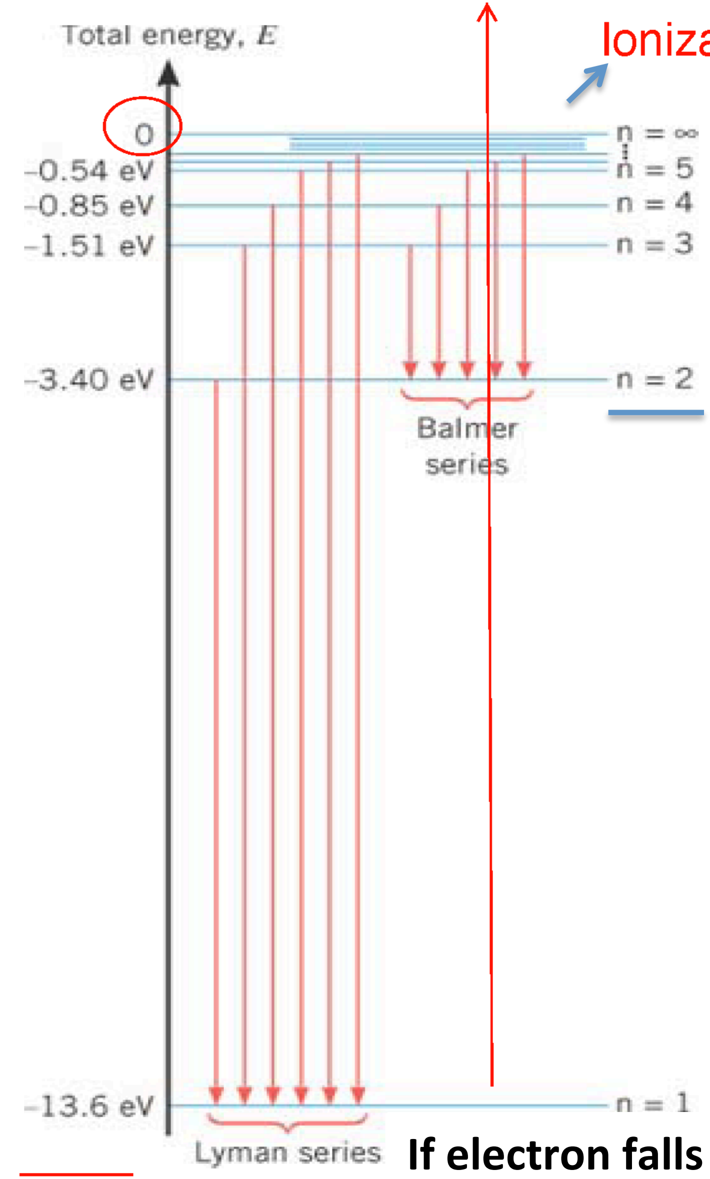
When an electron in a hydrogen atom "jumps" from the 4th energy level to the 2nd energy level it emits a photon which represents the second line in the Balmer series.

[✓ 1.Yes, this statement is correct.]

2.No, this statement is wrong



$$\frac{1}{\lambda} = \frac{2\pi^2 mk^2 e^4}{h^3 c}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

$$n_i, n_f = 1, 2, 3, \ldots \qquad n_i > n_f$$

The first three wavelengths in the Balmer series are:

n = 3, l = 656 nm

n = 4, l = 486 nm

n = 5, l = 434 nm

If electron falls from 4th level, how many lines can be generated?

If NOW we have 64 radioactive atoms and in 1 hour we have only 32 of those atoms left, how long should we wait from NOW until the *last* atom decays?

Hint:
$2^0 = 1$
$2^1 = 2$
$2^2 = 4$
$2^3 = 8$
$2^4 = 16$
$2^5 = 32$
$2^6 = 64$
$2^7 = 128$
$2^8 = 256$
$2^9 = 512$
$2^{10} = 1024$

Starting from 64 how many hours do we have to wait until 60 nuclei decay?

If NOW we have 64 radioactive atoms and in 1 hour we have only 32 of those atoms left, how long should we wait from NOW until the *last* atom decays?

$$\overset{4}{N} = \frac{\overset{64}{N_0}}{2^n}$$

Hint:

$2^0 = 1$

$2^1 = 2$

$2^2 = 4$

$2^3 = 8$

$2^4 = 16$

$2^5 = 32$

$2^6 = 64$

$2^7 = 128$

$2^8 = 256$

$2^9 = 512$

$2^{10} = 1024$

~~1.60~~ 2.4

Starting from 64 how many hours do we have to wait until 60 nuclei decay?

NOW we have a 128 kg sample of a radioactive material with activity 1024 Bq and in 1 hour its activity is 256 Bq. Suppose, all the daughter particles remain contained in the sample. What will be the activity of 32 kg of the sample after 4 hours from now?

Hint:

$2^0 = 1$

$2^1 = 2$

$2^2 = 4$

$2^3 = 8$

$2^4 = 16$

$2^5 = 32$

$2^6 = 64$

$2^7 = 128$

$2^8 = 256$

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$2^{10} = 1024$

NOW we have a 128 kg sample of a radioactive material with activity 1024 Bq and in 1 hour its activity is 256 Bq. Suppose, all the daughter particles remain contained in the sample. What will be the ~~activity of 32 kg of the sample after 4 hours from now?~~

mass of the sample in 4 H?

Hint:

$2^0 = 1$

$2^1 = 2$

$2^2 = 4$

$2^3 = 8$

$2^4 = 16$

$2^5 = 32$

$2^6 = 64$

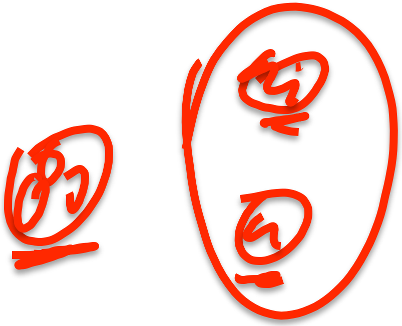
$2^7 = 128$

$2^8 = 256$

$2^9 = 512$

$2^{10} = 1024$

1. 128 kg
2. 64 kg
3. 32 kg
4. 16 kg
5. 8 kg
6. 4 kg
7. 2 kg
8. 1 kg



Radioactive dating

Radioactivity can be used to determine how old something is. When carbon-14 is used, the process is called radiocarbon dating, but radioactive dating can involve other radioactive nuclei. The trick is to use a half-life which is of the order of, or somewhat smaller than, the age of the object.

Carbon-14 is useful because all living things take up carbon from the atmosphere, where there is about 1 atom of C-14 for every 8.3×10^{11} atoms of carbon. The production rate caused by cosmic rays in the atmosphere balances the decay rate, to establish this level.

Radiocarbon dating

After an organism dies, freshly made C-14 is no longer circulated through it, and the initial amount of carbon-14 decays. Carbon-14 has a half life of 5730 years, so it is useful for measuring ages of objects that are several hundred years, to several tens of thousands of years, old.

Applications of radiocarbon dating include dating of the shroud of Turin (to the 13th-14th centuries), and of Ötzi the Iceman (3300 BC), found in the Alps in 1991.

Example problem

A sample of wood has an activity of 0.22 Bq from carbon-14. An equivalent piece of wood cut from a growing tree would have an activity of 0.88 Bq from its carbon-14. How old is the sample?

$$\frac{0.88}{2} \rightarrow 0.44$$

$$\frac{0.44}{2} \rightarrow 0.22$$

How many half lives had passed?

1
2
3
4
5
6

$$\underline{R = \lambda \cdot N}$$

$$\lambda N = \frac{\lambda N_0}{2^n}$$

$$R = \frac{R_0}{2^n}$$

Example problem

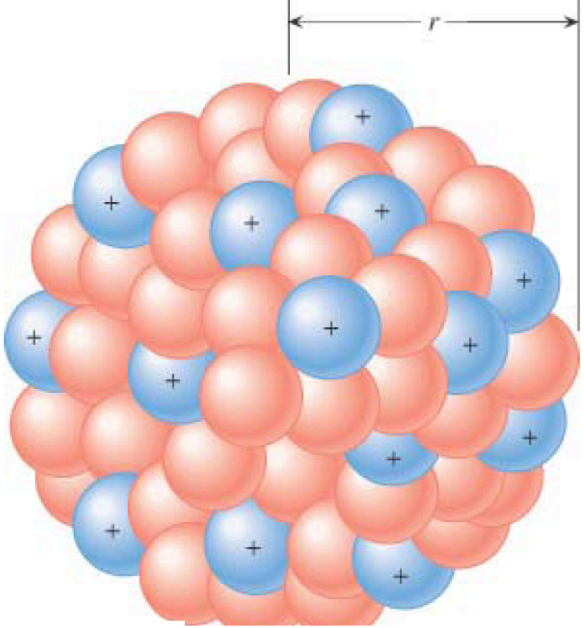
A sample of wood has an activity of 0.22 Bq from carbon-14. An equivalent piece of wood cut from a growing tree would have an activity of 0.88 Bq from its carbon-14. How old is the sample?

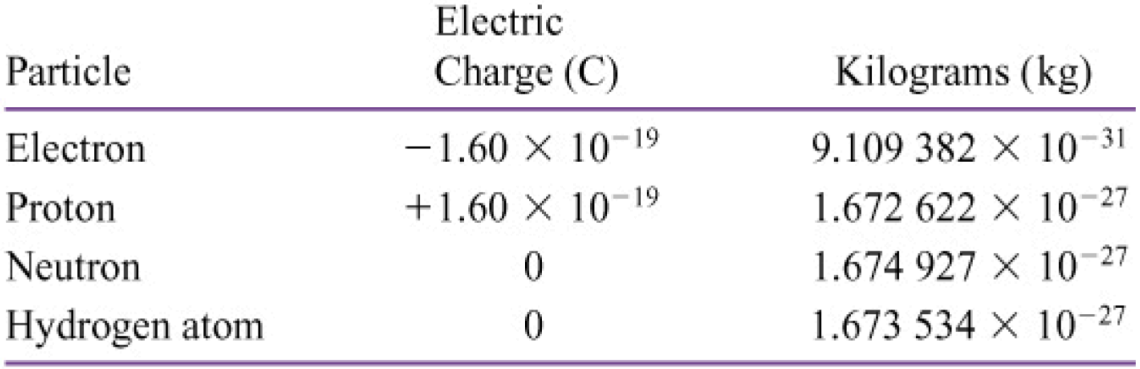
how many half-lives have passed?

The activity is ¼ of the original activity, so exactly two half-lives have gone by. Multiplying the half-life of C-14, which is 5730 y, by 2 gives 11460 years.

Nuclear Structure

The atomic nucleus consists of positively charged protons and neutral neutrons.





Particle	Electric Charge (C)	Kilograms (kg)
Electron	-1.60×10^{-19}	$9.109\,382 \times 10^{-31}$
Proton	$+1.60 \times 10^{-19}$	$1.672\,622 \times 10^{-27}$
Neutron	0	$1.674\,927 \times 10^{-27}$
Hydrogen atom	0	$1.673\,534 \times 10^{-27}$

:(

A table of masses

One atomic mass unit (u) is defined as 1/12th the mass of a carbon-12 atom.

Particle	Mass (kg)	Mass (u)	Mass (MeV/c^2)
1 atomic mass unit	1.660540×10^{-27}	1.000	931.5
neutron	1.674929×10^{-27}	1.008664	939.57
proton	1.672623×10^{-27}	1.007276	938.28
electron	9.109390×10^{-31}	0.00054858	0.511

The most famous equation in physics

$$E = mc^2 \quad \Rightarrow \quad \Delta E = \Delta m \cdot c^2$$

The missing mass is the binding energy of the atom (almost all of which is in the nucleus).

At the rate of 931.5 MeV per u, the mass defect of 0.098931 u corresponds to 92.15 MeV worth of binding energy in the carbon-12 atom.

$$\underline{1\,\mathrm{u} \leftrightarrow 931.5\,\mathrm{MeV}}$$

Units of mass and energy

$E = mc^2$

u is the atomic mass unit

$$1\,u = \frac{1}{12} M_{{}^{12}_{6}C}$$

$1\text{ u} = 1.660540 \times 10^{-27}\text{ kg} = 931.5\text{ MeV}/c^2$

or

$$\underline{1\,\mathrm{u} \leftrightarrow 931.5\,\mathrm{MeV}}$$

$\underline{1u{*}c^2} = \underline{931.5}\ \underline{\text{MeV}} = 931.5{*}10^6\text{ eV}$

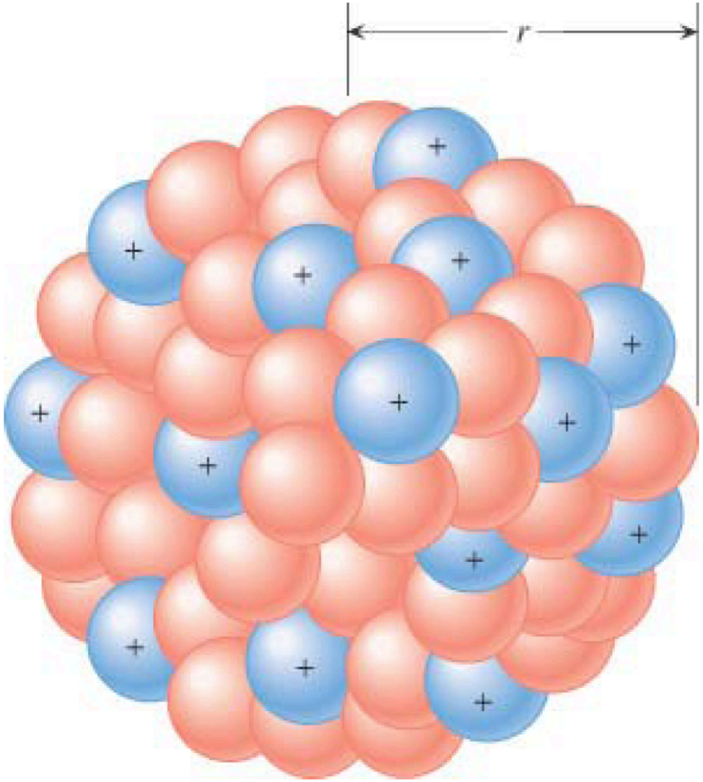
$1\text{ eV} = 1.6{*}10^{-19}\text{ J}$

$1\text{ MeV} = 10^6\text{ eV}$

1 mass atomic unit is worth of 931.5 MeV of energy!

The strong nuclear force keeps protons and neutrons together.

We have to spend a certain amount of **energy** ***(do some work) to take a nucleus apart or to build a nucleus from individual protons and neutrons.***



The mass defect

Each carbon-12 atom is made up of 6 neutrons, 6 protons, and 6 electrons, which separately have a mass of:

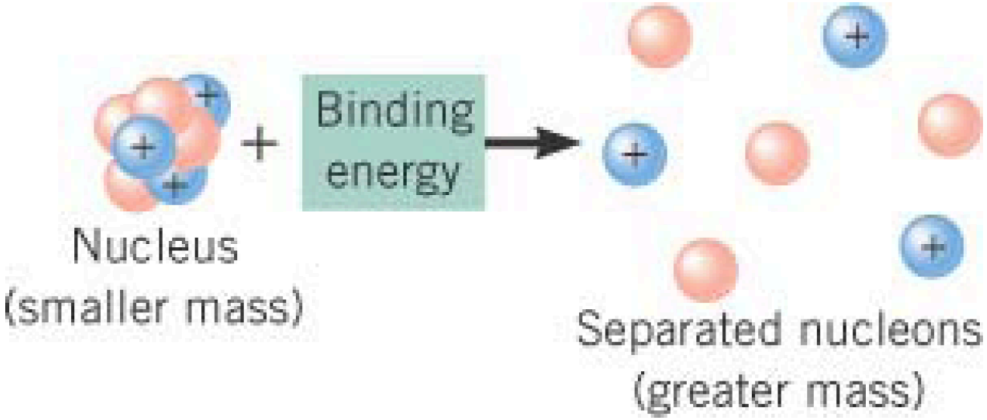
$$\text{six neutrons: } 6 \times 1.008664 \text{ u} = 6.051984 \text{ u}$$

$$\text{six protons: } 6 \times 1.007276 \text{ u} = 6.043656 \text{ u}$$

$$\text{six electrons: } 6 \times 0.00054858 \text{ u} = 0.00329148 \text{ u}$$

$$\text{Sum} = 12.098931 \text{ u}$$

When these are combined into a carbon-12 atom, the atom has a mass of precisely 12.000000 u. The missing 0.098931 u worth of energy is the mass defect.



The energy needed to be spent to break a nucleus into individual protons and neutrons is called the **binding energy** of the nucleus.

The existence of binding energy is the result of the existence of *mass defect!*

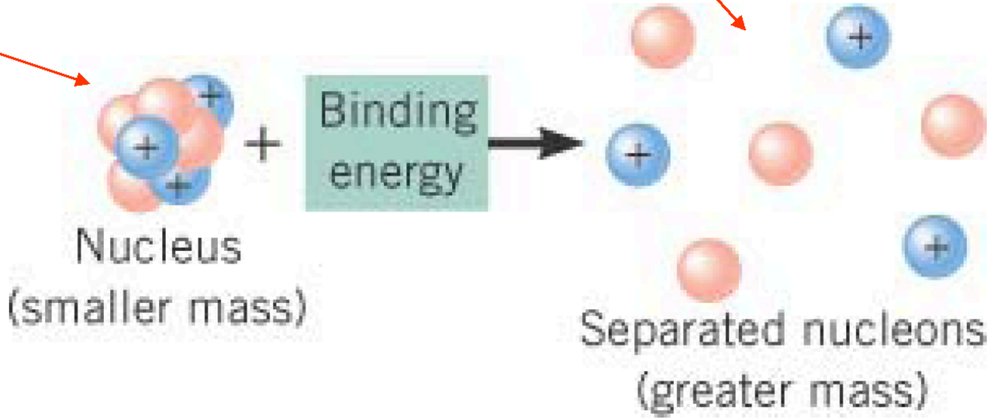
Mass vs. energy

$E = mc^2$ ⇐ **The famous Einstein equation**

M_{total} is the total mass of individual protons and neutrons

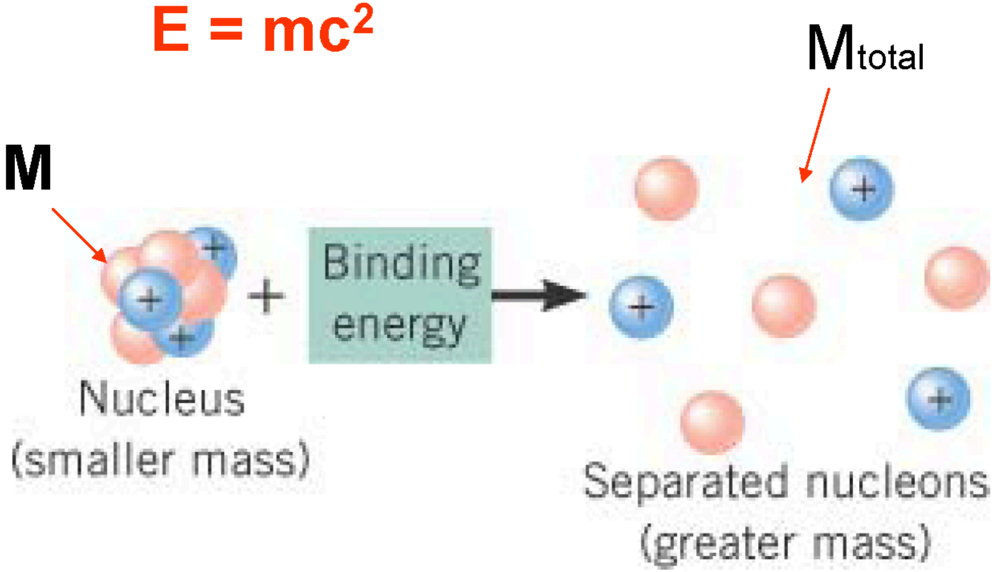
$$M_{total} > M$$

M is the mass of the nucleus



$$\text{Mass deficit} = \Delta m = M_{total} - M$$

$E = mc^2$



$$\text{Mass deficit} = \Delta m = M_{\text{total}} - M$$

$$\text{Binding energy} = (\text{Mass deficit})c^2 = (\Delta m)c^2$$

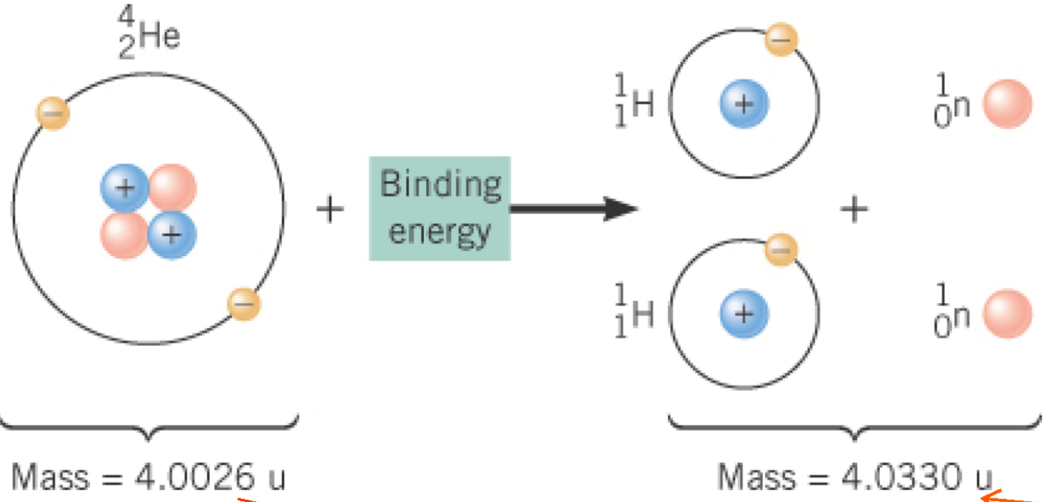
$$= (N_p * m_p + N_n * m_n + N_p * m_e - M_{atom}) * c^2$$

The Binding Energy of the Helium Nucleus

The atomic mass of helium is 4.0026 u and the atomic mass of hydrogen is 1.0078 u. Using atomic mass units, instead of kilograms, obtain the binding energy of the helium nucleus.

$m_a = 4.0026 u$

$\Delta m = (2 \cdot m_p + 2 \cdot m_n + 2 \cdot m_e - 4.0026) u$



$m_n = 1.008664$ u

$m_p = 1.007276$ u

$m_e = 0.00054858$ u

$m_H = 1.0078$ u

$\boxed{2*1.0078+2*1.008664=4.03\text{ u}}$

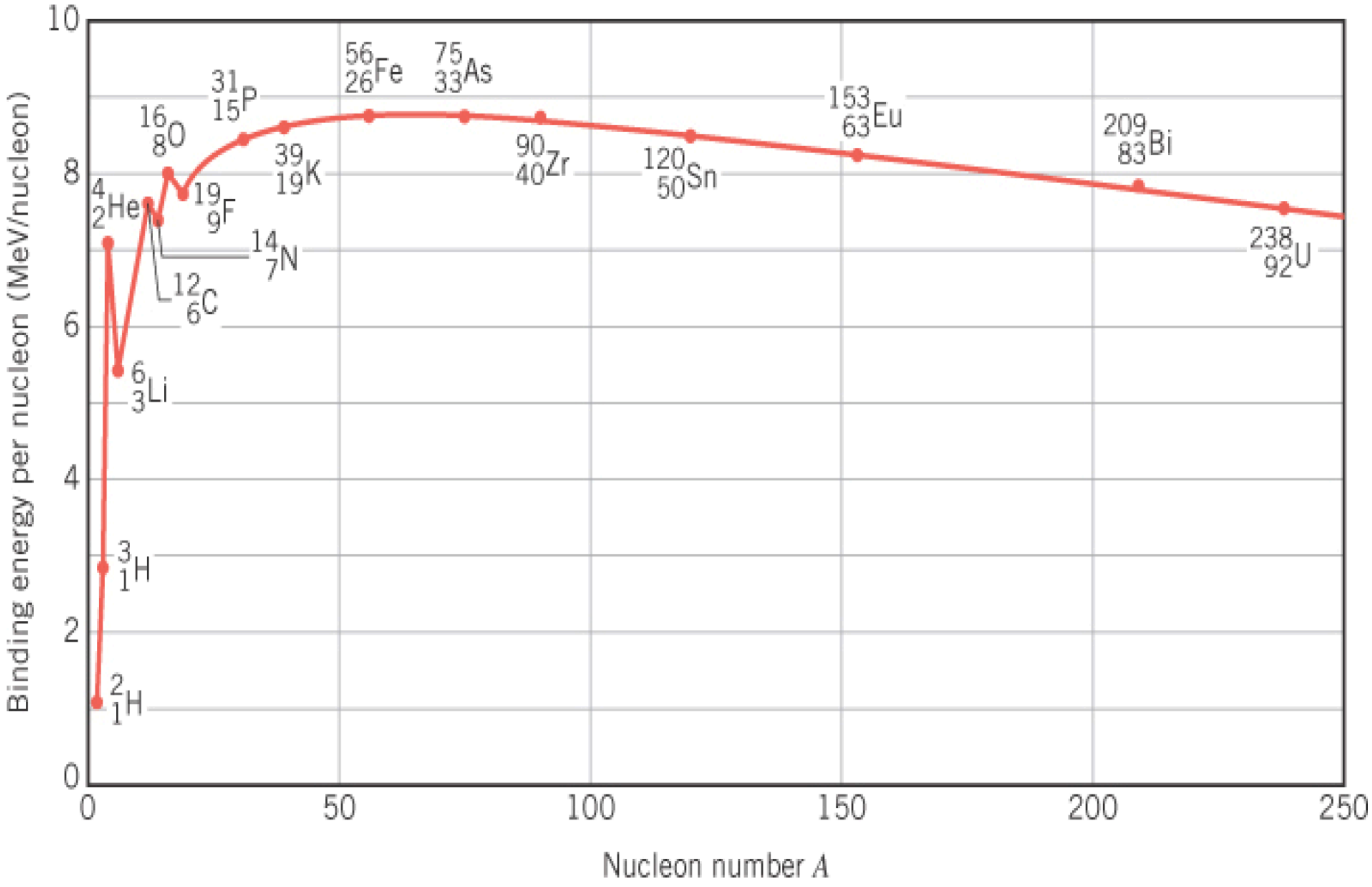
$$\Delta m = 4.0330\text{ u} - 4.0026\text{ u} = 0.0304\text{ u}$$

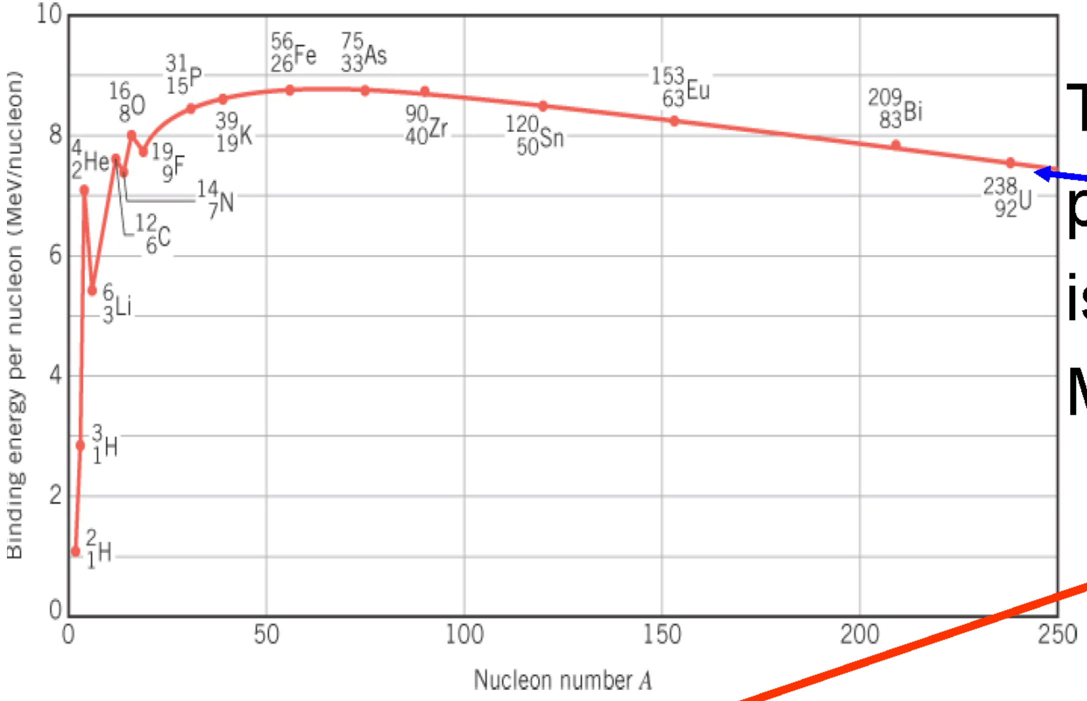
$$1\text{ u} \leftrightarrow 931.5\text{ MeV}$$

Binding energy = 28.3 MeV

$$0.0304\text{ u} \cdot 931.5\text{ MeV} = 28.3\text{ MeV}$$

Nuclear Binding Energy per nucleon





The binding energy per nucleon for $^{238}_{92}U$ is about 7.7 Mev/nucleon

$$\frac{E_{binding}}{A} = 7.7\ MeV$$

$$E_{binding} = A \cdot 7.7\ MeV = 238 \cdot 7.7\ MeV = 1832.6\ MeV$$

The total mass of free nuclei is

92*1.007276 u + (238 – 92)*1.008664 u = 239.642336 u

$${}^{238}_{92}U \longrightarrow \quad E_{binding} = 238 \cdot 7.7\ MeV = 1832.6\ MeV$$

The total mass of free nuclei is $M_{total} = 239.642336$ u

So, the energy stored in them is

$E_{total} = M_{total\text{-}(in\ kg)}{}^{*}c^{2} = M_{total(in\ u)}{}^{*}931.5 = 223226.84$ MeV

The mass of the nucleus is

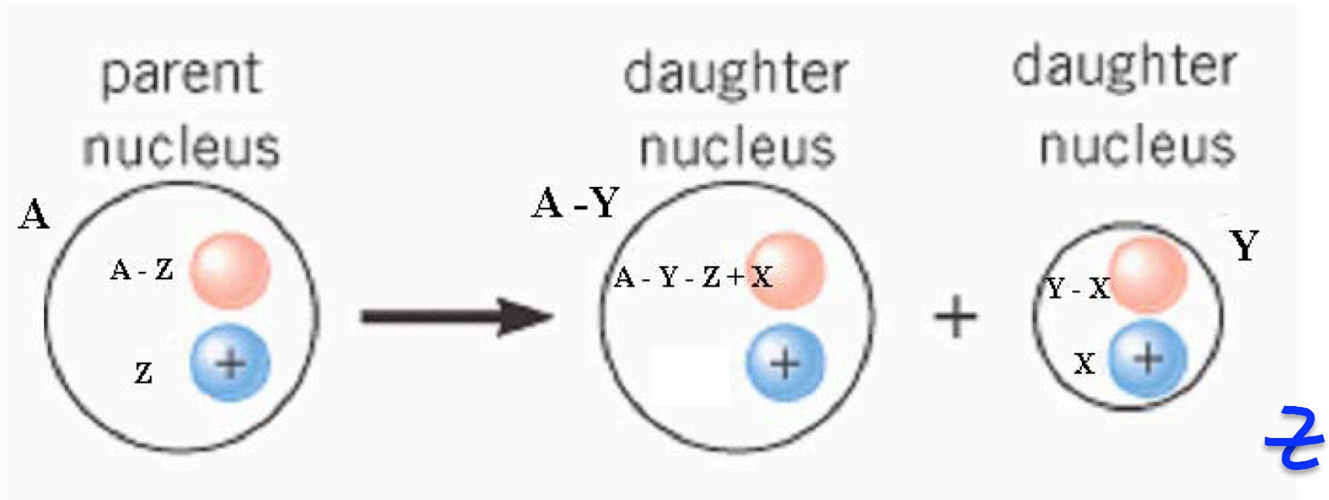
$M = (E_{total} - E_{binding})/c^{2} = (223226.84 - 239.64)/931.5 =$

$= 239.3$ u

$$\boxed{m_{nu} + Z \cdot m_e = \underline{\underline{m_a}}}$$

$$\begin{tikzcd}
 & m_{nu} \arrow[dl, bend right] \arrow[d, leftrightarrow, "\delta m"] \\
m_e \arrow[d, leftrightarrow, "\delta m"'] \arrow[r, dash] & m_{id\ par}\ (\text{with no } ee) \\
m_{id\ par}\ (\text{with } ee) &
\end{tikzcd}$$

A Radioactive DECAY



$$ {}^{A}_{Z}P \rightarrow {}^{A-Y}_{?}D_1 + {}^{Y}_{X}D_2 $$

$z = ? + X$

$? = z - X$

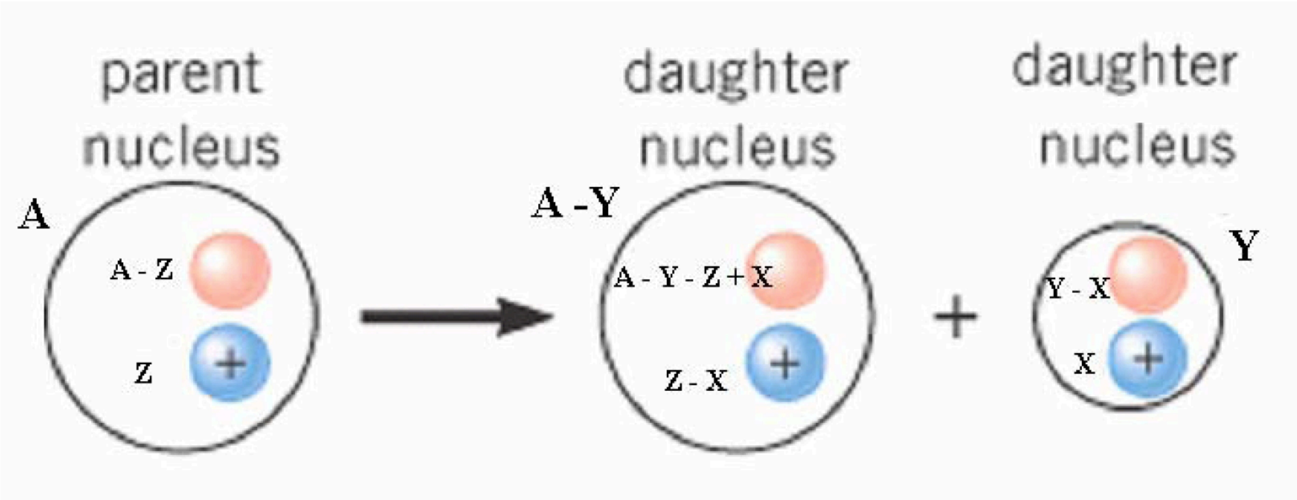
PRS

1. Z
2. X
3. Z - X
4. Z + X

The total charge stays the same!

The total mass (energy) stays the same!

A Radioactive DECAY

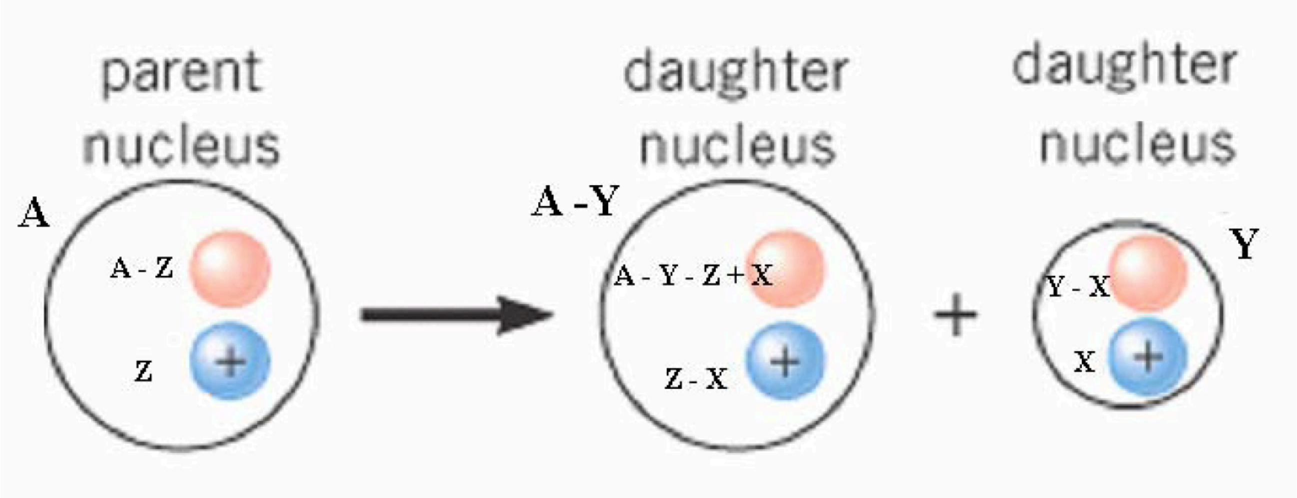


$$ {}^{A}_{Z}\mathrm{P} \rightarrow {}^{A-Y}_{Z-X}\mathrm{D}_1 + {}^{Y}_{X}\mathrm{D}_2 $$

The total charge stays the same!

The total number of nucleons stays the same, too!

A Radioactive DECAY



$$ {}^{A}_{Z}\mathrm{P} \rightarrow {}^{A-Y}_{Z-X}\mathrm{D}_1 + {}^{Y}_{X}\mathrm{D}_2 $$

Do not forget about kinetic energy!

The total charge stays the same!

The total mass (energy) stays the same!

No matter how many parent nuclei are!

γ DECAY

$${}^{A}_{Z}\mathrm{P}^{*} \rightarrow {}^{A}_{Z}\mathrm{P} + {}^{0}_{0}\gamma$$

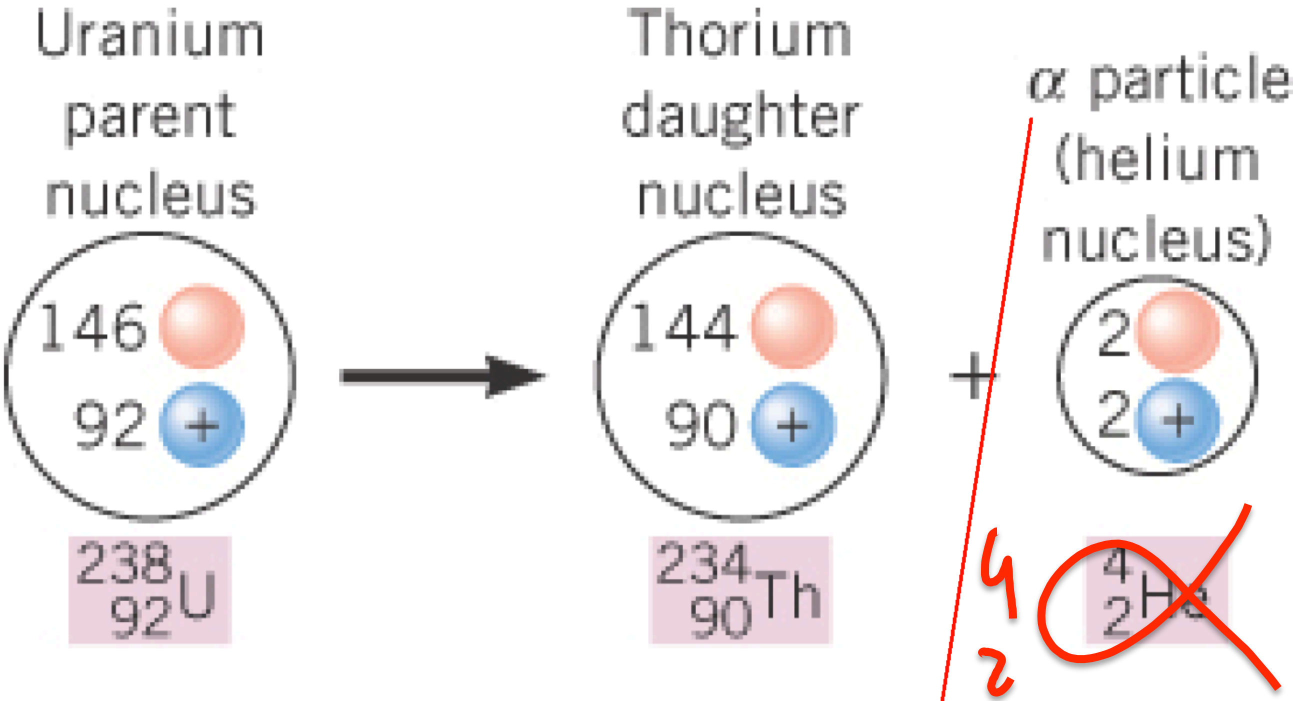
Photon

$\underline{E_{ph}} = \underline{h \cdot f}$

excited energy state

lower energy state

α DECAY



$$ {}^{A}_{Z}P \rightarrow {}^{A-4}_{Z-2}D + \underline{{}^{4}_{2}\mathrm{He}} $$

Alpha decay

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

Use data from the appendix in the textbook:

Atomic mass of U-238 is 238.050786 u
Atomic mass of Th-234 is 234.043596 u
Atomic mass of He-4 is 4.002603 u

The total mass on the left side of the equation is 238.050786 u.

The total mass on the right side of the equation is 234.043596 u + 4.002603 u = 238.046199 u.

The left side of the equation has more mass, by 0.004587 u. Where did the extra mass go?

Alpha decay

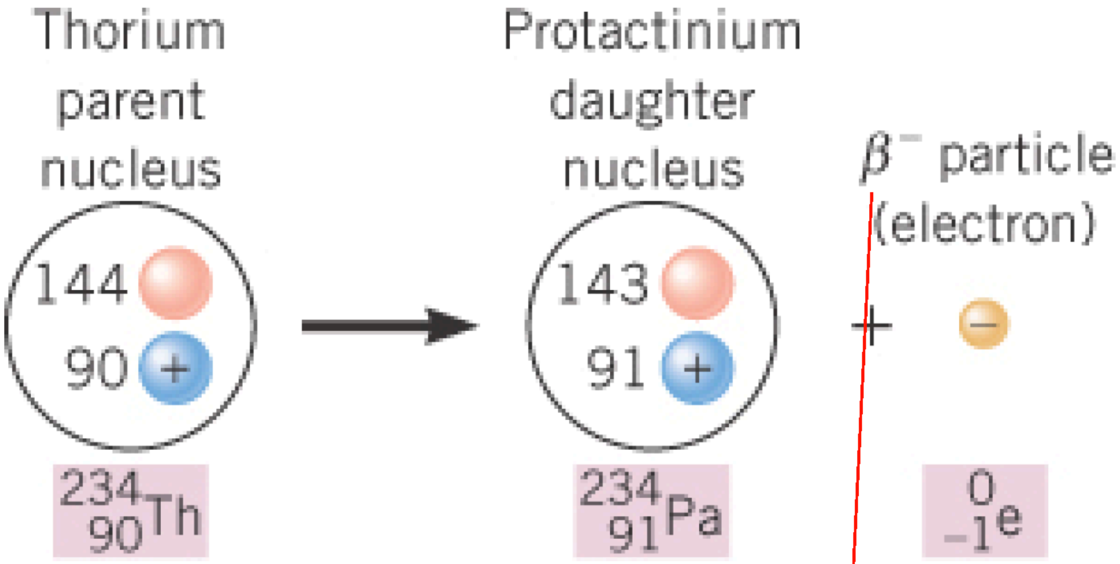
$$^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$$

The left side of the equation has more mass, by 0.004587 u. Where did the extra mass go?

The missing mass was converted to 0.004587 u × 931.5 MeV/u = 4.273 MeV of energy. This shows up in the kinetic energy of the two atoms after the reaction.

Reactions occur spontaneously when the total mass afterwards is less than the total mass before.

β DECAY



$$^{A}_{Z}\mathrm{P} \rightarrow {}^{A}_{\underline{Z+1}}\mathrm{D} + {}^{0}_{\underline{-1}}\mathrm{e}$$ **(beta-minus decay)**

C^{14} **for example!**

(can you write a general equation for beta-plus decay?)

$${}^{A}_{Z}P \rightarrow {}^{A}_{Z-1}D + {}^{0}_{+1}\beta$$

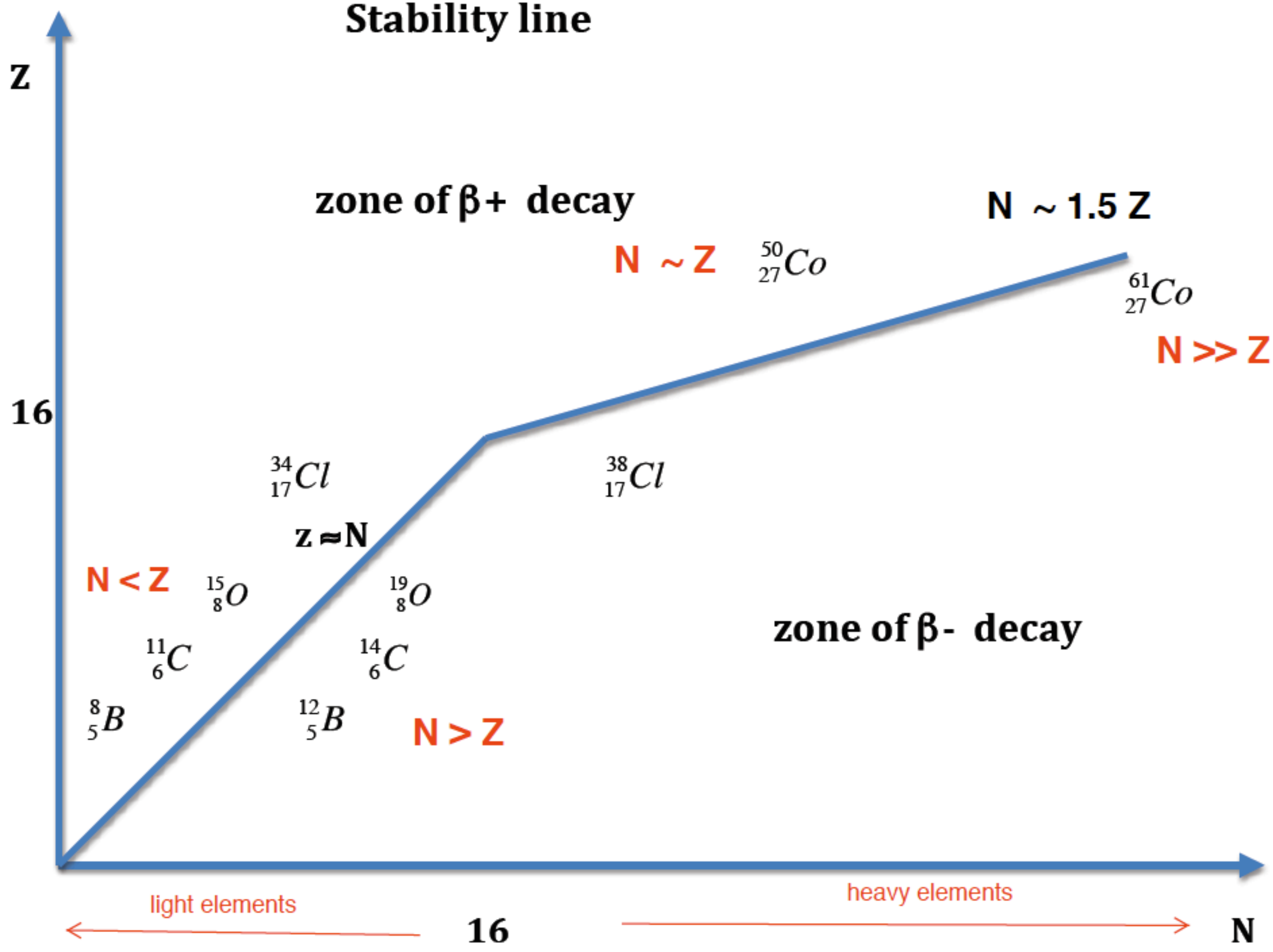
Beta decay

A beta particle is often an electron, but can also be a positron, a positively-charged particle that is the anti-matter equivalent of the electron. In terms of safety, beta particles are more penetrating than alpha particles, but less than gamma particles.

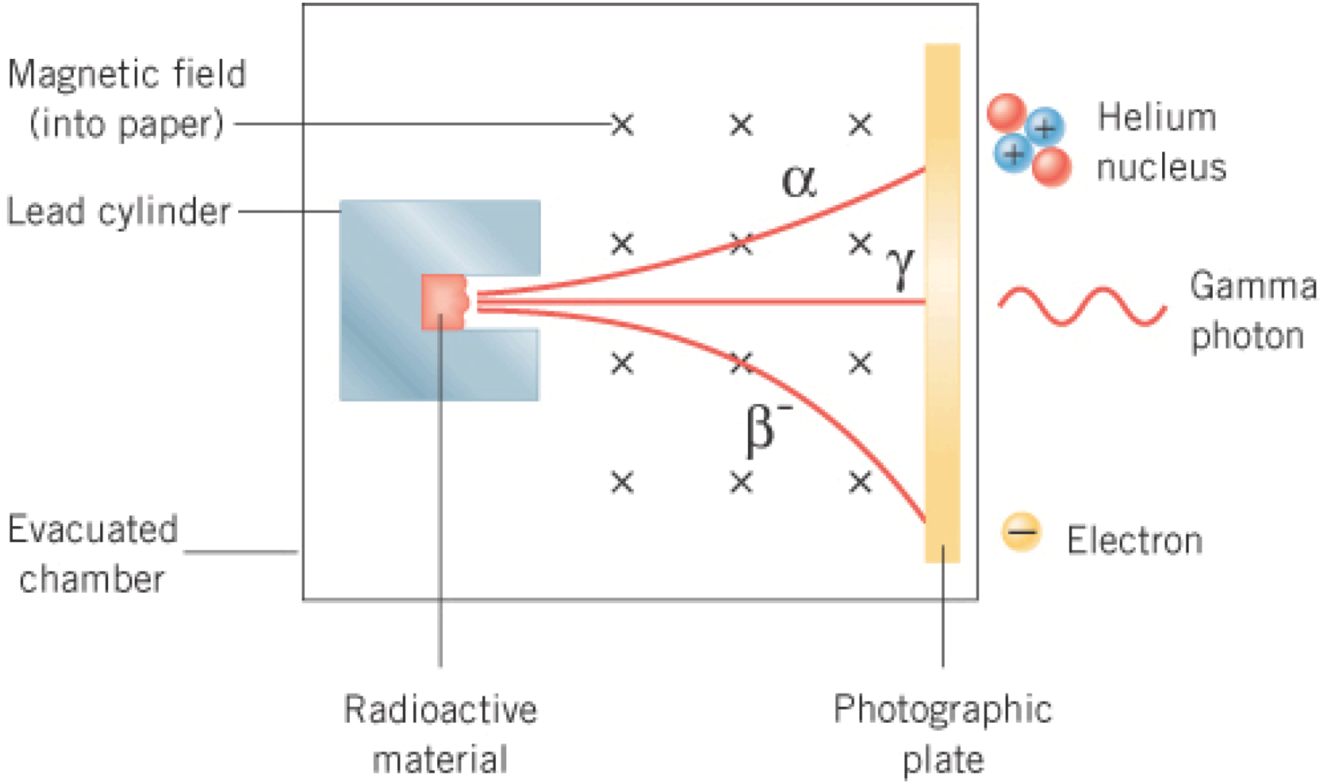
An important process in beta decay involves a neutron turning into a proton by giving up an electron:

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

Stability line



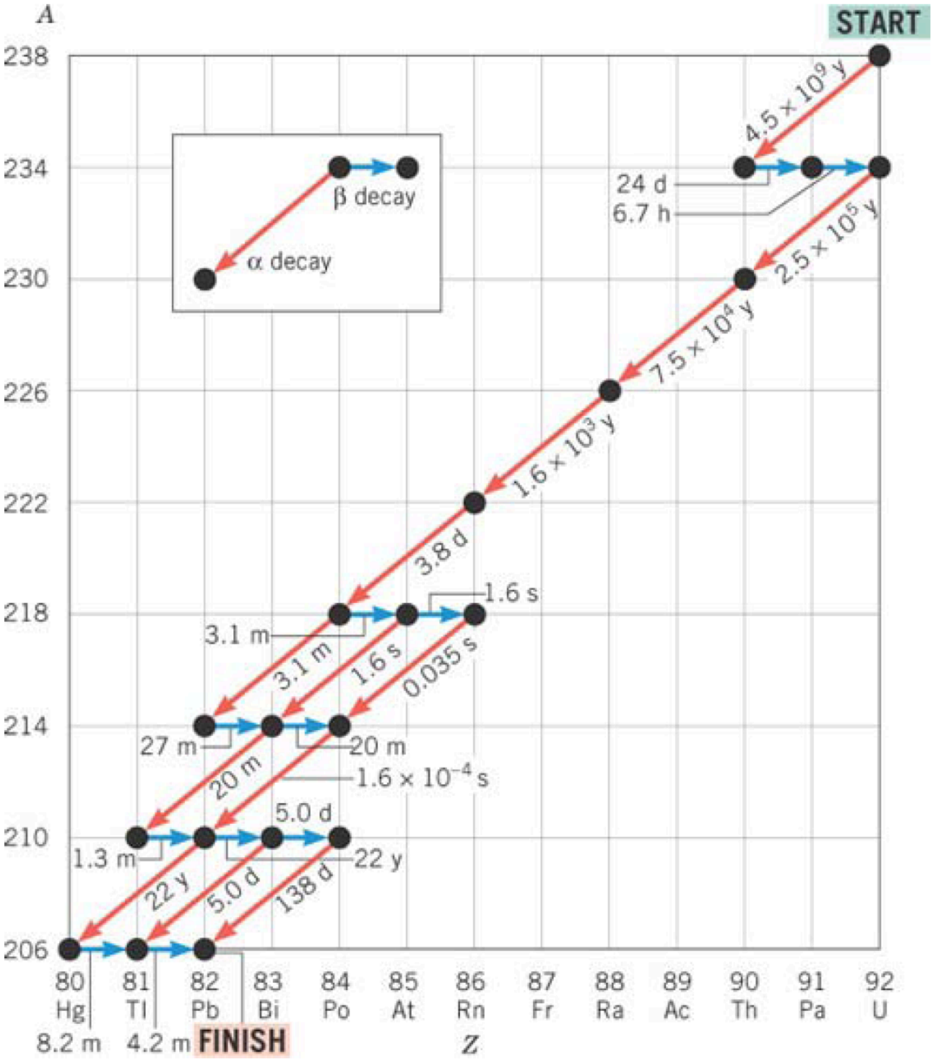
Radioactivity



There are many possible outcomes of a decay.

A magnetic field separates particles emitted by radioactive nuclei, so we can study the properties of the new particles.

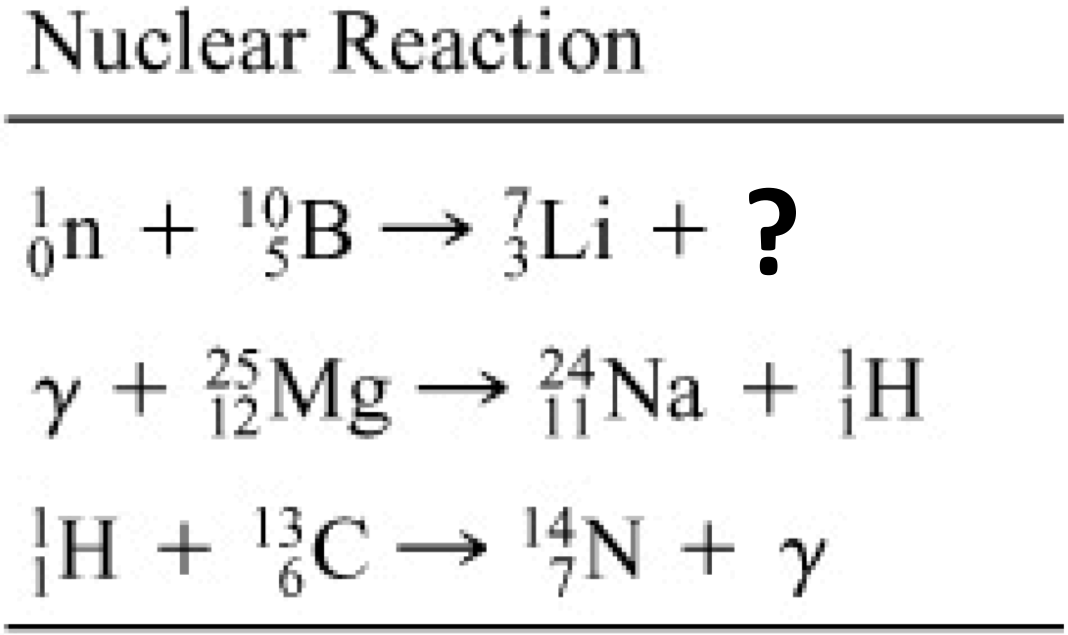
Radioactive Decay Series



Some useful notations

Electron	${}^{0}_{-1}e = {}^{0}_{-1}\beta$
Light, EMW, photons	${}^{0}_{0}\gamma$
alpha – particle	${}^{4}_{2}\alpha = {}^{4}_{2}He$
proton	${}^{1}_{1}p$
neutron	${}^{1}_{0}n$
positron	${}^{0}_{1}e={}^{0}_{1}\beta$

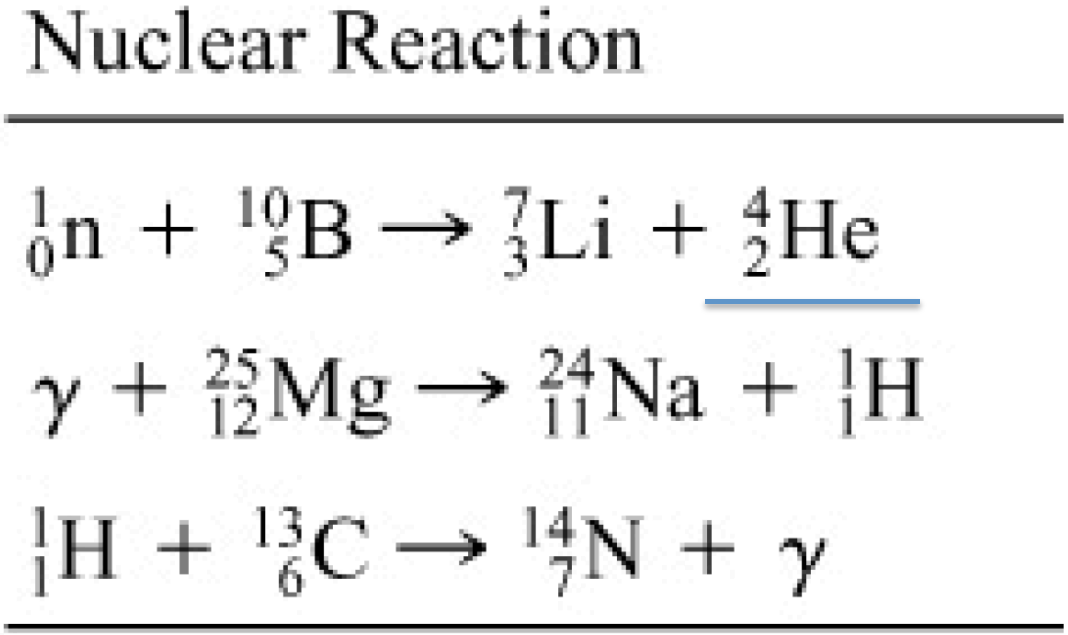
A ***nuclear reaction*** is said to occur whenever the incident nucleus, particle, or photon causes a change to occur in the target nucleus.



Nuclear Reaction
$^{1}_{0}n + {}^{10}_{5}B \rightarrow {}^{7}_{3}Li +$ **?**
$\gamma + {}^{25}_{12}Mg \rightarrow {}^{24}_{11}Na + {}^{1}_{1}H$
$^{1}_{1}H + {}^{13}_{6}C \rightarrow {}^{14}_{7}N + \gamma$

decay - spontaneous
reaction - induced

A ***nuclear reaction*** is said to occur whenever the incident nucleus, particle, or photon causes a change to occur in the target nucleus.



Nuclear Reaction
${}^{1}_{0}\mathrm{n} + {}^{10}_{5}\mathrm{B} \rightarrow {}^{7}_{3}\mathrm{Li} + \underline{{}^{4}_{2}\mathrm{He}}$
$\gamma + {}^{25}_{12}\mathrm{Mg} \rightarrow {}^{24}_{11}\mathrm{Na} + {}^{1}_{1}\mathrm{H}$
${}^{1}_{1}\mathrm{H} + {}^{13}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + \gamma$

decay - spontaneous
reaction - induced