Asymmetry of fission fragments

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GANIL, Caen

Outline

Motivation

Static calculations

- Fission paths
- Pre-scission points
- Pre-scission configuration
- Random neck rupture mechanism
- Results

Dynamic effects

- The model
- Probability current density
- Results - ^{256}Fm

Spontaneous fission half-lives

- Shell corrections
- Results

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Motivation

- Fission fragment mass yield is a one of the basic, measurable observable
- The shape of observed fragment mass distribution allows to determine the type of fission (symmetric, asymmetric, bimodal)
- Accuracy of reproduction of the experimental mass yields as a test of the theoretical models

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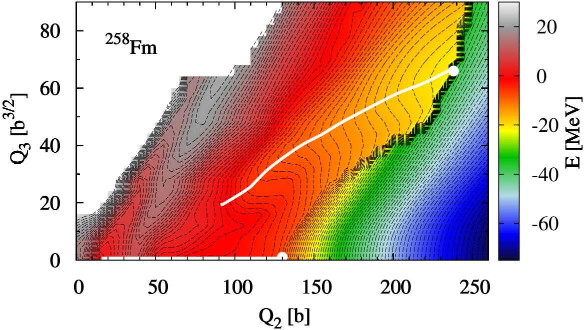
Potential energy surface



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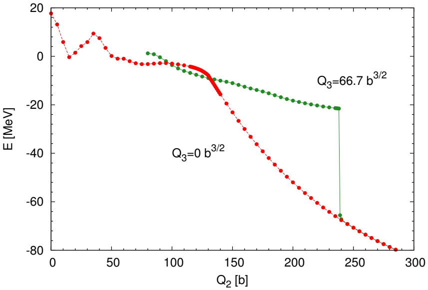
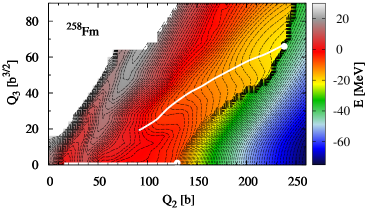
Fission paths





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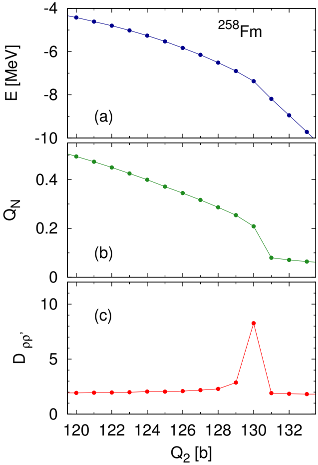
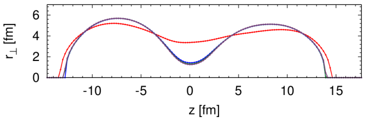
Searching for pre-scission points





$$D_{\rho\rho'} = \int_0^\infty |\rho(\vec{r}) - \rho'(\vec{r})| d\tau$$

N. Dubray et al., Comp. Phys. Comm. **183** (2012) 2035.

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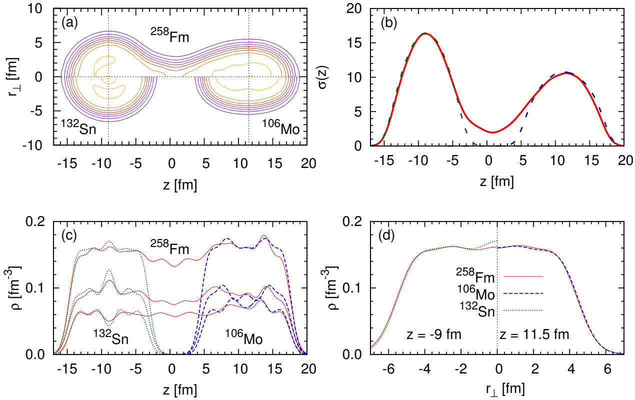
Pre-scission configuration



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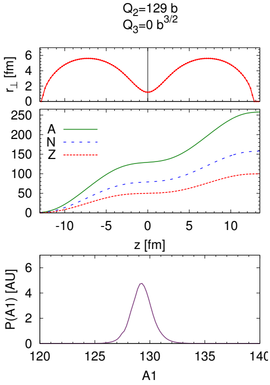
The neck rupture probability



- Neck rupture probability:
  $P(z) = \exp[-2\gamma\sigma(z)/T]$
- Linear density of a nucleus:
  $$\sigma(z) = 2\pi \int_0^\infty r_\perp \rho(z, r_\perp) dr_\perp$$
- Surface tension coefficient:
  $\gamma = 0.9517[1 - 1.7826(1 - 2Z/A)^2]$
- Temperature:
  $T = \sqrt{12E^{\mathrm{sc}}/A}$
- Excitation energy:
  $E^{\mathrm{sc}} = E_{\mathrm{g.s.}} - E^{\mathrm{sc}}_{\mathrm{def}}$

Brosa U., Phys. Rev. **C38** 1944 (1988).

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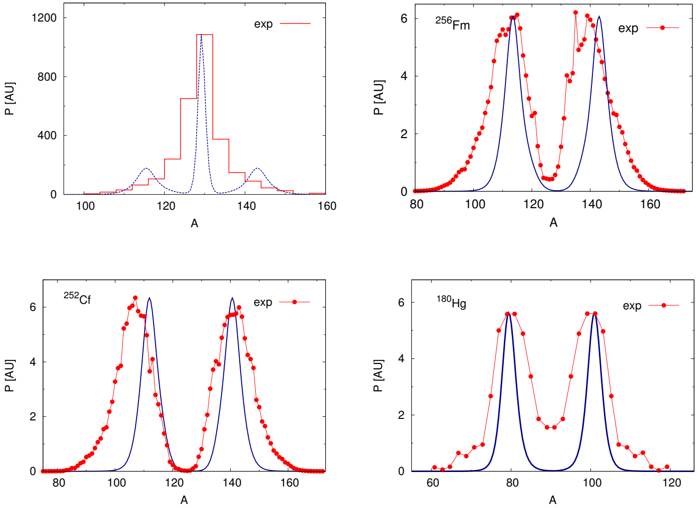
Results



M. Warda, A. Zdeb, Phys. Scr. (2015). – in print [arXiv:nucl-th 1502.05564]

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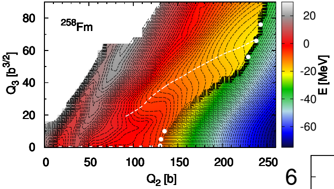
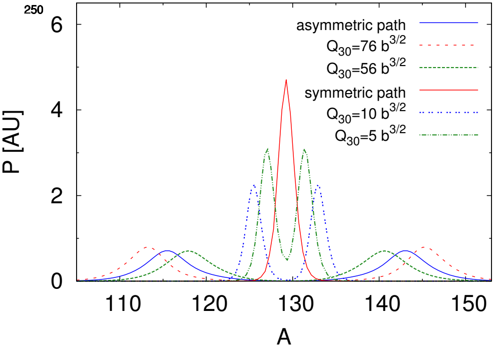
Dynamic effects





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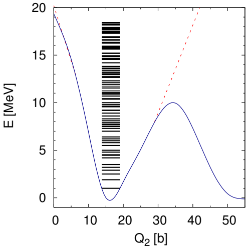
The model

$$\widehat{H}_{\rm coll} = -\frac{\hbar^2}{2}\sum_{i,j=2}^{3}\frac{\partial}{\partial Q_i}B_{ij}(Q_2,Q_3)\frac{\partial}{\partial Q_j} + V(Q_2,Q_3),$$

$$B_{ij} = \mathcal{M}_{ij}^{-1}$$

$$\widehat{H}'_{\rm coll}\, g_n^\pi(Q_2,Q_3,t=0) = E_n^\pi g_n^\pi(Q_2,Q_3,t=0)$$



$$\widehat{H}_{\rm coll}\, g(Q_2,Q_3,t) = i\hbar\frac{\partial g(Q_2,Q_3,t)}{\partial t}$$

H. Goutte et. al, Phys. Rev. **C71** 024316 (2005).

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Probability current density

$$\frac{\partial |g|^2}{\partial t} = -\frac{\hbar}{2i} \nabla \cdot \underbrace{(g^* \underline{B} \nabla g - g \underline{B} \nabla g^*)}$$

$$\Downarrow$$

$$\frac{\partial |g|^2}{\partial t} = -div\vec{J}$$

$$J_{Q_2} = \frac{\hbar}{2i}[g^* B_{22} \frac{\partial g}{\partial Q_2} - g B_{22} \frac{\partial g^*}{\partial Q_2} + g^* B_{23} \frac{\partial g}{\partial Q_2} - g B_{23} \frac{\partial g^*}{\partial Q_2}],$$

$$J_{Q_3} = \frac{\hbar}{2i}[g^* B_{33} \frac{\partial g}{\partial Q_3} - g B_{33} \frac{\partial g^*}{\partial Q_3} + g^* B_{32} \frac{\partial g}{\partial Q_3} - g B_{32} \frac{\partial g^*}{\partial Q_3}],$$

$$Y(Q_2, Q_3) = \int_0^T \vec{J}(Q_2, Q_3, t) \cdot \vec{n} \ dt$$

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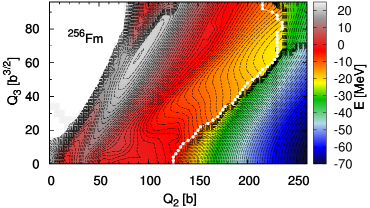
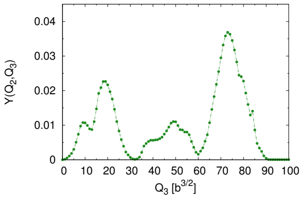
Results - ^{256}Fm





$$Y(Q_2, Q_3) = \int_0^T \vec{J}(Q_2, Q_3, t) \cdot \vec{n} dt$$

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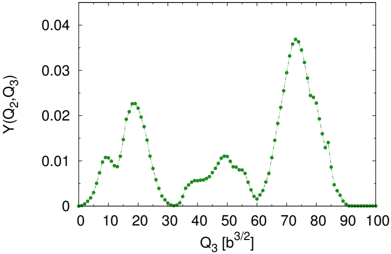
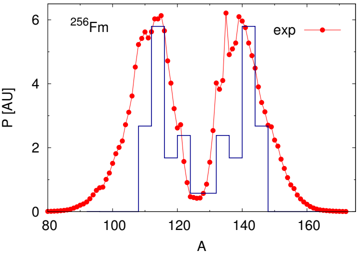
Results - ^{256}Fm





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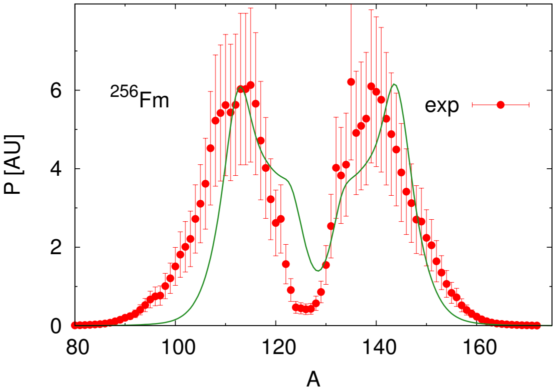
^{256}Fm - dynamic effects + RNR machanism



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Conclusions I

- Fragment mass distribution obtained after application of macroscopic method (Brosa) to microscopically calculated pre-scission configuration
- Time-dependent formalism applied to describe fission process
- The broadness of the distribution is improved, when the time-dependent formalism is combined with the macroscopic method of Brosa

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Spontaneous fission half-lives

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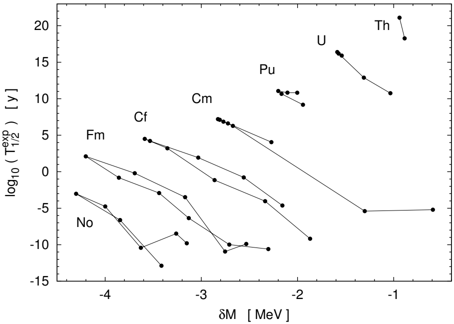
Shell corrections and spontaneous fission



$$\delta M = M_{exp} - M_{LSD}$$

K. Pomorski, J. Dudek, *Phys. Rev.* **C67**, 044316 (2003).

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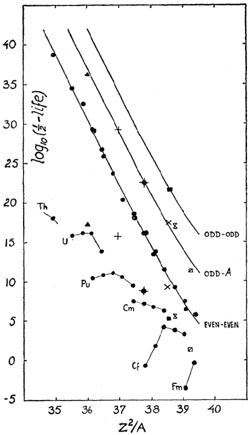
Swiatecki observation



W J. Swiatecki, *Phys. Rev.* **100**, 937 (1955).

$$\log_{10}(T^{sf}_{1/2}) = f(Z^2/A) - k\delta M$$

$$f(\theta) = -7.8\theta + 0.35\theta^2 + 0.073\theta^3 + a_i$$
$$a_{ee} = 18.2$$
$$a_{oe} = 24.8$$
$$a_{oo} = 29.7$$

$$\theta = Z^2/A - 37.5$$
$$k = 5 - \theta$$

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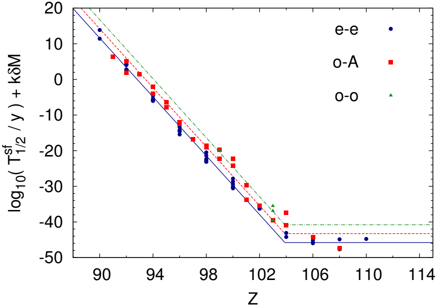
Swiatecki formula - modern version



$$\log_{10}(T^{sf}_{1/2}) = f(Z) - k\delta M$$

$$k = 7.7\ \mathrm{MeV}^{-1}$$

$$f(Z) = \begin{cases} -4Z + 380.2 & Z \leq 103 \\ -42.8 & Z \geq 104 \end{cases}$$

A. Zdeb, M. Warda, K.Pomorski, Phys. Scr. **89**, 054015 (2014).

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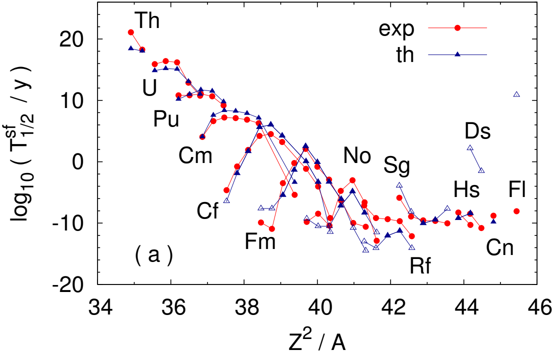
Even-even isotopes



$$\log_{10}(T^{sf}_{1/2}) = -4.1Z + 380.2 - 7.7\delta M$$

K.Pomorski, M. Warda, A. Zdeb, Phys. Scr., arXiv:1501.03912

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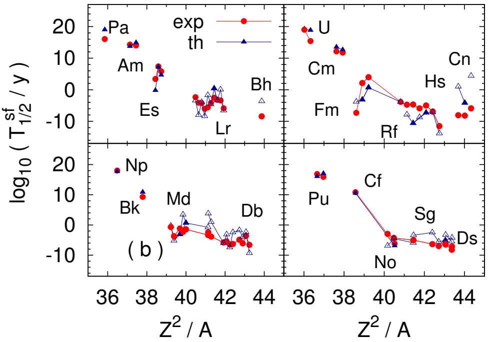
Odd isotopes



$$\log_{10}(T^{sf}_{1/2}) = -4.1Z + 380.2 - 7.7\delta M + h$$

$$h_{odd} = 2.5, h_{odd-odd} = 5$$

K.Pomorski, M. Warda, A. Zdeb, Phys. Scr., arXiv:1501.03912

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Conclusions II

- Semi-empirical formula for the spontaneous fission half-lives, depending on proton number and the ground state microscopic corrections, reproduces data for even-even super-heavy nuclei with rea- sonable accuracy.
- Quality of spontaneous fission half-lives evaluation breaks down for nuclei with not measured yet masses.
- Simple formula might be useful for predictions of spontaneous fission half-lives of unknown isotopes in the region $90 \leq Z \leq 104$.

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Thank you!