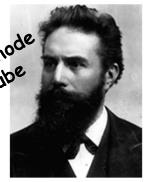
Polonium and radium

Marie Curie
1867 - 1934

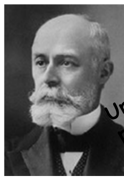


X-Rays emitted by cathode ray tube

Wilhelm Roentgen
1845 - 1923

Radioactivity

Spontaneous emission of radiation from the nucleus of an unstable isotope.



Uranium produced X-rays

Antoine Henri Becquerel
1852 - 1908

Nuclear Physics

A ⟹ 6
Z ⟹ 3

$^{6}_{3}\mathrm{Li}$

Nucleus = Protons+ Neutrons (nucleons)

Periodic_Table

Lead Isotope
Checkpoint

- A material is known to be an isotope of lead, although the particular isotope is not known. Which of the following can be specified?

1. The atomic mass number
2. The neutron number
3. The number of protons

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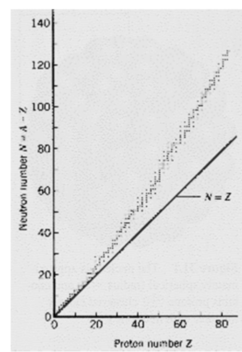
protons = # neutrons

But protons repel one another (Coulomb Force) and when Z is large it becomes harder to put more protons into a nucleus without adding even more neutrons to provide more of the Strong Force. For this reason, in heavier nuclei N>Z.



Lead Isotope Checkpoint

Where does the energy released in the nuclear reactions of the sun come from?

1. covalent bonds between atoms
2. binding energy of electrons to the nucleus
3. binding energy of nucleons

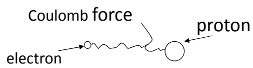
Strong Nuclear Force

- Acts on Protons and Neutrons
- Strong enough to overcome Coulomb repulsion
- Acts over very short distances

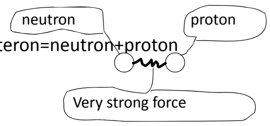
  Two atoms don't feel force

Strong Nuclear Force

Hydrogen atom: Binding energy =13.6eV
(of electron to nucleus)



Simplest Nucleus: Deuteron=neutron+proton



Binding Energy

Example

Einstein's famous equation $E = m c^2$

Proton: mc^2 = 938.3MeV

Neutron: mc^2= 939.5MeV

Adding these, get 1877.8MeV

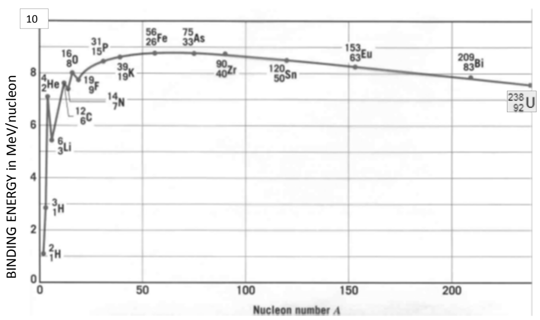
Deuteron: mc^2 =1875.6MeV

Difference is Binding energy, 2.2MeV

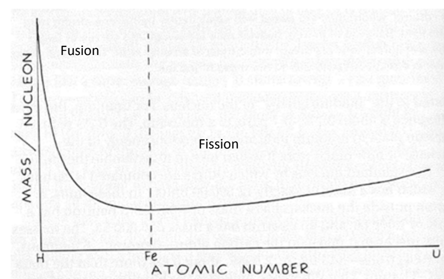
$M_{Deuteron} = M_{Proton} + M_{Neutron} - |\text{Binding Energy}|$

Binding Energy Plot

Iron (Fe) has the most binding energy/nucleon. Lighter have too few nucleons, heavier have too many.



Mass/Nucleon vs Atomic Number



$E = mc^2$

E: energy

m: mass

c: speed of light

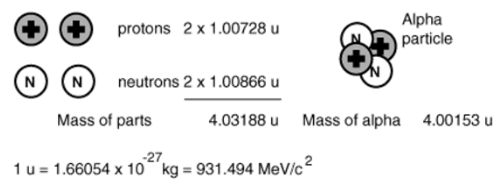
$c = 3 \times 10^8$ m/s

$E = mc^2$

Mass Defect in Fission

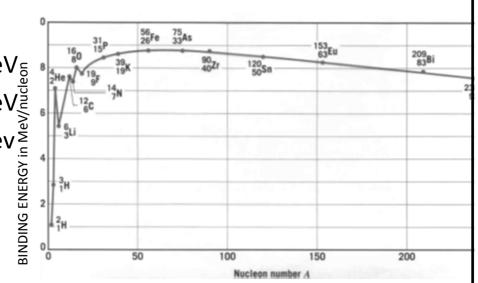
- When a heavy element (one beyond Fe) fissions, the resulting products have a combined mass which is less than that of the original nucleus.

Mass Defect of Alpha Particle

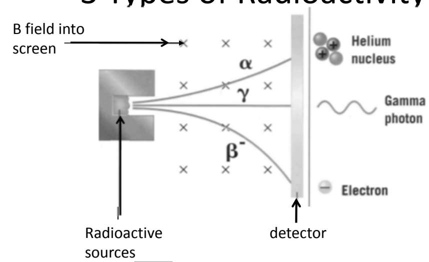


Which of the following is most correct for the total binding energy of an Iron atom (Z=26)?

1. 9 MeV
2. 234 MeV
3. 270 MeV
4. 504 Mev

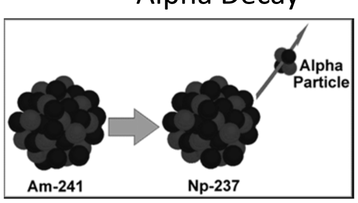


3 Types of Radioactivity

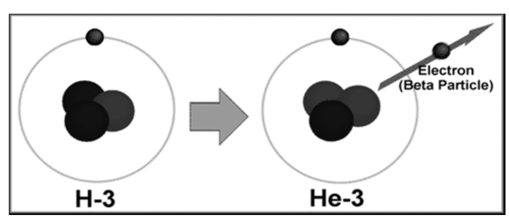


α particles:	^4_2He nucleii	Easily Stopped
β^- particles:	electrons	Stopped by metal
γ :	photons (more energetic than x-rays) penetrate!	

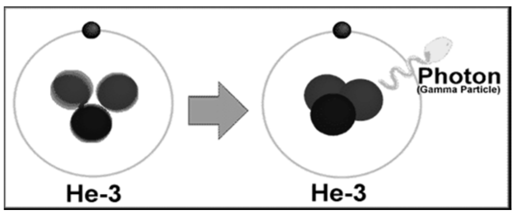
Alpha Decay



Beta Decay



Gamma Decay



Example

Decay Rules

1) Nucleon Number is conserved.
2) Atomic Number (charge) is conserved.
3) Energy and momentum are conserved.

α: example $^{238}_{92}\mathrm{U} \rightarrow ^{234}_{90}\mathrm{Th} + \alpha$ recall $^{4}_{2}\mathrm{He} = \alpha$

β: example $^{1}_{0}\mathrm{n} \rightarrow ^{1}_{1}\mathrm{p} + ^{0}_{-1}e^{-} + ^{0}_{0}\overline{\nu}$

γ: example $^{A}_{Z}P^{*} \rightarrow ^{A}_{Z}P + ^{0}_{0}\gamma$

A nucleus undergoes α decay. Which of the following is FALSE?

1. Nucleon number decreases by 4
2. Neutron number decreases by 2
3. Charge on nucleus increases by 2

The nucleus $^{234}_{90}\mathrm{Th}$ undergoes β^{-} decay. Which of the following is true?

1. The number of protons in the daughter nucleus increases by one.
2. The number of neutrons in the daughter nucleus increases by one.

Radioactive Decay

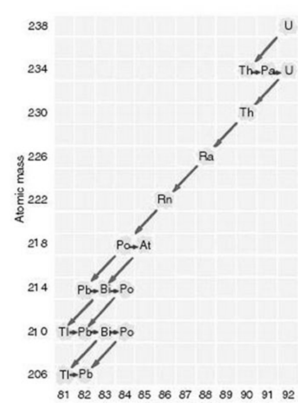
$$^{238}_{92}U \rightarrow \; ^{4}_{2}He + \; ^{234}_{90}$$

$$^{0}_{-1}e +$$

$$\rightarrow \; ^{0}_{-1}e +$$

U 238 Decay

- Decay Series



Which of the following decays is NOT allowed?

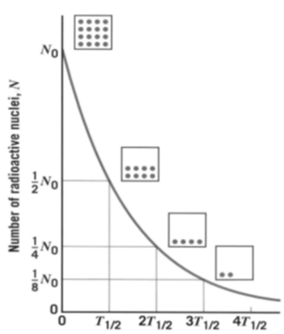
1. $^{238}_{92}U \rightarrow ^{234}_{90}Th + \alpha$
2. $^{214}_{84}Po \rightarrow ^{210}_{82}Pb + ^{4}_{2}He$
3. $^{14}_{6}C \rightarrow ^{14}_{7}N + \gamma$
4. $^{40}_{19}K \rightarrow ^{40}_{20}p + ^{0}_{-1}e^{-} + ^{0}_{0}\overline{\nu}$

Decays per second, or "activity": $\frac{\Delta N}{\Delta t} = -\lambda N$ (N: No. of nuclei present; λ: decay constant)

If the number of radioactive nuclei present is cut in half, how does the activity change?

1. It remains the same
2. It is cut in half
3. It doubles

Decay Function



Radioactivity Quantitatively

Decays per second, or "activity" → $\frac{\Delta N}{\Delta t} = -\lambda N$ (N: No. of nuclei present; λ: decay constant)

Survival: $N(t) = N_0 e^{-\lambda t}$

$N(t)$: No. of nuclei present at time t; N_0: No. we started with at t=0

Instead of base e we can use base 2:

$$e^{-\lambda t} = 2^{-\frac{t}{T_{1/2}}}$$ where $$T_{1/2} = \frac{0.693}{\lambda}$$

Half life

Then we can write $$N(t) = N_0 e^{-\lambda t} = N_0 \cdot 2^{-\frac{t}{T_{1/2}}}$$

Carbon Dating

- Cosmic rays cause transmutation of Nitrogen to Carbon-14

$$^{1}_{0}n + ^{14}_{7}N \rightarrow ^{1}_{1}H + ^{14}_{6}C$$

- C-14 is radioactive with a half-life of 5730 years
  - It decays back to Nitrogen by beta decay

$$^{14}_{6}C \rightarrow ^{0}_{-1}e + ^{14}_{7}N$$

- The ratio of C-12 (stable) atoms to C-14 atoms in our atmosphere is fairly constant – about $10^{12}/1$
- This ratio is the same in living things that obtain their carbon from the atmosphere

Example

You are radioactive!

One in 8.3×10^{11} carbon atoms is ^{14}C which β^{-} decays with a ½ life of 5730 years. Determine # of decays/gram of Carbon.

Carbon Dating

We just determined that living organisms should have a decay rate of about 0.23 decays/ gram of carbon.

Example

The bones of an ice man are found to have a decay rate of 0.115 decays/gram. We can estimate he died about 6000 years ago.

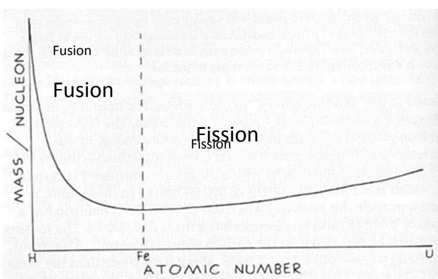
Summary

- Nuclear Reactions
  - Nucleon number conserved
  - Charge conserved
  - Energy/Momentum conserved
  - α particles = $^{4}_{2}He$ lei
  - β^- particles = electrons
  - γ particles = high-energy photons

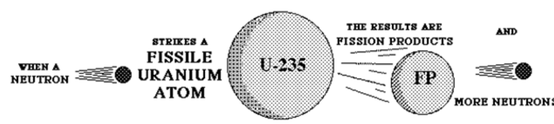
Survival: $N(t) = N_0 e^{-\lambda t}$ $T_{1/2} = \frac{0.693}{\lambda}$

- Decays
  - Half-Life is time for ½ of atoms to decay

Mass/Nucleon vs Atomic Number



U-235 -- Fissile



Abundance of U-235

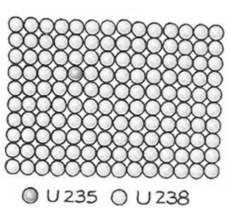
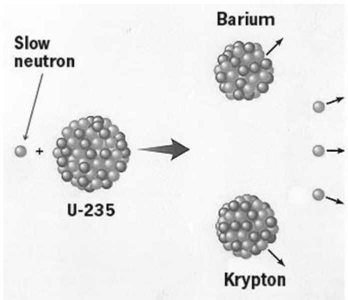


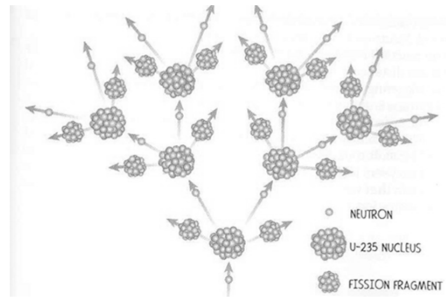
Figure 40.3 ▲
Only 1 part in 140 of naturally occurring uranium is U-235.

U-235 Fission by Neutron Bombardment

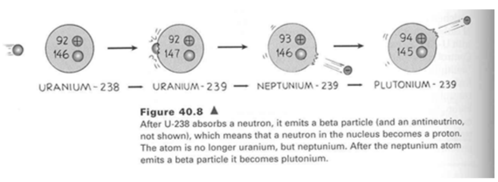
Possible U-235 Fission



Chain Reaction

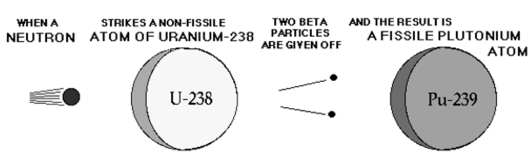


Plutonium Production



U-238 – Not Fissile

Breeder Reaction



Breeder Reactor

- Small amounts of Pu-239 combined with U-238
- Fission of Pu frees neutrons
- These neutrons bombard U-238 and produce more Pu-239 in addition to energy