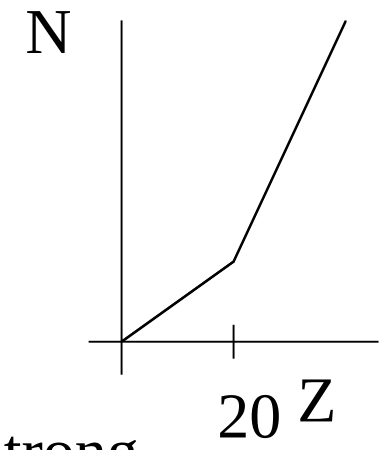
Nuclear Physics

- Atoms have nuclei that are composed of protons and neutrons
- Protons and neutrons are very similar: both *baryons*, both have mass about 2,000 times that of an electron (938.26 MeV for proton, 939.5 MeV for neutron); both have spin 1/2 (fermions); both have isotopic spin of 1/2 (+1/2 for proton; -1/2 for neutron); both are composed of three *quarks* (uud for proton; udd for neutron)
- Differences: Electric charge (proton: 1; neutron: 0)

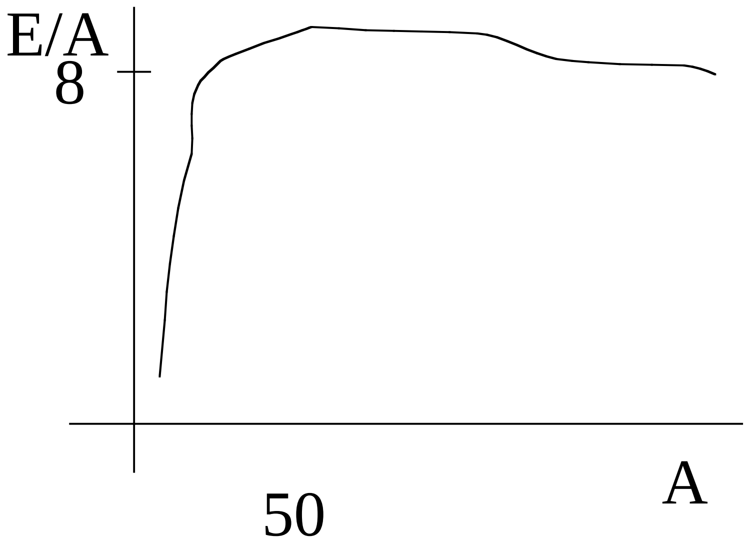
Bound Nuclei



- Protons and neutrons in nuclei are bound by the strong force; they are repelled by exclusion principle
- Shapes of nuclei can be determined by electron scattering; most nuclei are approximately spherical $R=R_0A^{1/3}$, where R_0 is about 1.5 fermis (10^{-13} m) (liquid drop model)
- Z=atomic number; A=atomic weight; N=number of neutrons (isotopes have same Z; different A)
- Large nuclei are more stable with more neutrons; trade-off between strong attraction and electromagnetic repulsion

Bound Nuclei

- Mass of a nucleus is less than the mass of its parts due to binding energy
- Typical binding energies are 10's of MeV



Radioactivity

- Alpha—fragment is a ^{4}He nucleus (strong interaction)
- Beta—fragments are an electron (positron) and an anti-neutrino (neutrino)—weak interaction
- Gamma—fragment is photon (electromagnetic interaction)
- All decays are stochastic

Radioactivity

$$dN = -\lambda N dt$$

$$\frac{dN}{N} = -\lambda dt$$

$$\ln N = -\lambda t + C$$

$$N = e^{-\lambda t + C} = e^{C} e^{-\lambda t} = N_0 e^{-\lambda t}$$

$$\tau = \frac{1}{\lambda}$$

$$t_{1/2} = \frac{\ln 2}{\lambda} = 0.693\tau$$

Beta Decay

- Pauli postulated neutrino based on conservation of energy in beta decay
- Neutrino is left-handed; aligned nuclei have aligned beta decays
- Beta decay lifetimes are long; used for carbon dating
- Typical electron energies are 0.5 MeV; not very penetrating

Gamma Decay

- Results from nucleons “dropping down” to lower energy levels; typical energies are 1 MeV
- Half-lives are short; gamma decay usually follows another radioactive decay that leaves an excited nucleus
- Gammas are very penetrating and dangerous; Cobalt 60

Alpha Decay

- Emits a helium nucleus with 4-7 MeV
- Alpha is heavy and slow; will not penetrate skin; dangerous in lungs
- Alpha decays have wide range of half-lives; lower energy means longer half-life
- Example of QM barrier penetration