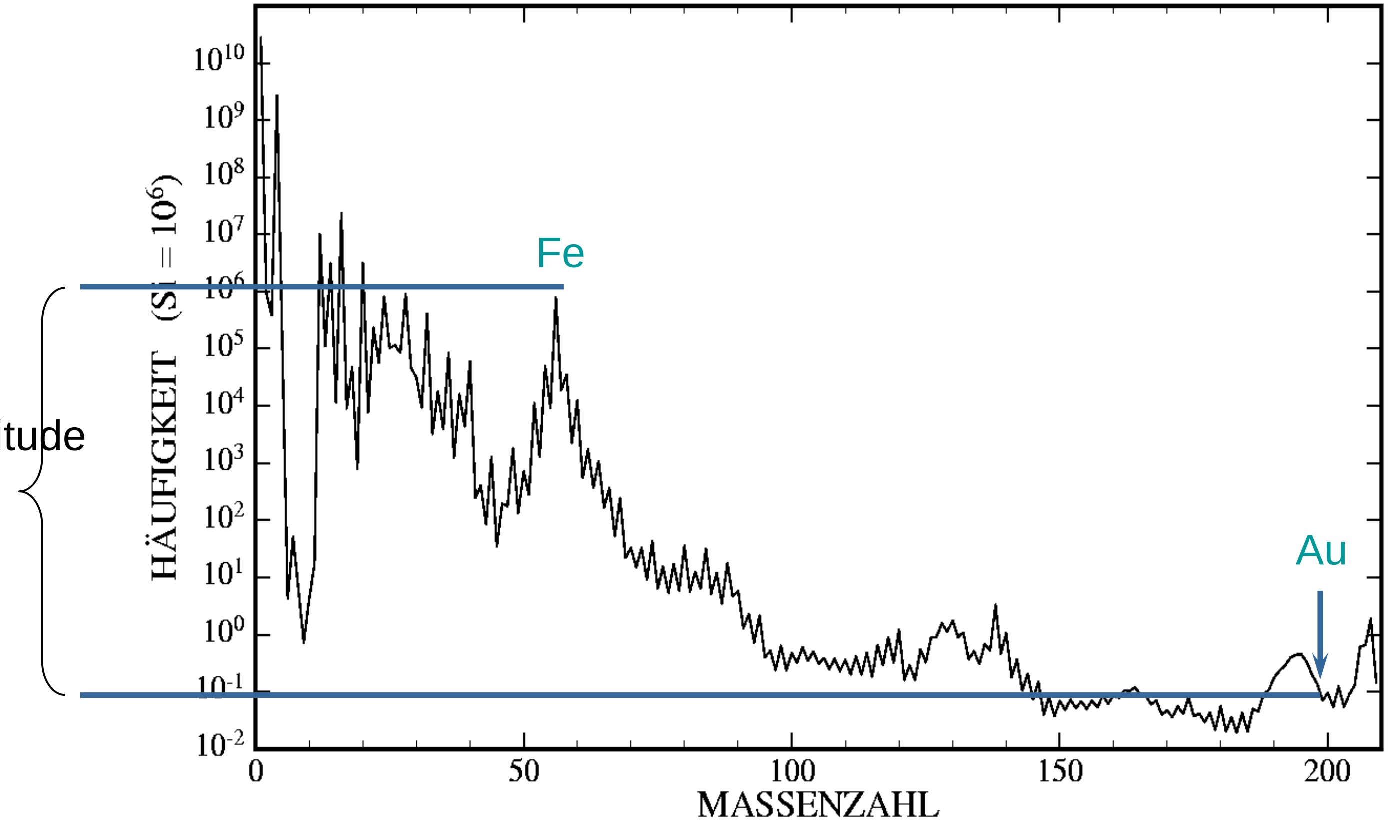
Abundance of atomic mass in solar system

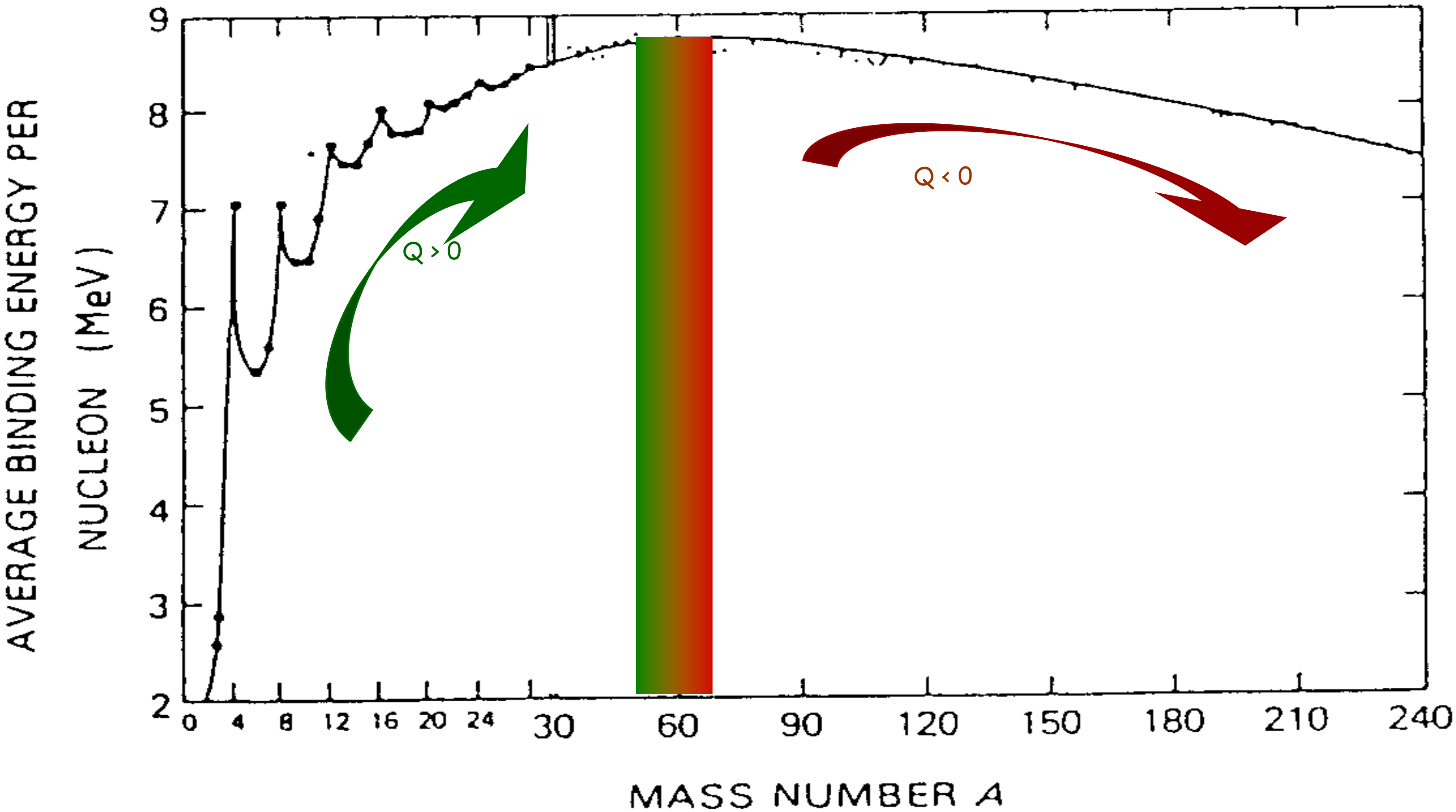
7 orders of magnitude difference



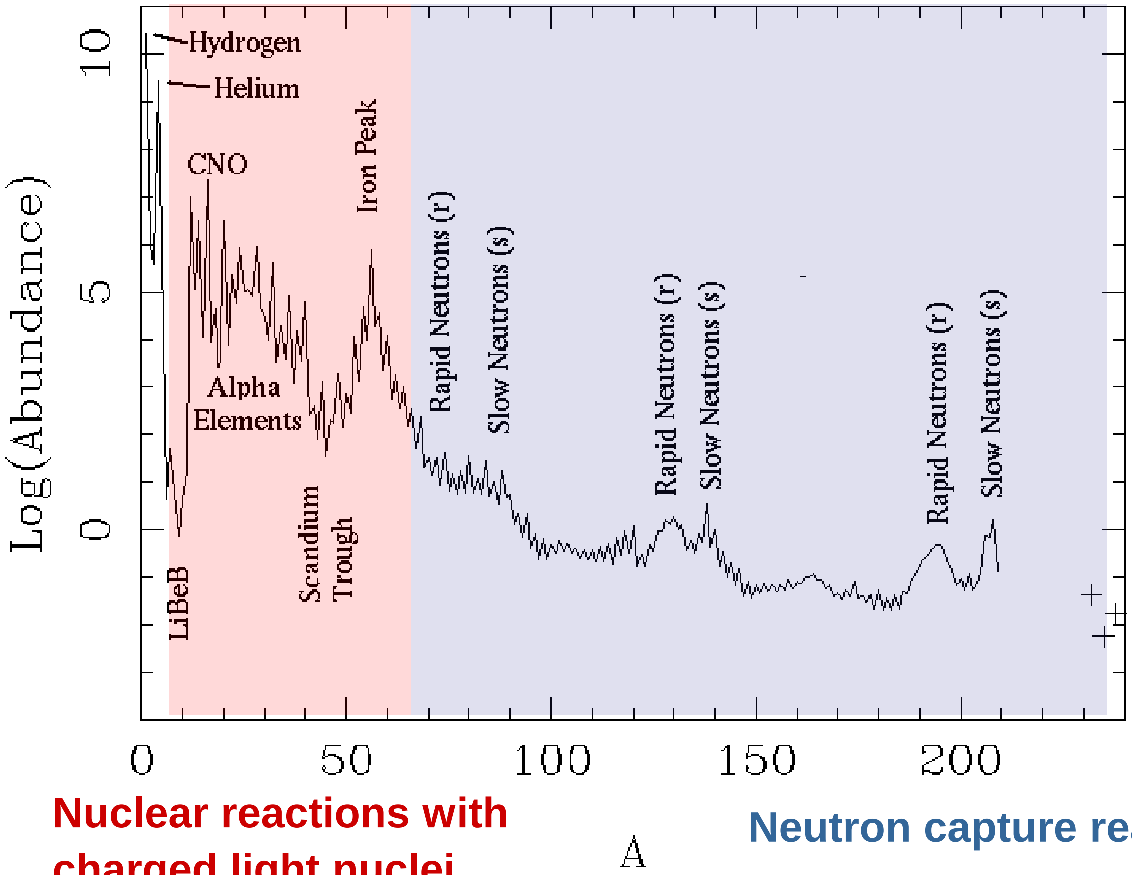
"The 11 Greatest Unanswered Questions of Physics"
National Academy of Science Report, 2002

binding energy curve ⇔ fusion reactions beyond iron are endothermic

How are nuclei beyond iron produced?



Abundance of mass



Nuclear reactions with charged light nuclei

during quiet, stable phases
of stellar evolution

mainly STABLE NUCLEI

Neutron capture reaction

during explosive phases
as part of stellar evolution

mainly UNSTABLE NUCLEI

Introduction & Reminder

Nuclear reactions in stars:

a) energy conversion

b) synthesis of chemical elements

stars = cauldrons of univers

Literatur: Cauldrons in the Cosmos
C. E. Rolfs, W. S. Rodney
The University of Chicago Press

for reaction: T(p,e)R (T=Target, p=Projectile, e=Ejectile, R=Recoil)

Reaction Q-value: $Q=[(m_p+m_T)-(m_e+m_R)]c^2$

(energy per single reaction)

for $Q > 0 \Rightarrow$ netto production of energy per reaction

In general: consider reaction **1+2 → 3+4** in a plasma

Nuclei of type **1** and type **2** are destroyed via the nuclear reaction **1+2** and nuclei of type **3** and type **4** **produced**.

The reaction rate is determined by:

- Particle density (number of particles/volume)
- Kinectic energy/ relative velocity of reaction partners
- Reaction cross section which depends on energy/velocity in CM system

N_i = density of interacting particles [number/volume]= [number/ m^3]
v = relative velocity [m/s]
$\phi(v)$ = velocity distribution in plasma
$\sigma(v)$ = reaction cross section [m^2]

reaction rate depends on two factors :

(i) Effective area, which contributes to reaction rate, is proportional

$\sigma(v) \cdot N_1$

(ii) particle flux

$v \cdot N_2$

reaction rate per volume is proportional $[1/(\text{time} \cdot \text{volume})$ units $1/[\text{s} \cdot \text{m}^3]]$

$r = N_1 N_2 \sigma(v) v$

velocity is given with a certain probability distribution :

$$\int_0^\infty \Phi(v)dv = 1$$

reaction rate per particle pair and volume

$$\langle \sigma v \rangle = \int_0^\infty \Phi(v) v \sigma(v) dv$$

N_i = density of interacting particles	[number/ m³]
v = relative velocity	[m/s]
φ(v) = velocity distribution in plasma	
σ(v) = reaction cross section	[m²]

for exothermal reaction; integration starts from $v = 0$ until $v = \infty$

for endothermal reaction; integration starts from $v \propto Q^{1/2}$ until $v = \infty$

totale reaction rate

$$r = \frac{1}{1+\delta_{12}} N_1 N_2 \langle \sigma v \rangle$$

Kronecker delta applies for identical particles to avoid double counting.

Consider reaction: **1+2 → 3**

Nuclei of type **1** are destroyed via the capture reaction with type **2** nuclei;

type **3** nuclei are produced.

average live time of type **1** nuclei in stellar environment is given by differential equation:

$$\left(\frac{dN_1}{dt}\right)_2 = -\lambda N_1 = -\frac{1}{\tau} N_1$$

Mean lifetime
Decay constant

or

$$\left(\frac{dN_1}{dt}\right)_2 = -(1+\delta_{12})\, r = -N_1 N_2 \langle \sigma v \rangle$$

Kronecker symbol disappears,
often the following equations are given:

$$= -N_1 \rho N_A \frac{X_2}{A_2} \langle \sigma v \rangle = -N_1 \rho N_A Y_2 \langle \sigma v \rangle$$

$$r = \frac{1}{1+\delta_{12}} N_1 N_2 \langle \sigma v \rangle$$

$$N_i = \rho N_A \frac{X_i}{A_i} = \rho N_A Y_i$$

number density	N_i
Matter density	ρ
Avogadro‘s number	N_A
Mass fraction	X_i
Atomic mass	A_i
Mol fraction	Y_i