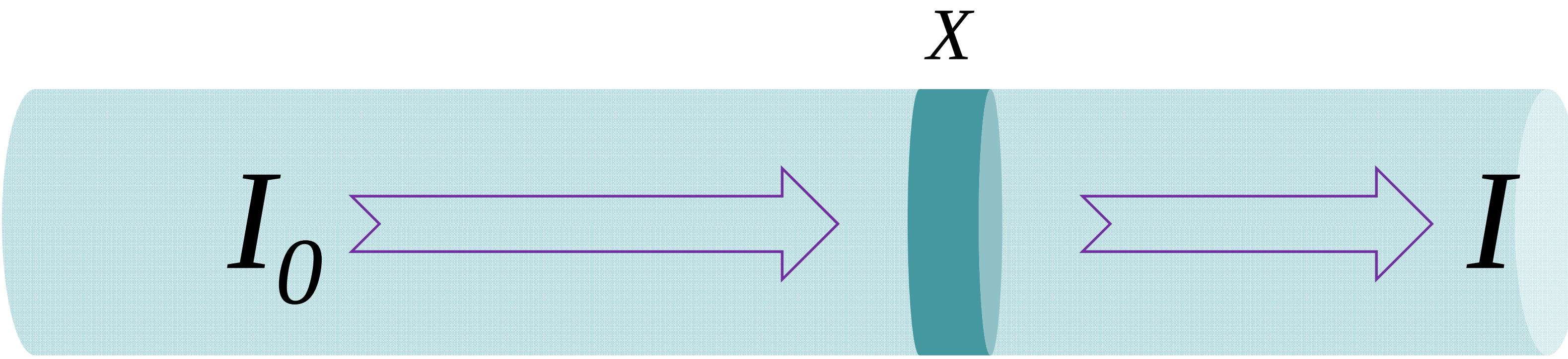
Neutron Attenuation



Recall $\Sigma_t = N\,\sigma_t$

Probability per unit path length.

$$I(X) = I_0 e^{-\Sigma_t X}$$

mfp for scattering $\lambda_s = 1/\Sigma_s$

mfp for absorption $\lambda_a = 1/\Sigma_a$

....

total mfp $\lambda_t = 1/\Sigma_t$

Probability

$$P_{\text{no-interaction}}(X) = e^{-\Sigma_t X}$$

$$P_{\text{interaction}}(X) = 1 - e^{-\Sigma_t X}$$

Neutron Moderation (revisited)

Show that, after ***elastic*** scattering the ratio between the final neutron energy $E^\backslash$ and its initial energy E is given by: **HW 6**

$$\frac{E^\backslash}{E} = \frac{A^2 + 1 + 2A\cos\theta^{CM}}{(A+1)^2} = \frac{\left[\cos\theta + \sqrt{A^2 - \sin^2\theta}\right]^2}{(A+1)^2}$$

^{1}H ?

For a head-on collision: $\left(\frac{E^\backslash}{E}\right)_{\min} = \left(\frac{A-1}{A+1}\right)^2 \equiv \alpha$ **Collision Parameter**

After n ***s*-wave** collisions: $\ln E_n^\backslash = \ln E - n\zeta$

where the average change in **lethargy** $u = \ln(E_M / E)$ is

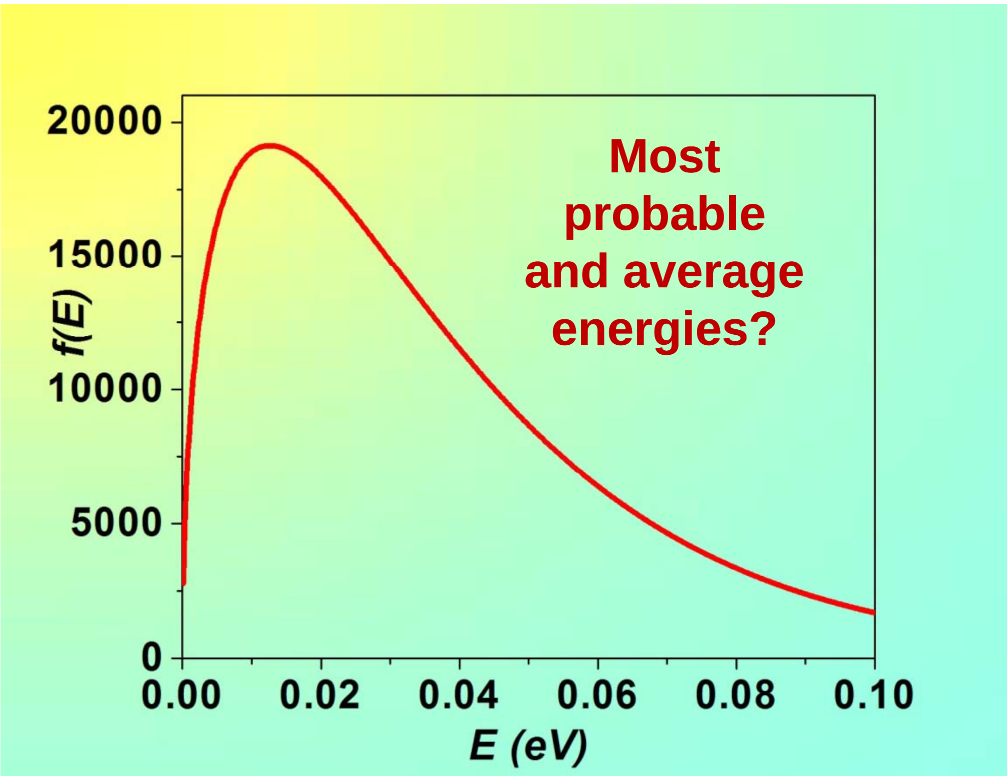
$$\overline{\Delta u} = \zeta = \left[\ln\frac{E}{E^\backslash}\right]_{av} = 1 + \frac{(A-1)^2}{2A}\ln\frac{A-1}{A+1}$$

Reference

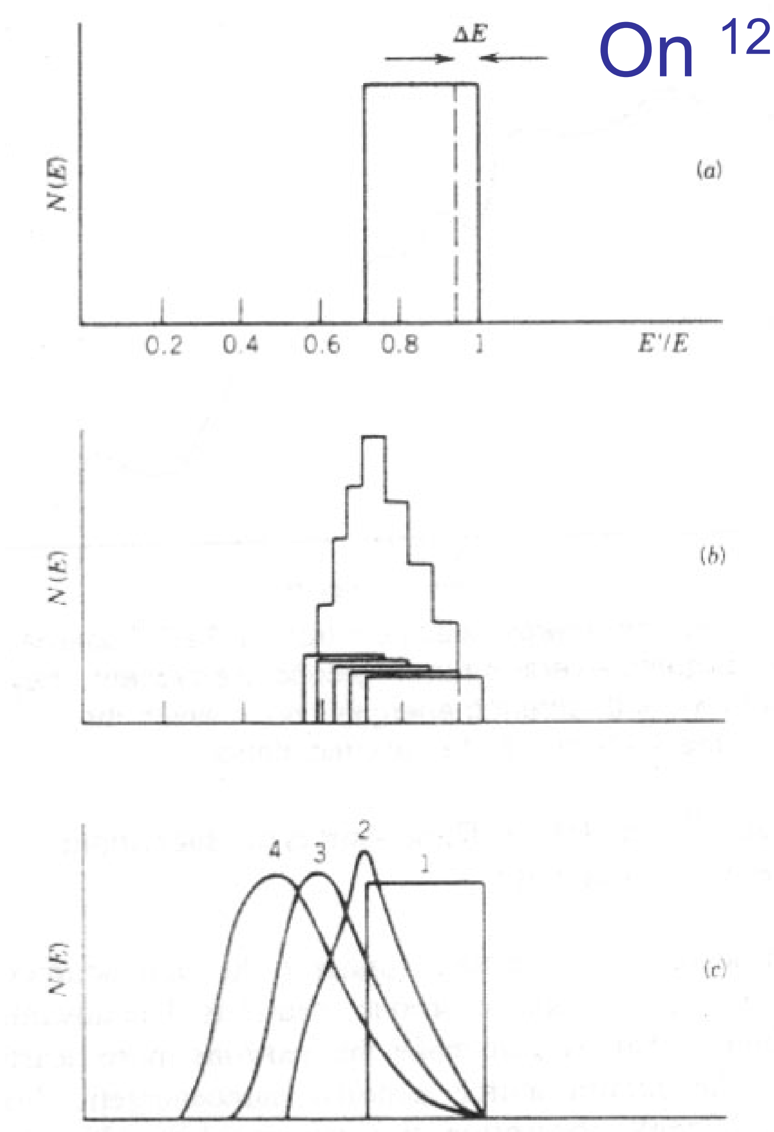
Average decrease in ln(E) after one collision.

Neutron Moderation <u>**HW 6 (continued)**</u>

- Reproduce the plot.
- Discuss the effect of the thermal motion of the moderator atoms.



On ^{12}C.



Neutron Moderation **HW 6 (continued)**

Neutron scattering by light nuclei $\overline{E'} = \frac{1}{2}(1+\alpha)E$

then the average energy loss $\overline{\Delta E} = E - \overline{E'} = \frac{1}{2}(1-\alpha)E$

and the average fractional energy loss

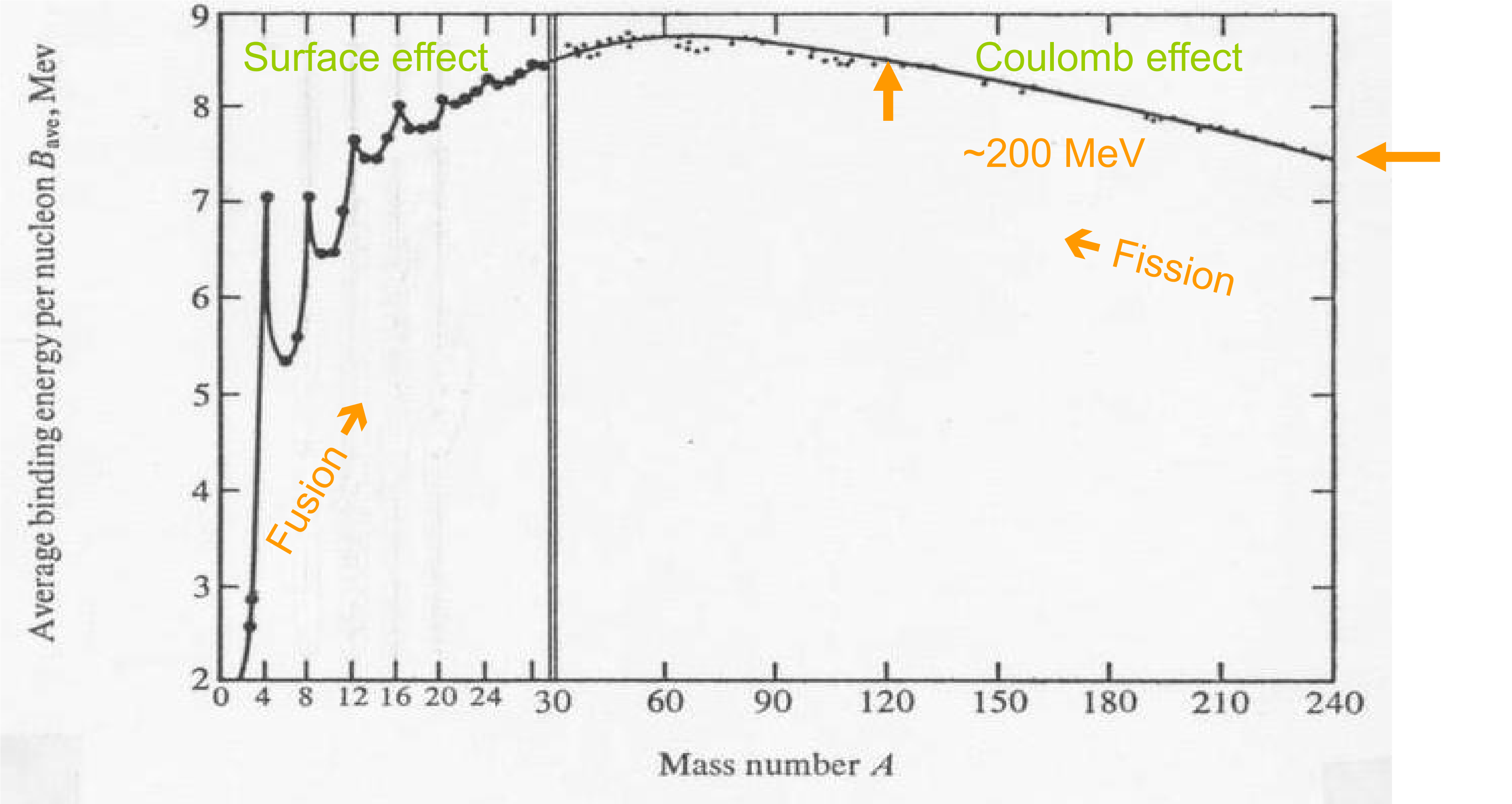
$$\frac{\overline{\Delta E}}{E} = \frac{1}{2}(1-\alpha)$$

- How many collisions are needed to thermalize a 2 MeV neutron if the moderator was:

  ^{1}H ^{2}H ^{4}He graphite ^{238}U ?

- What is special about ^{1}H?
- Why we considered elastic scattering?
- When does inelastic scattering become important?

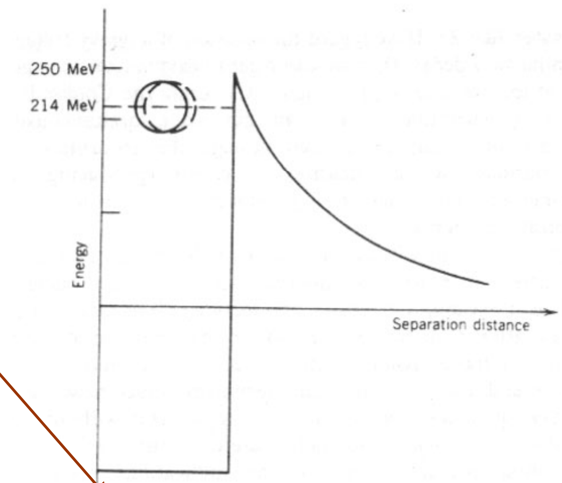
Nuclear Fission



Nuclear Fission

- B.E. per nucleon for ^{238}U (BE_U) and ^{119}Pd (BE_{Pd}) ?
- $2 \times 119 \times BE_{Pd} - 238 \times BE_U$ = ?? ▶ K.E. of the fragments ▶ $\approx 10^{11}\ J/g$
- Burning coal ▶ $10^5\ J/g$
- Why not spontaneous?
- Two ^{119}Pd fragments just touching ▶ The Coulomb "barrier" is:

Crude



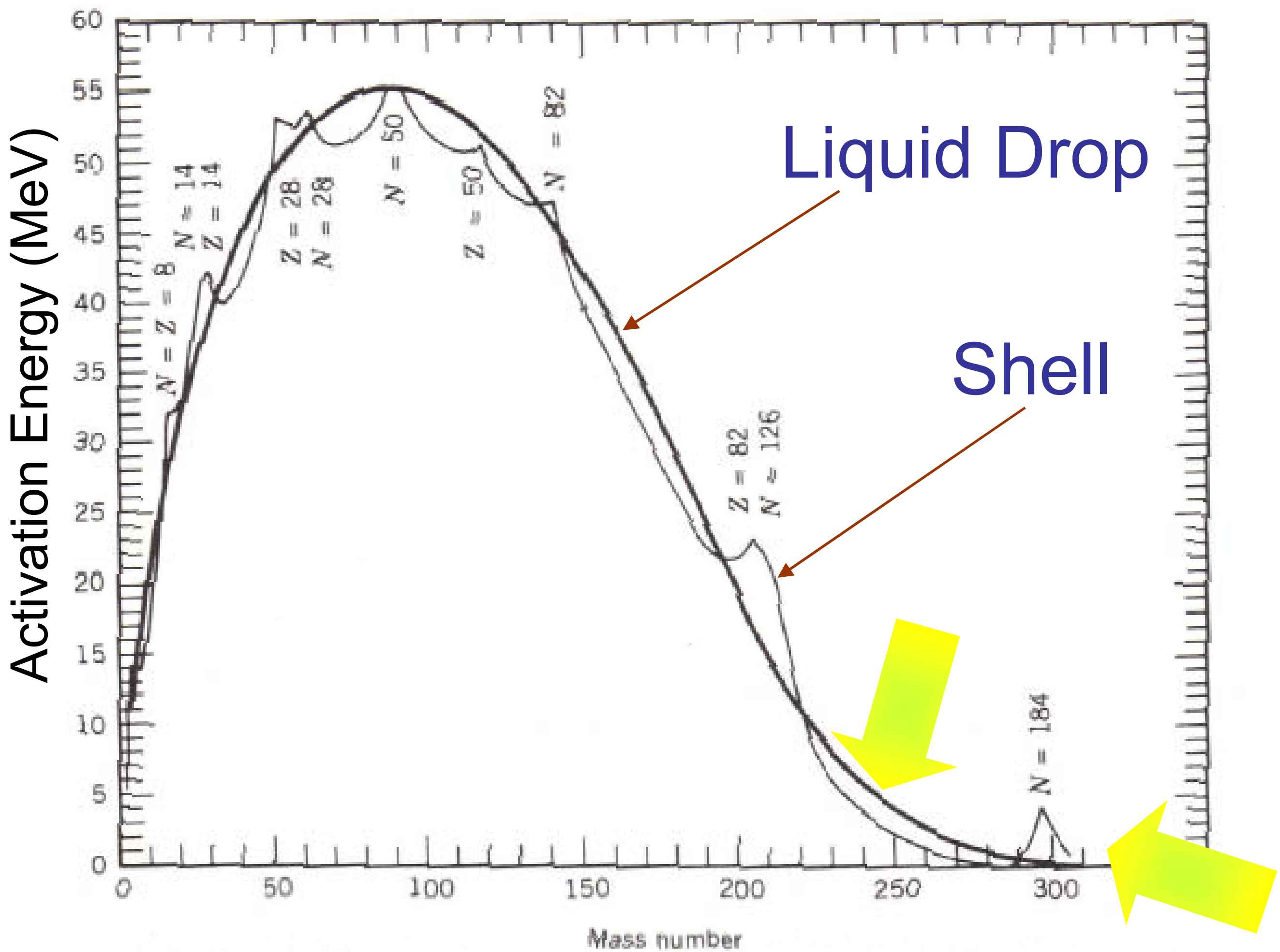
$$V = 1.44 MeV.fm \frac{(46)^2}{12.2\ fm} \approx 250 MeV > 214 MeV$$

- Crude …! What if ^{79}Zn and ^{159}Sm? Large neutron excess, released neutrons, sharp potential edge, spherical U…!

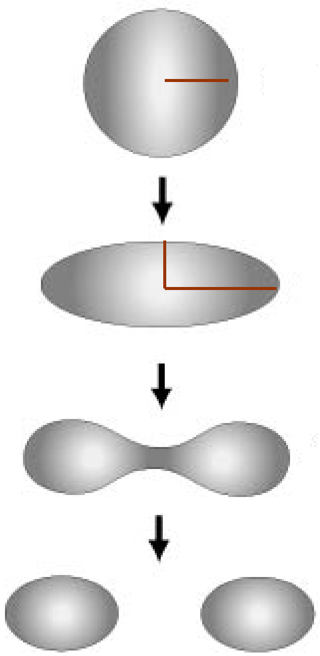
Nuclear Fission

- ^{238}U ($t_{½}$ = 4.5x10^9 y) for α-decay.
- ^{238}U ($t_{½} \approx 10^{16}$ y) for spontaneous fission.
- Heavier nuclei??
- Energy absorption from a neutron (for example) could form an intermediate state ▶ probably above barrier ▶ induced fission.
- Height of barrier is called activation energy.

Nuclear Fission



Nuclear Fission



$$\frac{4}{3}\pi R^3 = \frac{4}{3}\pi ab^2 \quad \longrightarrow \quad R^3 = ab^2$$

$$a = R(1+\varepsilon)$$

$$b = \frac{R}{\sqrt{1+\varepsilon}}$$

Volume Term (the same)

Surface Term $B_s = - a_s A^{2/3} \quad (1 + \frac{2}{5}\varepsilon^2 + \ldots)$

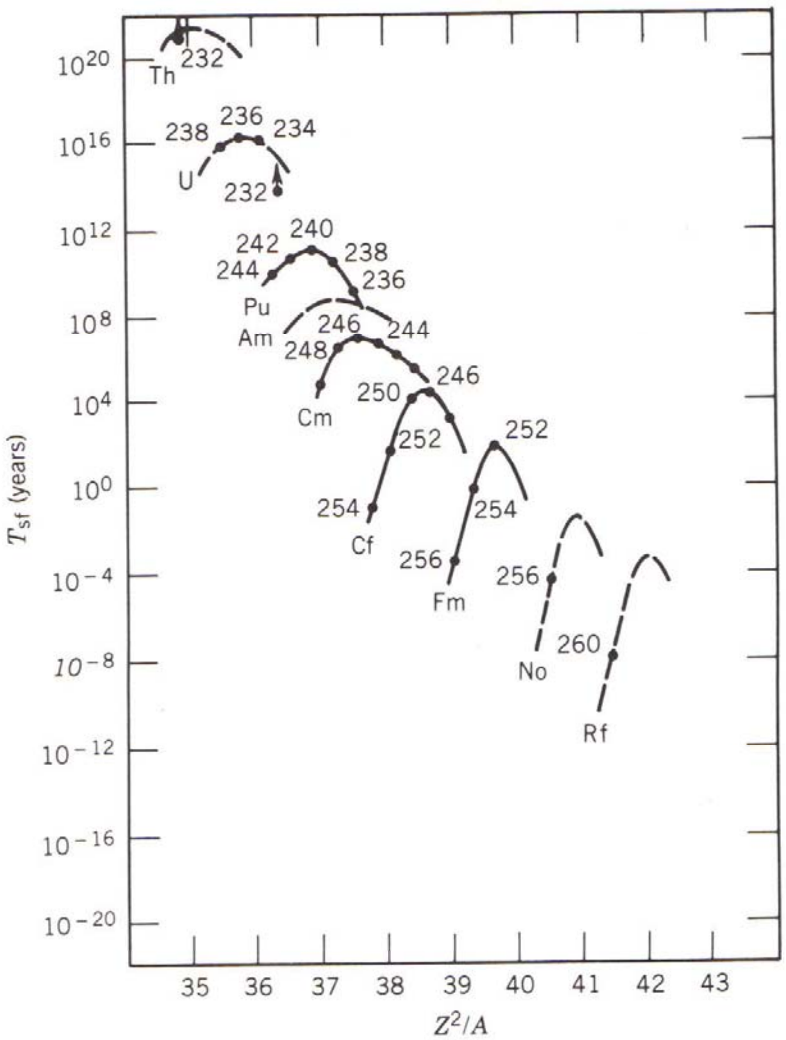
Coulomb Term $B_C = - a_C Z(Z-1) / A^{1/3} \quad (1 - \frac{1}{5}\varepsilon^2 + \ldots)$

$$\tfrac{1}{5} a_C Z(Z-1) A^{-1/3} > \tfrac{2}{5} a_S A^{2/3}$$ ▶ fission

$$\frac{Z^2}{A} >\sim 47$$

Crude: QM and original shape could be different from spherical.

Nuclear Fission



$$\frac{(120)^2}{300} = 48$$

Consistent with activation energy curve for A = 300.

Extrapolation to 47 ▶ ≈ 10^{-20} s.