Nuclear Physics

Nuclear composition

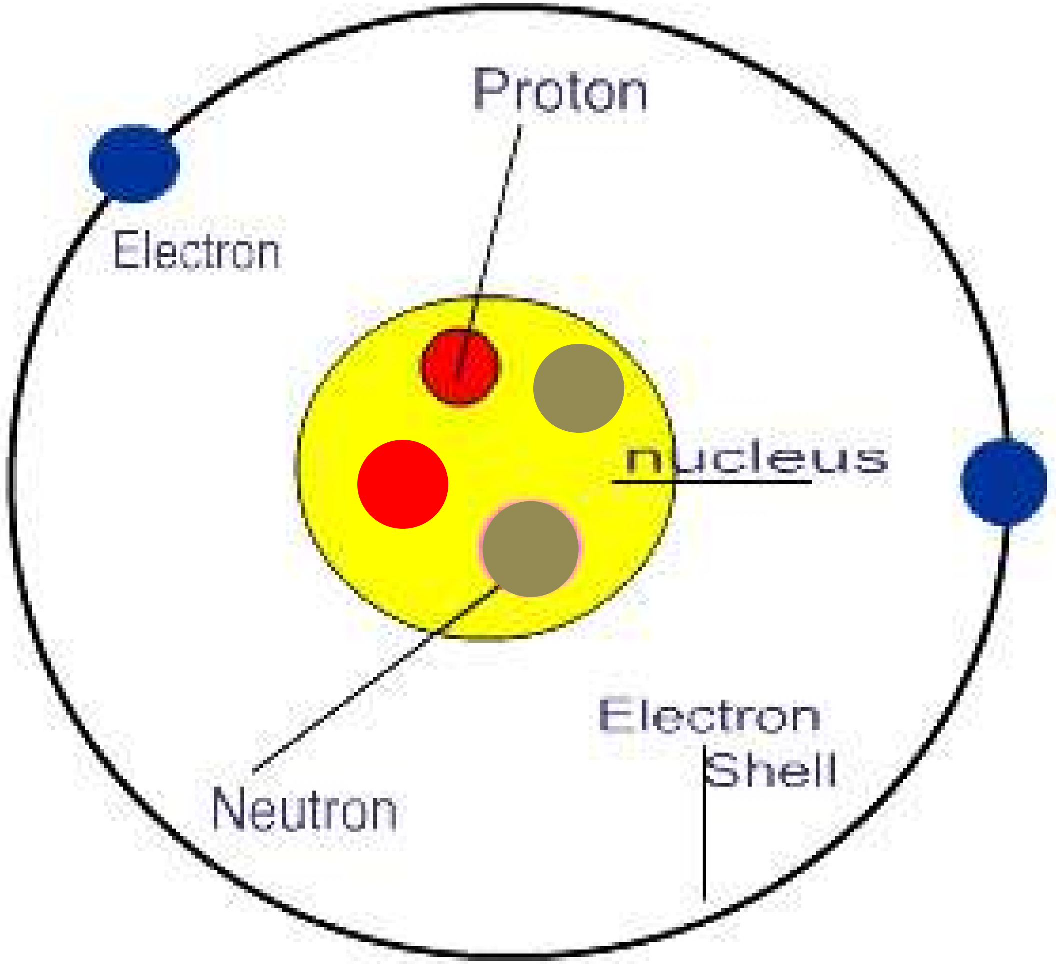
Radioactivity

Binding energy

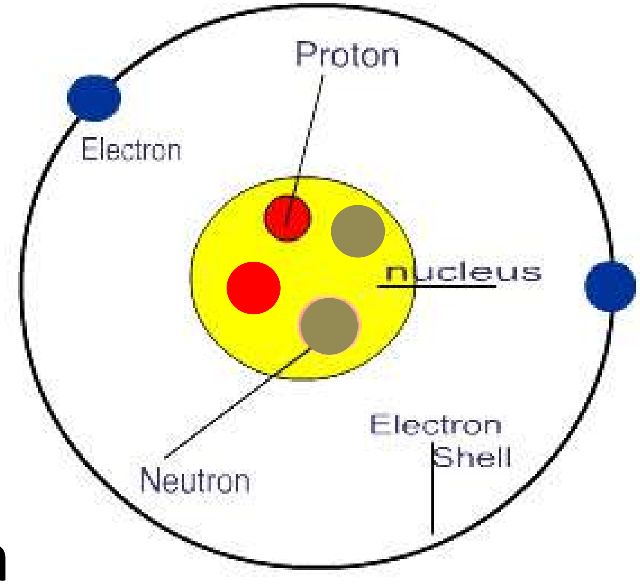
Nuclear reactions

Fission and Fusion

Model of an atom



Model of an atom



- Earth is the Atom 10^{-10}m
- Ross Hall would be nucleus 10^{-15}m
- An 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.

How many neutrons are in the following isotope? (The isotope may be uncommon or unstable.)

$^{11}_{3}\mathrm{Li}$

A. 8
B. 7
C. 6
D. 5
E. 4

How many neutrons are in the following isotope? (The isotope may be uncommon or unstable.)

$^{11}_{3}\mathrm{Li}$

A. **8**
B. 7
C. 6
D. 5
E. 4

How many neutrons are in the following isotope? (The isotope may be uncommon or unstable.)

$^{11}_{4}\mathrm{Be}$

A. 8
B. 7
C. 6
D. 5
E. 4

How many neutrons are in the following isotope? (The isotope may be uncommon or unstable.)

$^{11}_{4}\text{Be}$

A. 8
B. 7
C. 6
D. 5
E. 4

How many neutrons are in the following isotope? (The isotope may be uncommon or unstable.)

$^{11}_{5}\mathrm{B}$

A. 8
B. 7
C. 6
D. 5
E. 4

How many neutrons are in the following isotope? (The isotope may be uncommon or unstable.)

$^{11}_{5}\mathrm{B}$

A. 8
B. 7
C. 6
D. 5
E. 4

How many neutrons are in the following isotope? (The isotope may be uncommon or unstable.)

$^{11}_{6}C$

A. 8
B. 7
C. 6
D. 5
E. 4

How many neutrons are in the following isotope? (The isotope may be uncommon or unstable.)

$^{11}_{6}C$

A. 8
B. 7
C. 6
D. 5
E. 4

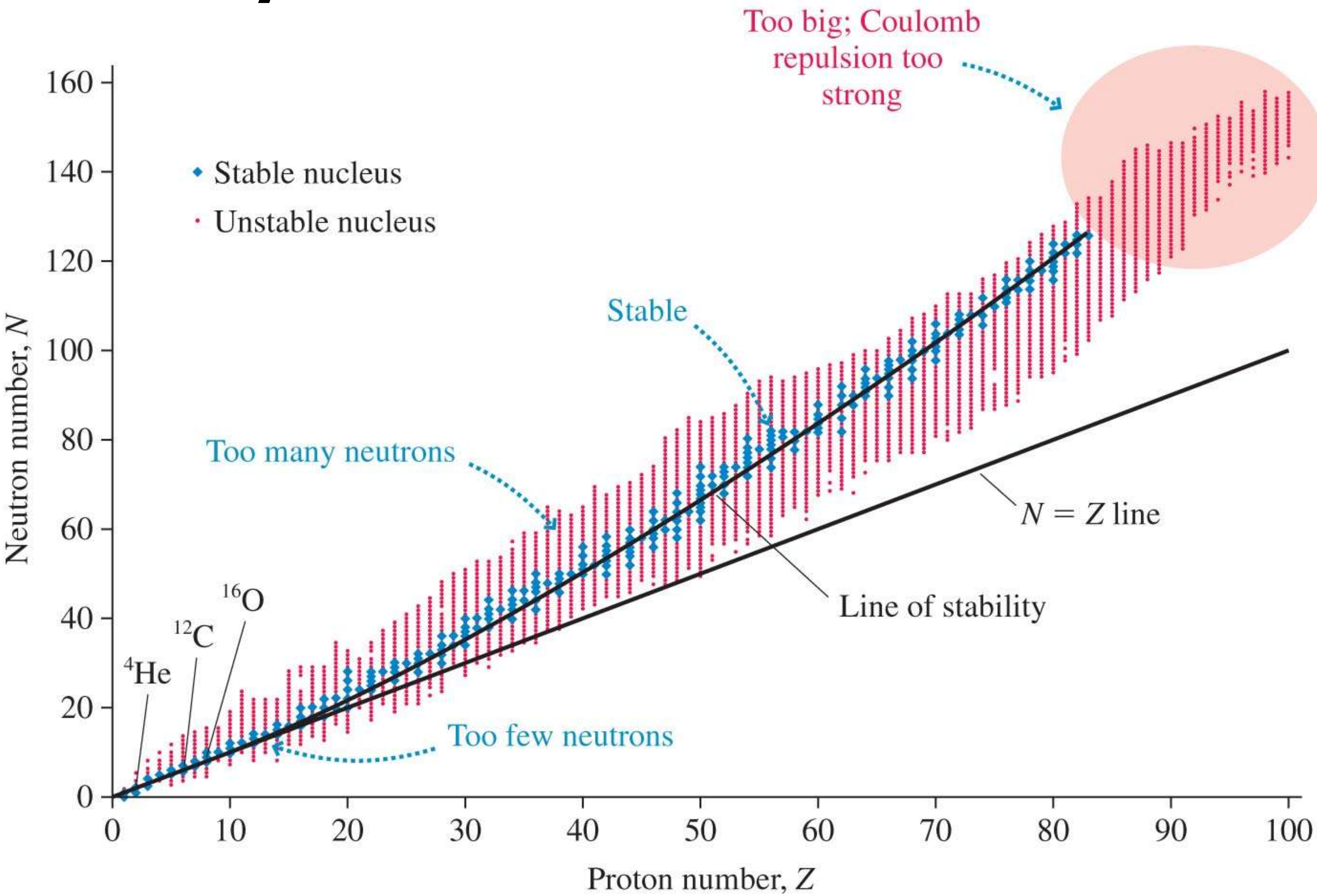
Three electrons orbit a neutral ^{6}Li atom. How many electrons orbit a neutral ^{7}Li atom?

A. 2
B. 3
C. 4
D. 7

Three electrons orbit a neutral ^{6}Li atom. How many electrons orbit a neutral ^{7}Li atom?

A. 2
B. 3
C. 4
D. 7

Stability



Too big; Coulomb repulsion too strong
160
140
120
100
80
60
40
20
0
Stable nucleus
Unstable nucleus
Neutron number, N
Stable
Too many neutrons
N = Z line
Line of stability
16O
12C
4He
Too few neutrons
0
10
20
30
40
50
60
70
80
90
100
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 neutrino)

3 mm of Aluminum

– Gama rays (γ)

photon (range of x-rays)

5 cm of Lead

-- Neutrons

- Neutron radiation is nasty stuff. A neutron is a heavy particle, weighing in at 1/4 the mass of the alpha particle. The unique thing about the neutron is that while it is heavy, it has no charge (it is neutral). This lack of charge gives it the ability to penetrate matter without interacting as quickly as the beta particles or alpha particles. Then after penetrating the material, when the neutron does interact it behaves like a bowling ball thrown into a room full of pingpong balls.

When a nucleus decays by giving off an electron, we call this _________ decay.

A. alpha
B. beta
C. gamma
D. neutron

When a nucleus decays by giving off an electron, we call this _________ decay.

A. alpha
B. beta
C. gamma
D. neutron

_________ decay results in a daughter nucleus that is the same as the parent nucleus.

A. Alpha
B. Beta
C. Gamma
D. neutron

________ decay results in a daughter nucleus that is the same as the parent nucleus.

A. Alpha
B. Beta
C. **gamma**
D. neutron

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

Nuclear Decay

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

Example:

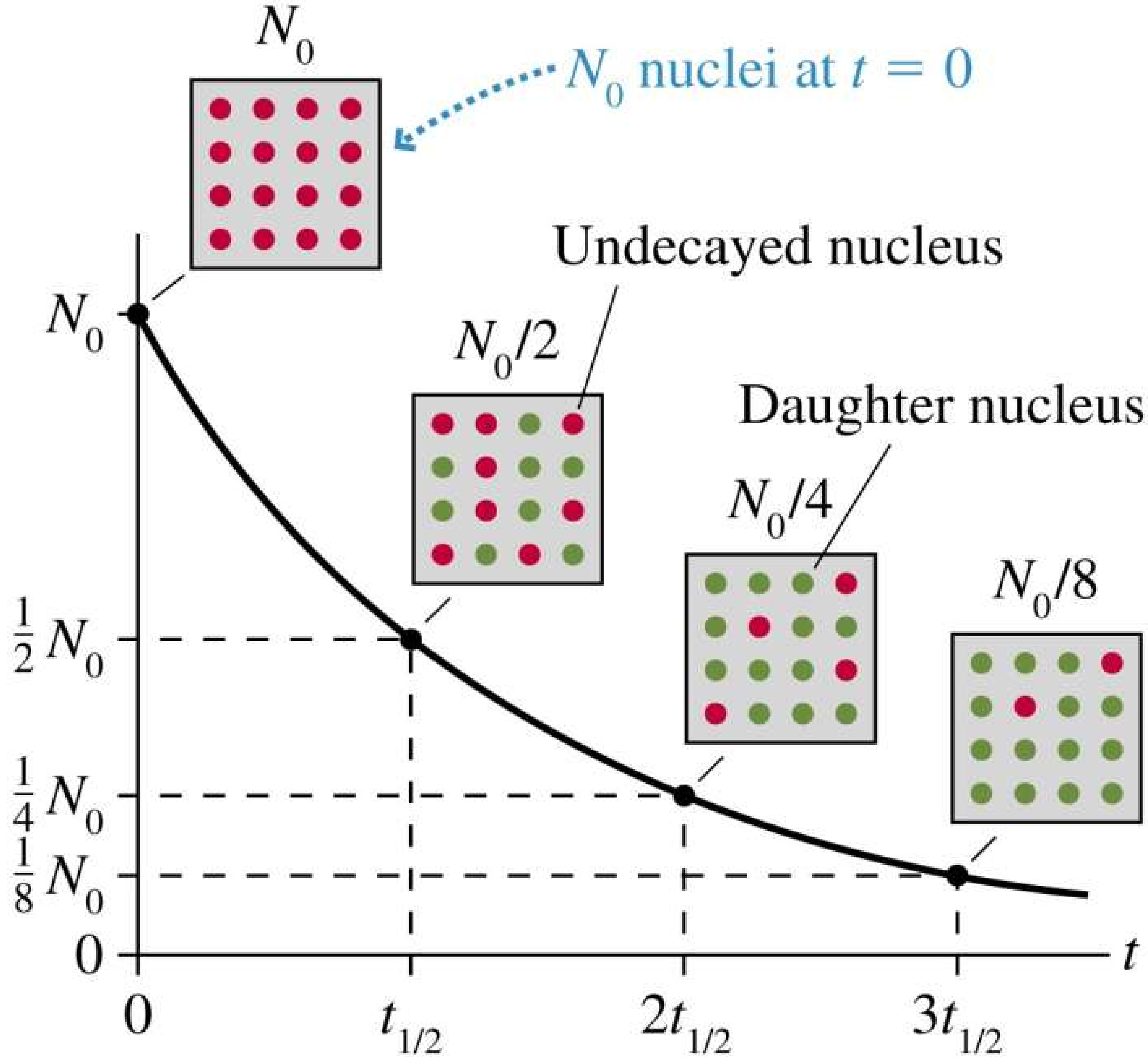
If $T_{1/2}$ = 1000 years

N_o = 500 nuclei

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

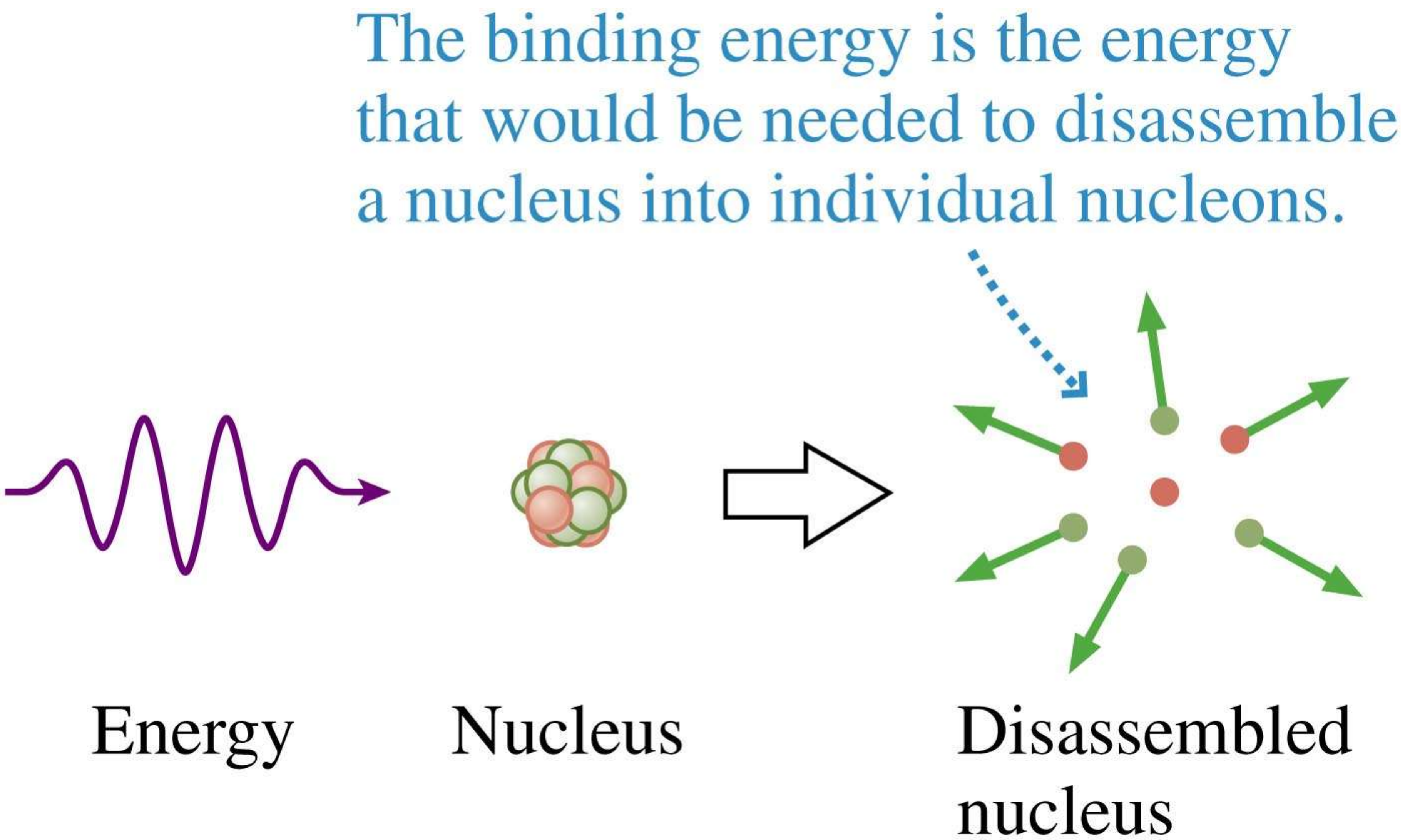
t = 2000 years -> N = 125 (1/4 N_o)

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

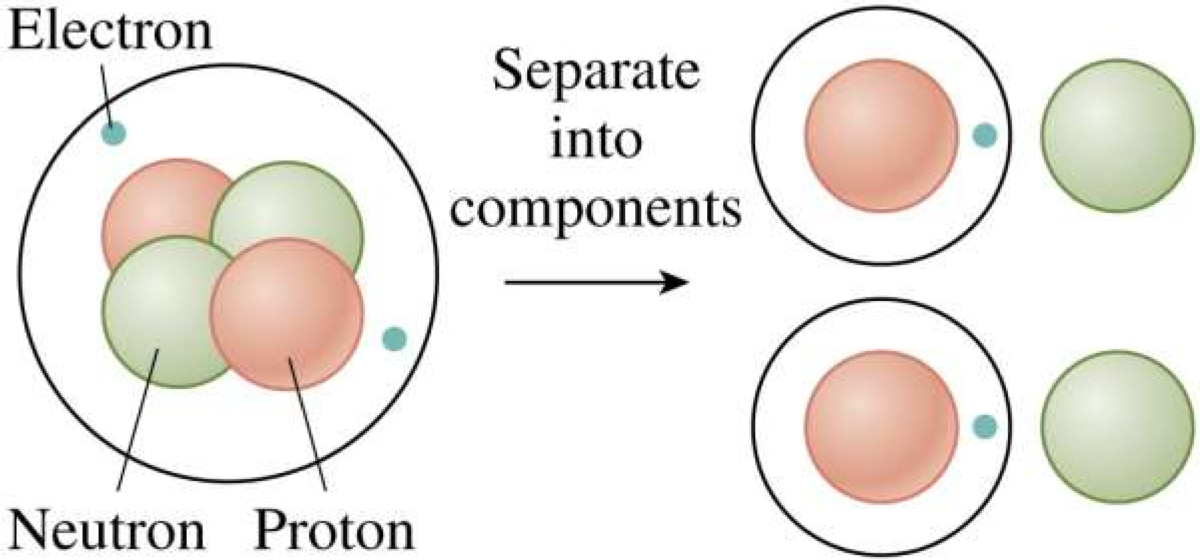


N_0
N_0 nuclei at $t = 0$
Undecayed nucleus
$N_0/2$
Daughter nucleus
$N_0/4$
$N_0/8$
N_0
$\frac{1}{2} N_0$
$\frac{1}{4} N_0$
$\frac{1}{8} N_0$
0
t
0
$t_{1/2}$
$2t_{1/2}$
$3t_{1/2}$

Binding Energy



Binding Energy of a Helium Nucleus



Helium atom

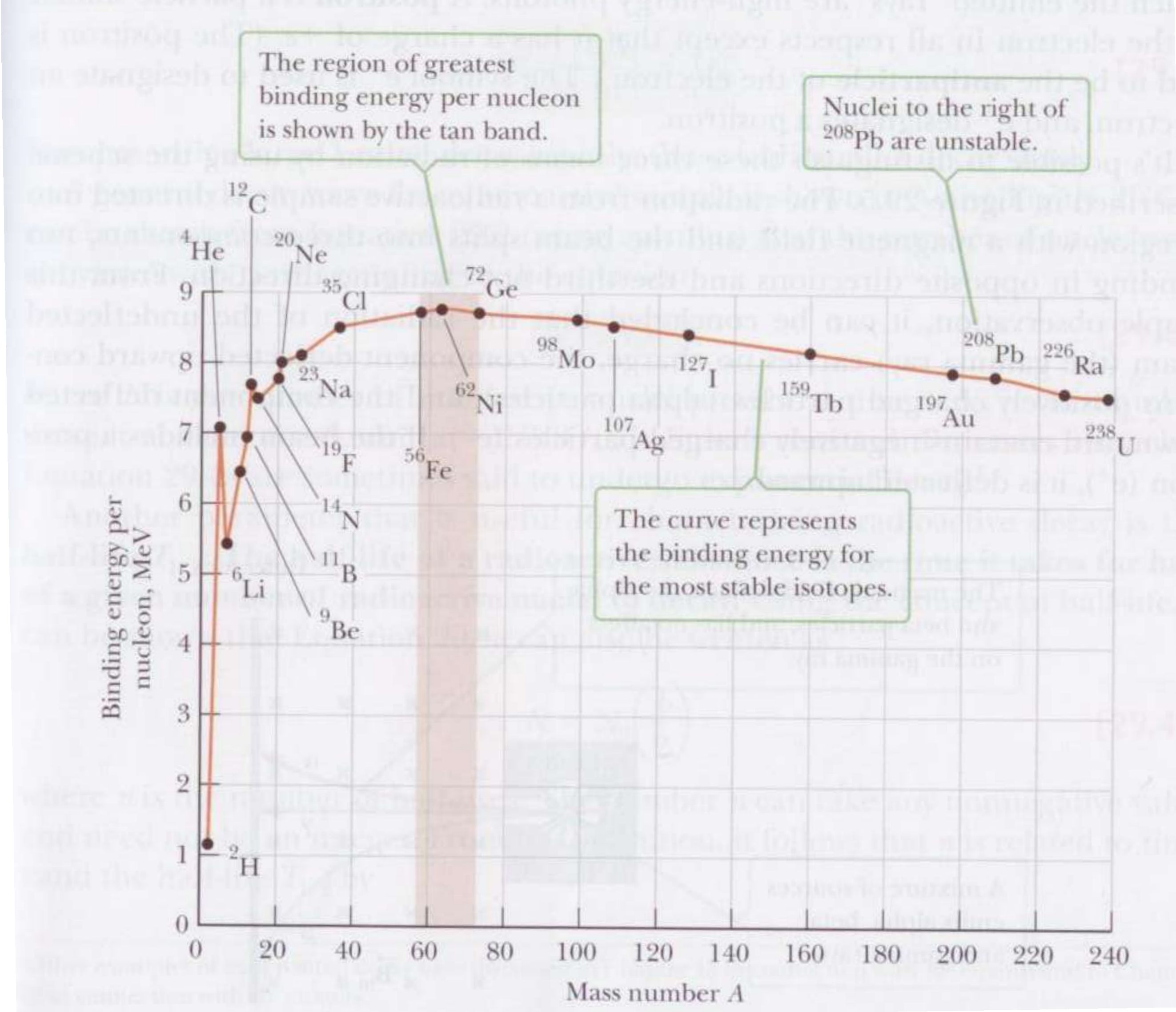
Mass:
4.00260 u

2 hydrogen atoms,
2 neutrons

Mass:

2 H atoms:	2.01566 u
+ 2 neutrons:	2.01732 u
Total mass:	4.03298 u

Difference in mass:
$\Delta m = 0.03038$ u



- Light nuclei can become more stable through fusion.
- Heavy nuclei can become more stable through fission.
- All nuclei larger than a certain size spontaneously fission.

Binding energy

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

$$E = mc^2$$

- A bound nucleus weighs less than its constituent protons and neutrons.

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

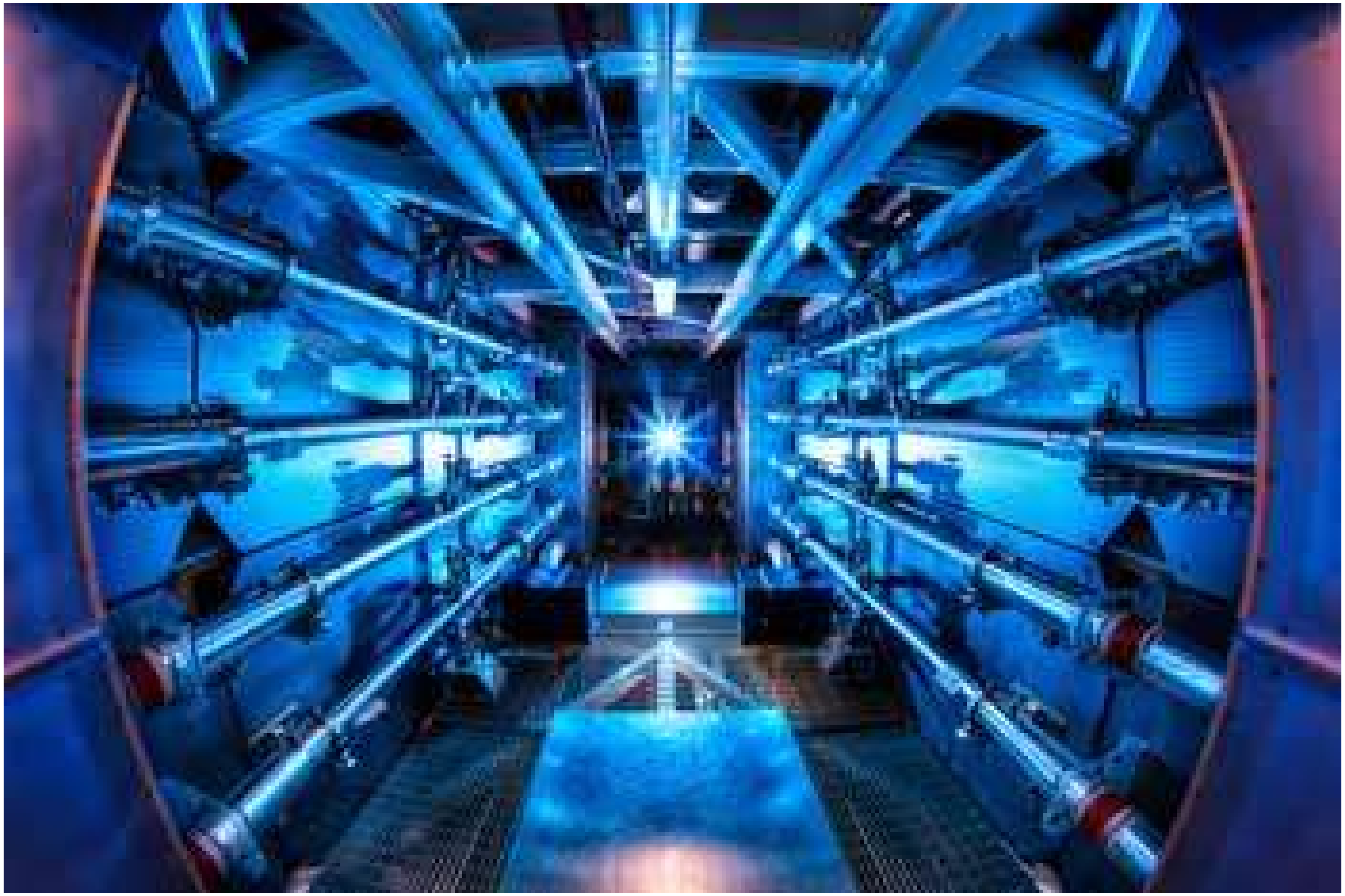
Fusion

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

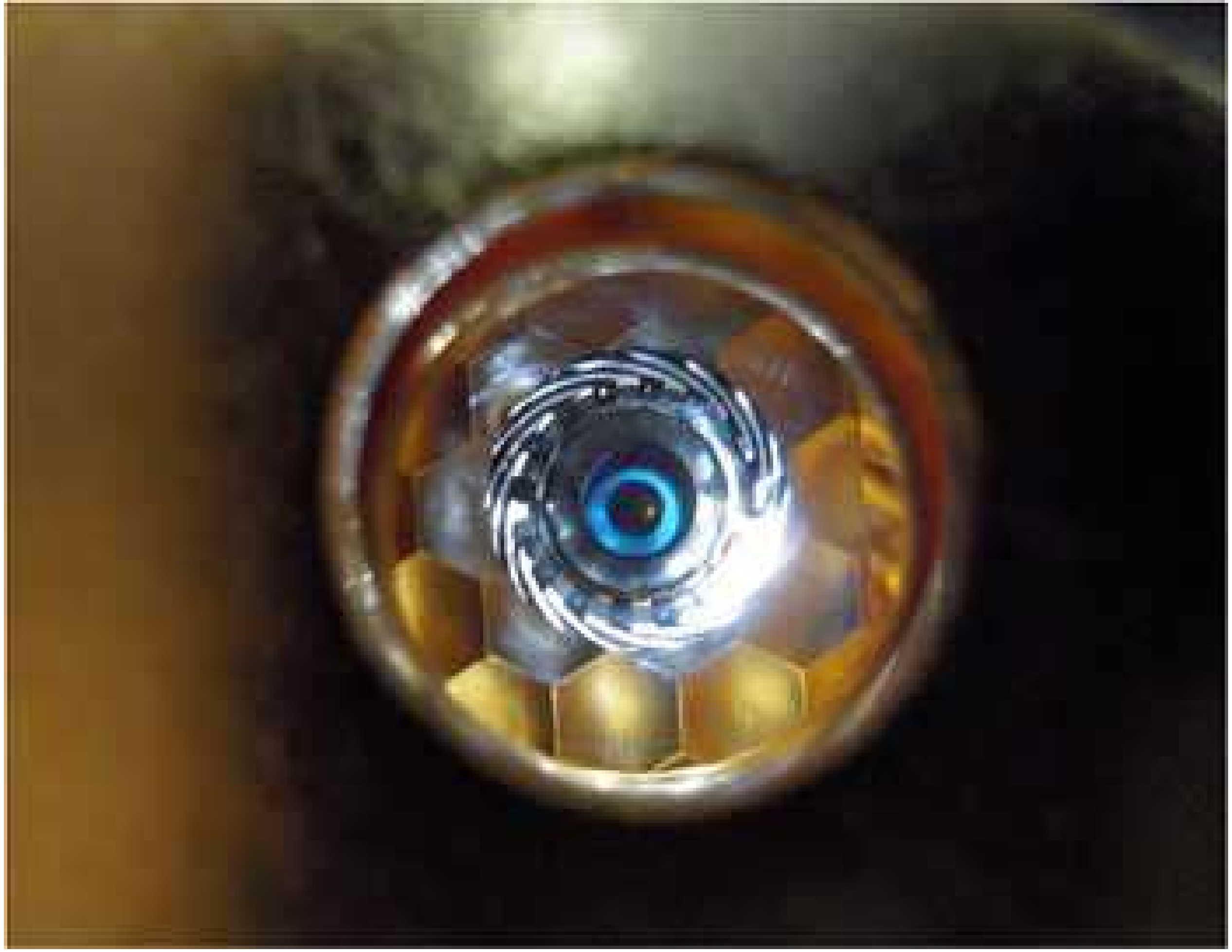
Fusion

- **Ignition** – Reactions produce enough energy to be self-sustaining (external energy source cut off)

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



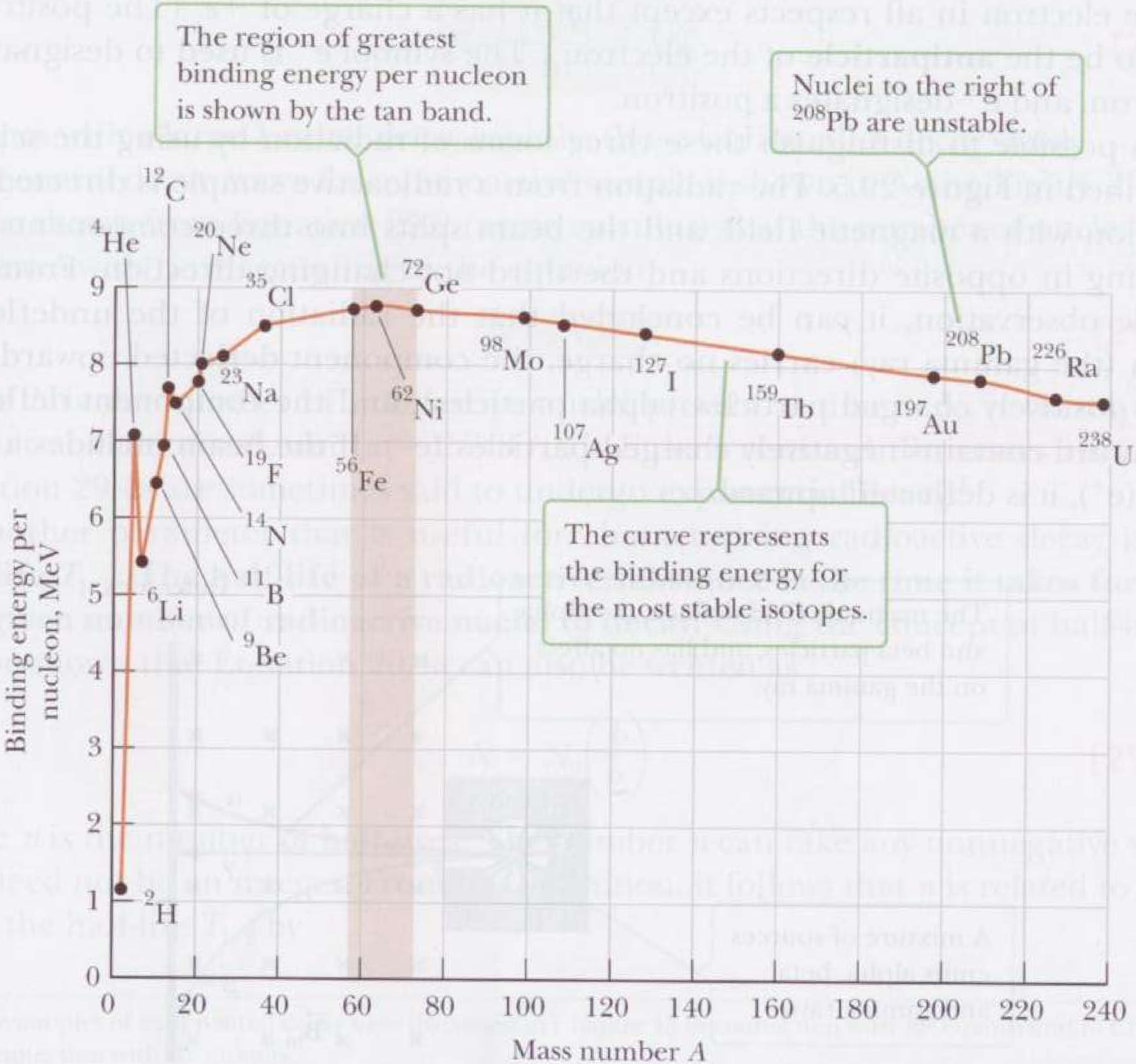
The preamplifiers of the National Ignition Facility are the first step in increasing the energy of laser beams as they make their way toward the target chamber. NIF recently achieved a 500 terawatt shot - 1,000 times more power than the United States uses at any instant in time.
Photo credits: Damien Jemison/LLNL



A view of a cryogenically cooled NIF target as "seen" by the laser through the hohlraum's laser entrance hole. In ignition experiments, the hydrogen in the fuel capsule must be compressed to about 100 times the density of lead.

Fission

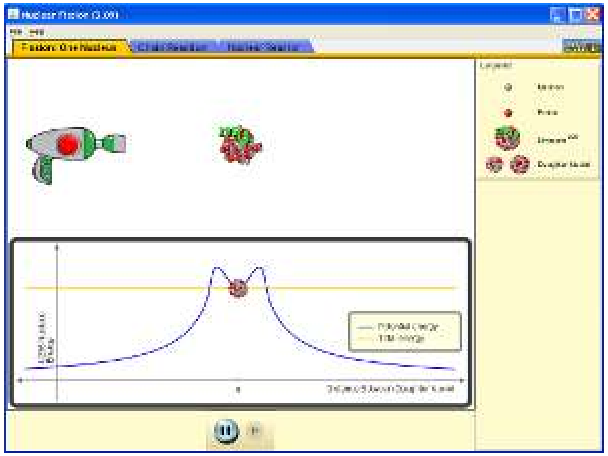
- Heavy nuclei have less Binding Energy than midrange ones.



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
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100
120
140
160
180
200
220
240
4He
12C
20Ne
35Cl
72Ge
98Mo
127I
208Pb
226Ra
23Na
62Ni
159Tb
197Au
238U
19F
56Fe
107Ag
14N
11B
6Li
9Be
2H

Fission

- Heavy nuclei have less Binding Energy than midrange ones.



Fission

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

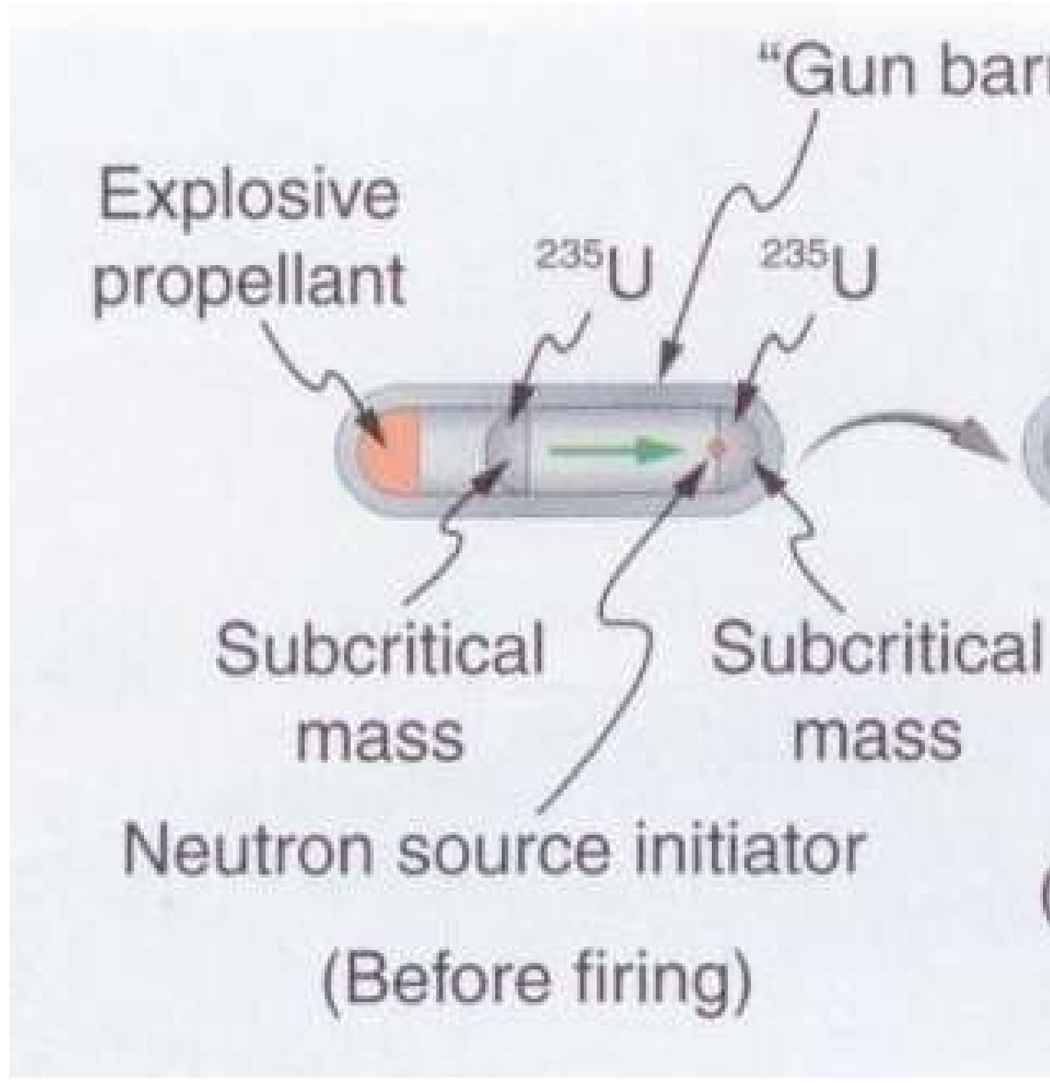
- ^{235}U and ^{238}U occur together in nature so they have to be separated – very expensive!

Fission

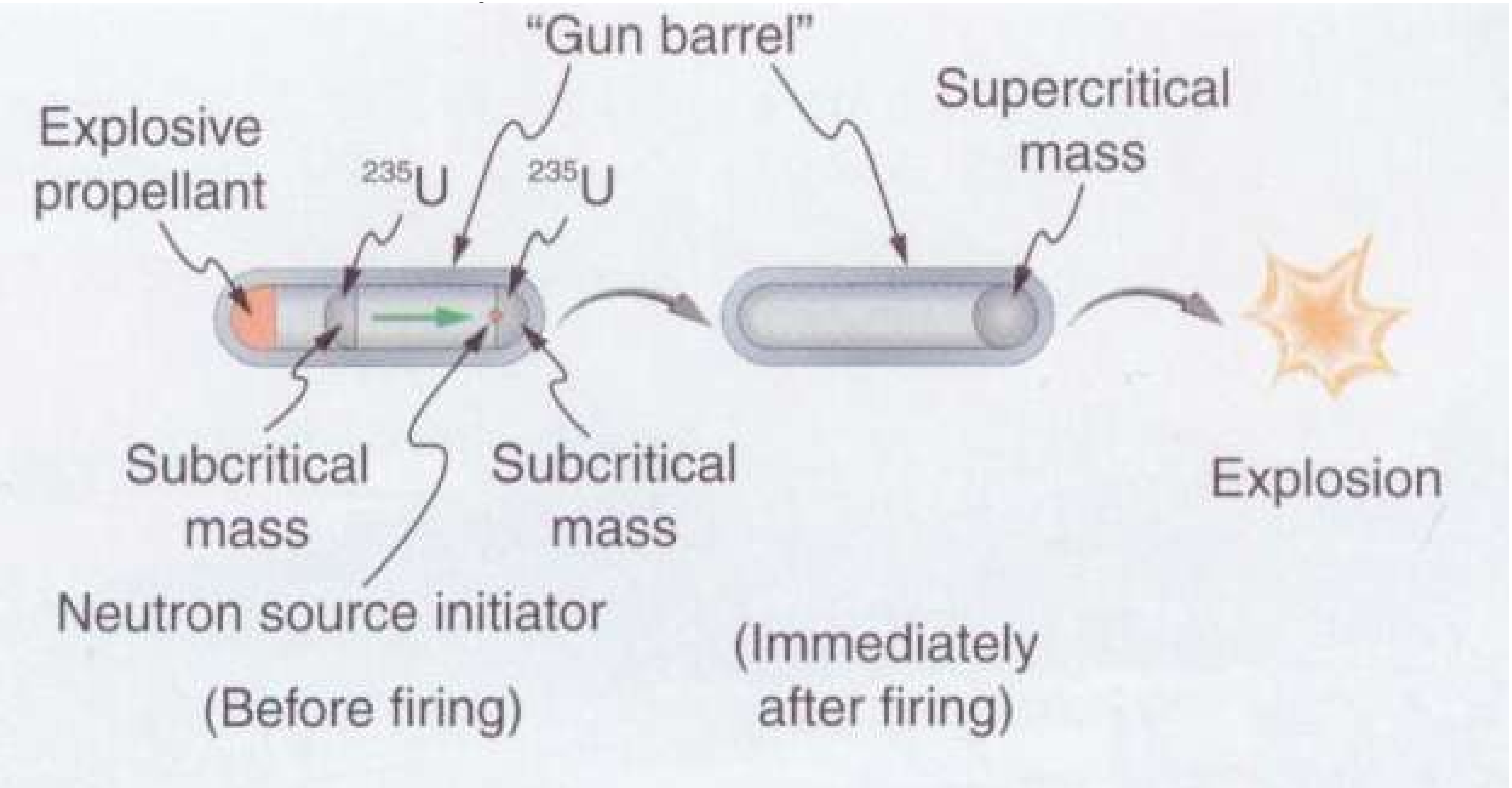
- Criticality – self-sustaining chain reaction
- Super-criticality – exponential increase in reactions
- Control rods – prevent super-criticality and control heading to avoid meltdown or explosion

Nuclear Weapons

- Fission Bombs

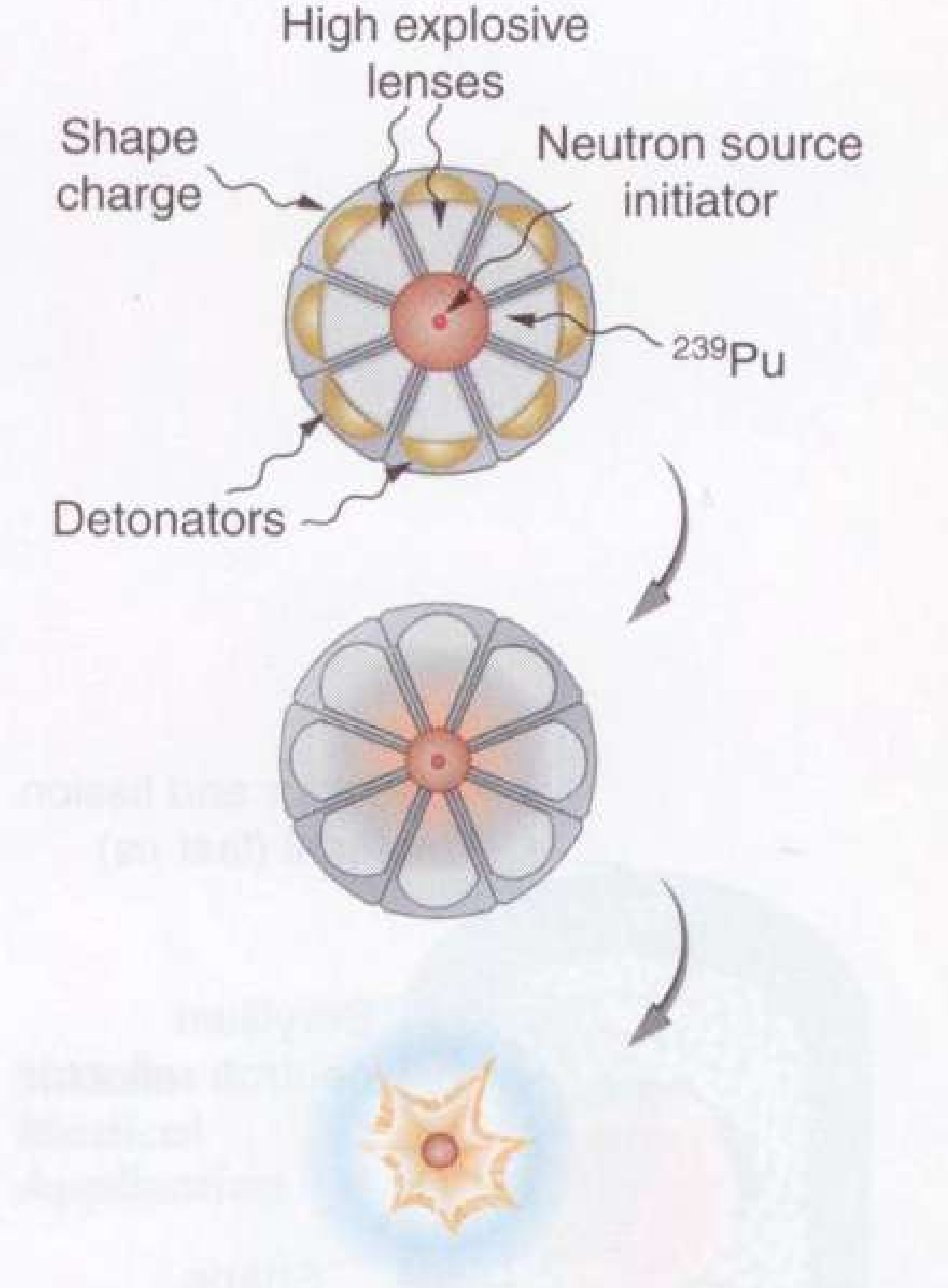


Nuclear Weapons



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.