Different type of nuclear reactions

- glossary -

- Elastic scattering

  projectile and target nuclei scatter without loss of kinetic energy

  $$a + X \rightarrow X + a \qquad Q = 0$$

  e.g. Rutherford scattering

- Inelastic scattering

  target- and/or beam particle are excited

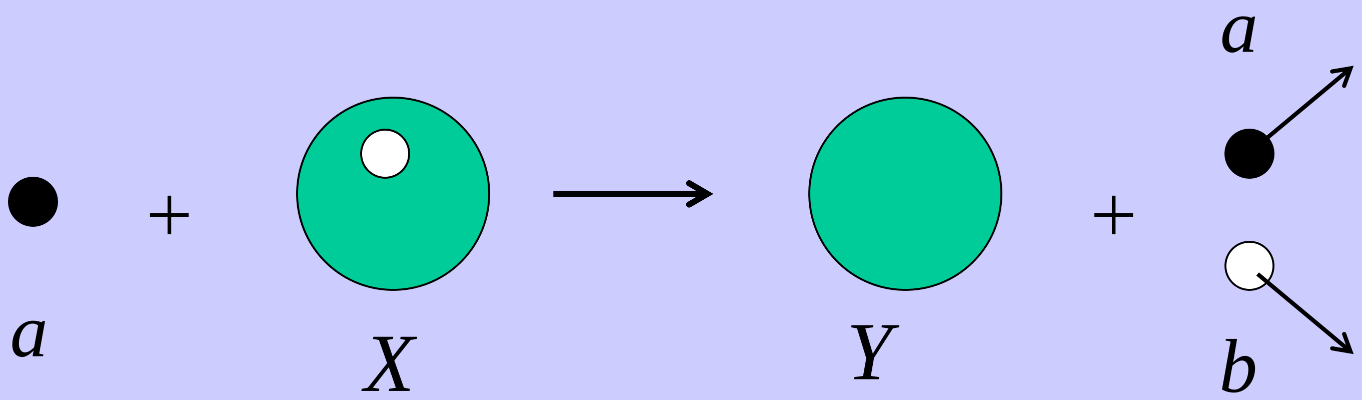
  $$a + X \rightarrow X^* + a,\ a + X \rightarrow X + a^*,\ a + X \rightarrow X^* + a^*$$

- In many cases exchange of mass, energy, momentum of reaction partner takes place during the collision and different isotopes are products of the nuclear reaction

  $$a + X \rightarrow b + Y + \ldots$$

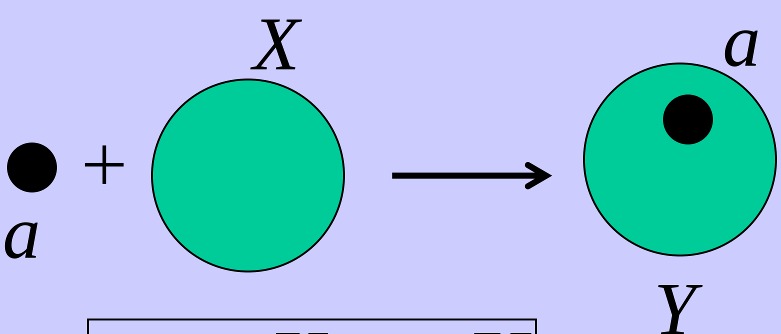
reaction glossary

- Knock-out reaction



$$a + X \rightarrow Y + a + b$$

- Capture reaction



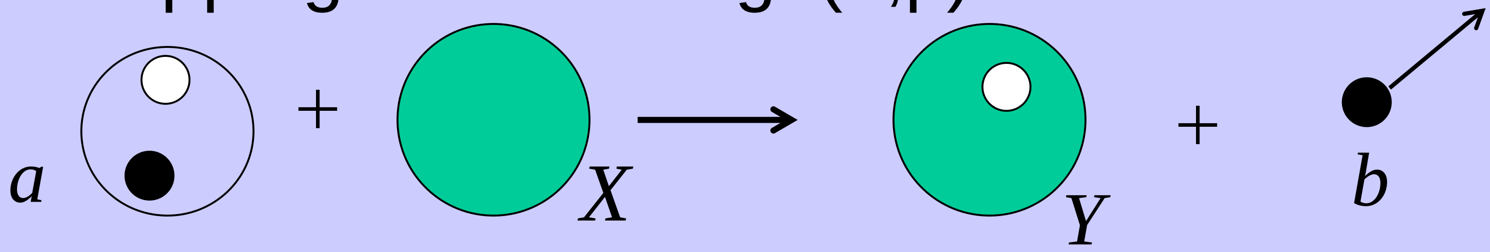
$$a + X \rightarrow Y$$

Direct reactions produce ejectile prefered under forward direction, parts of projectile move on.

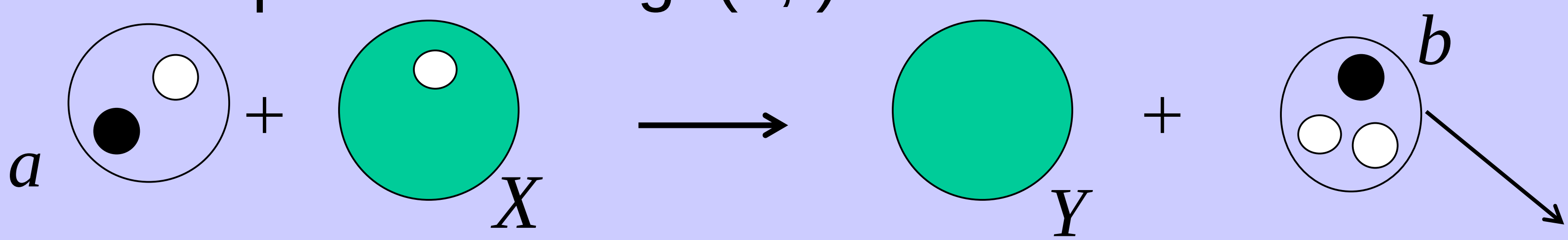
glossary: reactions

- transfer reaction: one nukleon or several nucleons are exchanged while projectil and target collide and cross each other. The recoil nuclei in the exit channel is typically in an excited state, but can be also ground state.

- Stripping reaction e.g. (d,p)



- Pick-up reaction e.g. (d,t)



Fermis Golden Rule

$$W_{fi} = \frac{2\pi}{\hbar} \left| H_{fi} \right|^2 \cdot \frac{dn}{dE_f} = \frac{2\pi}{\hbar} \left| M \right|^2 \cdot \rho(E_f)$$

W_{fi} - transition probability from initial state to final state

H_{fi} , M - matrix element
- -information about nuclear states
- -interaction mechanism

$\rho(E_f)$ - density of final states
phase space factor

Cross section

$$\sigma_{a\to b} = \frac{W}{n_a v_a} = \frac{16\pi^3}{h^4} \cdot \left| M_{if} \right|^2 \cdot \frac{p_b^2}{v_a v_b} \cdot (2 j_b + 1)(2 J_B + 1)$$

- matrix element
- **phase space and particle flux**
- spin degeneracy factor

simple conclusions from cross section

$$\sigma \approx \frac{p_b^2}{v_a v_b}$$

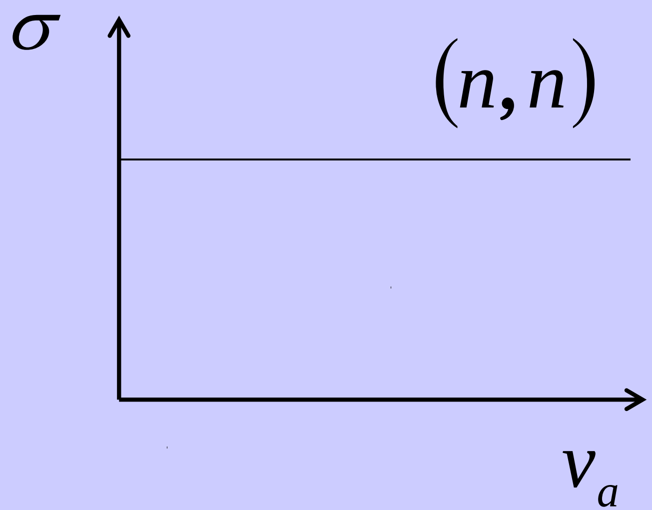
assumption:

$\left|H_{fi}\right|^2, \left|M_{fi}\right|^2$ are often constant in relevant energy range!

1. elastic scattering of uncharged particles

$$- v_a = v_b$$

$$- \frac{p_b^2}{v_b^2} = m_b^2 = \text{const.}$$



e. g. elastic neutron scattering

simple conclusions from cross section

2. exothermic, neutron induced reactions

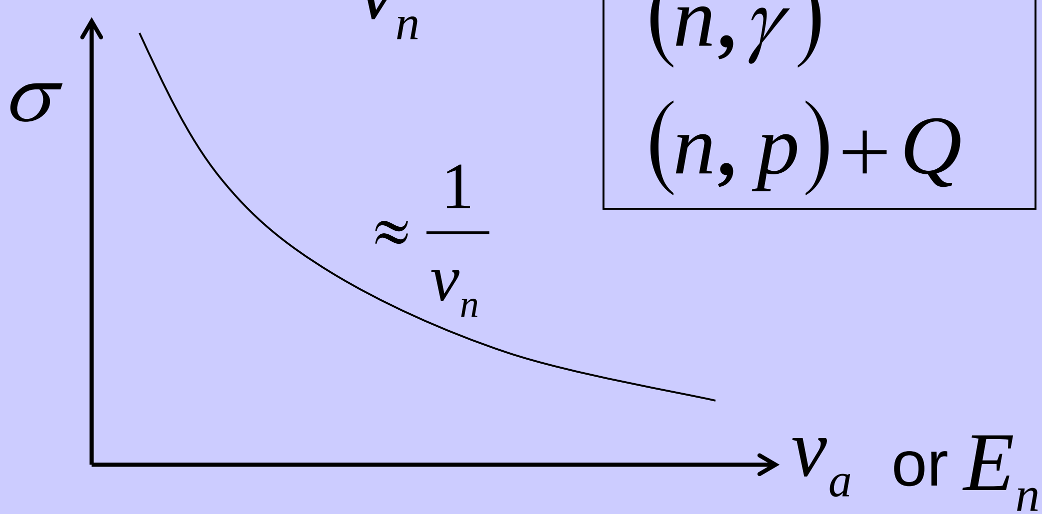
e.g. (n,γ), (n,p), (n,α)

positive Q value, ~MeV range

neutron energy ~eV range

$$-\frac{p_b^2}{v_a v_b} \rightarrow \frac{1}{v_n}\frac{p_b^2}{v_b} = \text{const} \times \frac{1}{v_n}$$

$$\sigma \approx \frac{1}{v_n}$$



(n,γ)

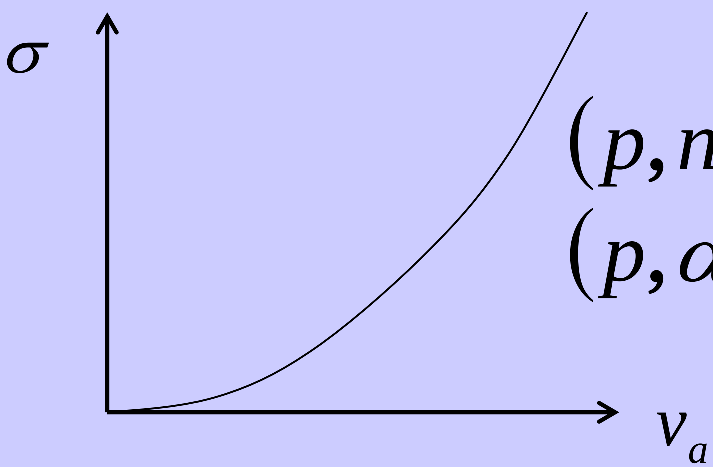
$(n,p)+Q$

simple conclusions from cross section

3. exothermic reactions with charged nuclei

$$\sigma \approx \frac{p_b^2}{v_a v_b} \approx \frac{1}{v_a} \cdot \exp\left(-G_a\right)$$

G_a - penetrability of tunnel effect - Gamow factor - strong energy dependence (similar to α-decay)



$$\left(p, n\right) + Q$$

$$\left(p, \alpha\right) + Q$$

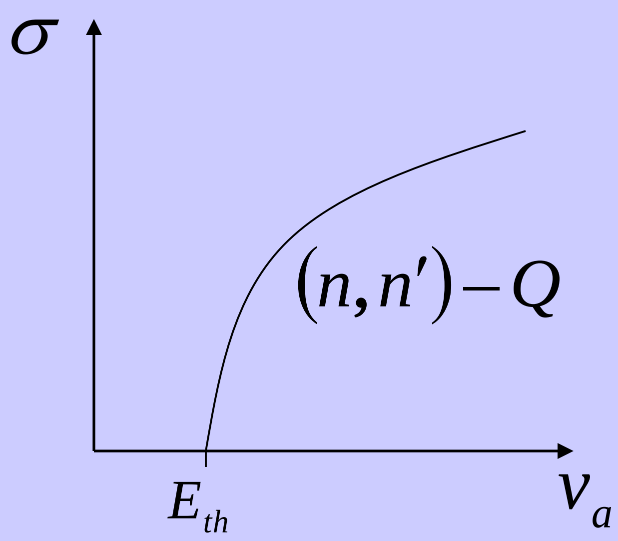
simple conclusions from cross section

4. endothermic reaction

neutron induced, inelastic scattering

$$E^* = -Q \quad \approx \quad \text{MeV range}$$

$$\sigma \propto \frac{p_b^2}{v_a v_b}$$



$$E_b \approx E_a - E_{th}$$

$$v_b \propto p_b \approx \sqrt{2m_b\left(E_a - E_{th}\right)}$$

$v_a = v_n$ fast neutron velocity is approximately constant close to threshold energy

$$\sigma \propto \sqrt{E_a - E_{th}} = \sqrt{E_n - E_{th}}$$

simple conclusions from cross section

5. endothermic reaction with charged particle as reaction product

$$\sigma \propto e^{-G_b} \cdot \left(\sqrt{E_n - E_{th}}\right)$$