# Basic Nuclear Physics and Decays

- Basic Ingredients

- Models (Fermi, Droplet, Shell)

- Decays and Stability

Source: Chapter 1 &2 , andCameron (1984)

# Players and Properties of Nuclei

**Nucleons:**

| | Mass | Spin | Charge |
|---|---|---|---|
| Proton | 938.272 MeV/c$^2$ | 1/2 | +1e |
| Neutron | 939.565 MeV/c$^2$ | 1/2 | 0 |

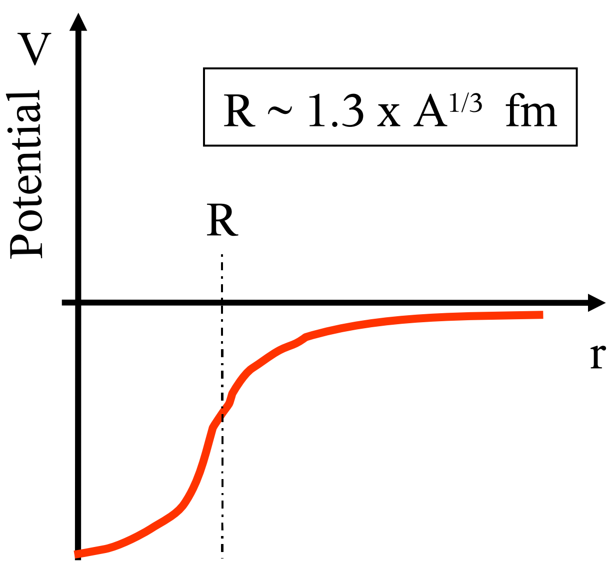
size: ~1 fm

**Forces**

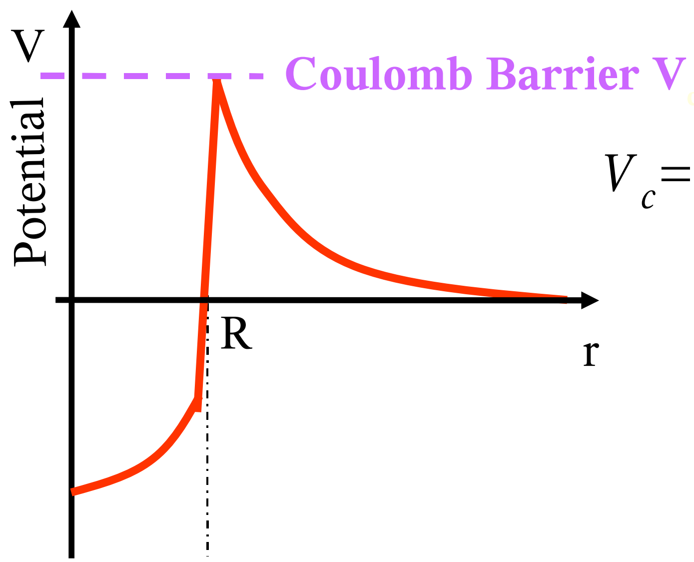
Strong force ( range ~ 1 fm) and electromagnetic force

## Nuclear Potentials

neutron




proton
(or any other charged particle)




$$V_c = \frac{Z_1 Z_2 e^2}{R}$$

Rem: Nuclear radii R are determined by electron scattering experiments

# Measured Core Radii from Electron Scattering

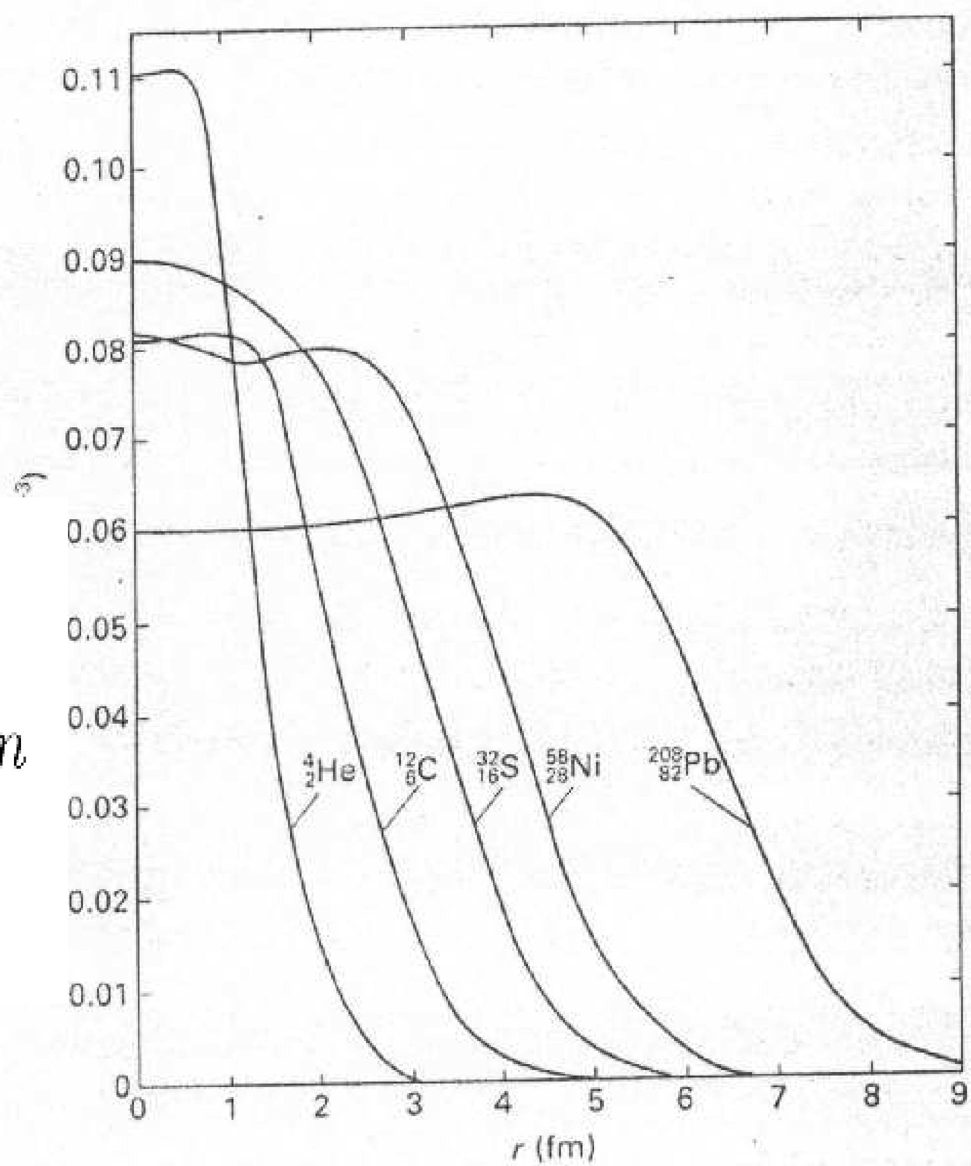
(see also Cross Sections)

Charge density can be approximated by a Saxon-Woods shape within about 10 %

$$\rho(r) = \frac{\rho_o}{1+e^{r-R}/a_V}$$

with $R = 1.18 \times A^{1/3} - 0.048 fm$

and $a_V = 0.055 \pm 0.07 fm$



# Binding Energy B of Nuclei with Z protons, N neutrons and Mass M(Z,N)

$$B(Z,N) = Zm_p + Nm_n - M(Z,N).$$

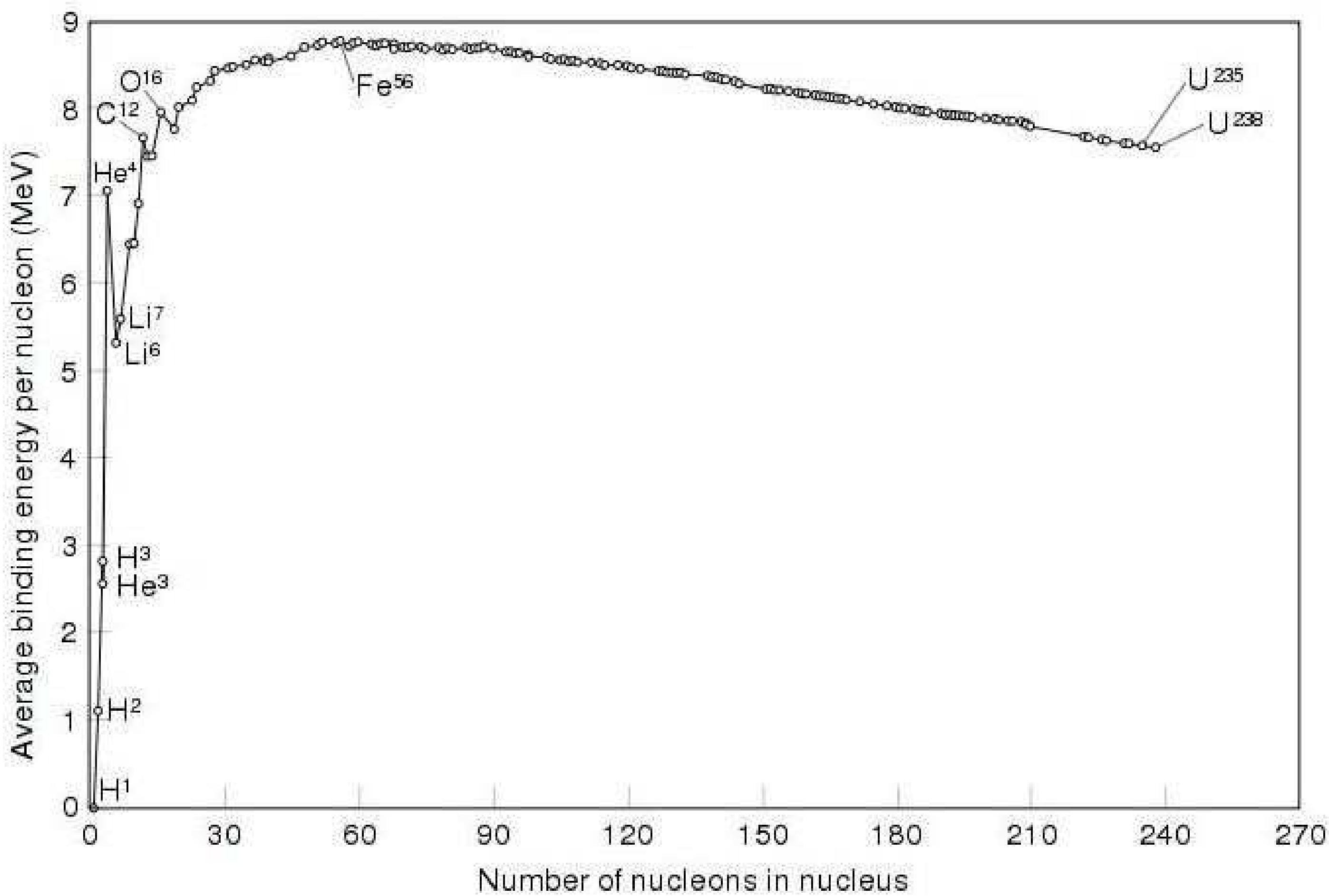
with $E=m\,c^2$, masses are measured in MeV.

**Remark:** Mass excess and atomic mass unit

$M_{ex}(Z,N) = M(Z,N) - A\,m_u$

u

# Measured Nuclear Binding Energies of Stable Nuclei




**Remark:** Binding energy is released by nuclear burning

# The Independent Particle Model

**Assumption:** Equilibrium distribution of cold Fermi-gas in a box like potential (last week, and see blackboard for details)

Phase Space

$$\Phi(E) = \frac{4\pi}{3}\frac{g}{h^3}(2m)^{3/2}E^{3/2}$$

$$\omega(E) = 2\pi\frac{g}{h^3}(2m)^{3/2}E^{1/2}.$$

$$E_F = \frac{h^2}{2m}\left(\frac{3}{8\pi}\frac{N}{V}\right)^{2/3}.$$

Mean binding energy per nucleon:

$$\bar{E} = \frac{1}{N}\int_0^{E_F} E \le (E)dE = \frac{1}{\Phi(E_F)}\int_0^{E_F} E \le (E)dE$$

$$= \left(\frac{8\pi}{3}\frac{(2m)^{3/2}}{h^3}E_F^{3/2}V\right)^{-1} \cdot \frac{2}{5}\frac{4\pi}{h^3}(2m)^{3/2}E_F^{5/2} \cdot V$$

$$\bar{E} = \frac{3}{5}E_F.$$

=> Mean energy/nucleon 8-12MeV
Potential V = 40MeV

# Droplet Model (Nuclear Mass Formula)

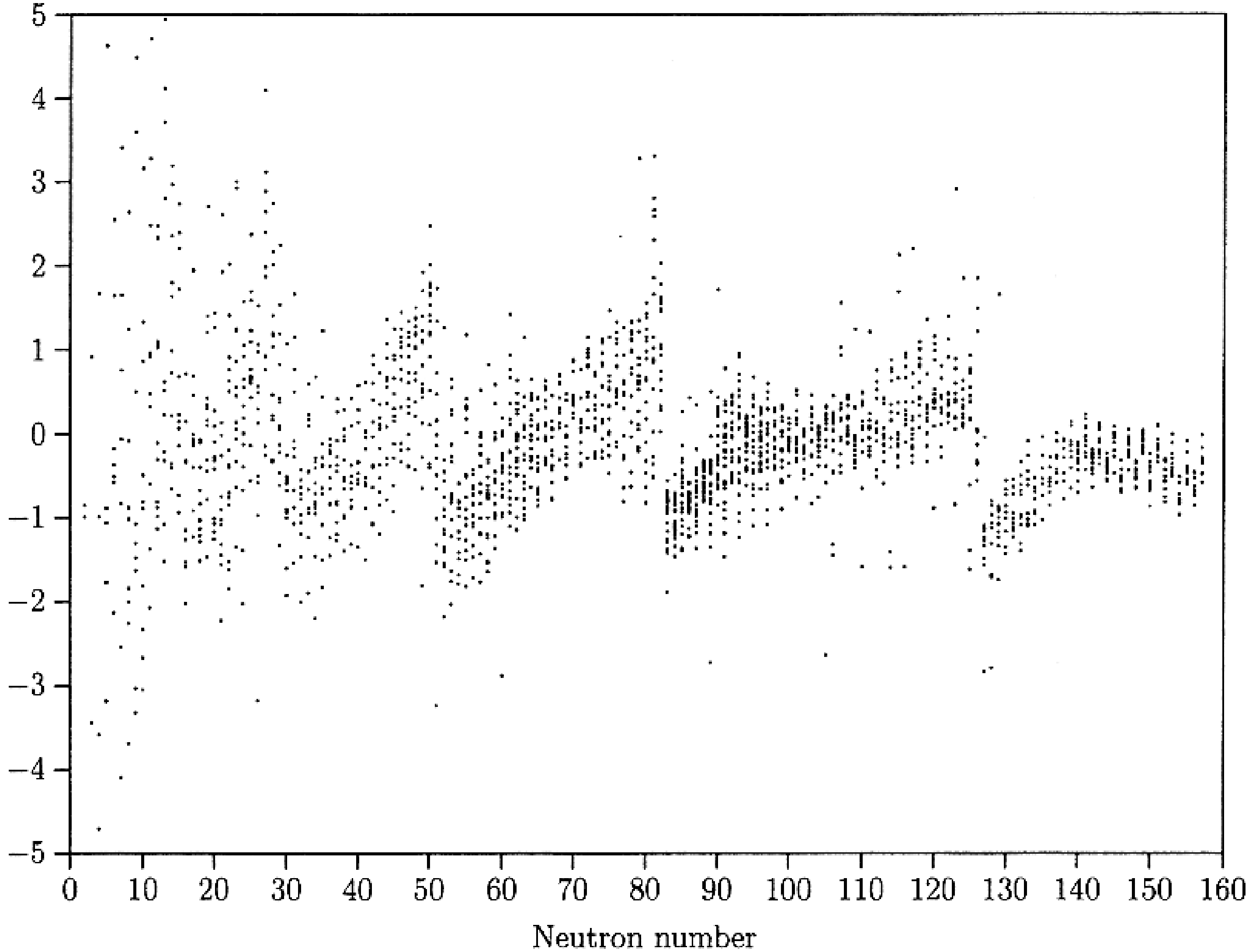
(Weizsacker, 1935, Bethe and Backer 1936)

| | |
|---|---|
| $B(Z,A) = a_V A$ | **Volume Effect (B = A (Potential – Ebar)** |
| $-a_s A^{2/3}$ | **Surface Effect (less neighbors for nuclear at surface)** |
| $-a_C \dfrac{Z^2}{A^{1/3}}$ | **Coulomb repulsion of protons** |
| $-a_A \dfrac{(Z-A/2)^2}{A}$ | **Asymmetry Effect from Pauli exclusion (see blackboard)** |
| $+\frac{12}{\sqrt{A}}$ if even-even; $0$ if odd A; $-\frac{12}{\sqrt{A}}$ if odd-odd. | **Cooper Pairs (pairing gap of Nucleons)** |

$$B(Z,N) = a_V A - a_S A^{2/3} - a_C Z^2 A^{-1/3} - a_{sym} \frac{(N-Z)^2}{A} + B_{pair}(Z,N)$$

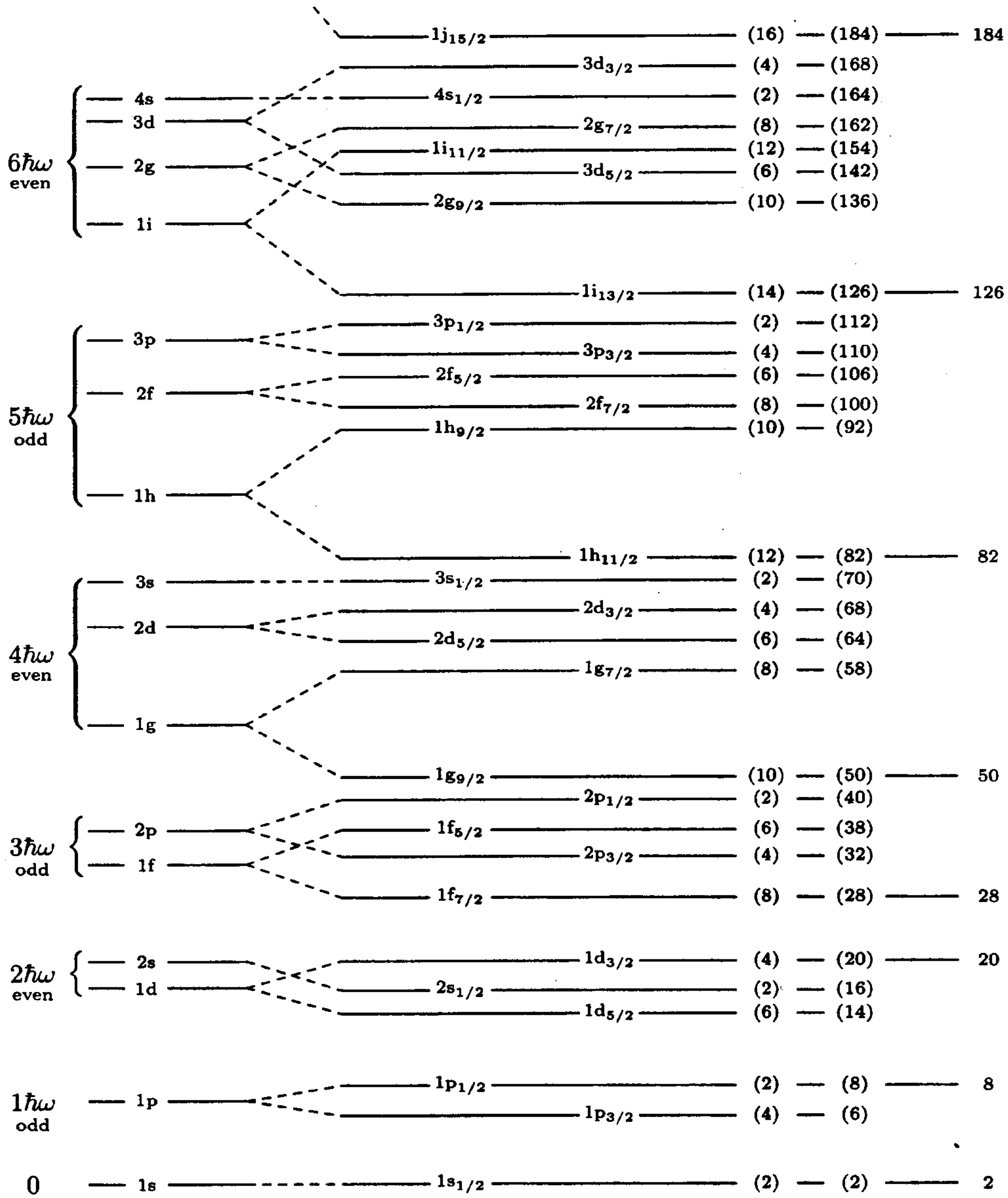
$$a_V = 16 \text{ MeV}, \quad a_S = 18.5 \text{ MeV}, \quad a_C = 0.72 \text{ MeV}, \quad \text{and} \quad a_{sym} = 23.4 \text{ MeV}.$$

# Differences between observed and predicted B(Z,N) [MeV]




(from Moeller et al. 1994)

# Solution: Shell Model and Magic Numbers (e.g. Moeller et al. 94)




- Non-uniform distribution of level by splitting

- Gaps in E

- coupling

-Magic numbers