
DANGER
STAY OUT UNTIL 12,000 AD

The previous images display some of our hopes and fears associated with nuclear radiation.

We know the images, and some of the uses, but what is “Nuclear Radiation” and where does “it” come from?

Nuclide

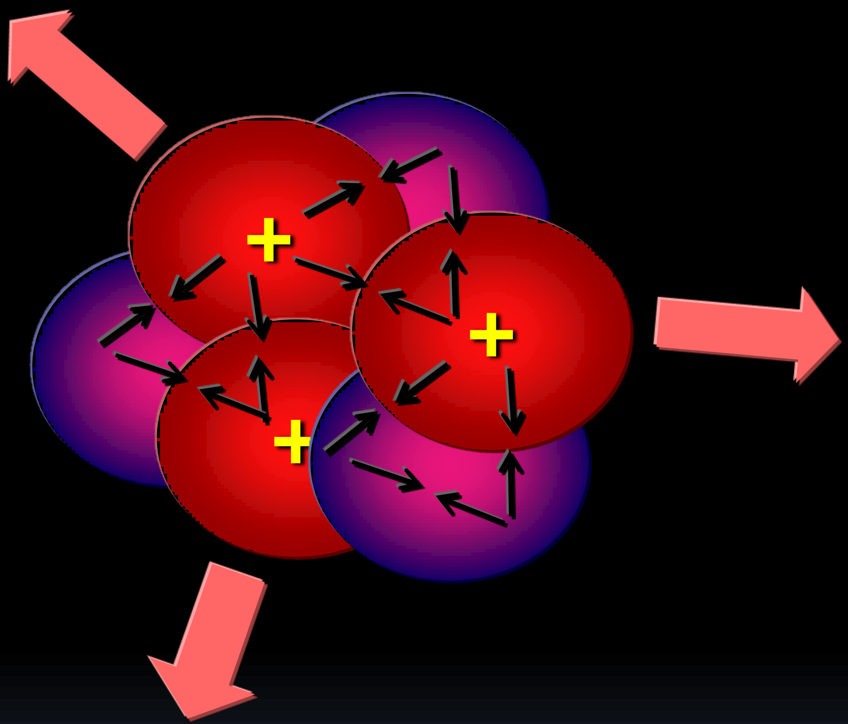
- In nuclear chemistry, an atom is referred to as a nuclide.
- It is identified by the number of protons and neutrons in the nucleus.
- Examples:

$^{238}_{92}U$ or Uranium-238

Mass Defect

- The mass of individual particles added together is different from the total mass of the atom
- Why?
- Because of the conversion of mass to energy when forming the nucleus.
- Einstein's famous equation $E=mc^2$ states that mass and energy can be converted to one another
  - E = energy released when a nucleus is formed.
  - m = mass lost
  - c = speed of light (3.00×10^8 m/s)

So why don't the protons just fly apart? Why are most nuclei stable?



There are 2 forces at work

- **The repulsive force & a strong nuclear force.**

- A strong nuclear charge set up by the neutrons

The **neutrons** in the nucleus act as the glue that holds the nucleus together.

All stable nuclei follow a distinct pattern

- For elements with atomic numbers between 1 and 20 stable nuclei have almost equal numbers of protons and neutrons.
- Beyond 20 protons, nuclei need increasingly more neutrons than protons to be stable.

- Nuclei are unstable not only if they contain too few neutrons, but also if they contain too many.

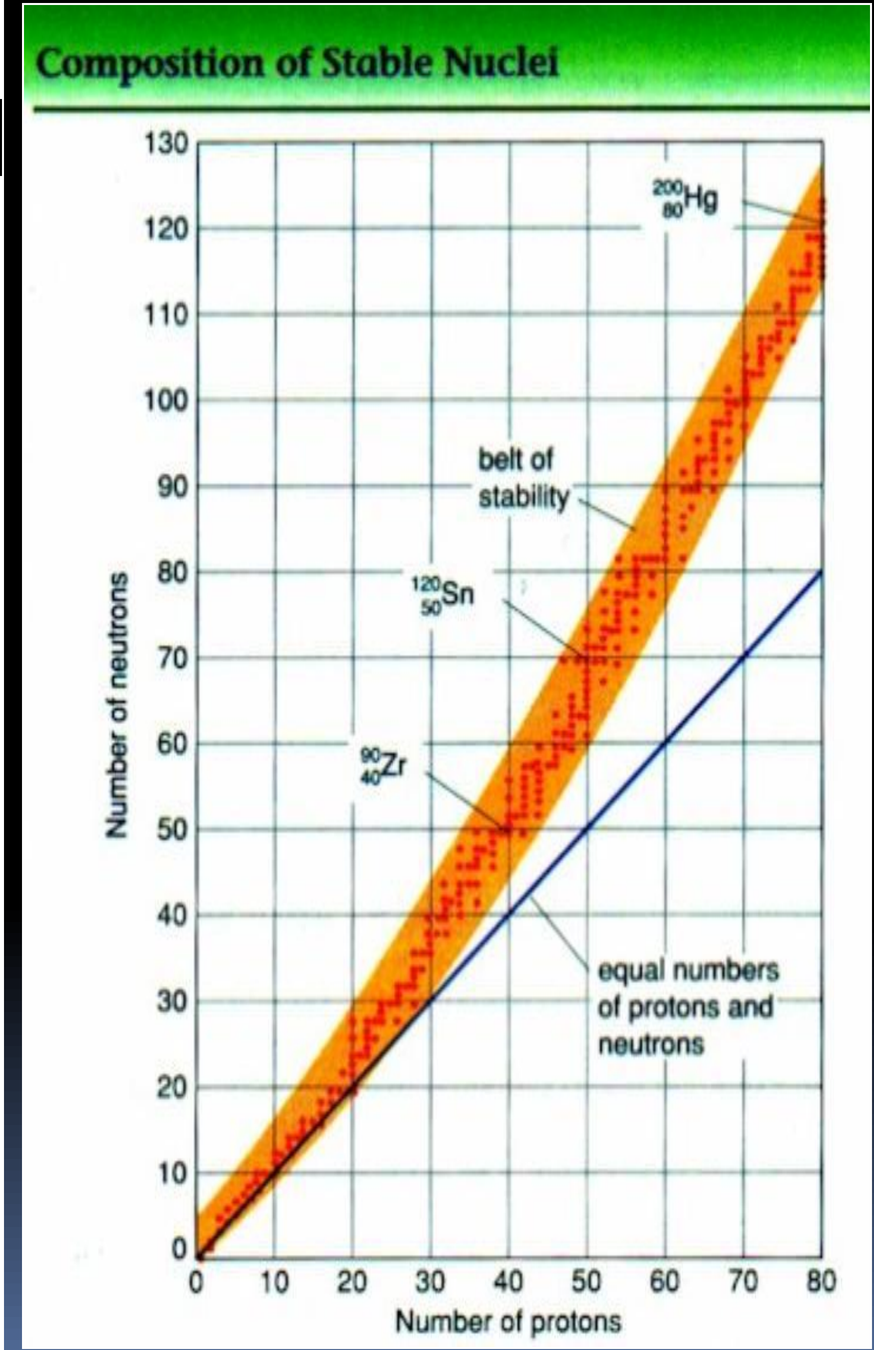


TABLE 26.2 Magic Numbers for Nuclear Stability

Number of Protons	Number of Neutrons
2	2
8	8
20	20
28	28
50	50
82	82
114	126
	184

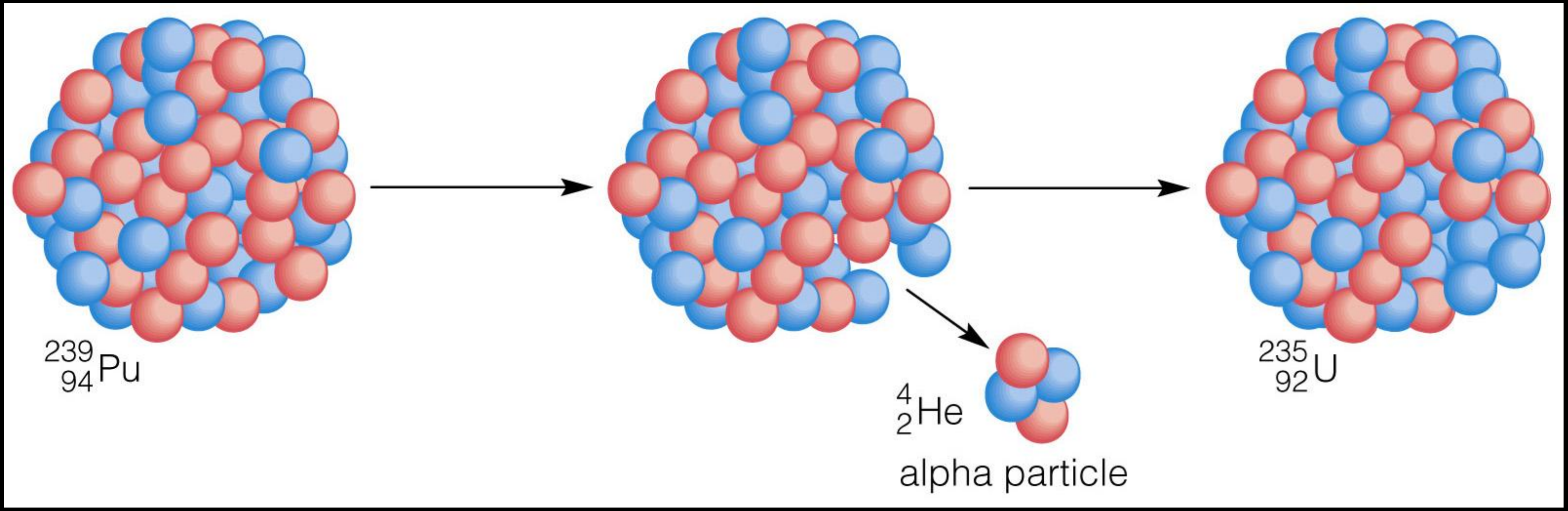
Nuclear Radiation Equations

- The Law of Conservation of Mass and Energy is followed during nuclear radiation production.
- The totals for the mass numbers and atomic numbers for the parent nuclide, daughter nuclide, and radiation particle must be equal across the reaction.

Alpha Radiation

- Alpha radiation (the alpha particle - α) is composed of 2 protons and 2 neutrons that have been ejected from an unstable nucleus.
- Alpha particles have the composition of the Helium-4 nucleus, but do not posses electrons.

Alpha Decay



In the above illustration, the plutonium-239 nucleus undergoes alpha decay to form the uranium-235 nucleus and the ejection of the alpha particle.

Nuclear Radiation Equations

The uranium-235 isotope undergoes alpha decay. Give the equation showing the formation of the alpha particle and daughter nuclide.

What do we know: Uranium has an atomic number of 92

The uranium isotope has a mass number of 235

The alpha particle is made of 2 protons and 2 neutrons (Z=2, A=4)

The alpha particle is formed during the process

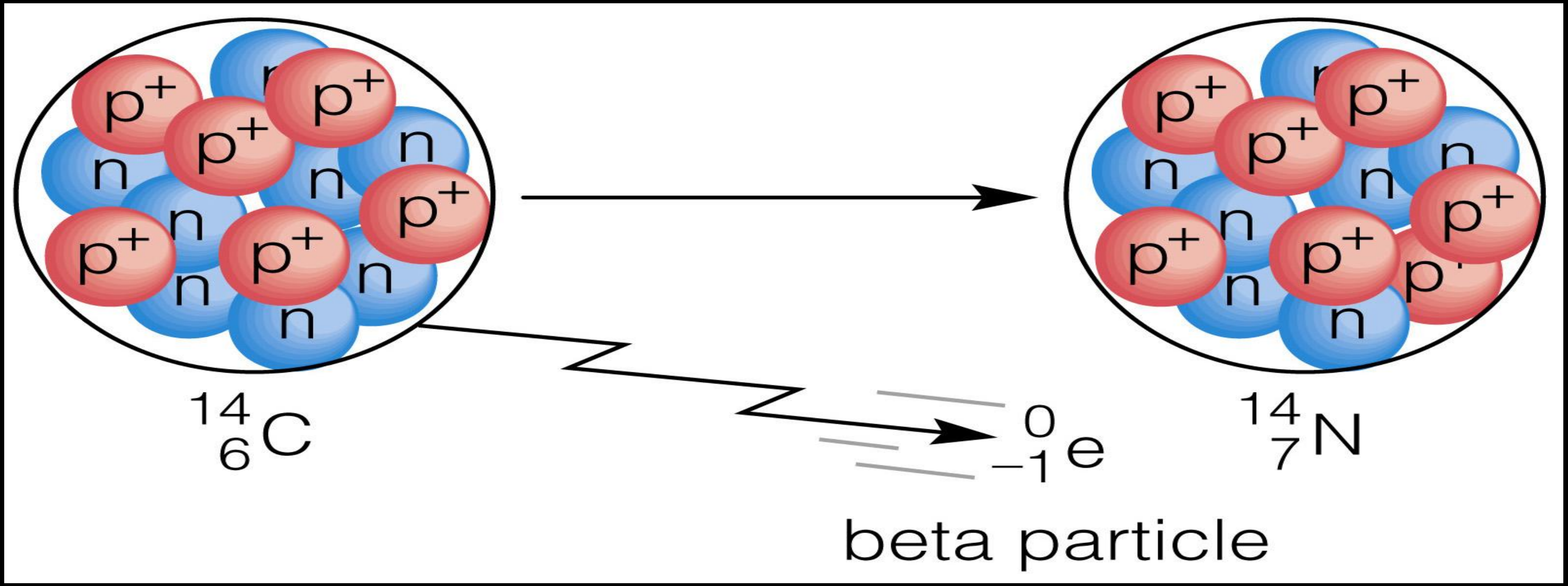
$$^{235}_{92}U \longrightarrow \underline{^{231}_{90}Th\quad\quad} + {}^{4}_{2}\alpha$$

The daughter nuclide is determined by simple subtraction: 235 – 4 = 231 and 92 – 2 = 90 ; the daughter nuclide is Thorium-231

Beta Radiation

- Beta radiation (the beta particle- β) is formed when a neutron within an unstable nucleus decays to form a proton and an electron. (Too many <u>neutrons)</u>
- The newly formed electron is ejected from the nucleus/atom. The high speed electron is the beta particle.

Beta Decay



In the above diagram, the carbon-14 isotope undergoes beta decay to form the nitrogen-14 isotope and eject a beta particle.

Nuclear Radiation Equations

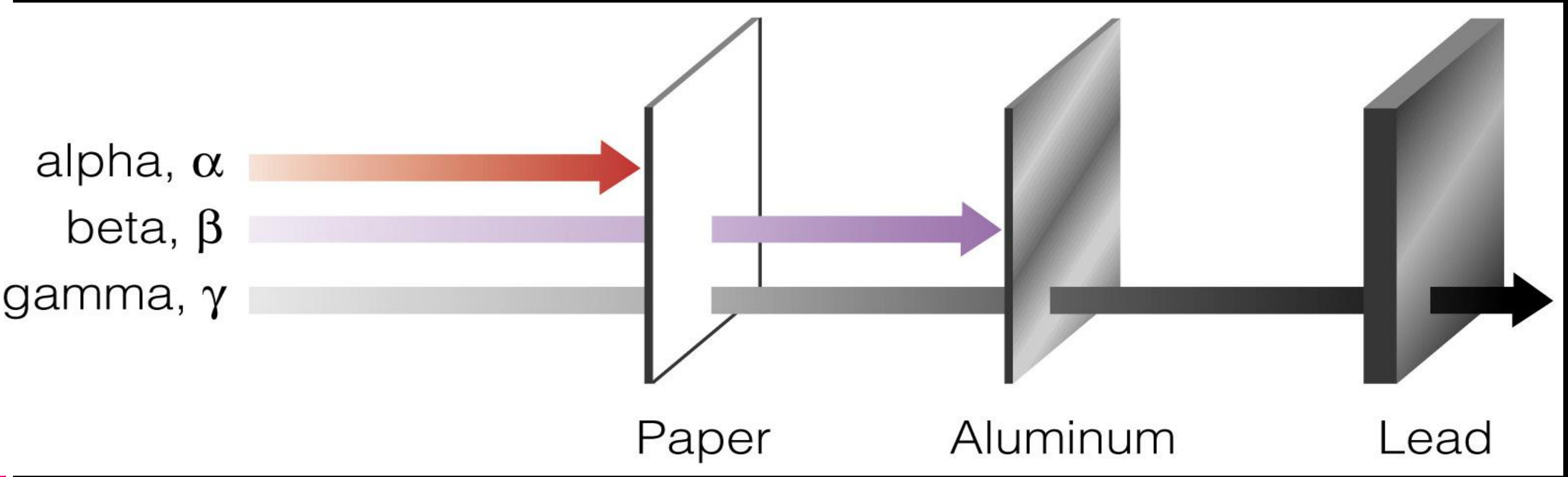
Potassium-40 undergoes beta decay. Give the nuclear equation for this decay process.

$$^{40}_{19}K \longrightarrow {}^{40}_{20}Ca + {}^{0}_{-1}\beta$$

Gamma Radiation

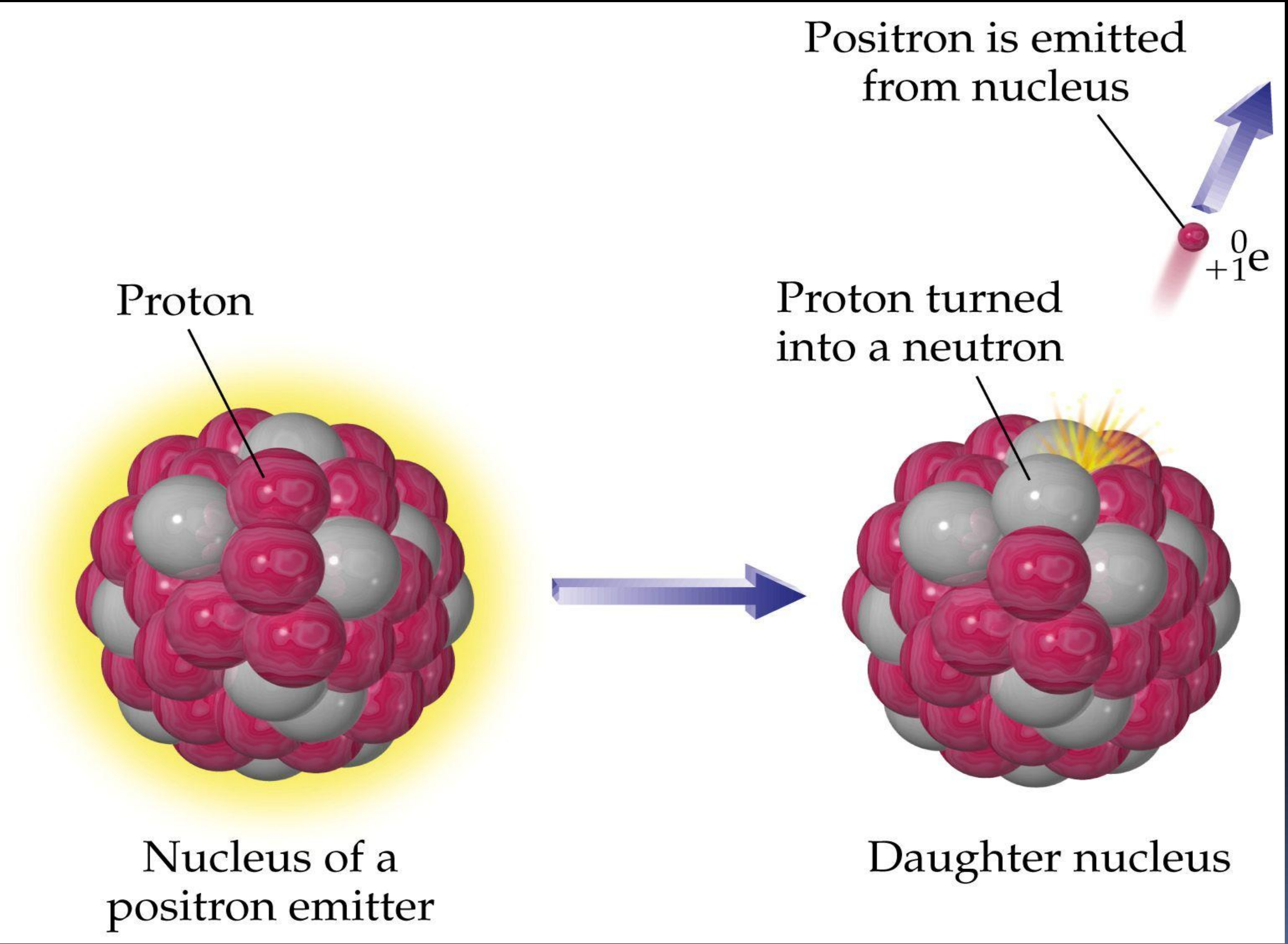
- Unlike the other forms of nuclear radiation, gamma radiation (γ) is in the form of an electromagnetic wave (EMR).
- Gamma radiation is emitted from an unstable nucleus as the nucleus undergoes some rearrangement process (Alpha decay).

Penetrating potential of α, β, γ

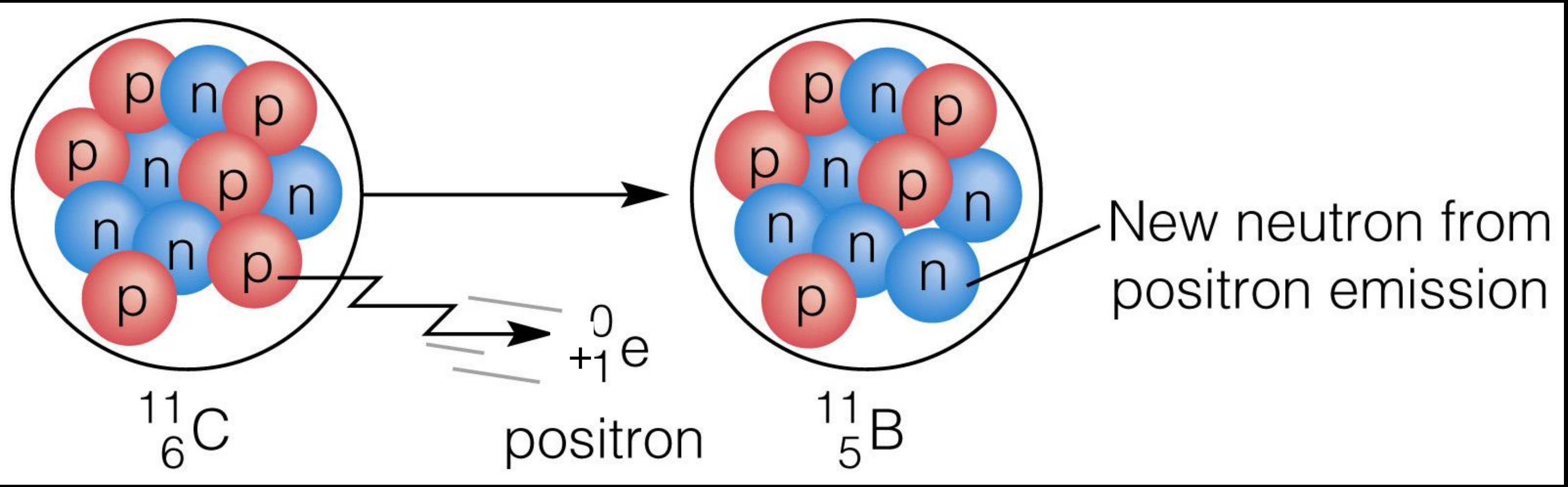


Positron Emission

- Positron emission occurs when a proton is converted to a neutron.(Too many protons)
- A positron is much like a high speed electron, but has a positive charge.


Positron is emitted
from nucleus
$^{0}_{+1}e$
Proton
Proton turned
into a neutron
Nucleus of a
positron emitter
Daughter nucleus

Position Emission

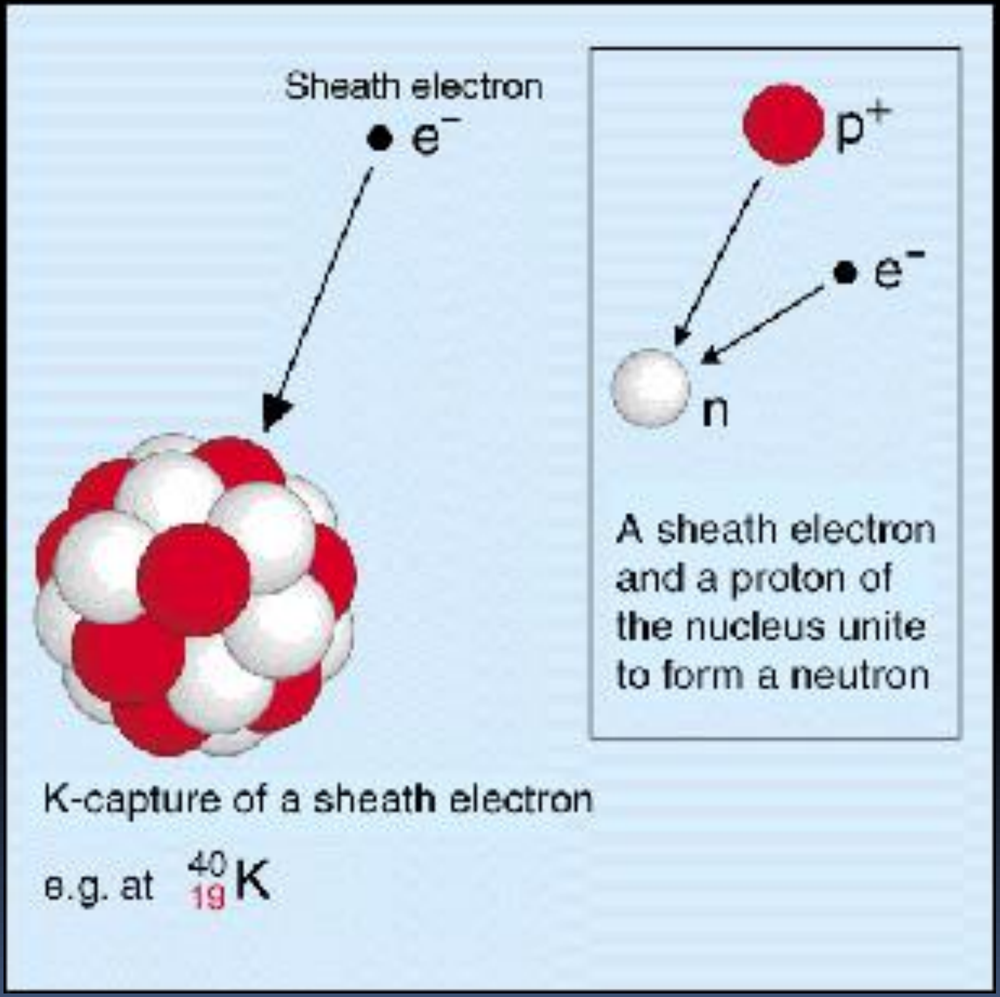


- In the above diagram, carbon-11 undergoes position emission to form boron-11 and the positron particle

Electron Capture

- Electron capture occurs when the nucleus of an atom attracts an inner shell electron (often called k-shell electron) to the nucleus.
- Once in the nucleus, the electron and a proton interact to form a neutron.
  - ${}^{106}_{47}Ag + {}^{0}_{-1}e \rightarrow {}^{106}_{46}Pd$
  - ${}^{22}_{11}Na + {}^{0}_{-1}e \rightarrow {}^{22}_{10}Ne$

Electron Capture



Symbols

Different symbols may be used to show the same type of radiation. Here are some common symbols for the radiation types:

$$\text{Alpha radiation / particle}: {}^{4}_{2}\alpha \ \text{ or } \ {}^{4}_{2}He$$

$$\text{Beta radiation / particle}: {}^{0}_{-1}\beta \ \text{ or } \ {}^{0}_{-1}e$$

$$\text{Gamma Radiation}: {}^{0}_{0}\gamma$$

$$\text{Positron}: {}^{0}_{+1}e$$

$$\text{Electron}: {}^{0}_{-1}e$$

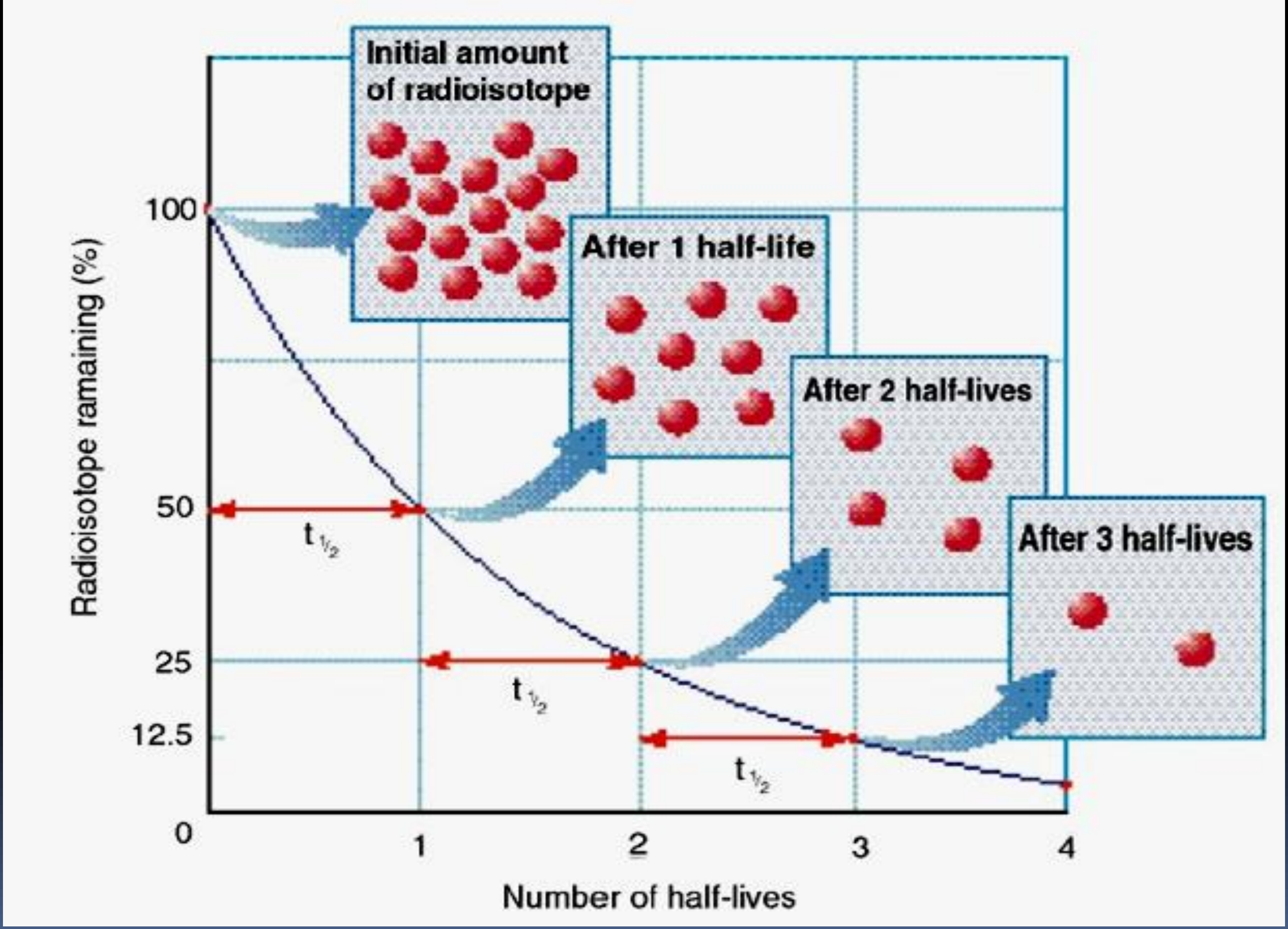
$$\text{Neutron}: {}^{1}_{0}n$$

Half-Life

- Every radioactive isotope has a unique rate of decay or half-life
  - 1 half life is the time required for ½ of nuclei of a radioactive sample to decay
  - After 1 half-life, ½ of the original nuclei have undergone transmutation
- Half lives may be as short as a fraction of a second or as long as billions of years

Half-life

- Most artificially produced radioactive isotopes have very short half-lives
  - Rapidly decaying isotopes do not pose long term bio-radiation hazards to med patients

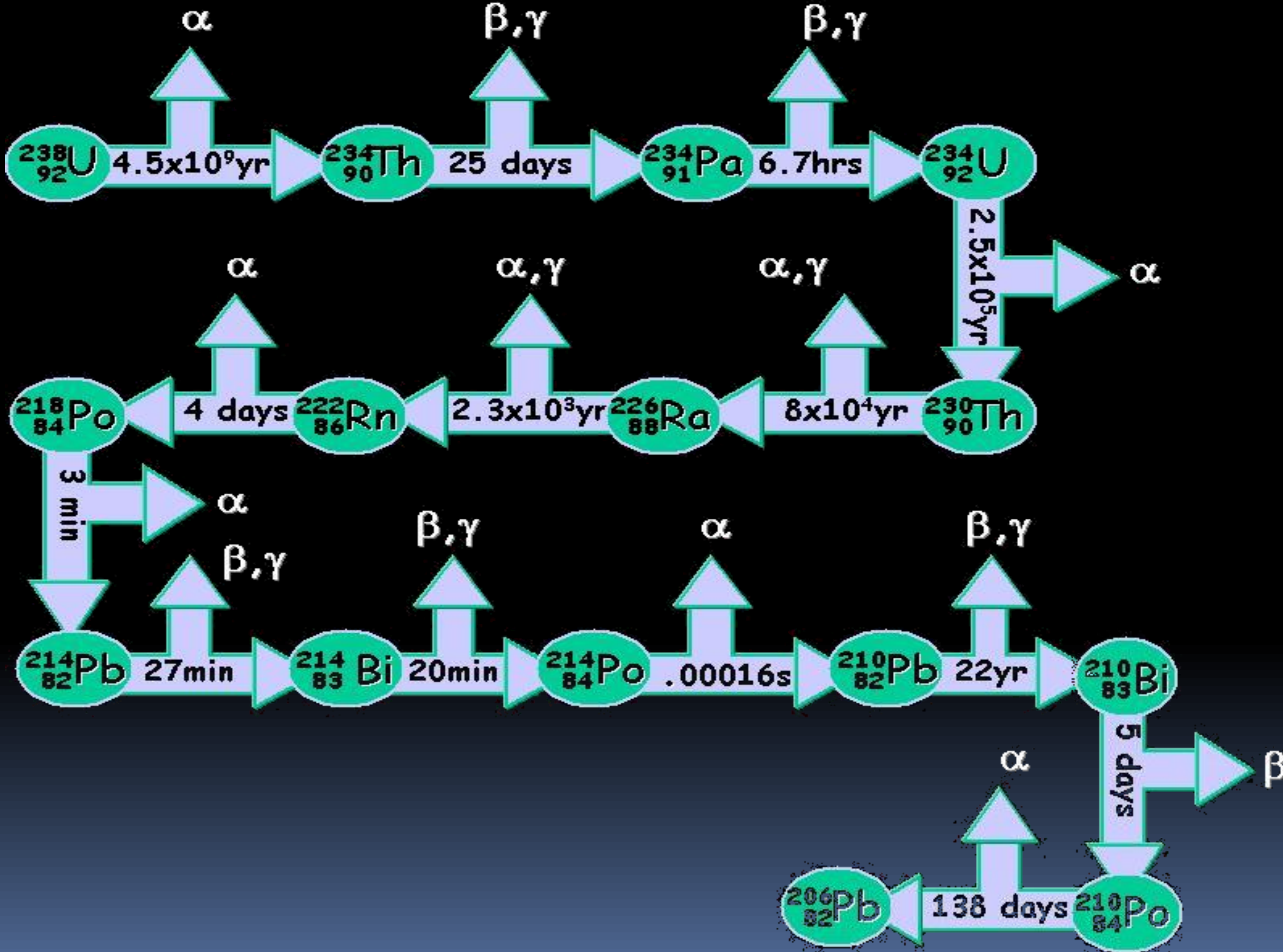

Initial amount of radioisotope
After 1 half-life
After 2 half-lives
After 3 half-lives
Radioisotope ramaining (%)
100
50
25
12.5
0
1
2
3
4
$t_{1/2}$
$t_{1/2}$
$t_{1/2}$
Number of half-lives

Half-Lifes & Radiation

Isotope	Half-life	Radiation emitted
Carbon-14	5730 years	β
Potassium-40	1.25×10^9	β, γ
Radon-222	3.8 days	α
Radium-226	1600 years	α, γ
Thorium-230	75,400yrs	α, γ
Thorium-234	24.1 days	β, γ
Uranium-235	7.0×10^8yrs	α, γ
Uranium-238	4.46×10^9yrs	α

Uranium Half- life

- One isotope that has a long half-life is U-238, which decays through a complex series of radioactive intermediates to the stable isotope of Pb-206
  - It's possible to use this method to date rocks nearly as old as the solar system



$^{238}_{92}U$
4.5x10⁹yr
α
$^{234}_{90}Th$
25 days
β,γ
$^{234}_{91}Pa$
6.7hrs
β,γ
$^{234}_{92}U$
2.5x10⁵yr
α
$^{230}_{90}Th$
8x10⁴yr
α,γ
$^{226}_{88}Ra$
2.3x10³yr
α,γ
$^{222}_{86}Rn$
4 days
α
$^{218}_{84}Po$
3 min
α
$^{214}_{82}Pb$
27min
β,γ
$^{214}_{83}Bi$
20min
β,γ
$^{214}_{84}Po$
.00016s
α
$^{210}_{82}Pb$
22yr
β,γ
$^{210}_{83}Bi$
5 days
β
$^{210}_{84}Po$
138 days
α
$^{206}_{82}Pb$

Radiocarbon Dating

Radioactive C-14 is formed in the upper atmosphere by nuclear reactions initiated by neutrons in cosmic radiation

$$^{14}N + {}^{1}_{0}n \longrightarrow {}^{14}C + {}^{1}H$$

The C-14 is oxidized to CO_2, which circulates through the biosphere.

When a plant dies, the C-14 is not replenished.

But the C-14 continues to decay with $t_{1/2} = 5730$ years.

Activity of a sample can be used to date the sample.

Limitations to radioactive dating

It is possible to heat igneous and metamorphic rocks to high enough temperatures that they no longer behave as “closed systems”.

That is some of the daughter products can “leak” out of the primary mineral, giving an erroneous parent/daughter ratio and hence a wrong age.

1. Phosphorus-32 has a half life of 14.3 days. How many milligrams of phosphorous-32 will remain after 57.2 days if you start with 4.0g of the isotope?

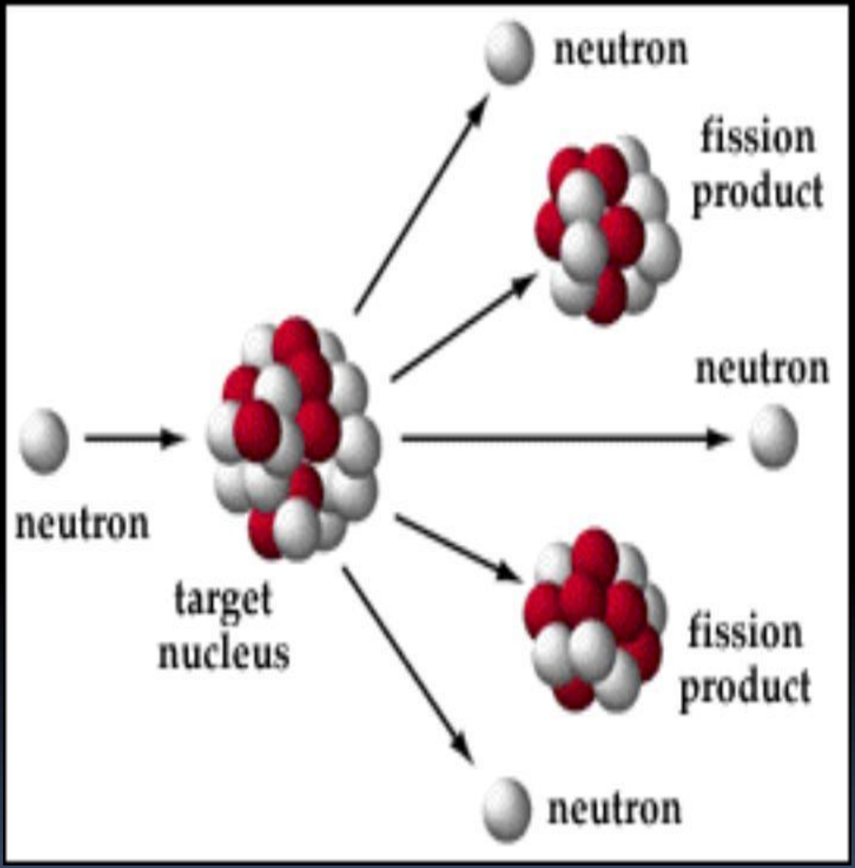
2. The half-life of iodine-131 is 8.040 days. What percentage of an iodine-131 sample will remain after 40.2 days?

Nuclear Fission

- In a nuclear fission reaction, a large nucleus is split into two smaller nuclei of approximately equal mass
- Fission rxns are used to provide what is commonly called nuclear power.

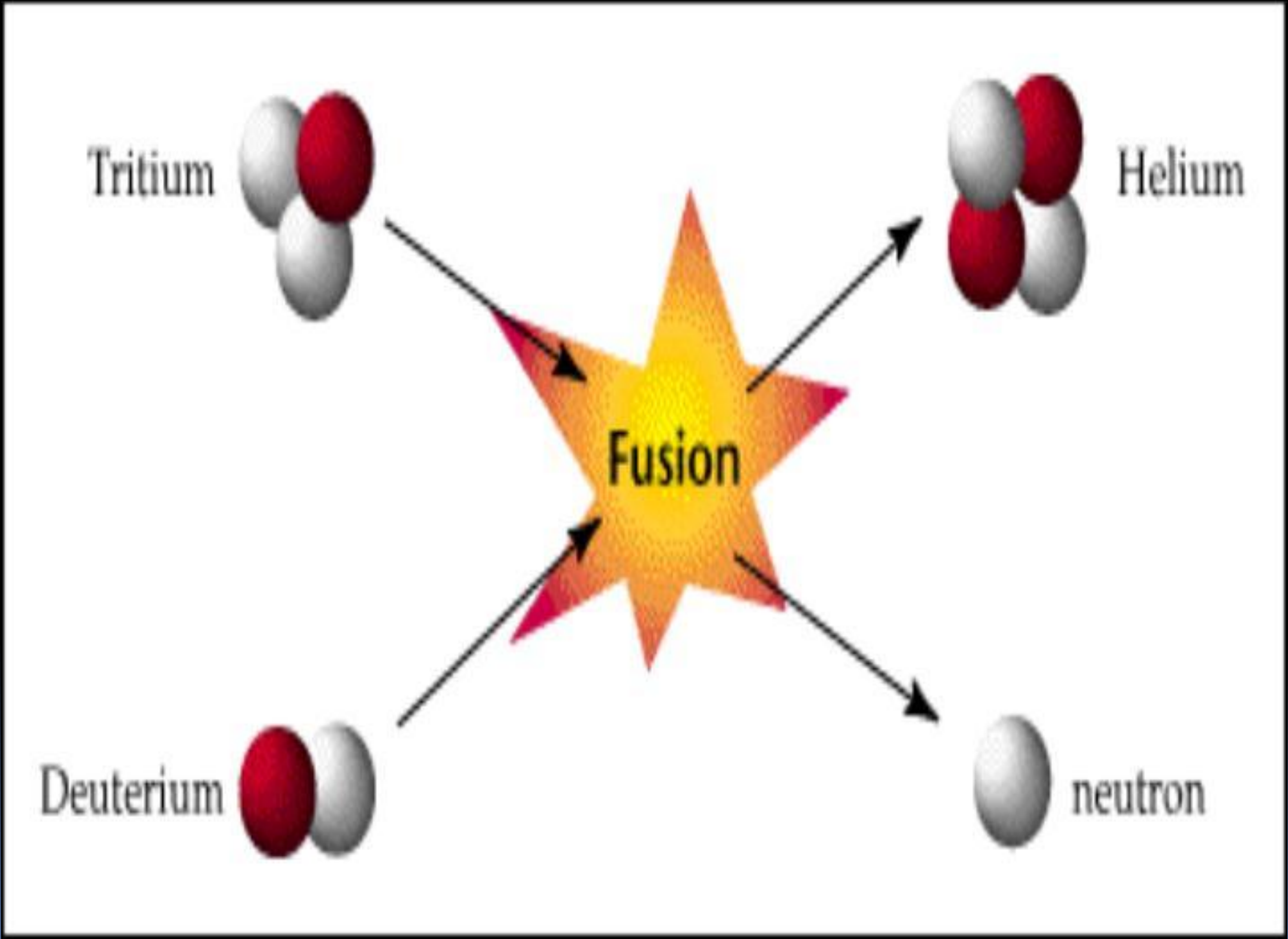
Nuclear Fission

- One fission rxn produces enough neutrons to start 3 more fission rxns, which in turn produces the neutrons needed to start 3 more rxns, and so on, in a series
called a nuclear chain reaction.



Nuclear Fusion

- In a nuclear fusion rxn, 2 small nuclei join to form a larger nucleus.
- Like a fission rxn, a fusion reaction converts some of the mass of the original nuclei into energy- a great deal of energy


Tritium
Helium
Fusion
Deuterium
neutron

Nuclear Fusion

- Fusion rxns are hard to produce and to control
- So far it takes a tremendous amount of heat to start
- Cold fusion is a natural research opportunity,
  - The goal is to harness the power of the sun