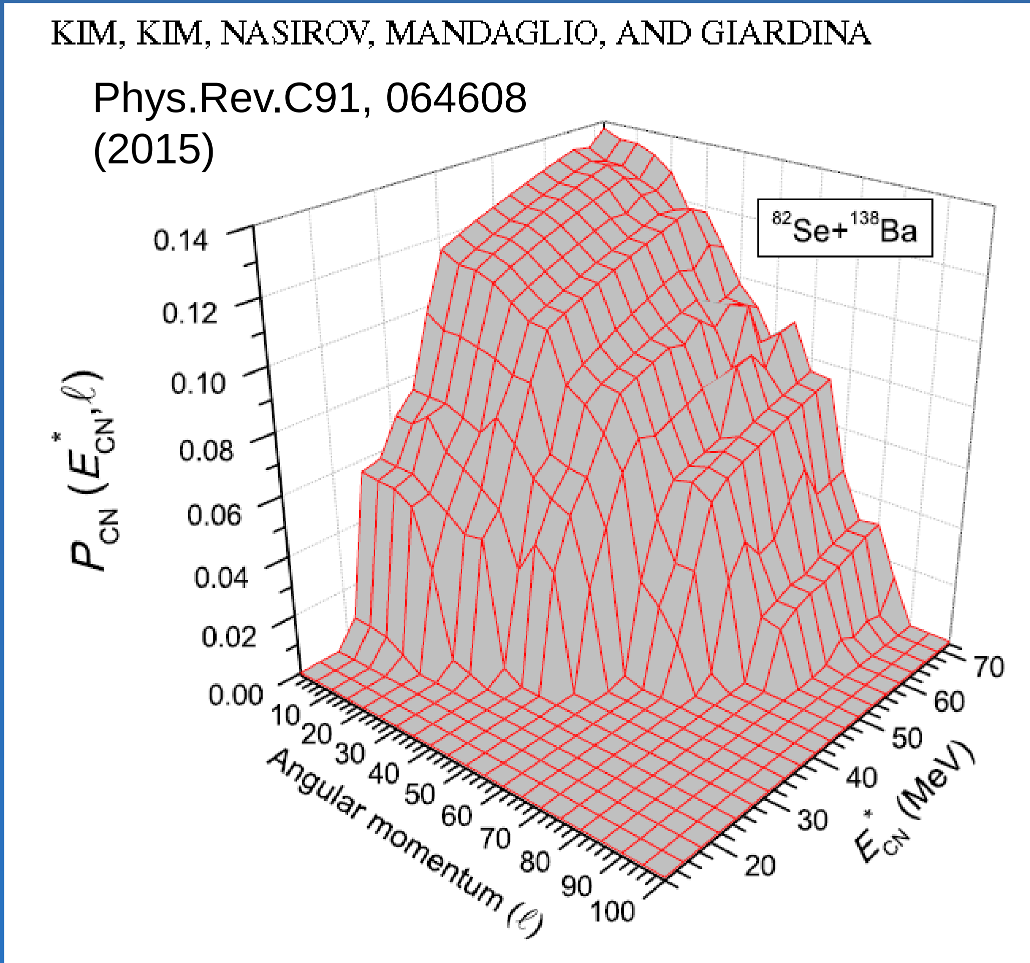
Probability of fusion as a function of the energy and angular momentum.

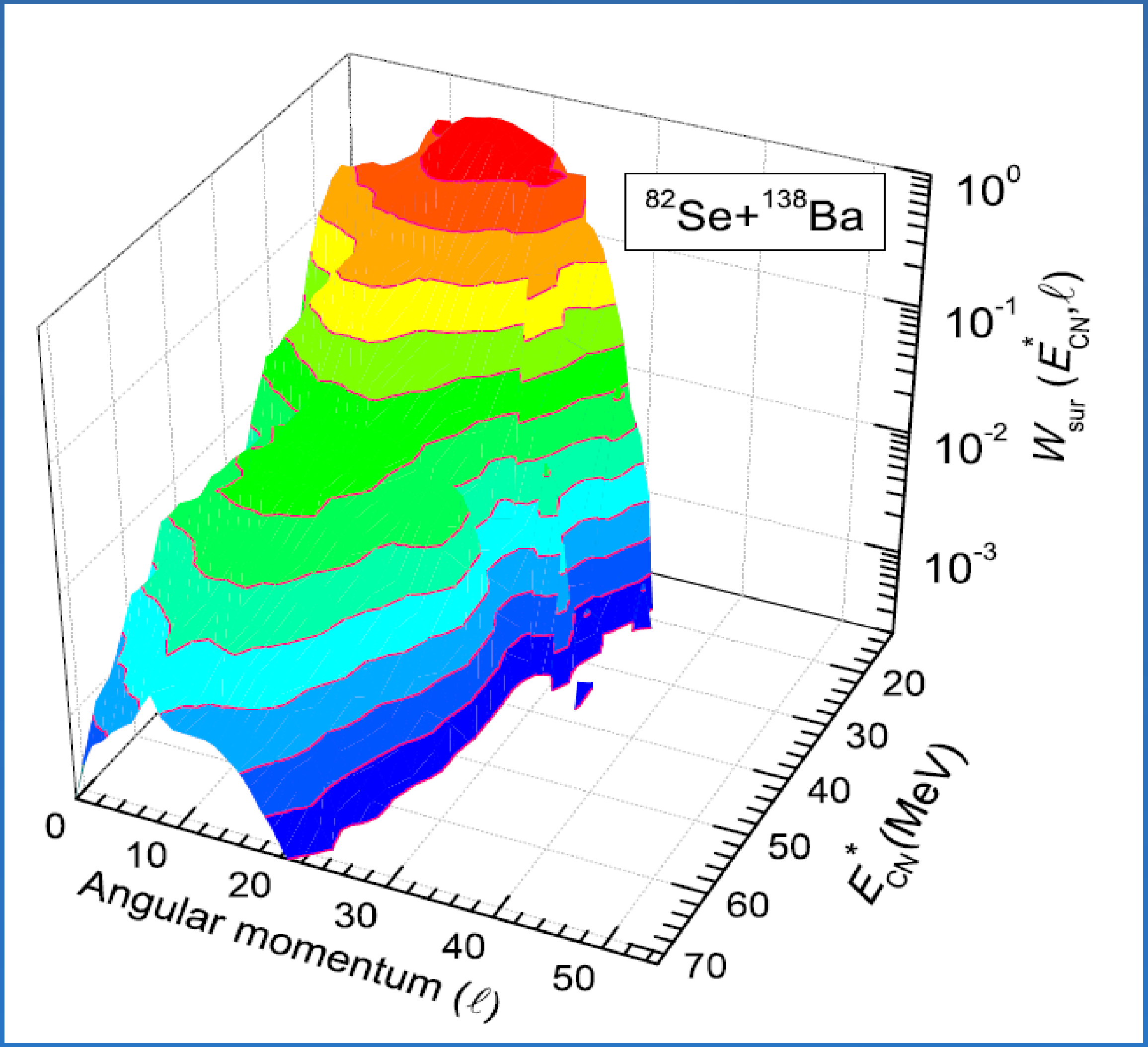


$$P_{CN}(E_{CN}, l) = \frac{\sigma_{fus}(E_{CN}, l)}{\sigma_{cap}(E_{CN}, l)}$$

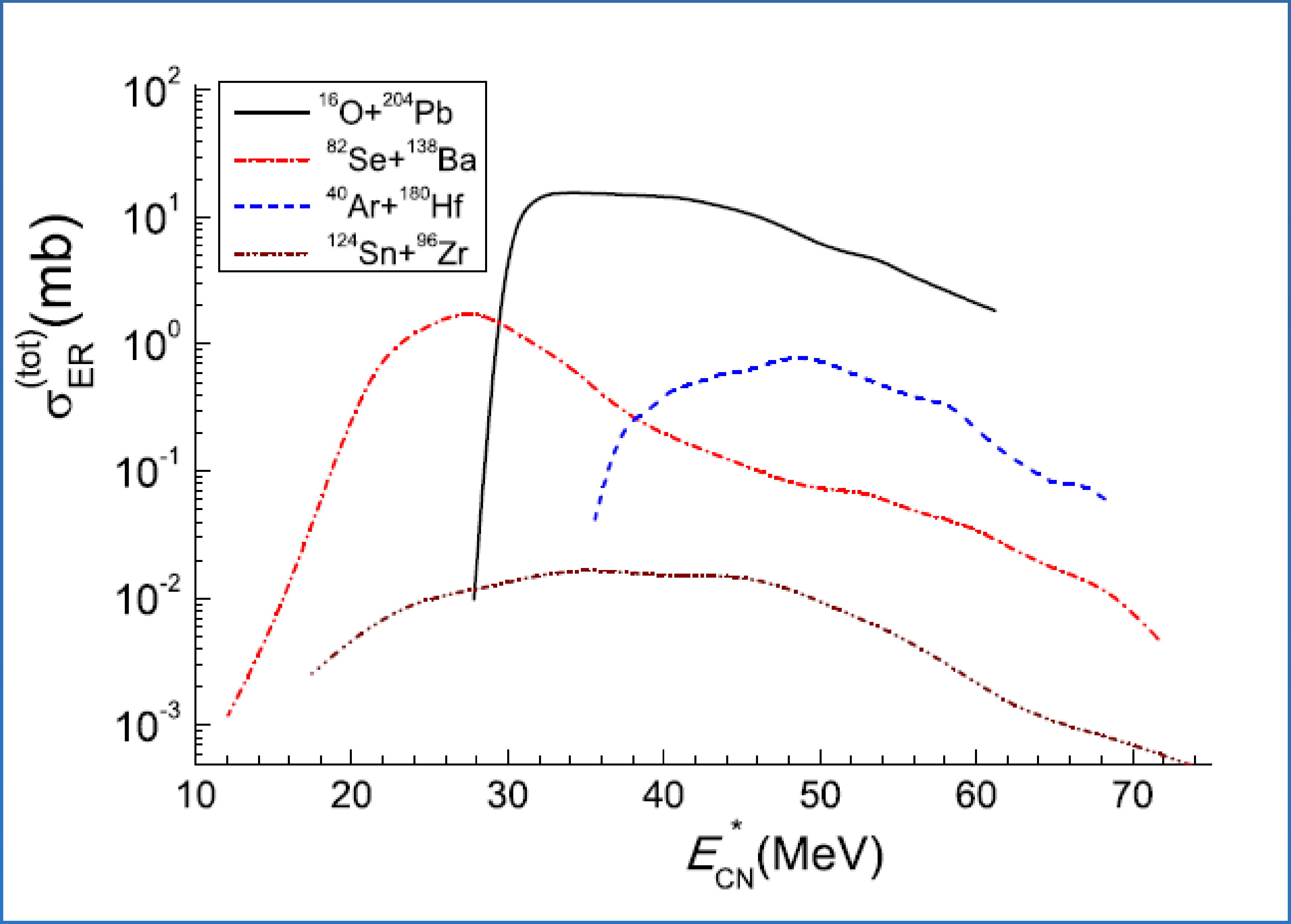
The partial fusion probability decreases by the increase of angular momentum ℓ but total cross section is proportional to ℓ.

$$\sigma_{ER} = \sum_{l=0}^{l_d} (2l+1)\sigma_l^{fus}(E,l)W_{surv}(E,l)$$

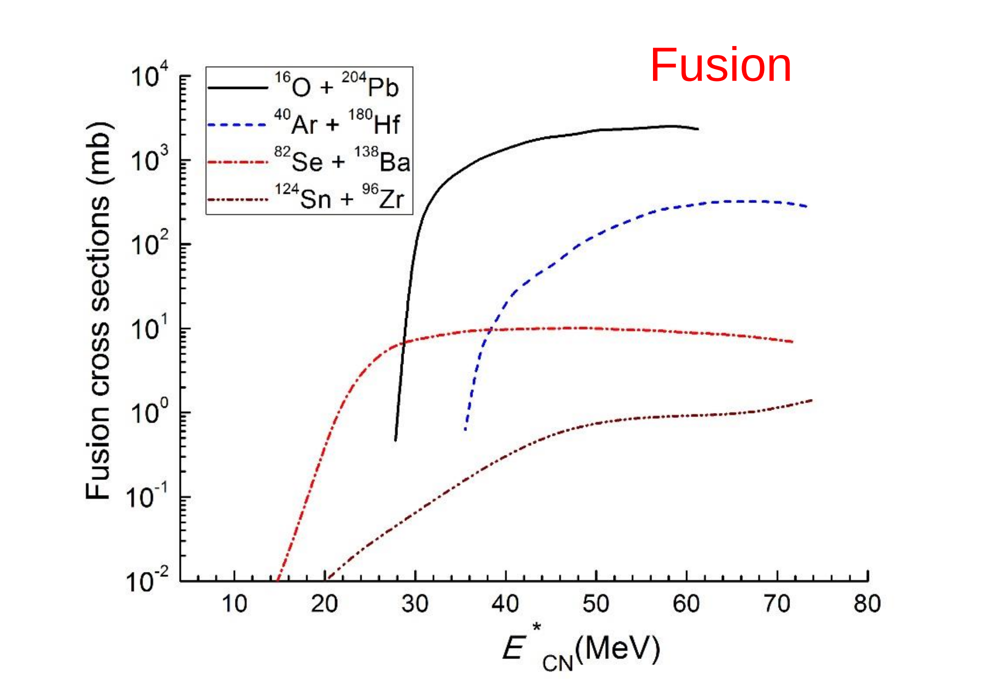
Probability of surviving the heated and rotating compound nucleus against fission as a function of the energy and angular momentum.

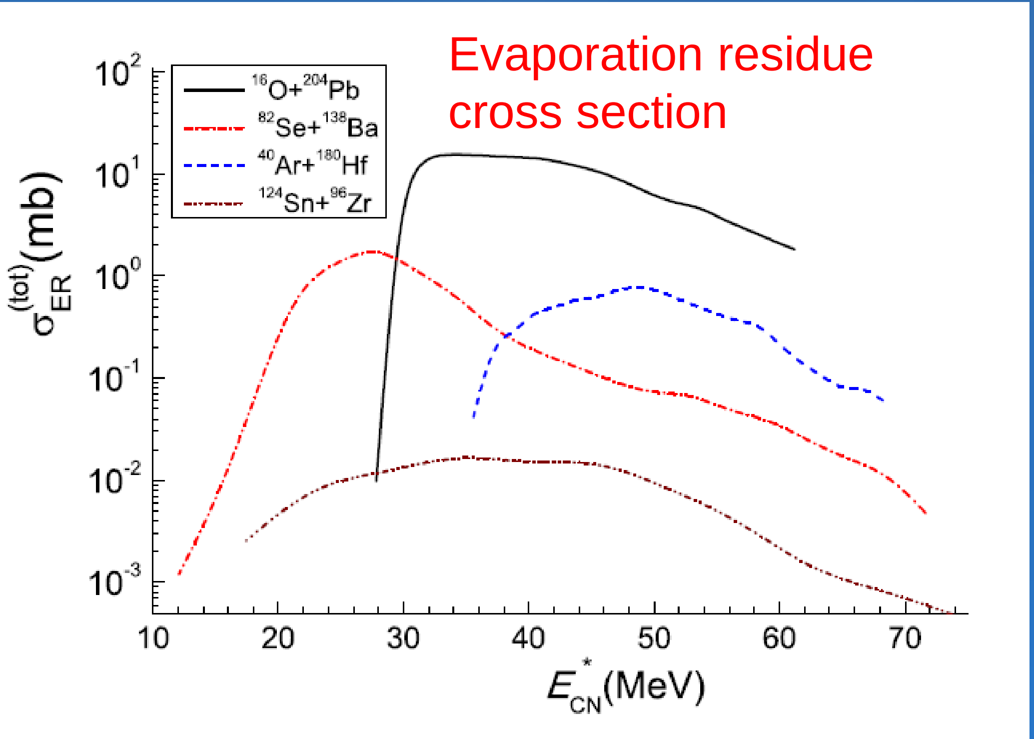


Comparison of the evaporation residue cross sections calculated for the 4 reactions leading to ^{220}Th.



The survived part of the compound nucleus against to fission.





Total cross section of the evaporation residues formation.

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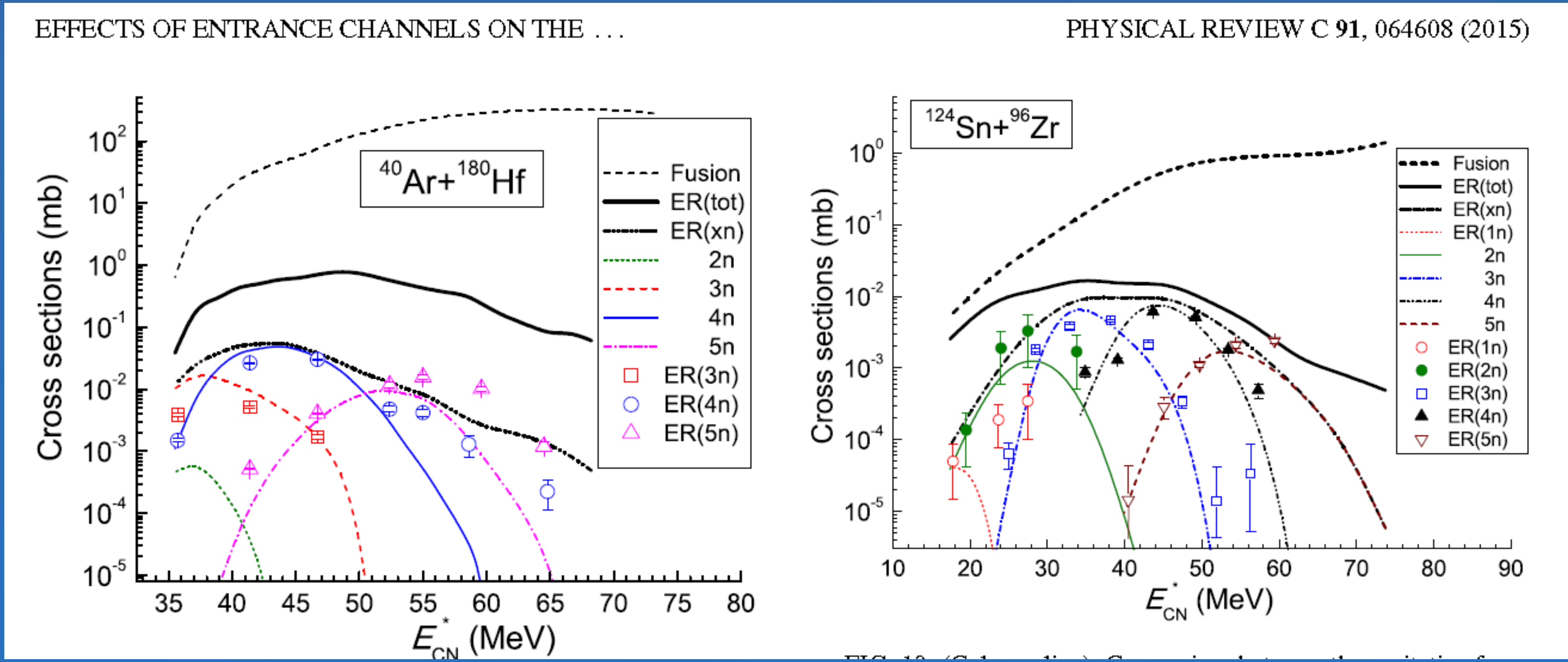
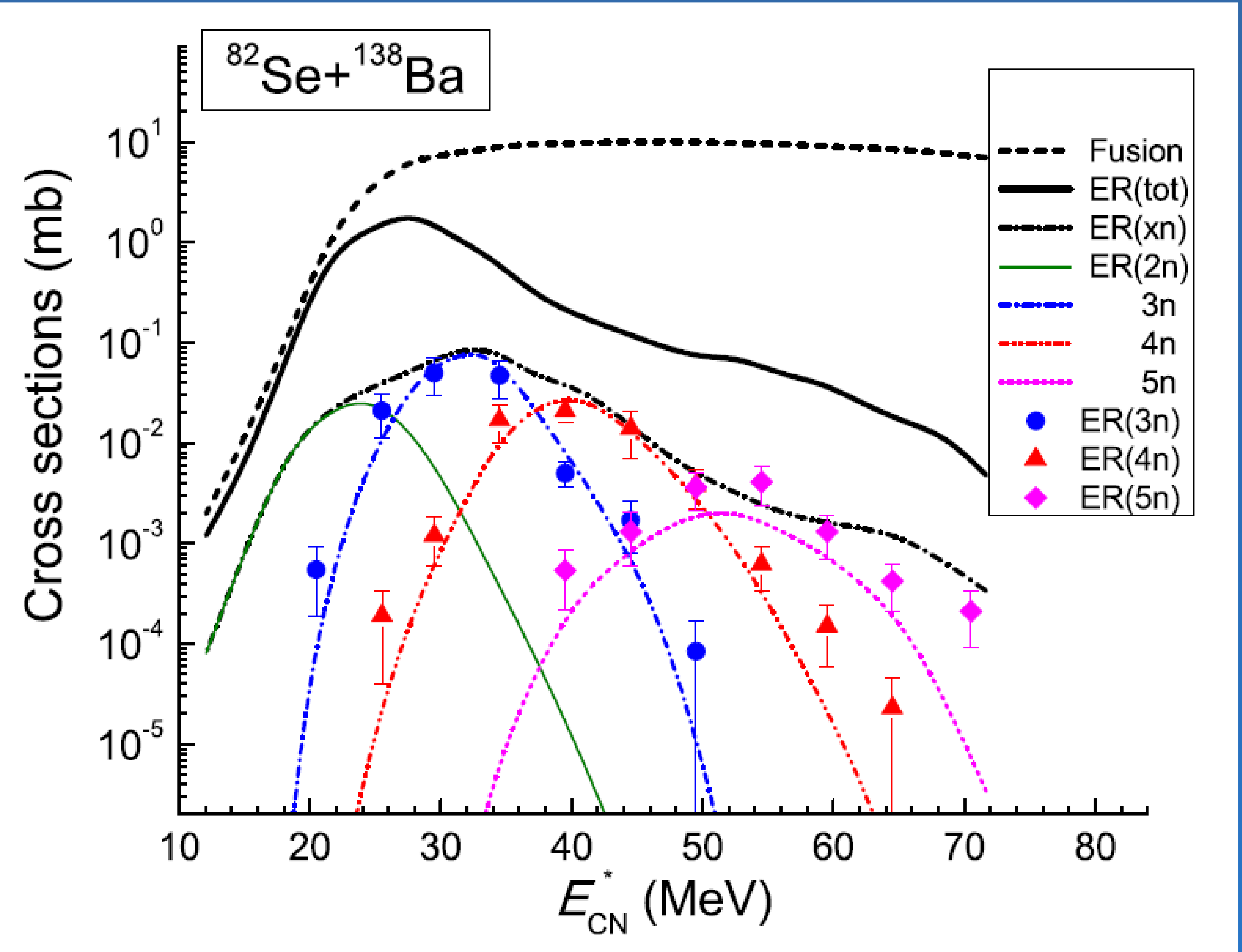
Comparison of the cross sections of the different neutron emission channels with the corresponding experimental data.



Comparison of the cross sections of the different neutron emission channels with the corresponding experimental data.



Conclusions

The experiments of synthesis of superheavy elements were successful cold and hot fusion reactions due to using favorable conditions for the entrance channel and properties of the being formed compound nucleus.

The strong hindrance to complete fusion increases in mass symmetric reactions.This hindrance is increase of the intrinsic fusion barrier which is determined by the landscape of the potential energy surface.

The hindrance to complete fusion is not so strong in hot fusion reactions because the mass asymmetry of those reactions is small. Initial system is already close to be fused. But large excitation energy can decrease of the survival probability of the compound nucleus against fission.

Therefore, it is important to analyze the fusion probability of colliding nuclei and the survival probability of the compound nucleus in order to choice reaction partners and beam energy.


Thank you for attention !
Thank you for warm hospitality !

About description of the events of the synthesis of superheavy elements

The measured evaporation cross section can be described by the formula:

$$\sigma_{ER}(E^*) = \sum_{\ell=0}^{\ell=\ell_f} \sigma_{\text{cap}}(E_{\text{c.m.}}, \ell)\, P_{\text{CN}}(E^*, \ell) W_{\text{surv}}(E^*, \ell)$$

where

$$\sigma_{\text{fus}}(E_{\text{c.m.}}, \ell) = \sigma_{\text{cap}}(E_{\text{c.m.}}, \ell)\, P_{\text{CN}}(E^*, \ell)$$

is considered as the cross section of compound nucleus formation; W_{surv} is the survival probability of the heated and rotating nucleus. The smallness of P_{CN} means hindrance to fusion caused by huge contribution of quasifission process:

$$\sigma_{\text{qfis}}(E_{\text{c.m.}}, \ell) = \sigma_{\text{cap}}(E_{\text{c.m.}}, \ell)\, (1 - P_{\text{CN}}(E^*, \ell))$$

Collective enhancement of level density of DNS

$$K_{rot}(E_{DNS}) = \begin{cases} (\sigma_\perp^2 - 1) f(E_{DNS}) + 1, & \text{if } \sigma_\perp > 1\,, \\ 1, & \text{if } \sigma_\perp \leq 1\,, \end{cases}$$

where $\sigma_\perp = J_{(DNS)} T/\hbar^2$; $f(E) = (1+\exp[(E-E_{cr})/d_{cr}])$; $E_{cr} = 120\widetilde{\beta}_2^2 A^{1/3}$ MeV; $d_{cr} = 1400\widetilde{\beta}_2^2 A^{2/3}$. $\widetilde{\beta}$ is the effective quadrupole deformation for the dinuclear system. We find it from the calculated $\mathcal{J}_\perp^{(DNS)}$.

Dependence of the fission barrier on the excitation energy and angular momentum of compound nucleus.

$$B_{\text{fis}}(J,T) = c\, B^{m}_{\text{fis}}(J) - h(T)\, q(J)\, \delta W,$$

with

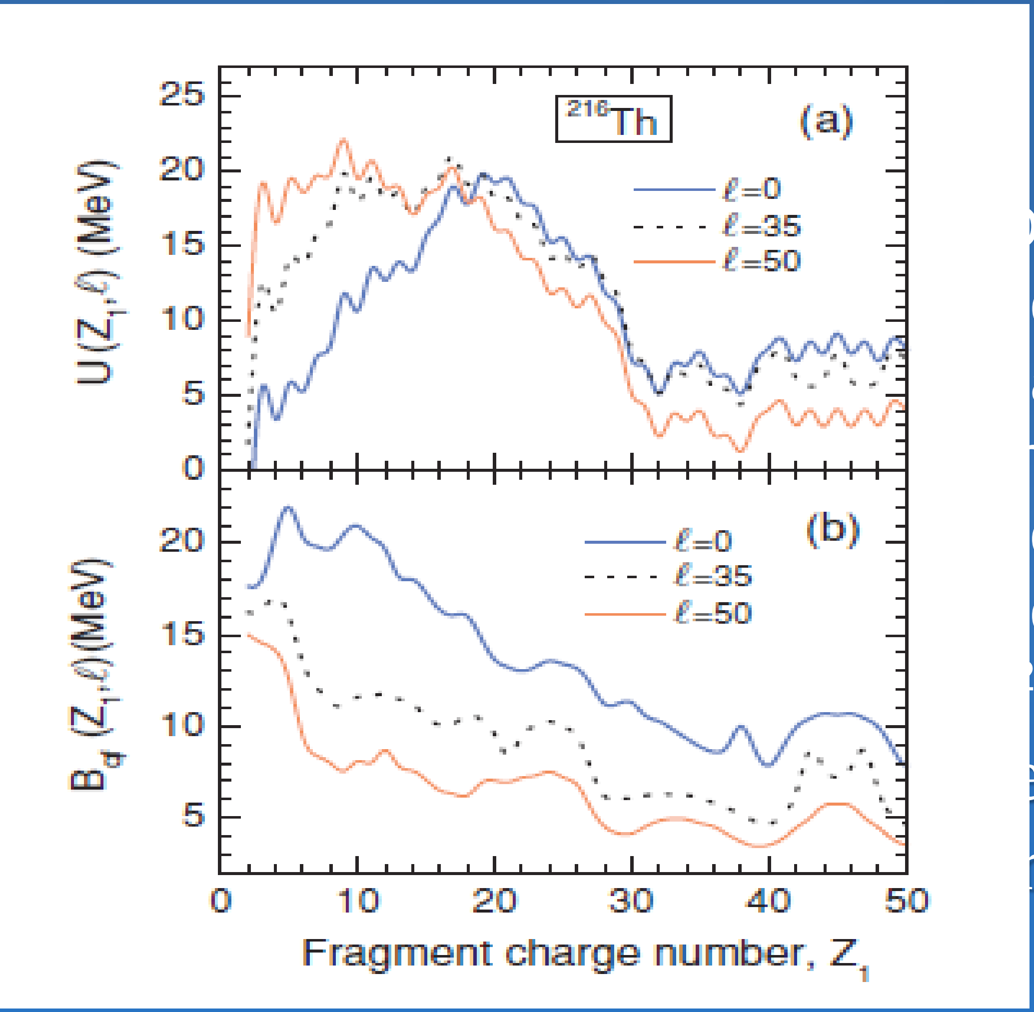
$$h(T) = \begin{cases} 1\,, & T \leq 1.65\ \text{MeV}\,, \\ k \exp(-mT)\,, & T > 1.65\ \text{MeV}, \end{cases}$$

and

$$q(J) = \{1 + \exp[(J - J_{1/2})/\Delta J]\}^{-1},$$

where $B^{\text{m}}_{\text{fis}}(J)$ is the parameterized macroscopic fission barrier [15] depending on angular momentum J, $\delta W = \delta W_{\text{sad}} - \delta W_{\text{gs}} \simeq -\delta W_{\text{gs}}$ is the microscopic (shell) correction to the fission barrier taken from the tables [8] and the constants for the macroscopic fission barrier scaling, temperature and angular momentum dependencies of the microscopic correction are chosen to be as follows: $c = 1.0$, $k = 5.809$, $m = 1.066\ \text{MeV}^{-1}$, $\Delta J = 3\hbar$; for nuclei with $Z > 102$ we use $J_{1/2} = 20\hbar$. This procedure let the shell corrections become dynamical quantities, too.

G.Giardina, et al. Eur. Phys. J. A **8**, 205–216 (2000)



...ependence of the driving ...otential and quasifission ...arrier on the angular ...omentum of dinuclear system ...ormed in reactions leading to ...ormation of compound nucleus ^{216}Th.

...es by increasing the ...m.