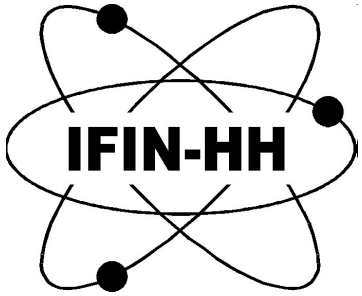


Lecture II.2
The basics of nuclear reactions

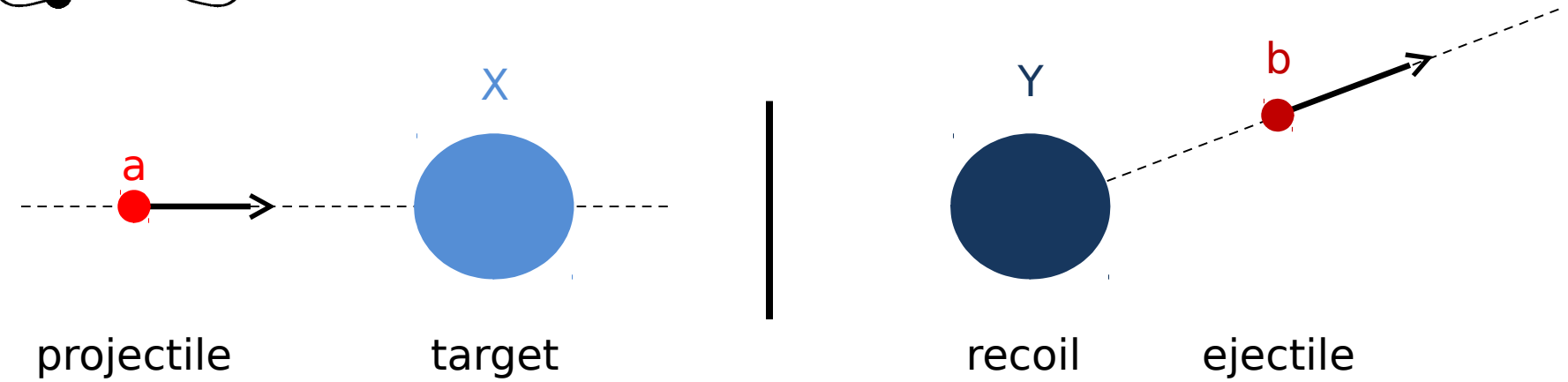
Alexandru Negret

Outline

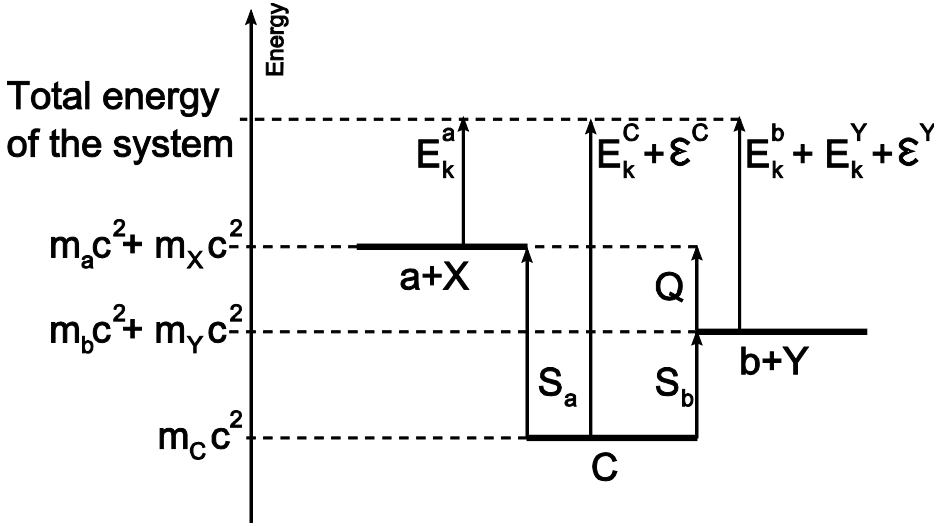
- Nuclear reaction kinematics
- Conservation laws: energy, momentum, angular momentum, parity
- Reaction mechanisms
- Nucleosynthesis
- Cross section databases

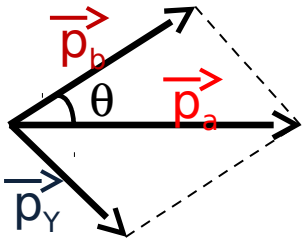
IFIN-HH

Nuclear reaction kinematics



X(a,b)Y

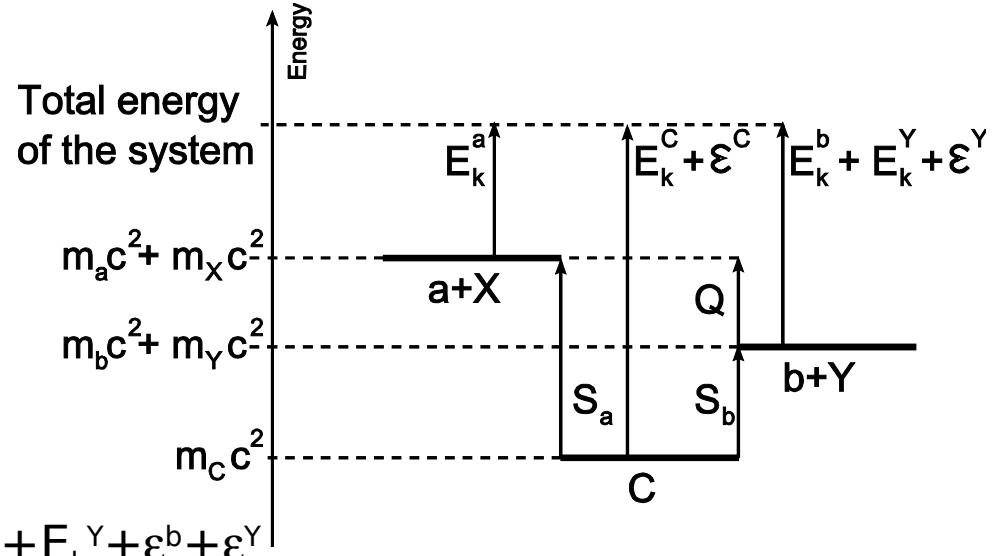




IFIN-HH

Conservation laws: The energy

X(a,b)Y



$m_a c^2 + m_X c^2 + E_k^a = m_b c^2 + m_Y c^2 + E_k^b + E_k^Y + \varepsilon^b + \varepsilon^Y$

$Q = E_k^{final} - E_k^{initial} = m_a c^2 + m_X c^2 - m_b c^2 - m_Y c^2$ Reaction energy (Q-value)

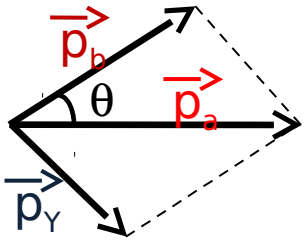
$E_{th} = - Q (m_a + m_X) / m_X$ Reaction threshold (only if Q<0)

QUESTION: Why is the reaction threshold larger than Q?

IFIN-HH

Conservation laws:
The momentum

X(a,b)Y



$$\vec{p}_a = \vec{p}_b + \vec{p}_Y$$

$$p_Y^2 = p_a^2 + p_b^2 - 2p_a p_b \cos\theta$$

The angular momentum

Center – of – mass system: $\vec{I}_X + \vec{S}_a + \vec{L}_{aX} = \vec{I}_Y + \vec{S}_b + \vec{L}_b$

The parity

$$\Pi_a \Pi_X (-1)^{L\_aX} = \Pi_b \Pi_Y (-1)^{L\_bY}$$

Reaction mechanisms

Reaction mechanisms:

- COMPOUND NUCLEUS @ Low interaction energy (Bohr postu
- PRE-EQUILIBRIUM
- DIRECT REACTION

Examples:

- Elastic scattering (shape elastic / compound elastic): (n, n), (α, α)
- Inelastic scattering: (p,pγ), (n,nγ)
- Coulex (Coulomb excitation)
- Charge exchange reaction: (p,n), (n,p)
- Transfer reaction: Stripping: (d,n), (d,p)
- Transfer reaction: Pick-up: (p, d)
- Capure: (n,γ), (p,γ)
- Fragmentation: ^{48}Ca + Be -> ^{44}S + … -> RIB, GSI – FRS
- Spallation: p(1.4 GeV @ ISOLDE) + ^{238}U -> RIB, CERN – ISOLDE
- Fission: ^{235}U(n,F)
- Fusion: ^{12}C(a, γ)^{16}O; d + t -> α + n

IFIN-HH

Exercise: guess the reaction type

$^{28}Si(p, p)^{28}Si$ Elastic / inelastic scattering

$^{12}C(\alpha, ^{3}He)^{13}C$ Stripping

$^{14}N(d, ^{2}He)^{14}C$ Charge exchange

$^{194}Pt(^{6}Li, 3n)^{197}Tl$ Fusion-evaporation

- Elastic scattering (shape elastic / compound elastic): (n, n), (α, α)
- Inelastic scattering: (p,pγ), (n,nγ)
- Coulex (Coulomb excitation)
- Charge exchange reaction: (p,n), (n,p)
- Transfer reaction: Stripping: (d,n), (d,p)
- Transfer reaction: Pick-up: (p, d)
- Capure: (n,γ), (p,γ)
- Fragmentation: ^{48}Ca + Be -> ^{44}S + …
- Spallation: p(1.4 GeV @ ISOLDE) + ^{238}U
- Fission: ^{235}U(n,F)
- Fusion: ^{12}C(a, γ)^{16}O; d + t -> α + n

IFIN-HH

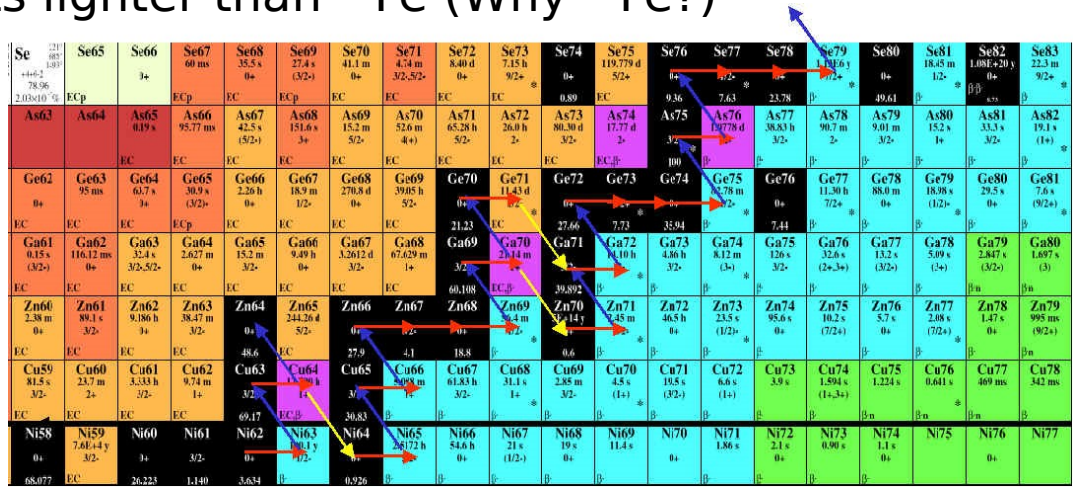
Nucleosynthesis

Where are the nuclei formed

During the Big Bang: H, He, very little amounts of Li, Be, B

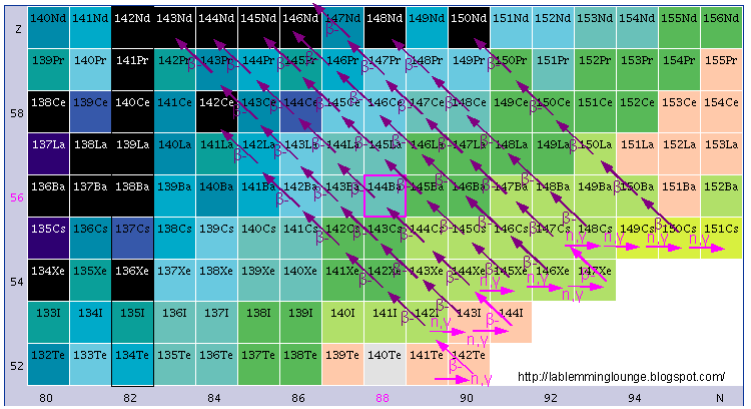
. In stars, through fusion: elements lighter than ^{56}Fe (Why ^{56}Fe?)

- CNO cycle: Nuclear fusion process of H occuring in stars and using C, N, and O.
- S-process: Sequence of n-capture reactions followed by beta decays producing elements heavier than Fe in the stars.



3. During the final explosion of a big star – Supernovae: elements heavier than ^{56}Fe, but also lighter elements: ^{24}Mg – ^{60}Ni.

- R-process: Sequence of n-capture reactions followed by beta decays producing heavy elements during the explosion.



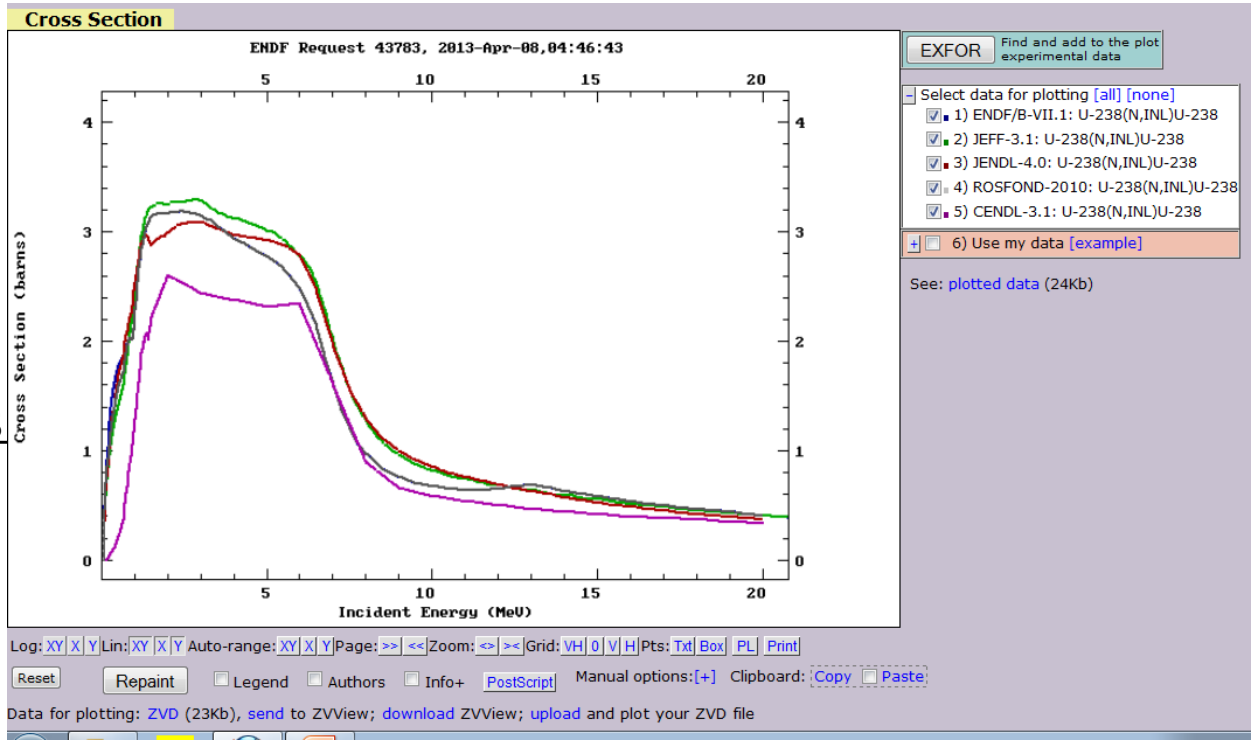
Reaction databases

Evaluated (theoretical) databases:

- ENDF/B-VII.1 (USA)
- JEFF-3.1 (Europe)
- JENDL-4.0 (Japan)
- CENDL-3.1 (China)
- ROSFOND (Russia)

Experimental databases

- EXFOR



Summary

- Nuclear reaction kinematics
- Conservation laws: energy, momentum, angular momentum, parity
- Reaction mechanisms
- Nucleosynthesis
- Cross section databases