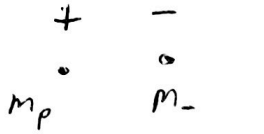
FYS3310 · lecture 4

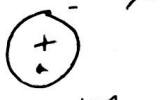
Energy production

$E = mc^2$

~ free



~ hydrogen atom



Chemical element E: ${}^{A}_{Z}E$ m_{12C}

Z: atomic number, no. of protons

A: (atomic) mass number, nucleon number, no. of protons + neutrons

*atomic mass: mass of atom in kg, or dalton [u]

1 dalton = $\frac{1}{12} m_{12C}$

$= m_u = u = 1.66e{-}27$ kg

$= 931.494$ MeV/c^2

* Relative isotope mass:
  - atomic mass of isotope / m_u
  - dimensionless number
* atomic weight, Ar, relative atomic mass:
  - average atomic mass of atoms of a chemical element in a given sample

$m_p = 1.007276466\,88\ u$

$m_e = 0.000\,548\,579\,911\ u$

$m_{1H} = 1.007\,825\,032\,14\ u$

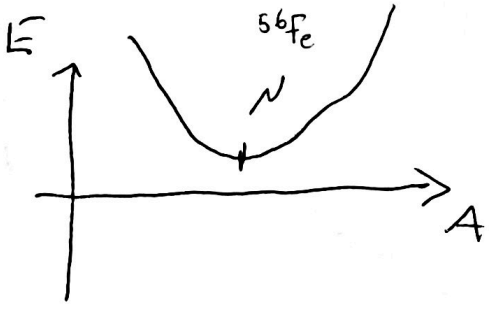
$(m_p + m_e) - {}^{m}_{1}H = 13.6\ eV$

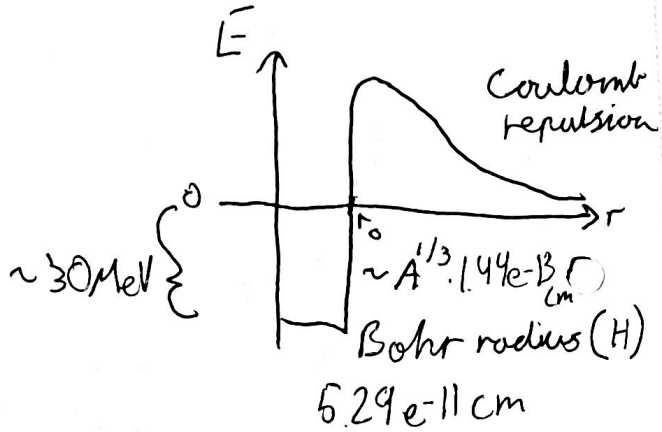
recombination of a free proton and electron to neutral hydrogen! → bound state of lower energy which releases energy

---

$4 \cdot m_{1H} - m_{4He} = 0.028\,70\ u = 26.73\ MeV$

- packing protons and neutrons → bound system of lower energy
- need to consider long-range repulsion of Coulomb force and short-range attraction of strong nuclear force

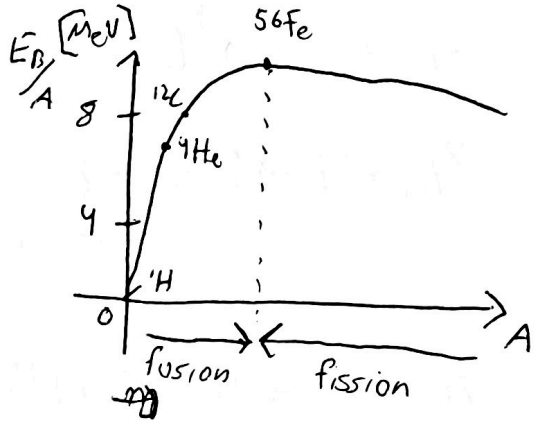




Fractional binding energy per nucleon

$$f = \frac{E_B}{A}$$

$^4He: \frac{28.73\ MeV}{4} = 6.68\ MeV$



- fusion: exothermal (release energy)

Fusion reaction chains

Hydrogen burning: pp-chain

(= γ (photon))

① $^1H + {}^1H \rightarrow {}^2D + e^+ + \nu_e + 0.15\ MeV$ (^2D = ^2H)

- very slow reaction because it requires both collision of two protons and decay proton into neutron

$p \rightarrow n + e^+$

$\sim 10^{10}$ years

mass deficit $\Delta m = 2 m_{^1H} - m_{^2D} = 1.44\ MeV$

very likely that

$e^+ + e^- \rightarrow 2\gamma = 1.02\ MeV$

free electron in star

energy released:

$Q = Q' + Q_\nu = Q_{pp} + Q_\nu = (0.15 + 1.02) + Q_\nu = 1.17\ MeV + 0.27\ MeV$

(Q_ν = neutrino)

1.17 MeV: adds to the energy of the thermal bath of the star

0.27 MeV: escapes

② $^2D + {}^1H \rightarrow {}^3He + \gamma$ (5.49 MeV)

③ PPI: $^3He + {}^3He \rightarrow {}^4He + 2\,{}^1H + \gamma$ (12.86 MeV)

④ PPII and PPIII: $^3He + {}^4He \rightarrow {}^7Be + \gamma$ (1.59 MeV)

PPI: 85.2%

PPII + PPIII = 14.8%

PPII: (inverse β decay)

$^7Be + e^- \rightarrow {}^7Li + \nu_e + \gamma$ → ground state of ^7Li — ν_e [0.86MeV]

→ excited state of $^7Li^*$

$^7Li + {}^1H \rightarrow 2\,{}^4He + \gamma$ — ν_e [0.81MeV]

17.346MeV

PPIII:

$^7Be + {}^1He \rightarrow {}^8B + 0.14MeV$

$^8B \rightarrow {}^8Be + e^+ + \nu_e + 6.88MeV$

↳

$Q_\nu \approx 7.2MeV$ > Q_{ν_e} < 1MeV

↳ can be detected on Earth

triple alpha process

$^8Be \rightarrow 2\,{}^4He + 3MeV$

- extremely likely reaction. ★
- half life 8.2e-17s

→ resonance: $^3He \rightarrow {}^{12}C$