Basic Nuclear Properties

Static nuclear properties (Time-independent):
Electric charge, radius, mass, binding energy, angular momentum, parity, magnetic dipole moment, electric quadrupole moment, energies of excited states.

Dynamic properties (Time-dependent):

- Self-induced (Radioactive decay).
- Forced (Nuclear reactions) ▶ cross sections.

Excited states: atomic intervals ~ eV.
nuclear intervals ~ $10^4 – 10^6$ eV.

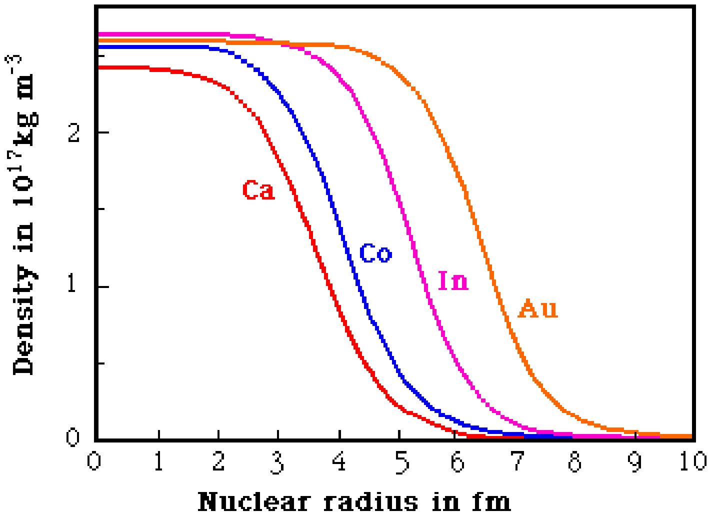
Decays and reactions: Conservation laws and selection rules.

The key to understand all properties: Interaction between individual nucleons. A big challenge to nuclear physicists.

Nuclear Size

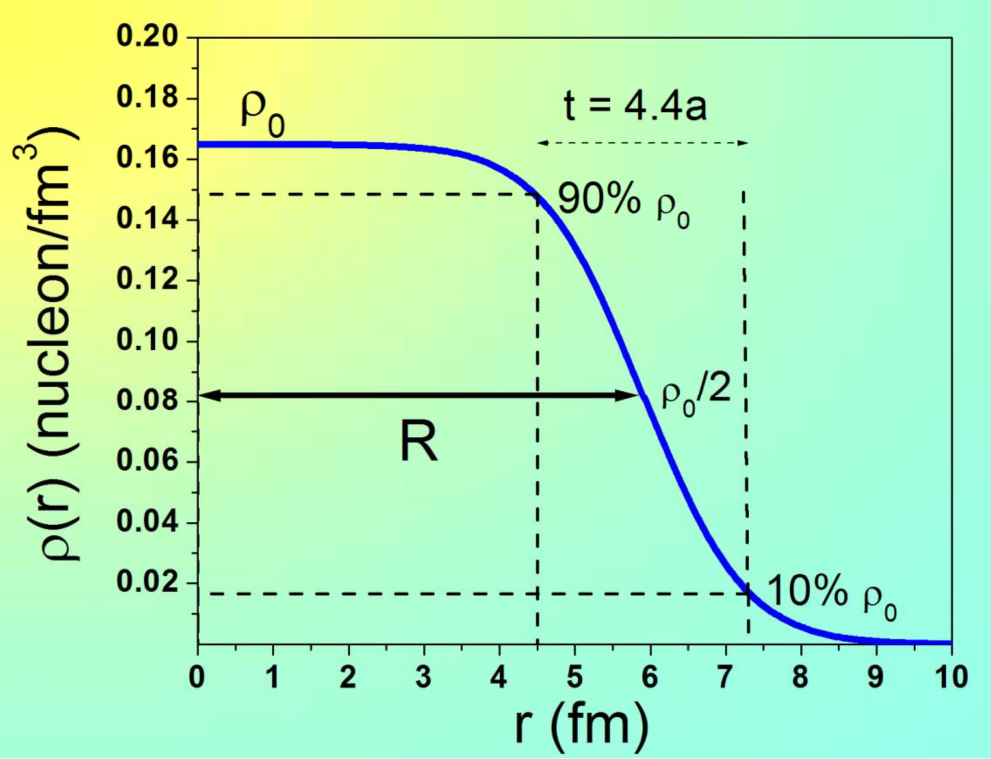
- Different experiments give different results ▶ Radius not well defined.
- Depends on probe and relevant physics.
- Probes should be close to the order of the size of the nucleus ~ 10^{-14} m.
- Visible light? λ much larger.
- 1 MeV γ? λ = ?? x 10^{-12} m. Interacts with orbital electrons.
- Suitable probes: p, n, α, e .... Charge distribution. Mass distribution.
- High energy, why?
- λ < 10 fm ▶ p > 100 MeV/c.
- All experiments agree qualitatively and somehow quantitatively.

$$\frac{A}{\frac{4}{3}\pi R^3} \sim \text{constant} \;\blacktriangleright\; R \propto A^{1/3}$$



$$R = r_0 A^{1/3}$$ with r_0 dependent on the method.

Nuclear Size



- Experiments show that $t = (2.4 \pm 0.3)$ fm for all nuclei.
- Is surface effect the same for all nuclei?

$$\rho(r) = \frac{\rho_0}{1 + e^{(r-R)/a}}$$

ρ_0 = nucleon density near the center.

t = "skin" thickness.

a = thickness parameter.

R = Half-density radius.

Compare for A = 4, 40, 120 and 235.

- Inside the nucleus the density is fairly uniform.
- The transitional surface layer is thin.

} Liquid Drop

Short range of nuclear force. Saturation.

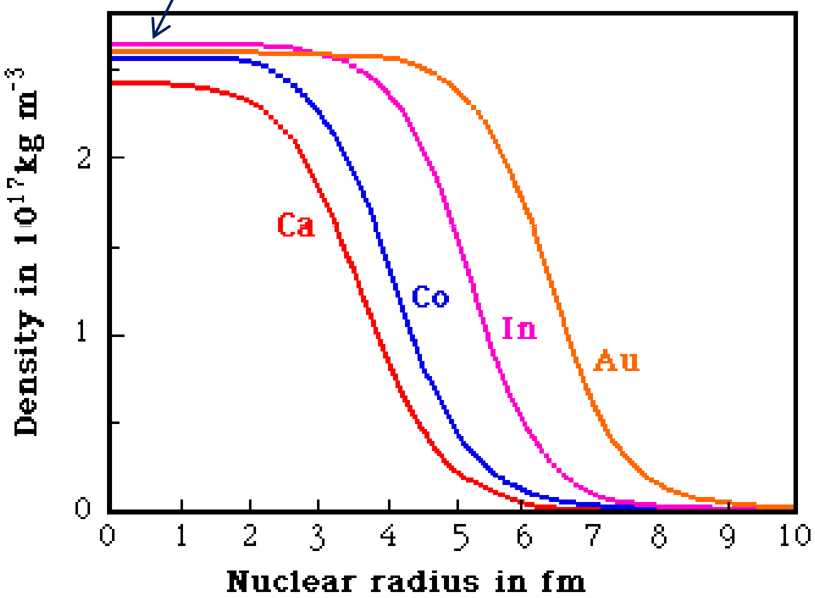
Nuclear Size

$R \propto A^{1/3}$

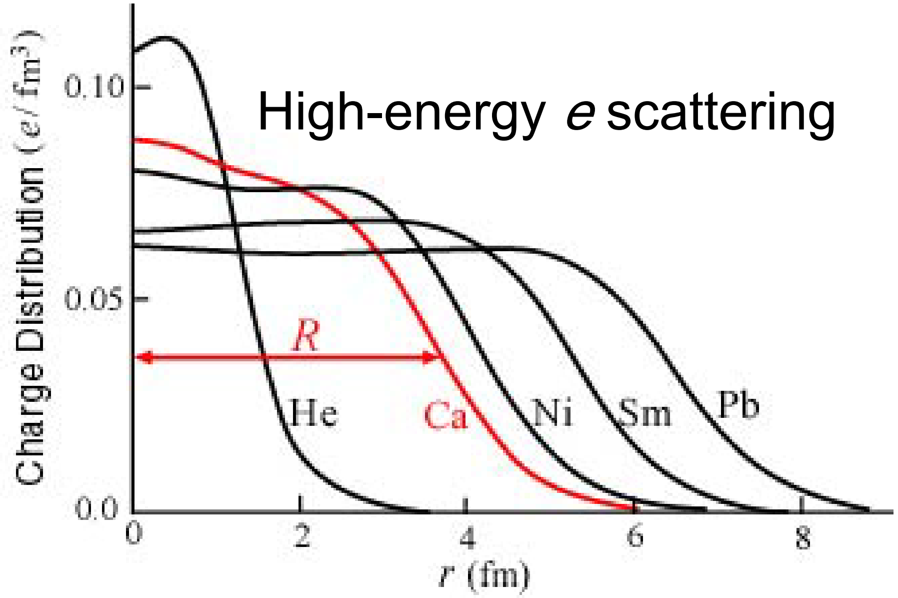
ρ_0 decreases with A?

$$\rho_{charge} = \frac{Z}{A}\rho_{matter}$$

No



Yes



Matter distribution ⇔ charge distribution.

Light nuclei?

From some experiments….!

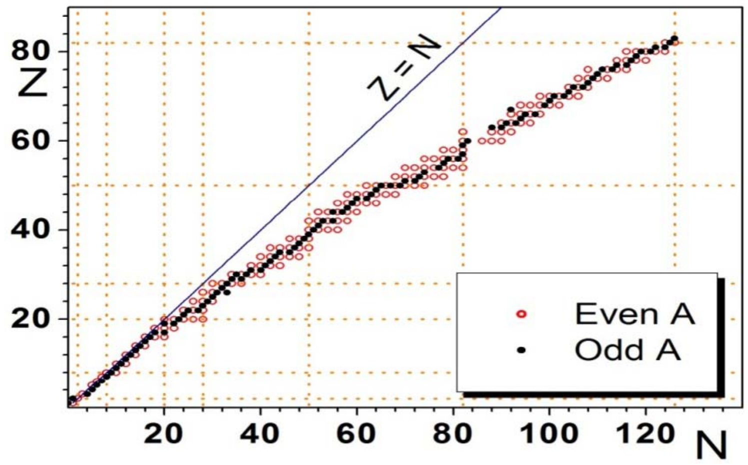
Charge distribution: r_0 = 1.07 fm. a = 0.55 fm.

Matter distribution: r_0 = 1.25 fm. a = 0.65 fm.

Why?

Nuclear Size

Nucleus	Z/A	Charge density
^{40}Ca	…..	…..
^{59}Co	…..	…..
^{115}In	…..	…..
^{197}Au	…..	…..



• Charge radius ~ nuclear radius, even though heavy nuclei have more neutrons than protons. Explain…

• Density of ordinary atomic matter ~ 10^3 kg/m^3. Density of nuclear matter ~ 10^{17} kg/m^3.

• Neutron stars, 3 solar masses, only 10 km across ….. !!!