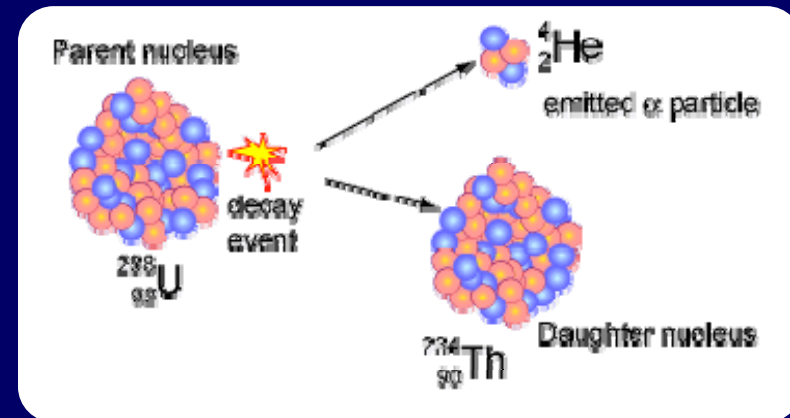
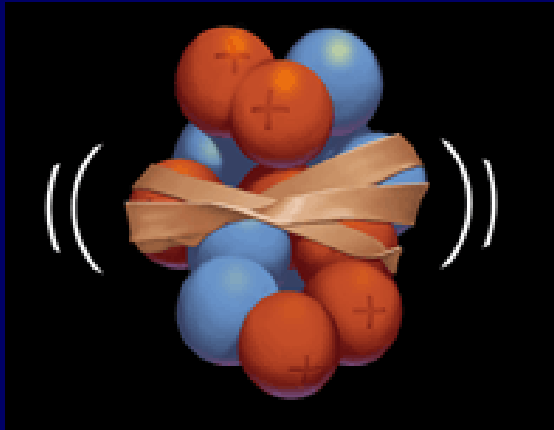


End-of-semester info

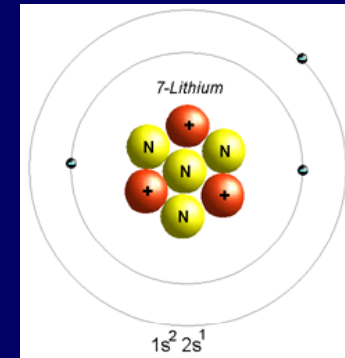
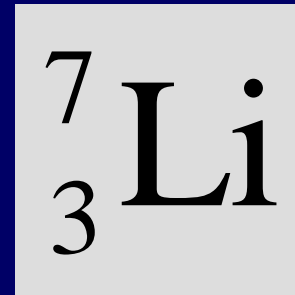
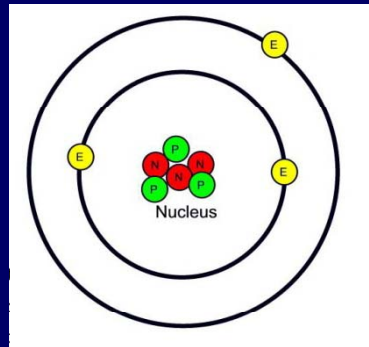
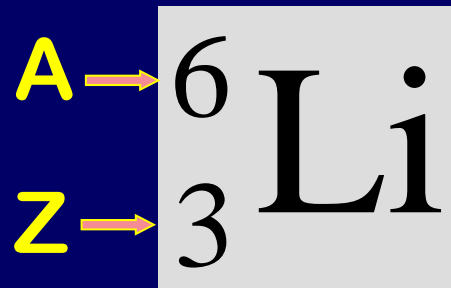
- **Final exam info:**
 - A1/A11: Thursday May 9, 1:30-4:30pm
 - A2/A22: Tuesday May 7, 1:30-4:30pm
 - Approximately 50 questions
 - Cumulative (all material from semester **covered evenly**)
- **CHECK GRADEBOOK!**
 - Missing iClicker points? – you need to show me you were in class!
- **Online ICES evaluation!**

Physics 102: Lecture 28

Nuclear Binding, Radioactivity



Nuclear Physics



Z = proton number (“atomic number”) = e^- number

Gives chemical properties (and name)

N = neutron number (different “isotopes”)

A = nucleon number (atomic mass number)

Gives you mass density of element

$$A = N + Z$$

Checkpoint 1.1

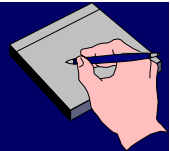
A material is known to be an isotope of lead.

Based on this information which of the following can you specify?

- 1) The atomic mass number
- 2) The neutron number
- 3) The number of protons

Chemical properties (and name) determined by number of protons (Z)

Lead  $Z=82$



Binding Energy

Einstein's famous equation $E = mc^2$

Example

proton:

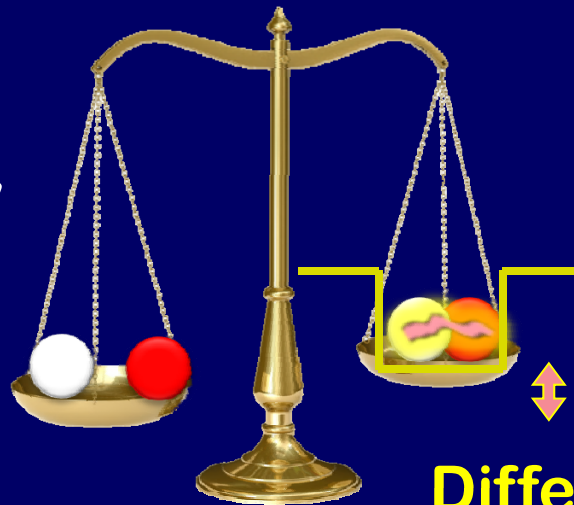
$$mc^2 = (1.67 \times 10^{-27} \text{ kg})(3 \times 10^8 \text{ m/s})^2 = 1.50 \times 10^{-10} \text{ J}$$

Proton:

$$mc^2 = 938.3 \text{ MeV}$$

Neutron:

$$mc^2 = 939.5 \text{ MeV}$$



Mass defect

Deuteron:

$$mc^2 = 1875.6 \text{ MeV}$$

Adding these = 1877.8 MeV

Difference = binding energy
= 2.2 MeV

$$M_{\text{Deuteron}} c^2 = M_{\text{Proton}} c^2 + M_{\text{Neutron}} c^2 - |\text{Binding Energy}|$$

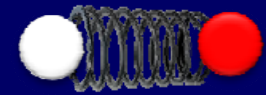
$$M_{\text{Deuteron}} = M_{\text{Proton}} + M_{\text{Neutron}} - |\text{Binding Energy}|/c^2$$



ACT: Binding Energy

Which system “weighs” more?

1) Two balls attached by a relaxed spring.



2) Two balls attached by a stretched spring.



3) They have the same weight.

$$M_1 = M_{\text{balls}} + M_{\text{spring}}$$

$$M_2 = M_{\text{balls}} + M_{\text{spring}} + E_{\text{spring}}/c^2$$

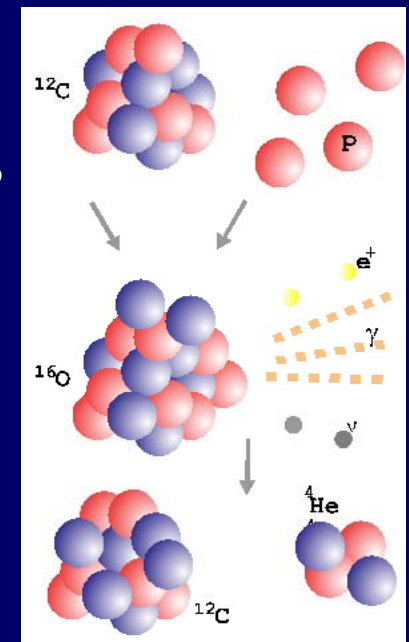
$$M_2 - M_1 = E_{\text{spring}}/c^2 \sim 10^{-16} \text{ Kg}$$

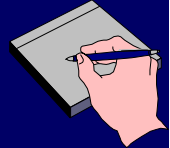
Checkpoint 1.2



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

- (1) covalent bonds between atoms 1eV
- (2) binding energy of electrons to the nucleus 10eV
- (3) binding energy of nucleons 1MeV

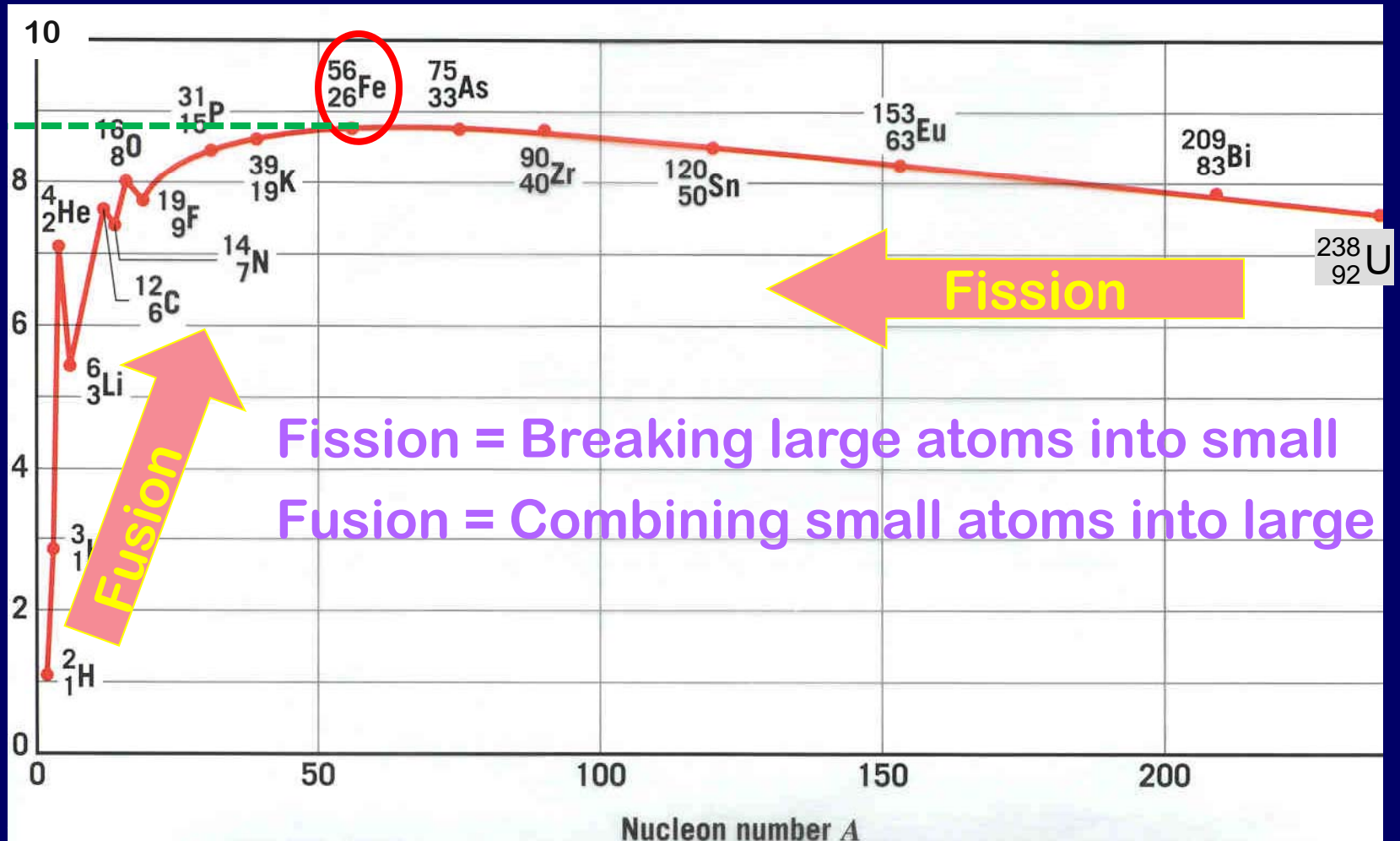




Binding Energy Plot

Iron (Fe) has most binding energy/nucleon!
(Checkpoint 2.1)

A
BINDING ENERGY in MeV/nucleon



Fission = Breaking large atoms into small
Fusion = Combining small atoms into large

Checkpoint 2.2

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

13% 9 MeV

39% 234 MeV

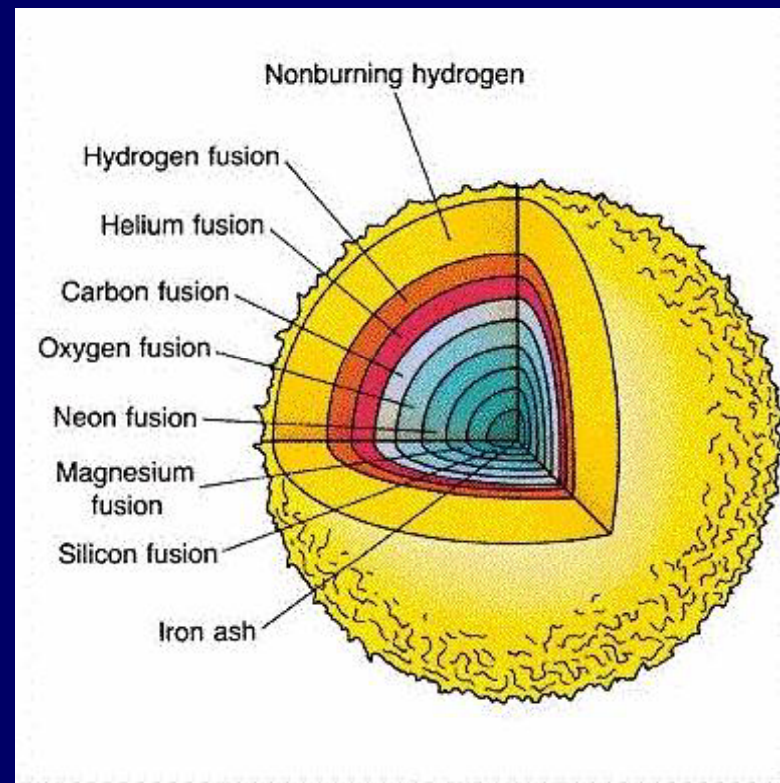
31% 270 MeV

17% 504 MeV

For Fe, B.E./nucleon \approx 9MeV

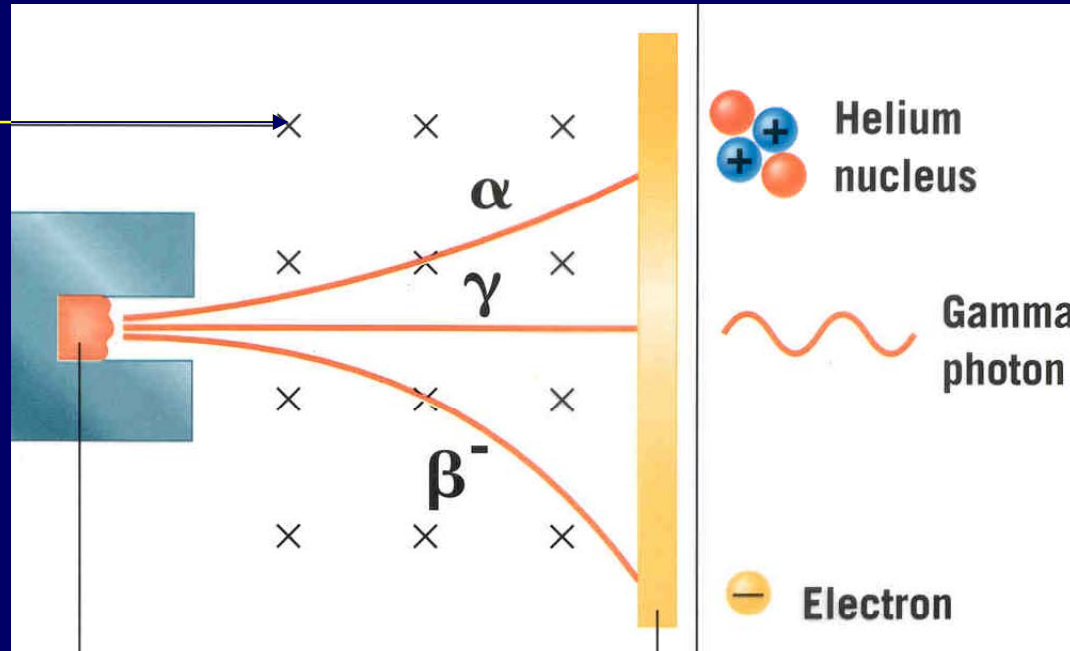
$A =$
 ${}_{26}^{56}\text{Fe}$ has 56 nucleons

$Z =$
Total B.E \approx 56x9=504 MeV



3 Types of Radioactivity

Magnetic field into screen



Radioactive sources

detector

α particles: ${}^4_2\text{He}$ nuclei

β^- particles: electrons

γ : photons (more energetic than x-rays) penetrate!

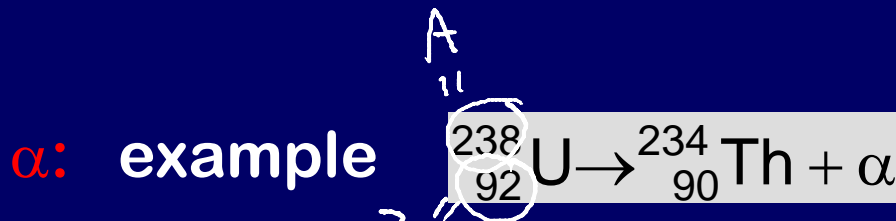
Easily Stopped

Stopped by metal

Example

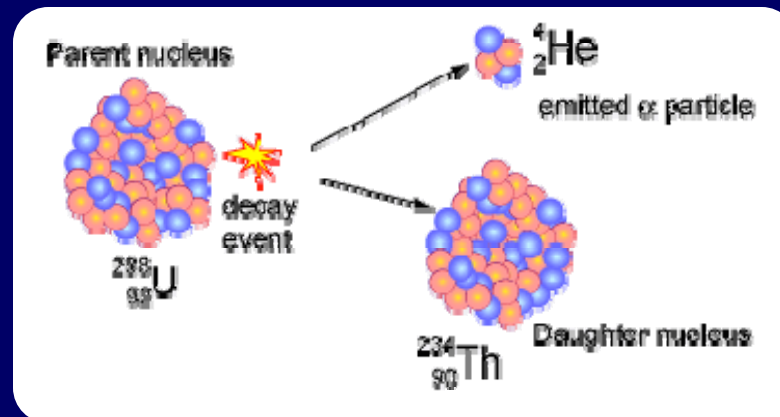
Decay Rules

- 1) Nucleon Number (A) is conserved.
- 2) Atomic Number (Z) is conserved. *Charge conservation*
- 3) Energy and momentum are conserved.



1) $238 = 234 + 4$
2) $92 = 90 + 2$

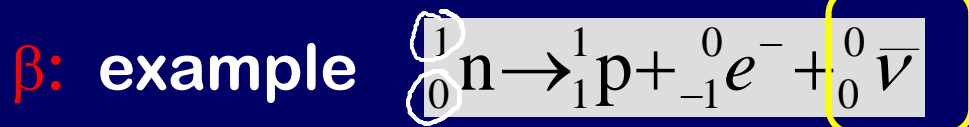
Nucleon number conserved
Charge conserved



Example

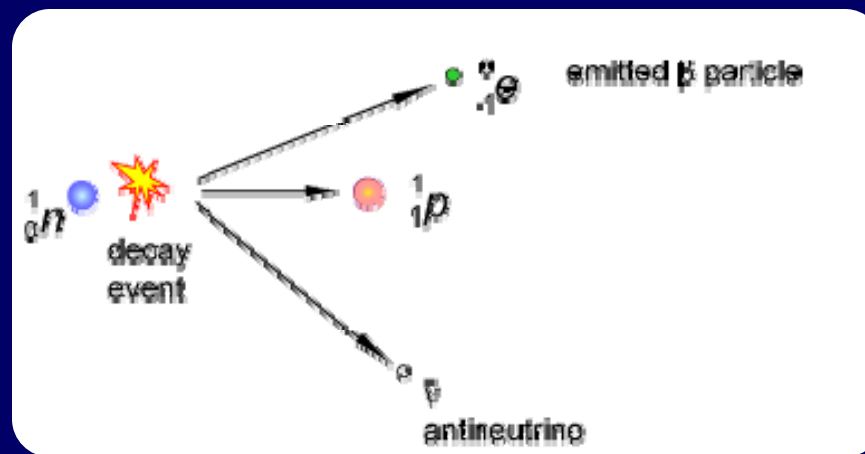
Decay Rules

- 1) Nucleon Number (A) is conserved.
- 2) Atomic Number (Z) is conserved.
- 3) Energy and momentum are conserved.



$$A: 1 = 1 + 0$$
$$Z: 0 = 1 - 1$$

anti-neutrino needed to conserve momentum.

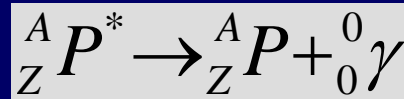


Example

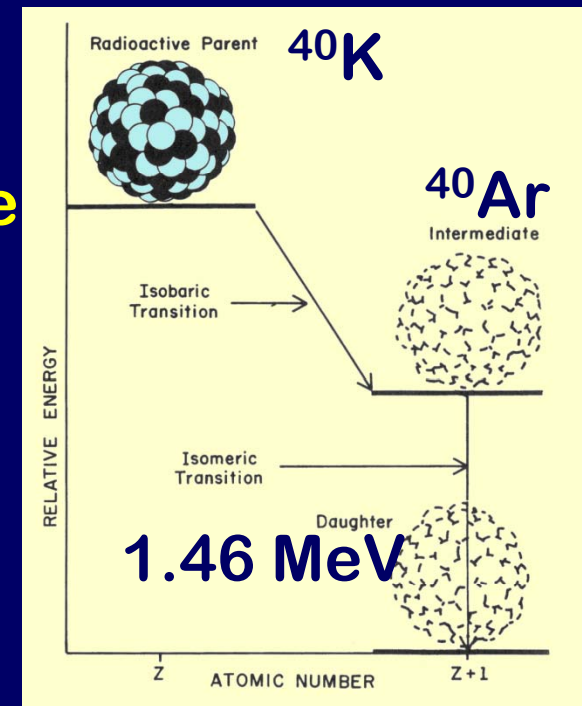
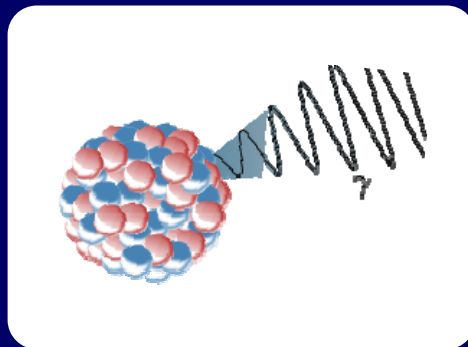
Decay Rules

- 1) Nucleon Number (A) is conserved.
- 2) Atomic Number (Z) is conserved.
- 3) Energy and momentum are conserved.

γ : example



“nuclear isomer”: excited state



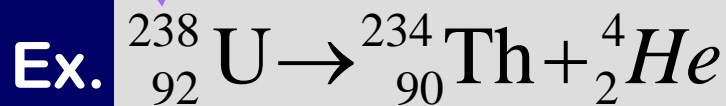
Checkpoint 3

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

1. Nucleon number decreases by 4 27%
2. Neutron number decreases by 2 39%
3. Charge on nucleus ^{de} increases by 2 34%

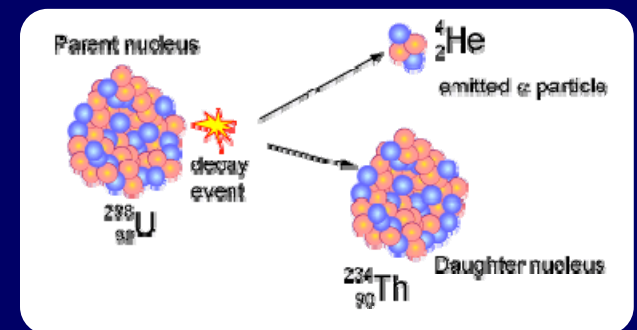
α decay is the emission of ${}^4_2\text{He} = \alpha$

A decreases by 4



Z decreases by 2

(charge decreases!)

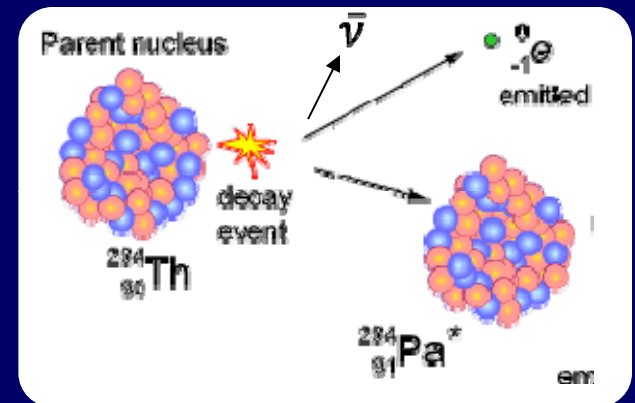


Checkpoint 4

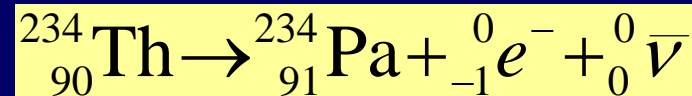
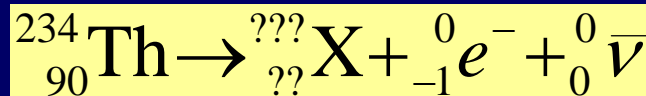
The nucleus ${}^{234}_{90}\text{Th}$ undergoes β^- decay.

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.



β^- decay is accompanied by the emission of an electron: creation of a charge -e.

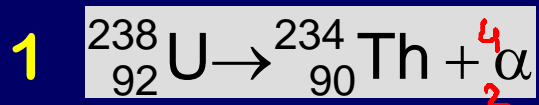


In fact, $n \rightarrow p + e^- + \bar{\nu}_e$ inside the nucleus, and the electron and neutrino “escape.”



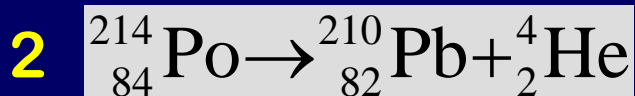
ACT: Decay

Which of the following decays is NOT allowed?



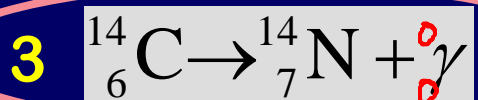
$$238 = 234 + 4$$

$$92 = 90 + 2$$



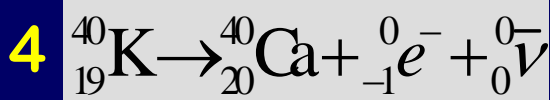
$$214 = 210 + 4$$

$$84 = 82 + 2$$



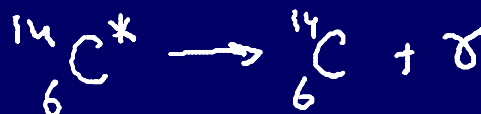
$$14 = 14 + 0$$

$$6 \neq 7 + 0$$



$$40 = 40 + 0 + 0$$

$$19 = 20 - 1 + 0$$



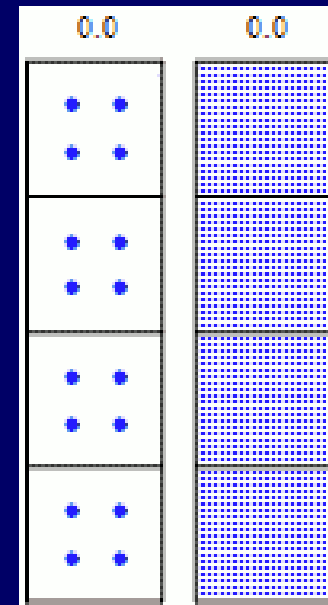
Radioactive decay rates

Decays per second or “activity”

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

No. of nuclei present

decay constant



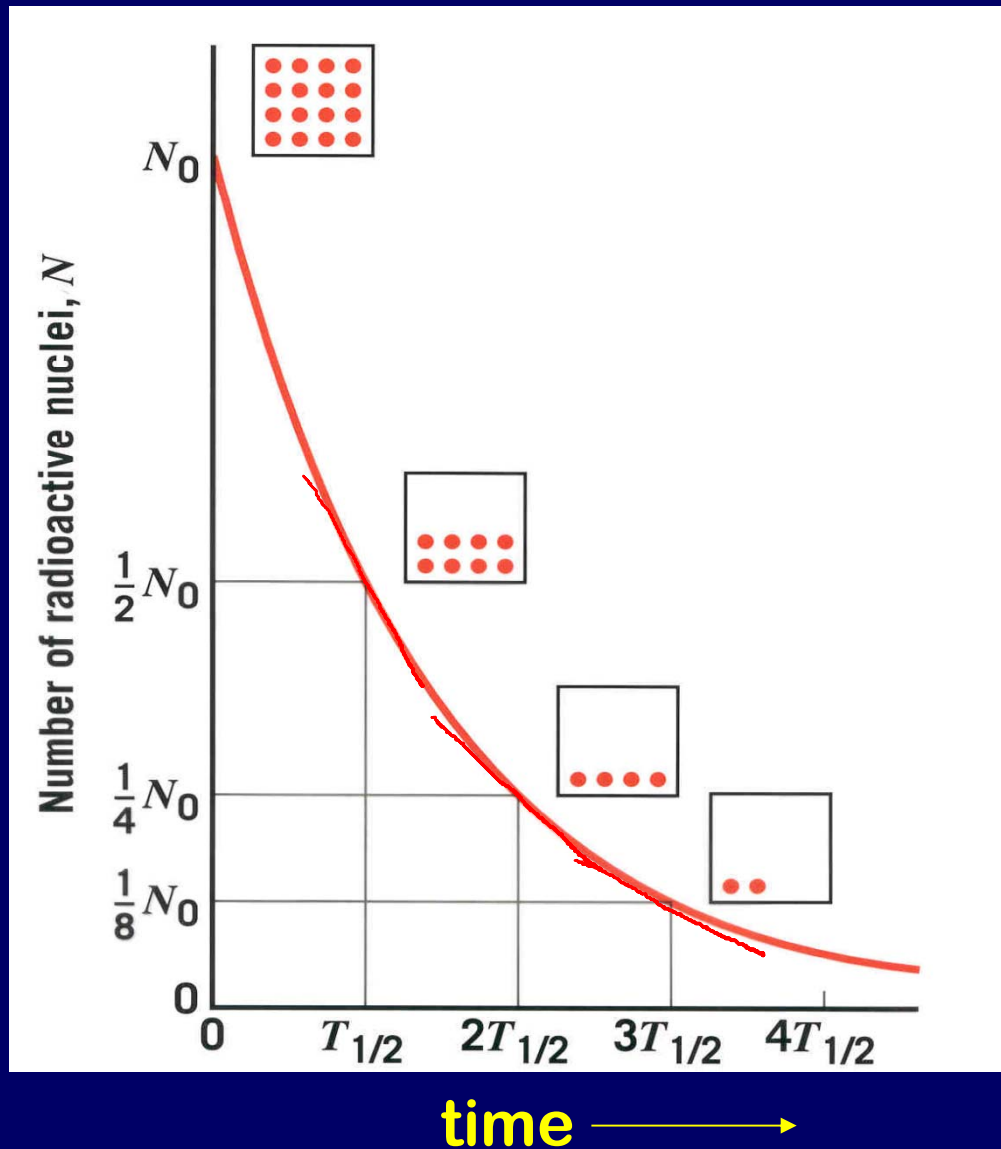
Checkpoint 5

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

- | | |
|-----------------------|-----|
| 1 It remains the same | 26% |
| 2 It is cut in half | 58% |
| 3 It doubles | 16% |

1 “becquerel” (Bq)
= 1 decay/s
1 “curie” Ci
= 3.7×10^{10} Bq

Decay Function



$$e^{-\lambda t} = e^{-\ln 2 \lambda t / \ln 2} = 2^{-\lambda t / \ln 2}$$

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

of nuclei present at time t

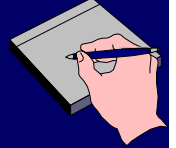
we started with at $t=0$

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

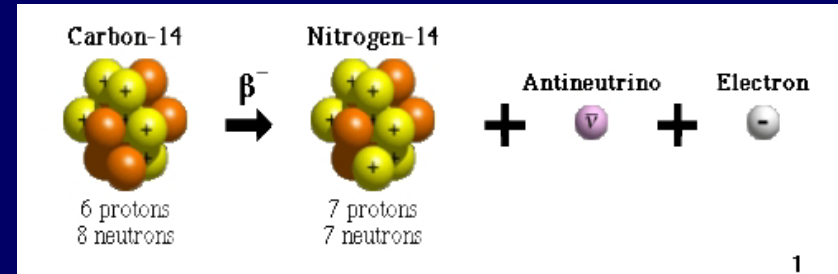
Half of the remaining atoms are lost after a “half life” that lasts $T_{1/2}$; the activity also is reduced by one half every $T_{1/2}$

Example

You are radioactive!



One in 8.3×10^{11} carbon atoms is ^{14}C which β^- decays with a $\frac{1}{2}$ life of 5730 years. Determine # of decays/s per gram of Carbon.



$$N_{14} = \left(\frac{1.0 \text{ mole}}{12 \text{ g}} \right) (6.02 \times 10^{23}) \left(\frac{1}{8.3 \times 10^{11}} \right) = 6 \times 10^{10} \frac{\text{atoms}}{\text{g}}$$

$$\lambda = \frac{.693}{T_{1/2}} = \frac{.693}{5730 \times 365 \times 24 \times 60 \times 60} = 3.83 \times 10^{-12} \text{ s}^{-1}$$

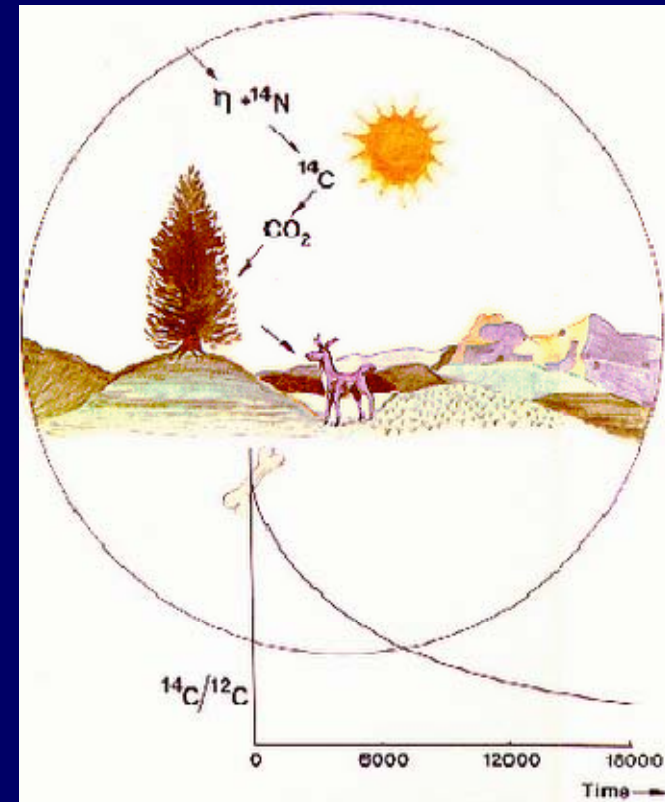
$$\frac{\Delta N}{\Delta t} = -\lambda N = 0.23 \text{ decays/s}$$

Example

Carbon Dating

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

The bones of a man from the last ice age are found to have a decay rate of $0.23/2$ events/s per gram. We can estimate he died about 6000 years ago.





ACT/Checkpoint 6

The half-life for beta-decay of ^{14}C is $\sim 6,000$ years. You test a fossil and find that only 25% of its ^{14}C is un-decayed. How old is the fossil?

1. 3,000 years

2. 6,000 years

3. 12,000 years

At 0 years: 100% remains



At 6,000 years: 50% remains



At 12,000 years: 25% remains

Summary

- Nuclear Reactions

- Nucleon number conserved
- Charge conserved
- Energy/Momentum conserved
- α particles = ${}^4_2\text{He}$ nuclei
- β^- particles = electrons
- γ particles = high-energy photons

Activity:

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

Survival:

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

$$T_{1/2} = \frac{0.693}{\lambda}$$

- Decays

- Half-Life is time for $\frac{1}{2}$ of atoms to decay