Nuclear Physics

Nuclear composition

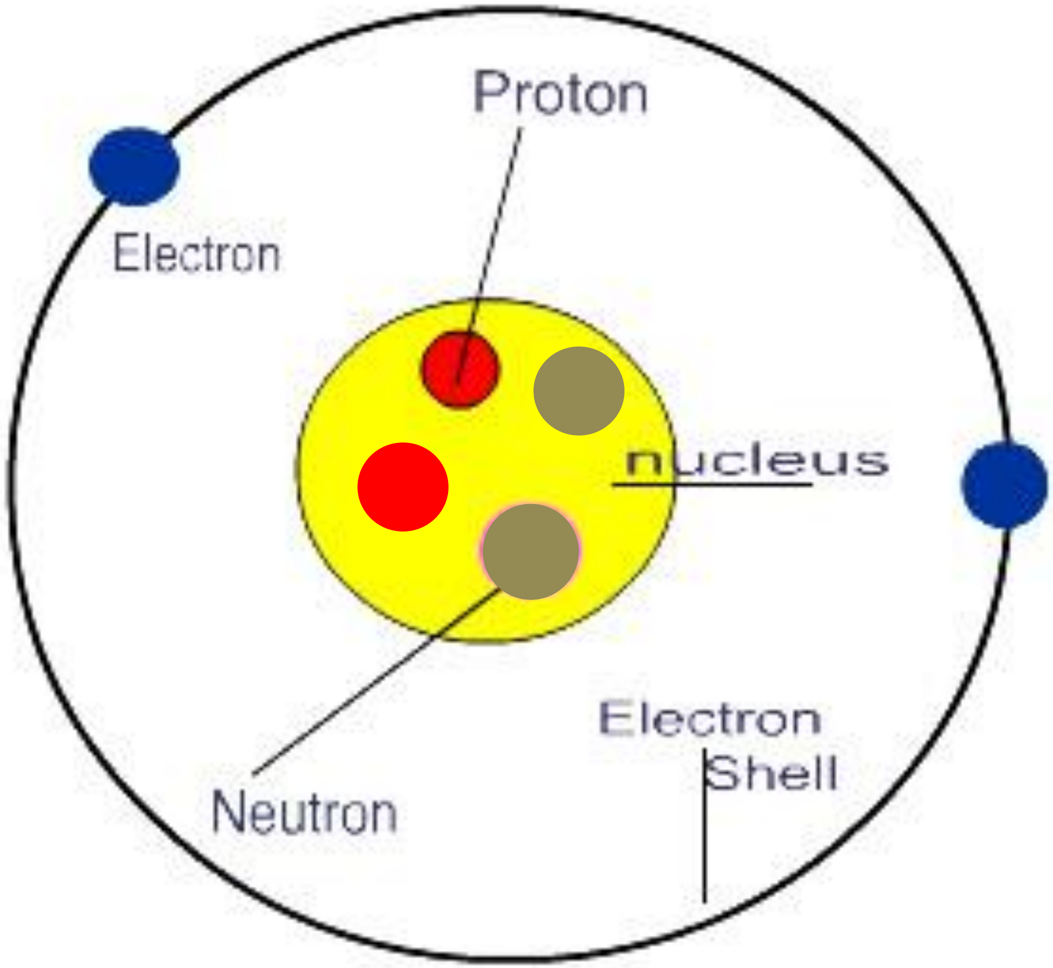
Radioactivity

Binding energy

Nuclear reactions

Fission and Fusion

Model of an atom



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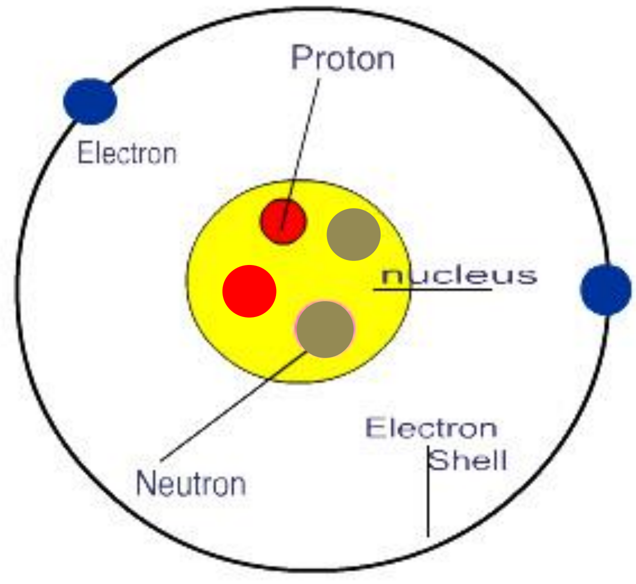


- Earth is the Atom 10^{-10}m
- Ross Hall would be nucleus 10^{-15}m
- Orange would be electrons 10^{-18}m

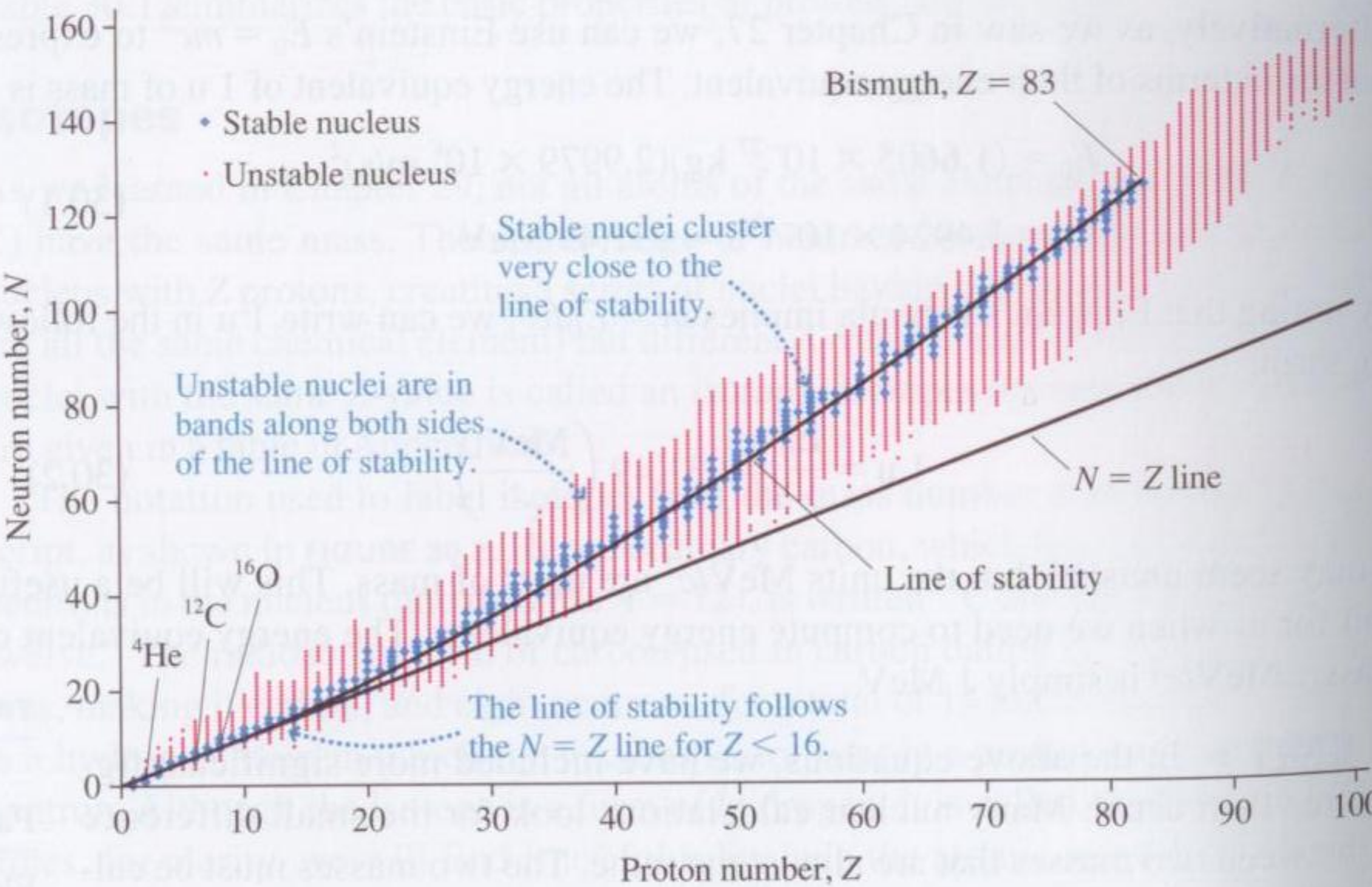
- Density is tremendous!

2×10^{17} kg/m^3 vs. Water 1×10^3 kg/m^3

Nuclear Force

- Gravitational Force
- Electrostatic Force
- Magnetic Force
- Nuclear Force
  - Short range force that attracts protons and neutrons to each other. Overcomes electrostatic repulsion of protons.

FIGURE 30.3 Stable and unstable nuclei shown on a plot of neutron number N versus proton number Z.



Nuclear Reactions

- Division or combination of protons/neutrons

<u>Radioactivity</u>

Spontaneous emission of radiation (electron transitions)

- alpha particles (α)

  ^{4}He nuclei: 2 protons and 2 neutrons Can't penetrate paper

- Beta rays (β)

  e^- or e^+ (plus a nuetrino) 3 mm of Aluminum

- Gama rays (γ)

  photon (range of x-rays) 5 cm of Lead

Nuclear Decay

- Unstable nuclei decay into more stable forms
- Half Life - Time for half of the sample to decay

Example:

If $T_{1/2}$ = 1000 years

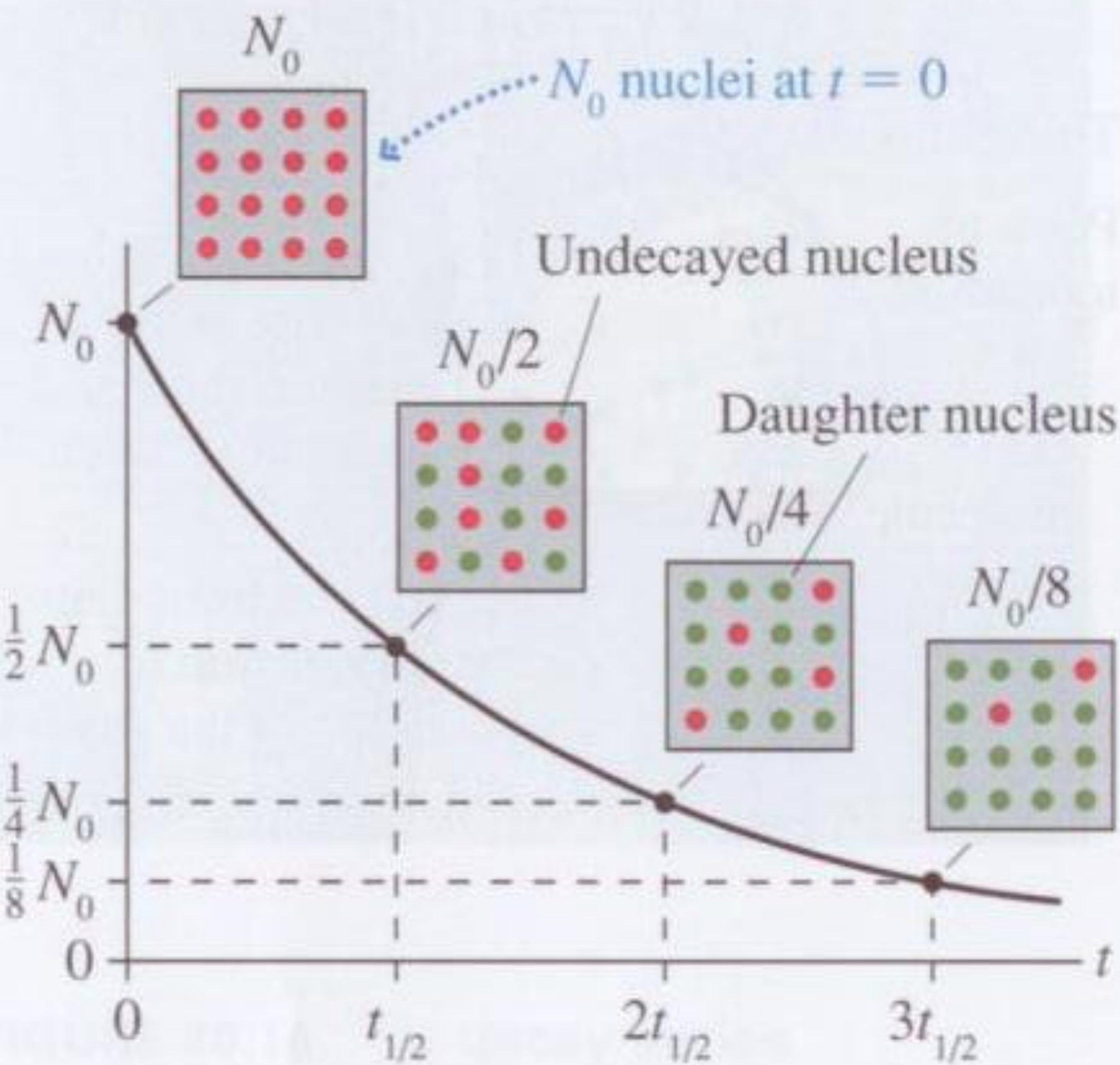
N_o = 500 nuclei

t = 1000 years -> N = 250 (1/2 N_o)

t = 2000 years -> N = 125 (1/4 N_o)

t = 3000 years -> N = 62.5 (1/8 N_o)

FIGURE 30.18 Half the nuclei decay during each half-life.



Radon

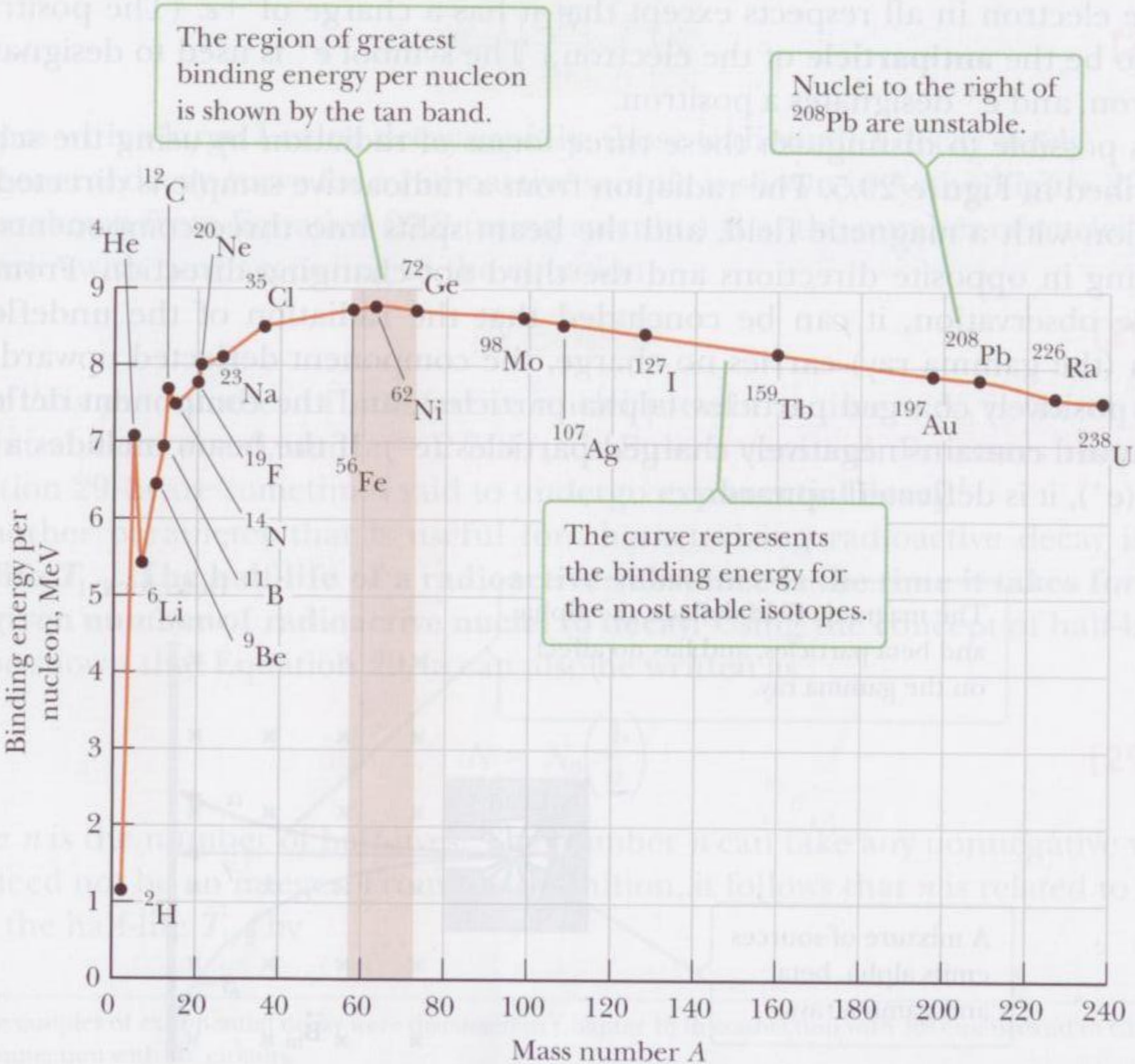
- $T_{1/2}$ = 3.83 days
- Radiation in the form of alpha (α) particles
- Can only damage body if internal.
- Appears to damage lungs of smokers
- If ingest it, body expels it in 100 minutes

Binding energy

- Energy required to totally disassemble a nucleus into protons and neutrons

$$E = mc^2$$

- A bound nucleus weighs less than it's constituent protons and neutrons.


The region of greatest binding energy per nucleon is shown by the tan band.
Nuclei to the right of 208Pb are unstable.
The curve represents the binding energy for the most stable isotopes.
Binding energy per nucleon, MeV
Mass number A
4He
12C
20Ne
35Cl
72Ge
23Na
62Ni
56Fe
19F
14N
11B
9Be
6Li
2H
98Mo
107Ag
127I
159Tb
197Au
208Pb
226Ra
238U
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100
120
140
160
180
200
220
240

Fusion

- A reaction in which two nuclei are combined, or fused to form a larger nucleus

Fission

- A reaction in which two nuclei are split (fissured)

Fusion

- Overcome coulomb repulsion of electrons
- Net gain of energy due to binding energy (like falling in a hole with a big wall around it)
- Sun not hot enough – very small probability some will get past (tunneling)
- Sun's reactions highly unlikely so life is 10 billion years

Sun: ^{1}H -> He

Reactors: ^{2}H deuterium -> He

Fusion

- Reactor requires:
  - Very high temperature 10^8 K
  - High density of material
  - time

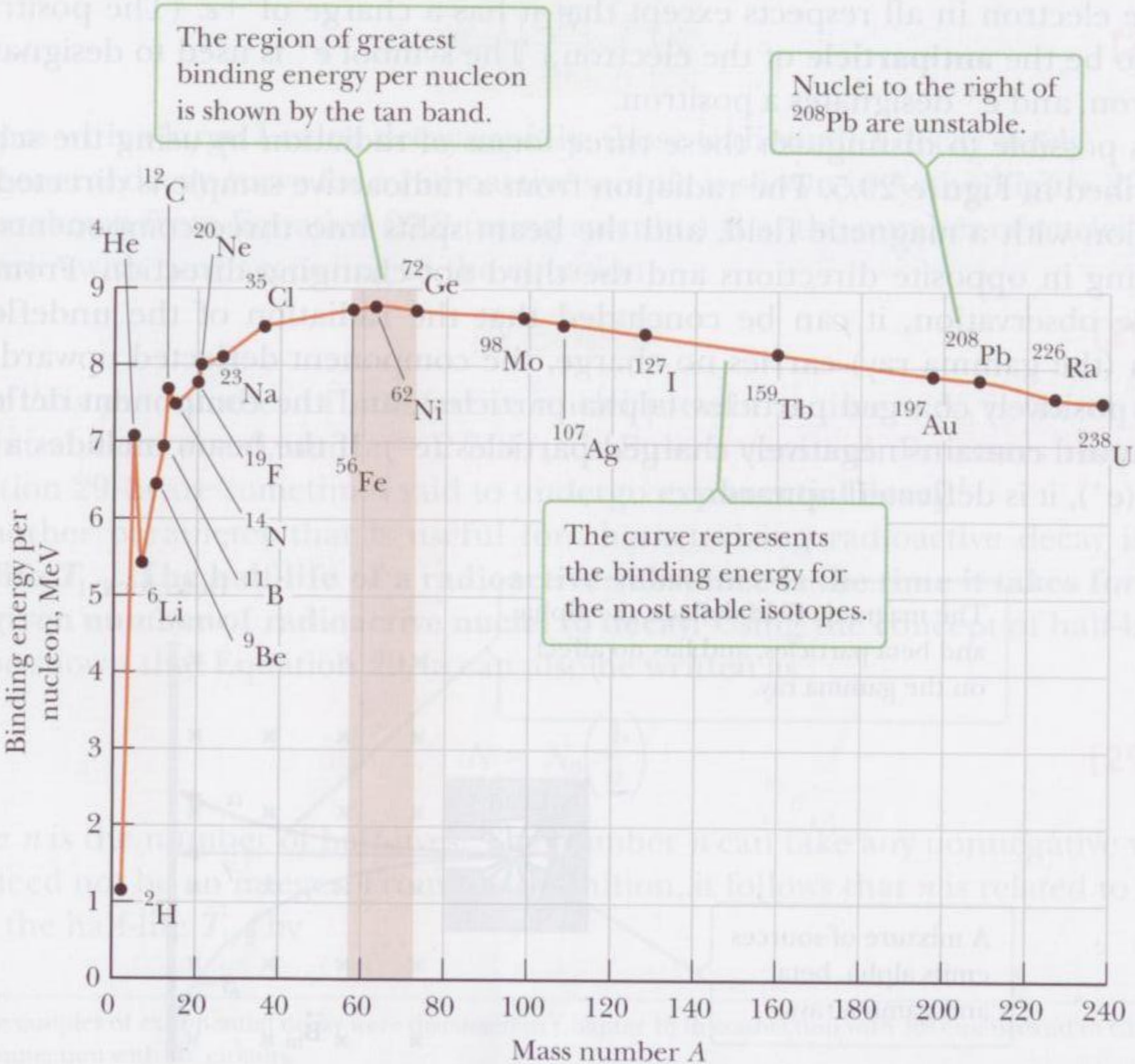
Fusion

- <u>Ignition</u> – Reactions produce enough energy to be self-sustaining (external energy source cut off)

- <u>Break even</u> – fusion power equals heating input
  - Been reached for a very short amount of time
  - NIF has a 192 Laser array used to ignite Hydrogen.
    - The Laser uses 1000 times more power than the US/sec.

Fission

- Heavy nuclei have less Binding Energy than midrange ones.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Fission

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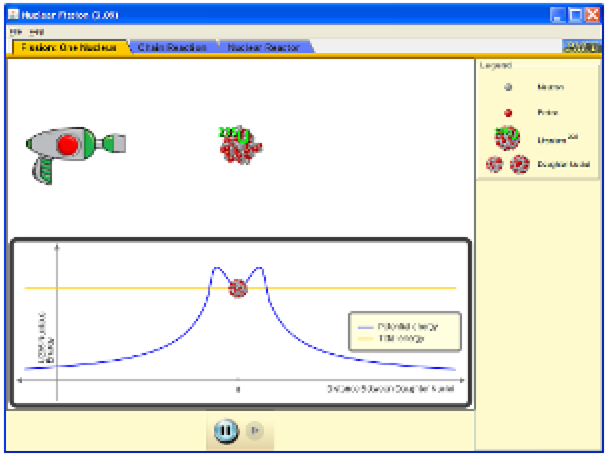


Fission

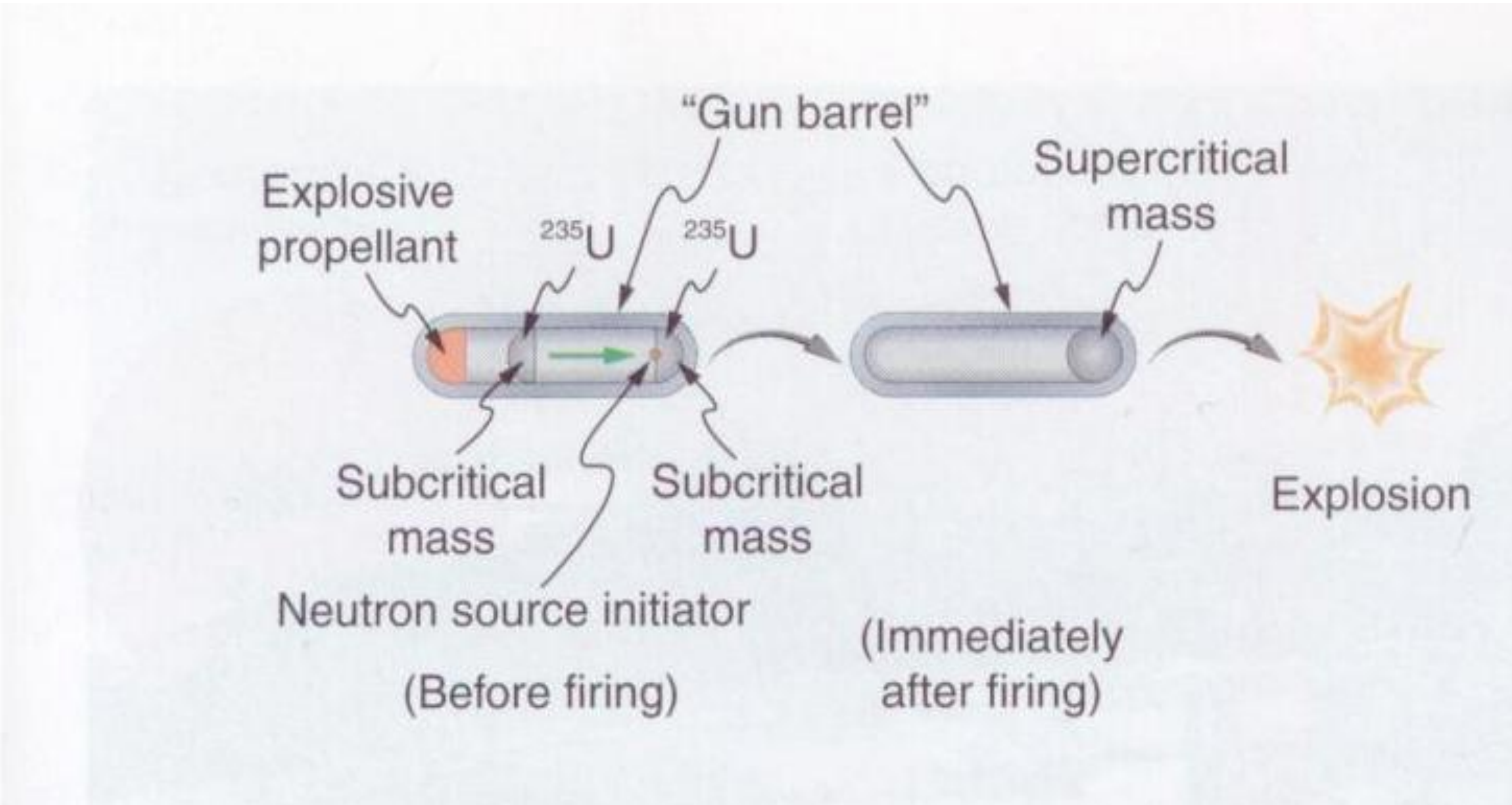
- Chain reaction – reactions produce excess neutrons some make more fissions
- Critical mass – Minimum amount of material needed for self sustained chain reaction

- ^{235}U and ^{238}U occur together in nature so they have to be separated – very expensive!

Fission

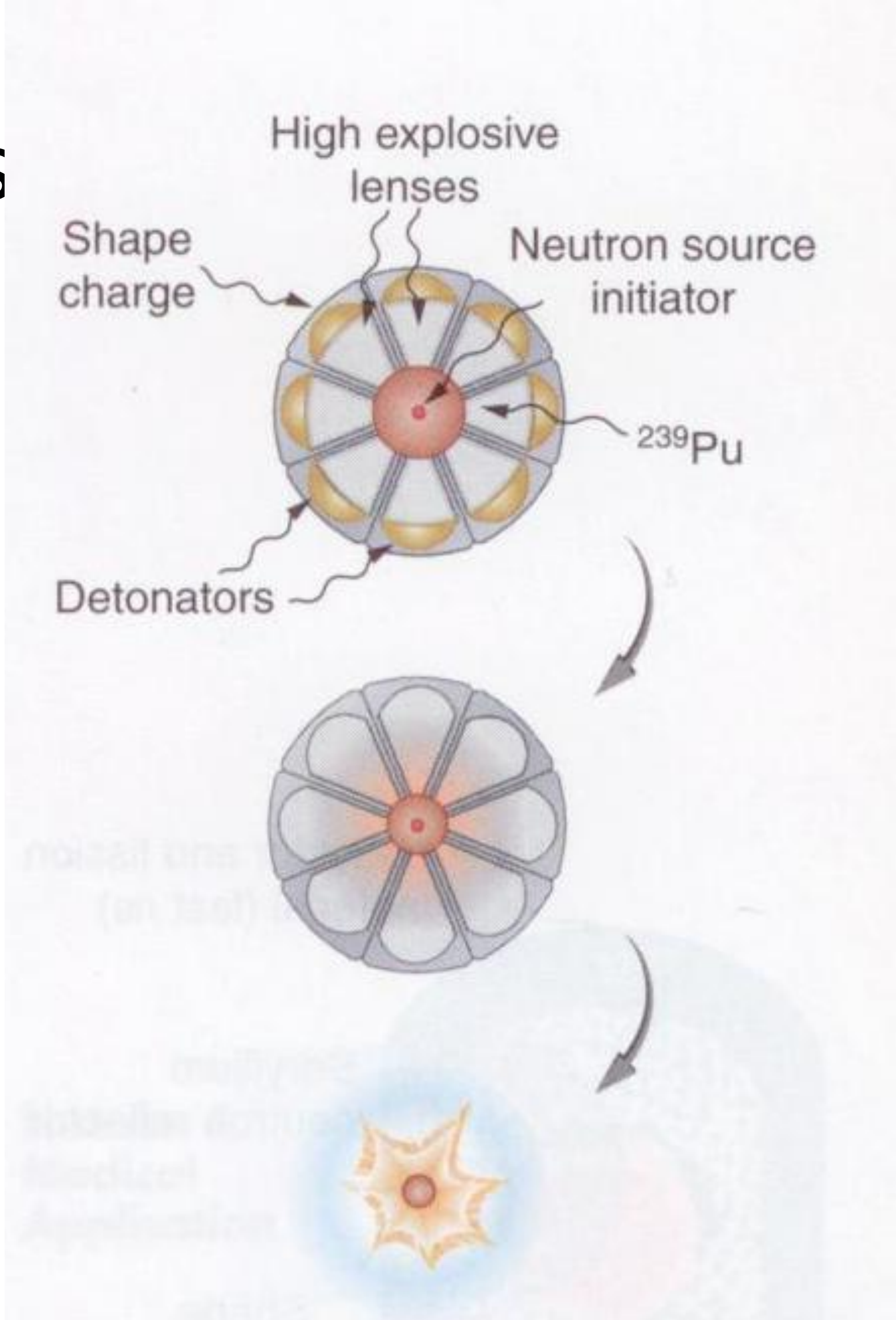
- Criticality – self-sustaining chain reaction
- Super-criticality – exponential increase in reactions
- Control rods – prevent super-criticality and control heading to avoid meltdown or explosion

Nuclear Weapons



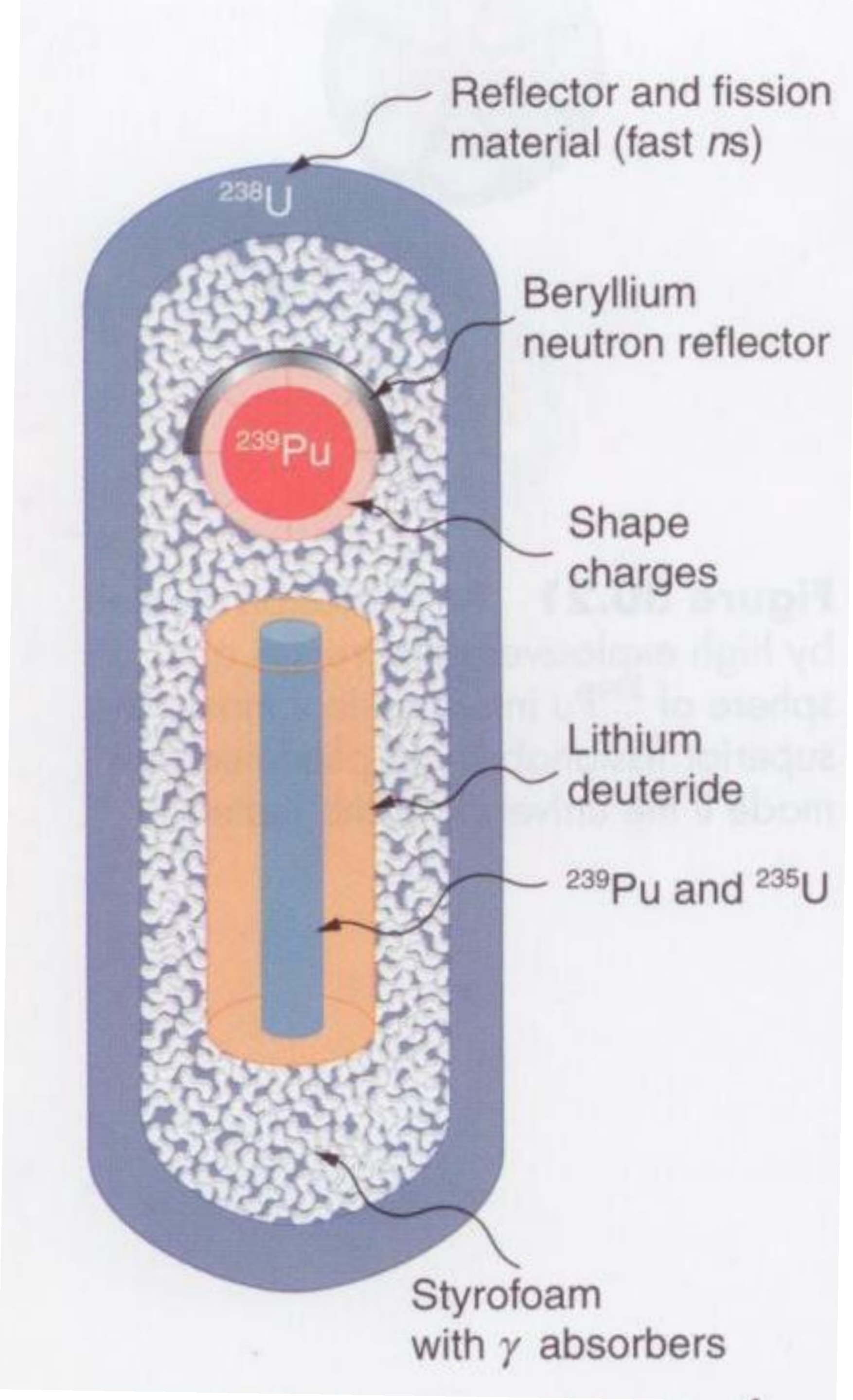
Nuclear Weapons

- Fission Bombs
- 1945 10 kT – 20kT (equivalent of 5000 conventional bombs)
- Hiroshima 15kT & Nagasaki was 20kT



Nuclear Weapons

- Fusion Bombs (H-bomb)
- 1952 10 MT (670 x Hiroshima)
- Soviets have detonated a 67MT device.



Adjust output