Alta Chemistry

CHAPTER 25

Nuclear Chemistry: Radiation, Radioactivity & its Applications

Nuclear Chemistry

- **Nuclear Chemistry** deals with changes in the *nucleus*
- The nucleus of an atom contains
  - Protons – Positively Charged
  - Neutrons – no charge
- **Atomic Number:** the number of *protons* in the nucleus, telling you what element you have.
- **Mass Number:** represents the total number of *protons* + *neutrons* in the nucleus, telling you what isotope of the element you have.

Element Shorthand

- Atomic Symbol for a given isotope of an element is generally given as noted to the right.
- Ex: Helium-4

Mass #

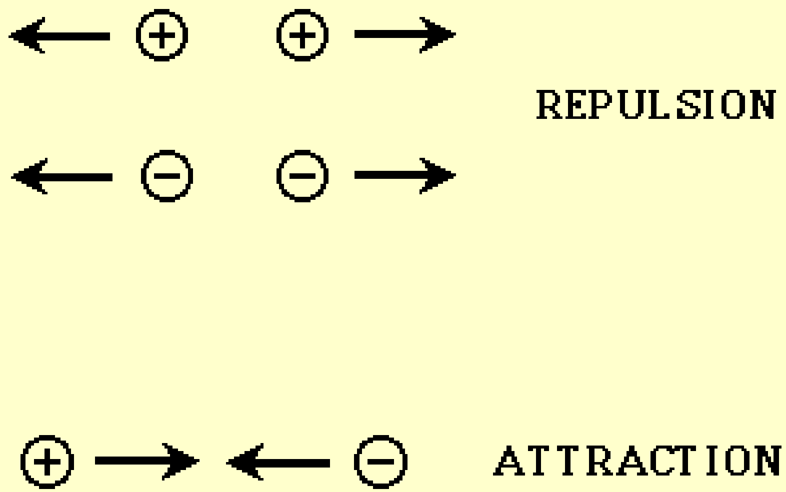
X

Atomic #

$$^{4}_{2}He$$

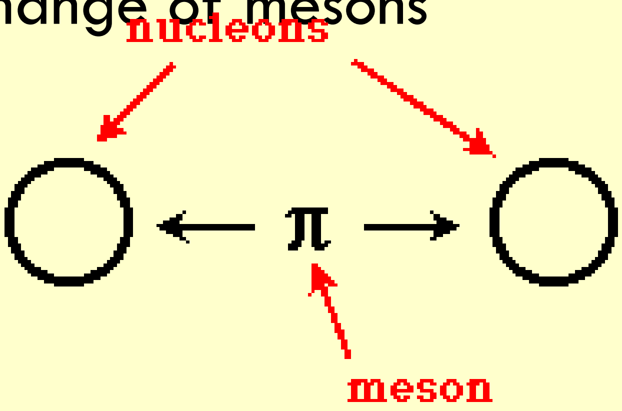
Electromagnetic Force

- ELECTROMAGNETIC FORCE: like charges repel and unlike charges attract



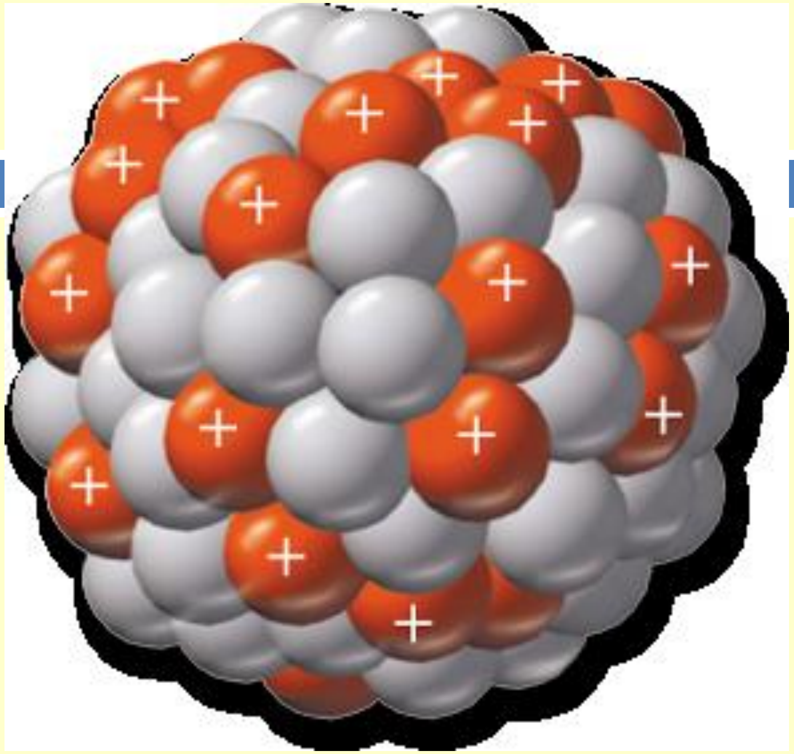
Strong Nuclear Force

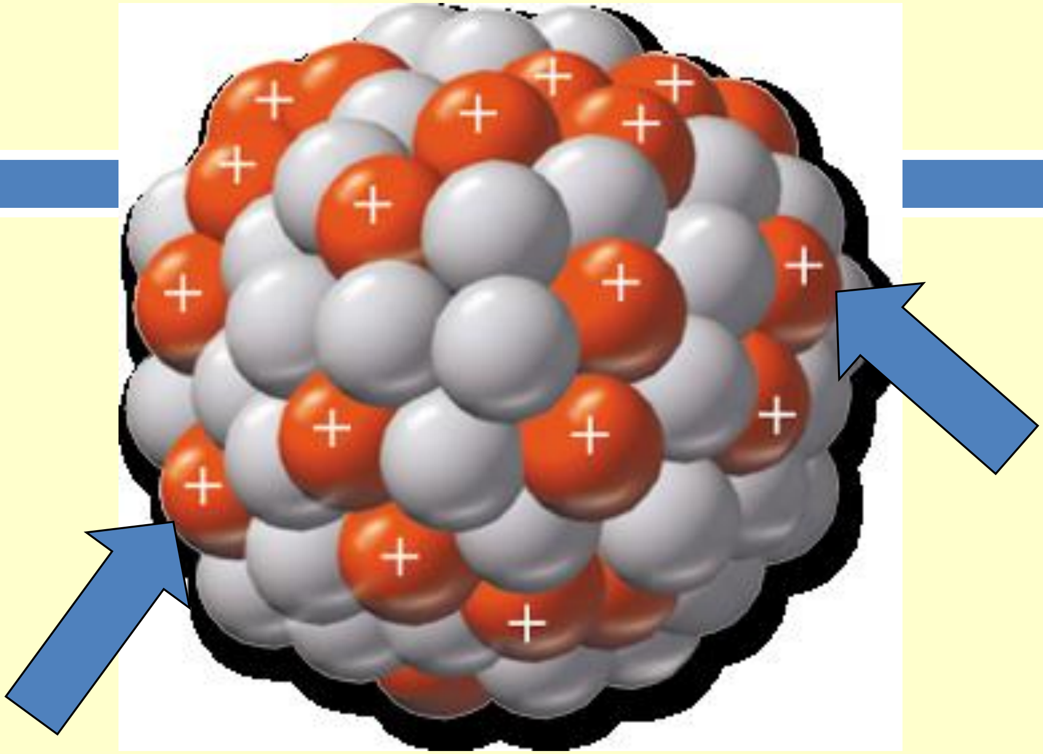
- **SO WHAT HOLD THE NUCLEAS TOGETHER???**
- STRONG NUCLEAR FORCE: strongest force in nature. Hold nucleons together (protons and neutrons) Only works when nuclear particles get really close to each other (about the width of a p+ or n°)
- Due to exchange of mesons



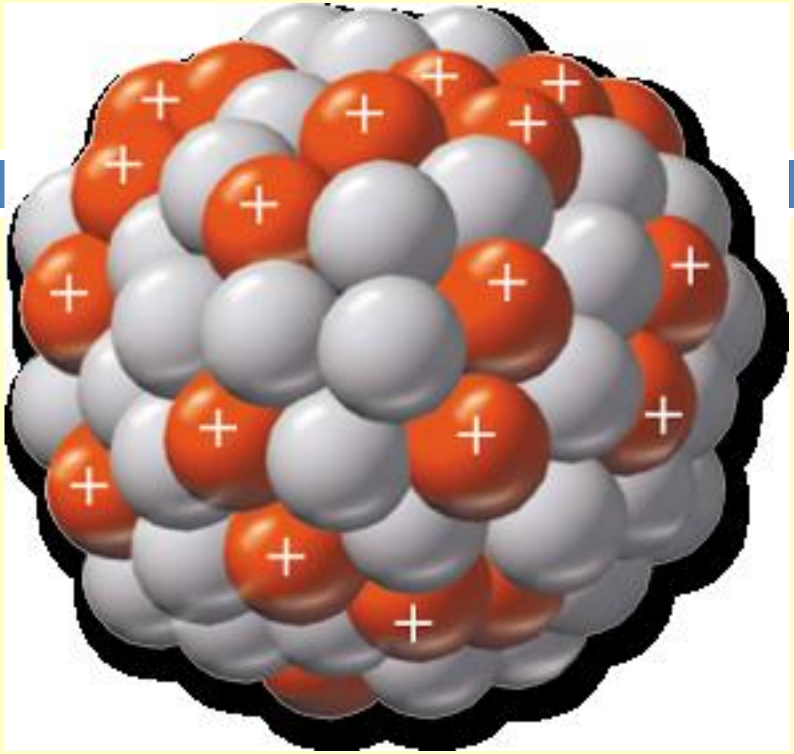
Strong Nuclear Force

- Neutrons help separate the protons and helps reduce the repulsion.
- Neutrons are neutral and will participate in this meson exchange.
- Explains why the nucleus is so dense.





These protons are not normally attracted to each other

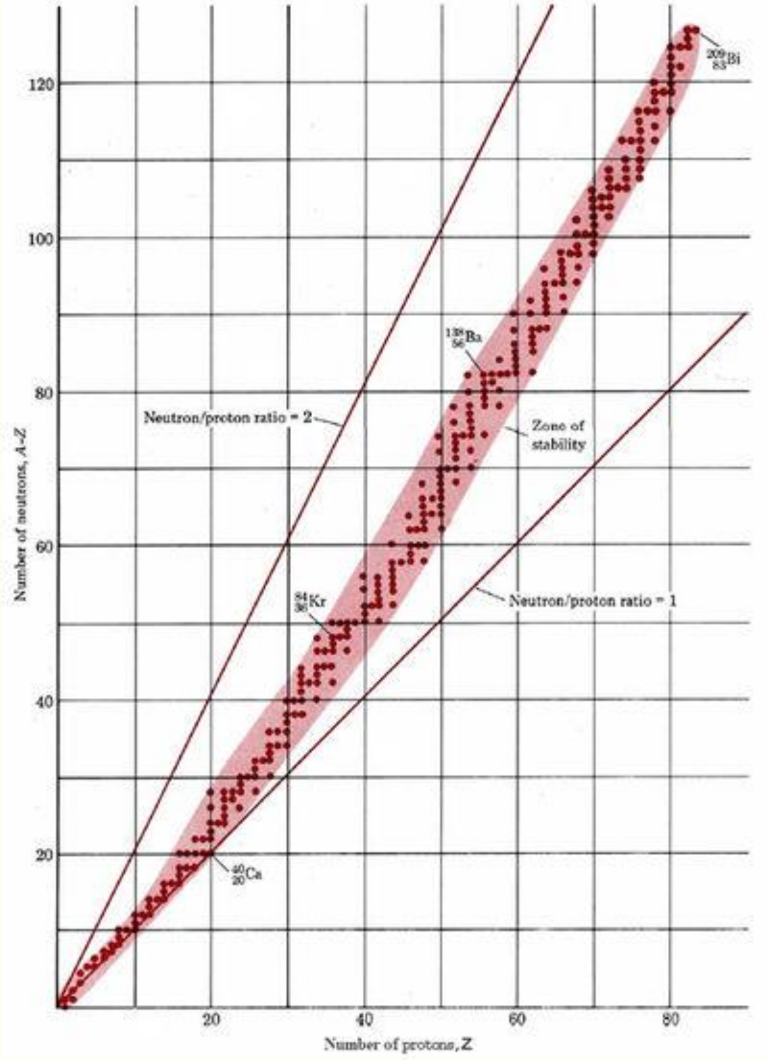


Neutrons are needed to create the strong nuclear force

Nuclear Stability

- Why are some nuclei stable and others are not?
  - If neutron to proton ratio is too low or too high, nuclei tend to be unstable.
  - Too Low: the electromagnetic force between protons takes over…
    - Neutrons help separate the protons so that they EMF doesn't take over
  - Too High: the electromagnetic force between protons takes over…
    - EMF acts over greater distances than the SNF. Therefore if too much space between protons, the EMF takes over and the nuclear crumbles.

Band of Stability: neutron to proton ratio



For lighter elements (atomic # <20) ideal ratio is 1:1

As atomic # increases, stability shifts to more neutrons

Nuclear Stability cont.

- Nuclei containing more than 83 p+ are unstable (radioactive)
- Nuclei with an even number of nuclear particles tend to be more stable than with an odd #
- Magic Numbers: 2, 8, 20, 28, 50, 82 and 126: meaning that nuclei with these number of p+ or n° tend to be stable.
  - Ex: $^{16}_{8}O$ or $^{208}_{82}Pb$

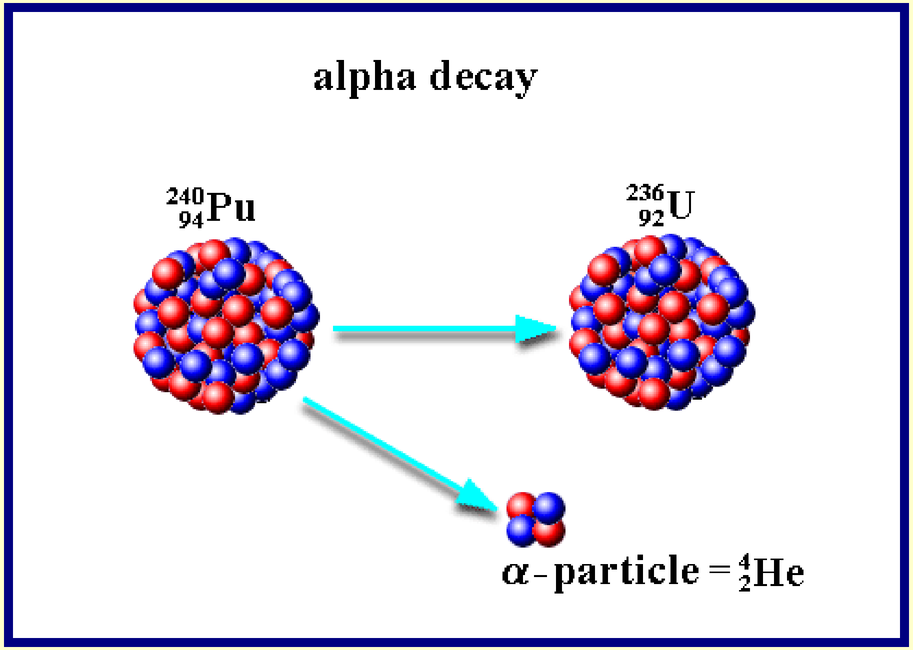
Radioactive Decay

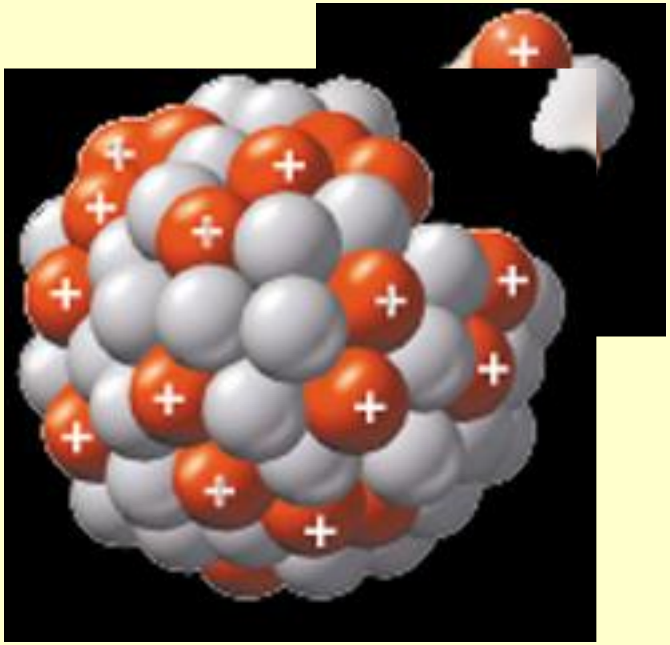
- If the nucleus is unstable (radioactive), it will breakdown, or **DECAY**, in order to become stable
- Decay is accompanied by the release of radioactive particles from the nucleus
- Can be written using **Nuclear Equations:**
  - Ex: $${}^{210}_{84}Po \longrightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$$
- There are three types of Decay:
  - **Alpha** (α) Decay
  - **Beta** (β) Decay
  - **Gamma** (γ) Decay

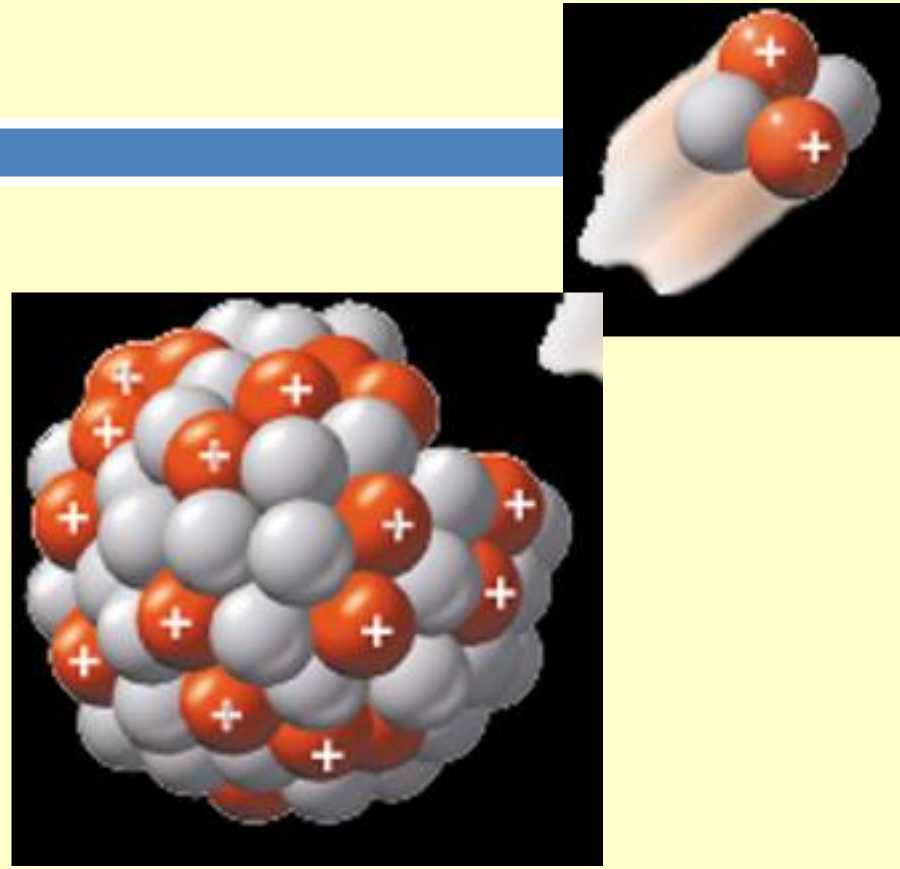
Alpha (α) Decay

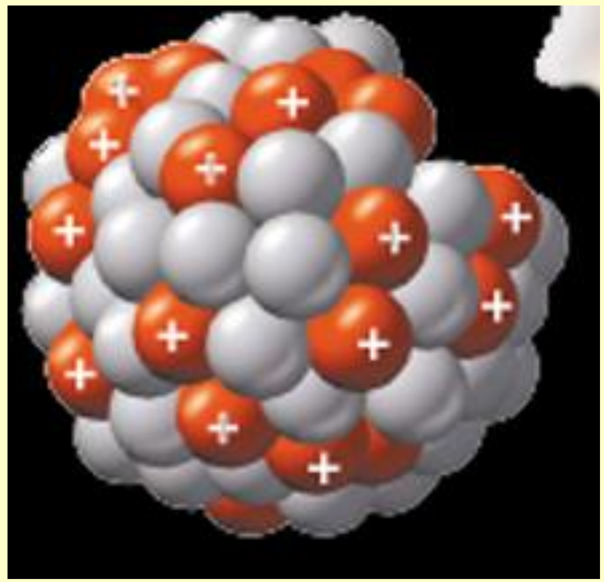
- The emission of the *nucleus of a helium atom* (2 p^+ and 2 n^o)
  - What is the charge on an alpha particle?
    - \+ positive
  - Can be stopped by a sheet of paper, is harmful only if ingested

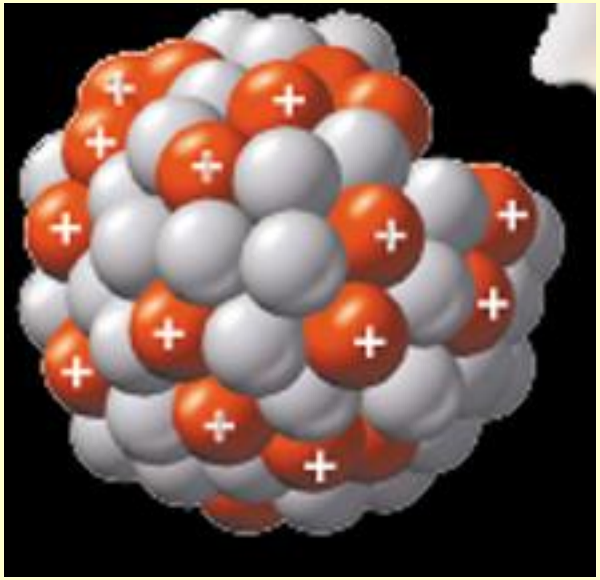
$$^{240}_{94}Pu \rightarrow ^{236}_{92}U + ^{4}_{2}He$$







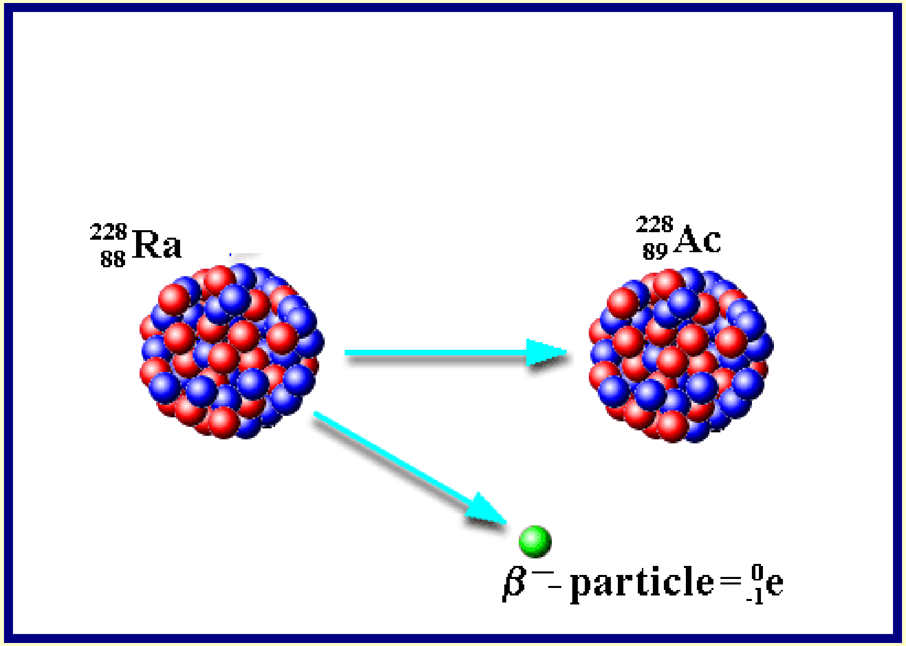




Beta (β) Decay

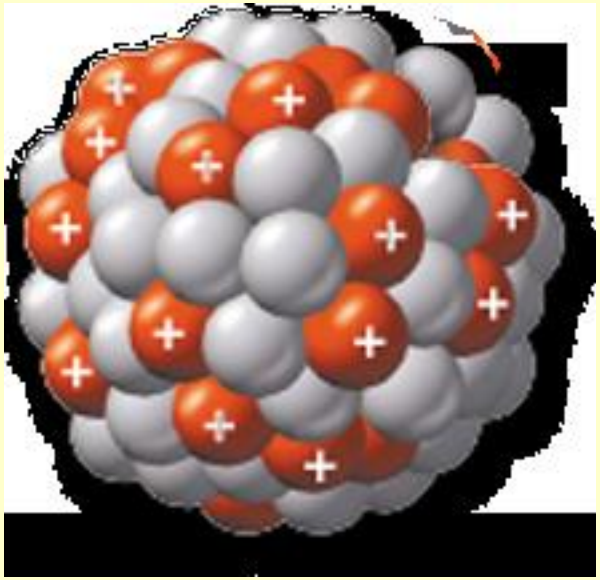
- The emission of an electron from the *breaking apart of a neutron* into a proton and electron
  - What is the charge on a beta particle?
    - \- negative
  - Can be stopped by a sheet of lead, is harmful to all living tissue

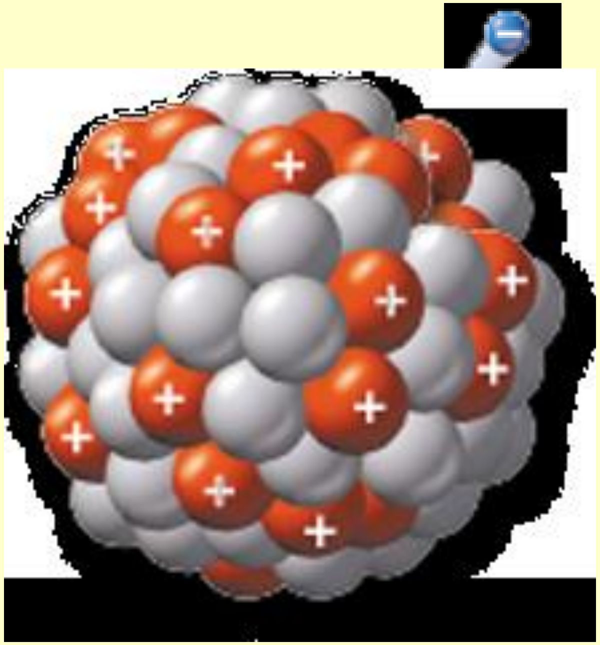
$$^{228}_{88}Ra \rightarrow ^{228}_{89}Ac + ^{0}_{-1}e$$

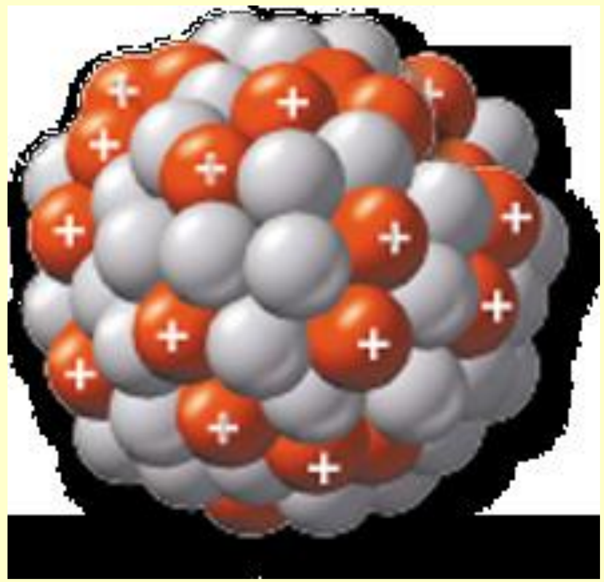


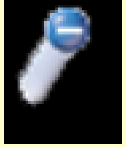
A lone neutron…

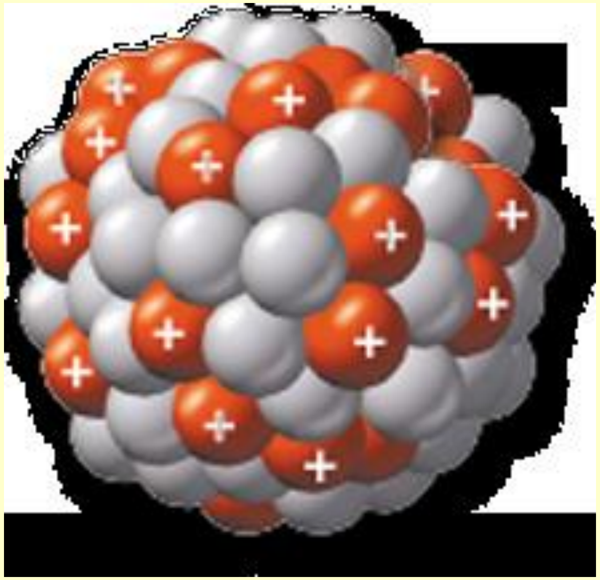
...converts to a proton!

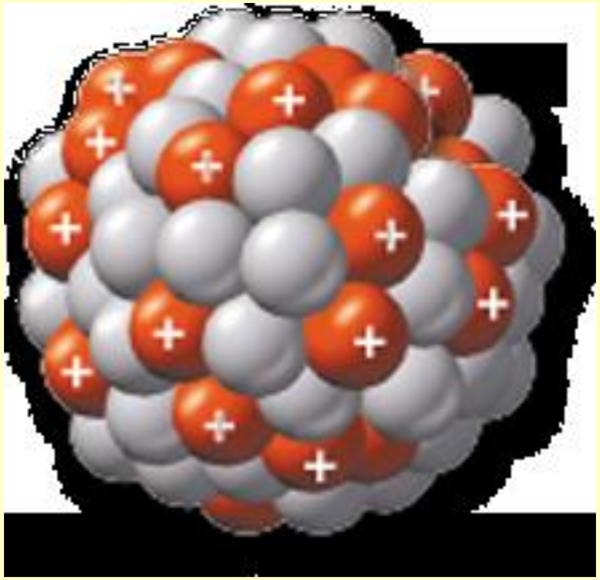










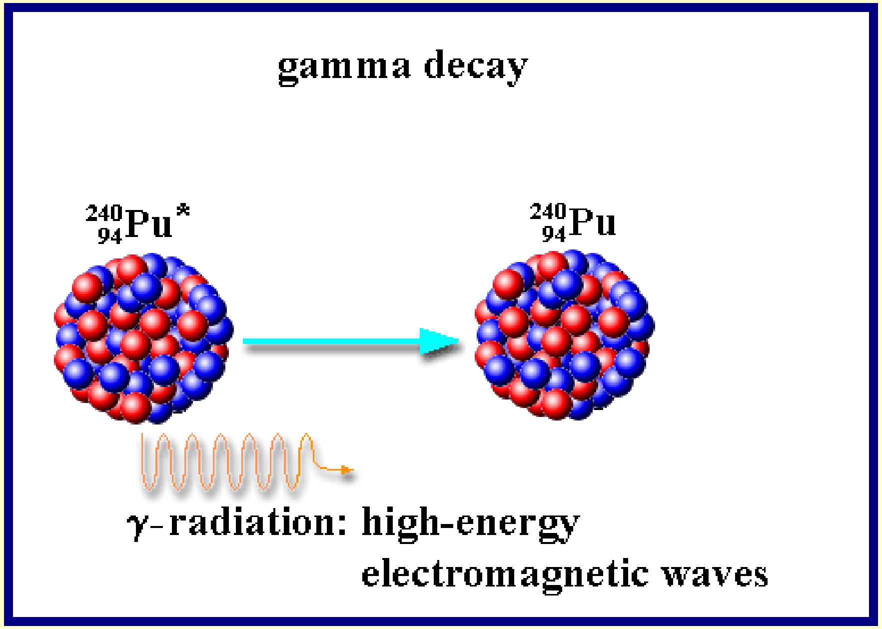


Hmm…extra proton?

Gamma (γ) Decay

- The emission of a high energy photon
  - Usually happens along with alpha or beta decay
  - What is the charge on a gamma particle?
    - no charge
  - Can be mostly stopped by very thick blocks of heavy, dense, substances like lead. Very harmful to all living tissue.

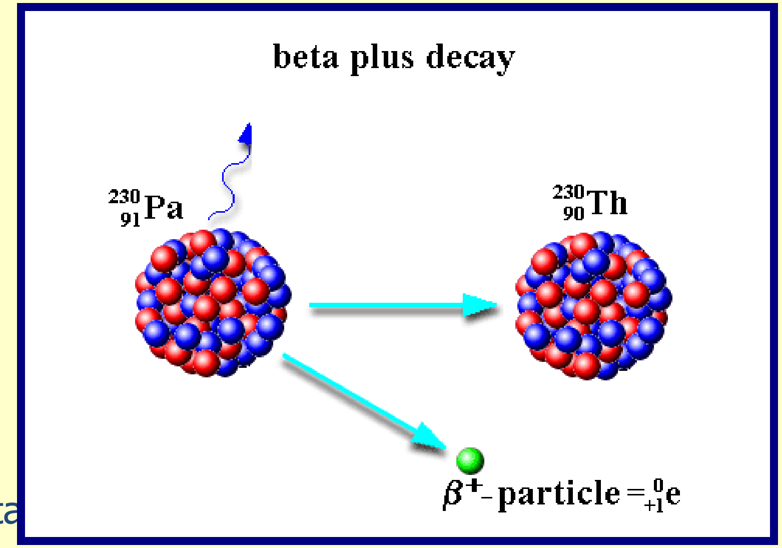
$$ {}^{240}_{94}Pu^* \rightarrow {}^{240}_{94}Pu + \gamma $$



Positron Emission (aka. Beta-plus)

- The emission of an + charged electron-sized particle (an anti-electron) from the *breaking apart of a proton*, which changes the proton into a neutron.
- What is the charge on a positron particle?
    - + positive
- Low energy emission: can be stopped by a sheet of aluminum foil.

$$^{230}_{91}Pa \rightarrow ^{230}_{90}Th + ^{0}_{+1}e$$



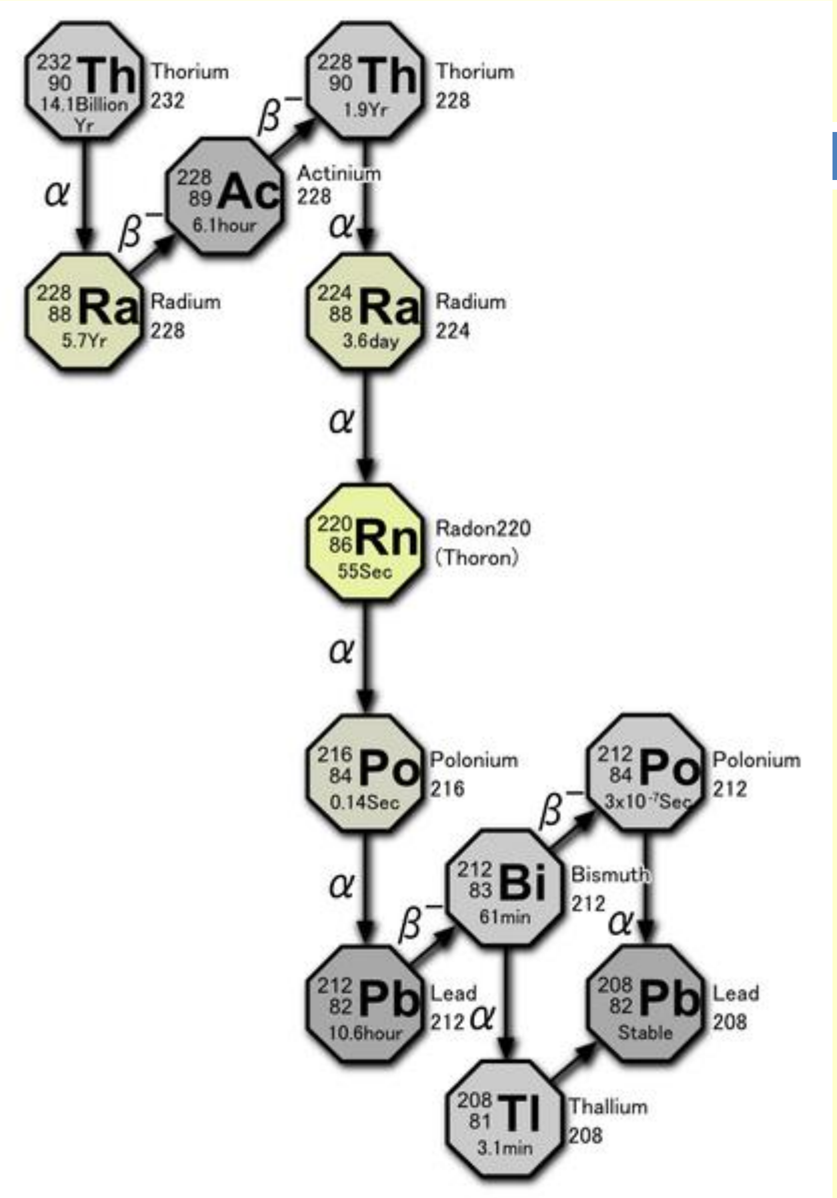
4 types of decay summary

Type of Decay	Particle Emitted	Change in Mass #	Change in Atomic #
Alpha (α)	${}^{4}_{2}He$	Decreases by 4 amu	Decreases by 2
Beta (β-)	${}^{0}_{-1}e$	Stays same	Increases by 1
Gamma (γ)	γ	Stays same	Stays same
Positron (β+)	${}^{0}_{+1}e$	Stays same	Decreases by 1
Electron Capture	x-ray	Stays same	Decreases by 1

- **When too many neutrons:** Alpha and Beta decay decrease neutron number
- **Too little neutrons:** Positron emission or electron capture increase neutron number

Decay Sequences

- Many radioactive isotopes that undergo decay will decay into elements that are themselves radioactive.
- This is also called a decay chain…



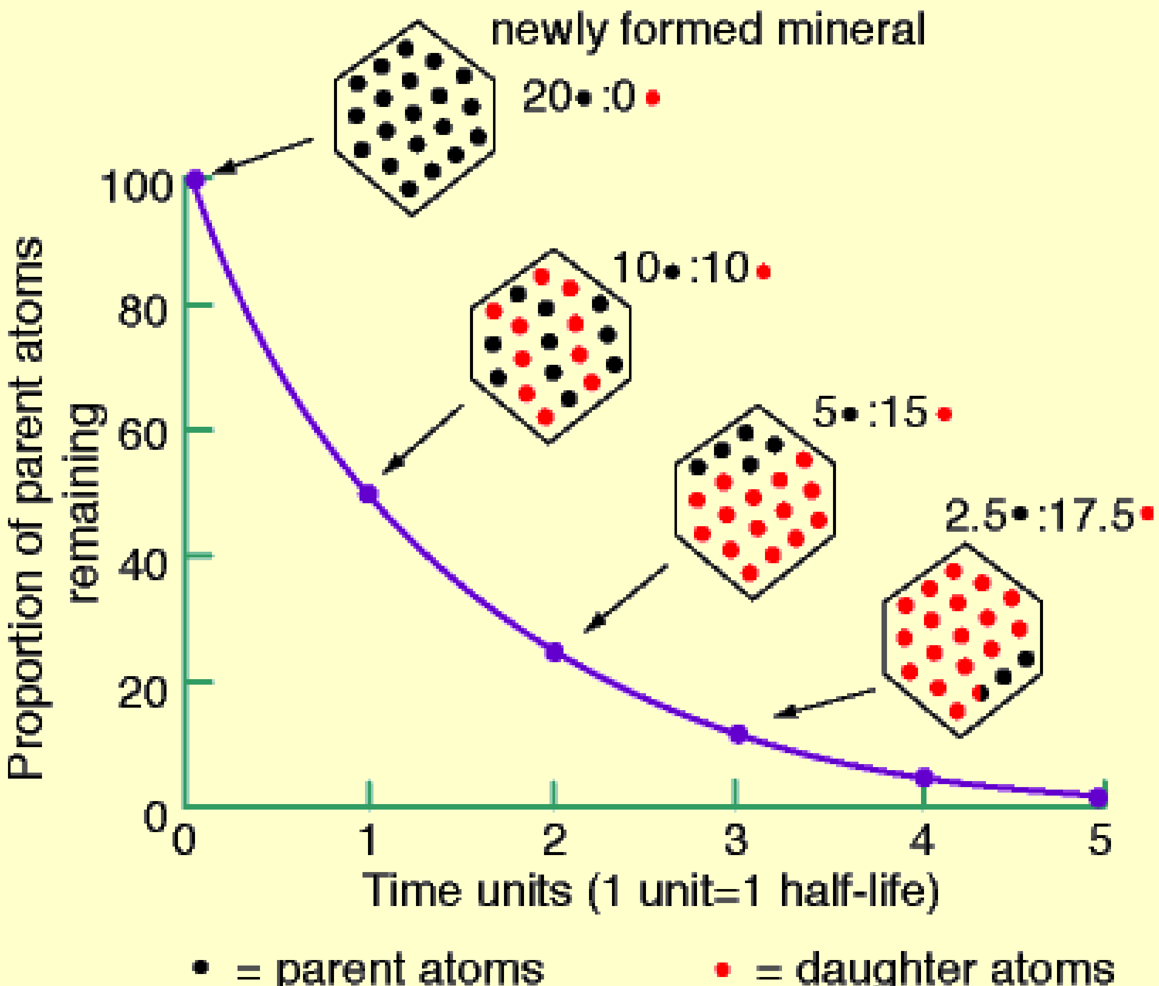
Nuclear Bombardment

- When stable nuclei are converted into a radioactive nucleus by bombarding the stable nucleus with either:
  - A neutron
    - Ex: $^{11}_{5}B + ^{1}_{0}n \rightarrow ^{11}_{4}B + ^{1}_{1}H$
  - A charged particle (positron, electron, alpha-particle)
    - Ex: $^{9}_{4}Be + ^{4}_{2}He \longrightarrow ^{12}_{6}C + ^{1}_{0}n$
- Used to make cancer treatment medications
- Used to make diagnostic medications

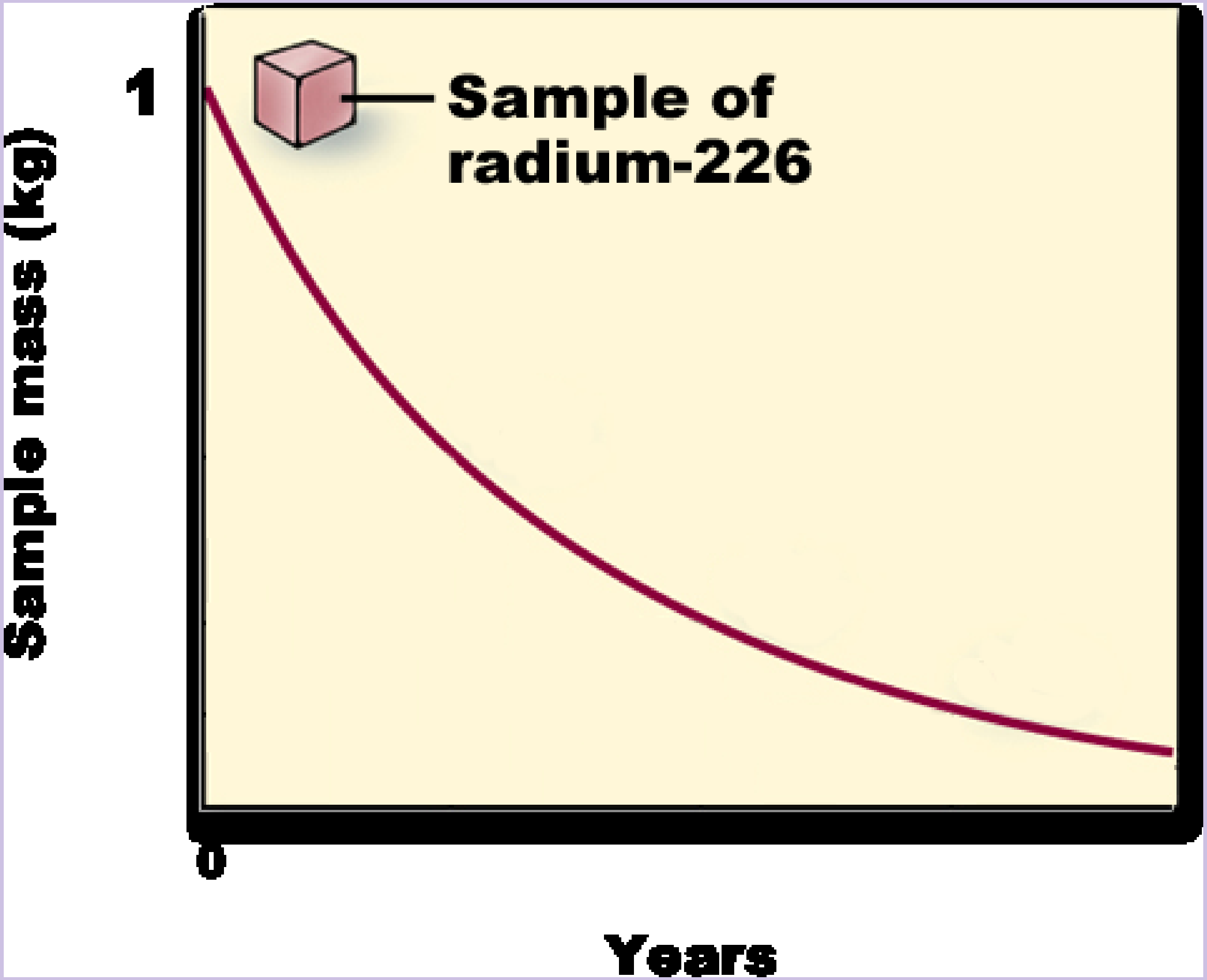
Radioactive Half-Life

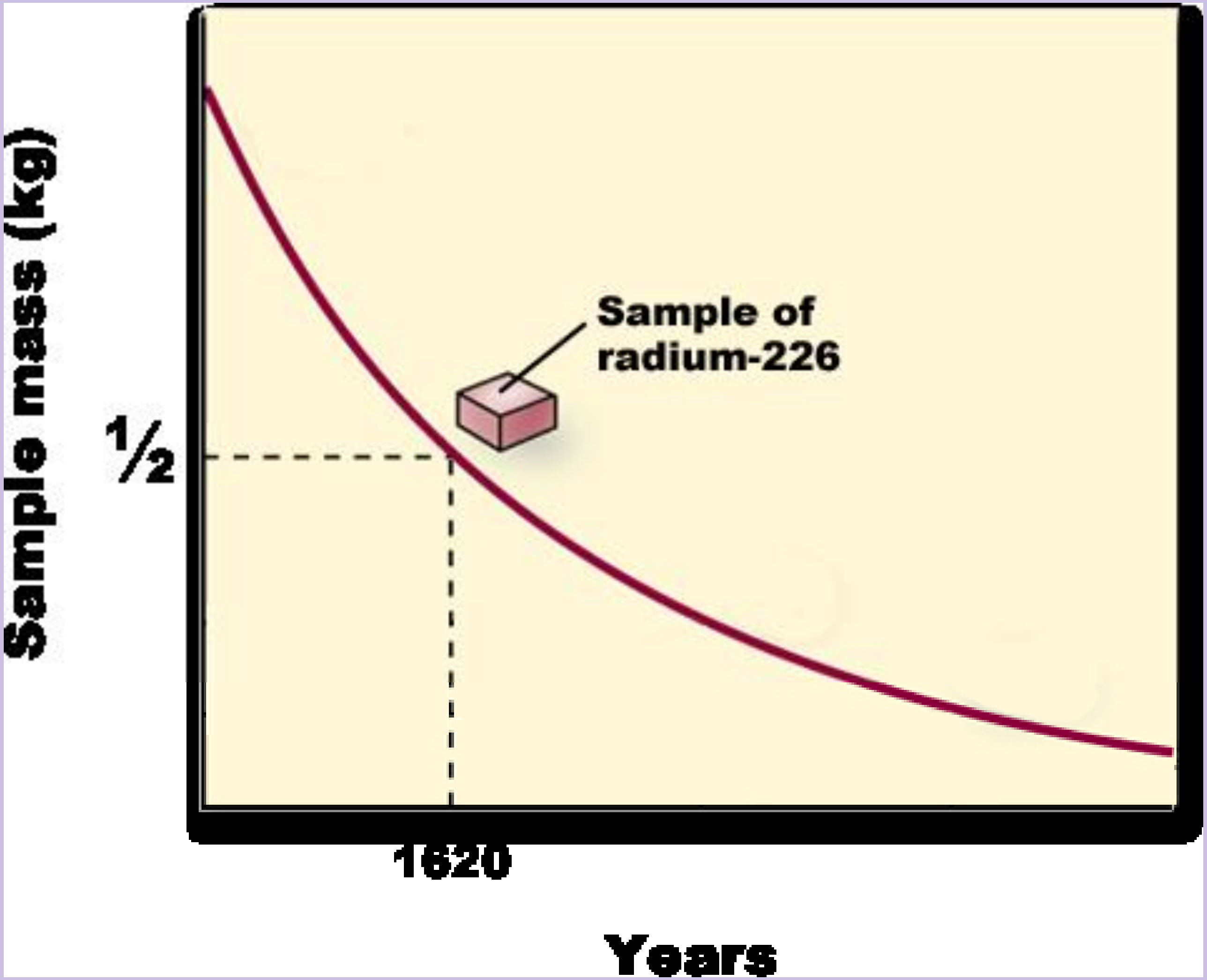
The Time it takes for *half* of a sample of a radioactive element to decay.

Element	Half Life
Uranium-238	4.5×10^9 years
Carbon-14	5730 years
Bismuth-210	5.0 days
Polonium-214	1.6×10^{-4} sec

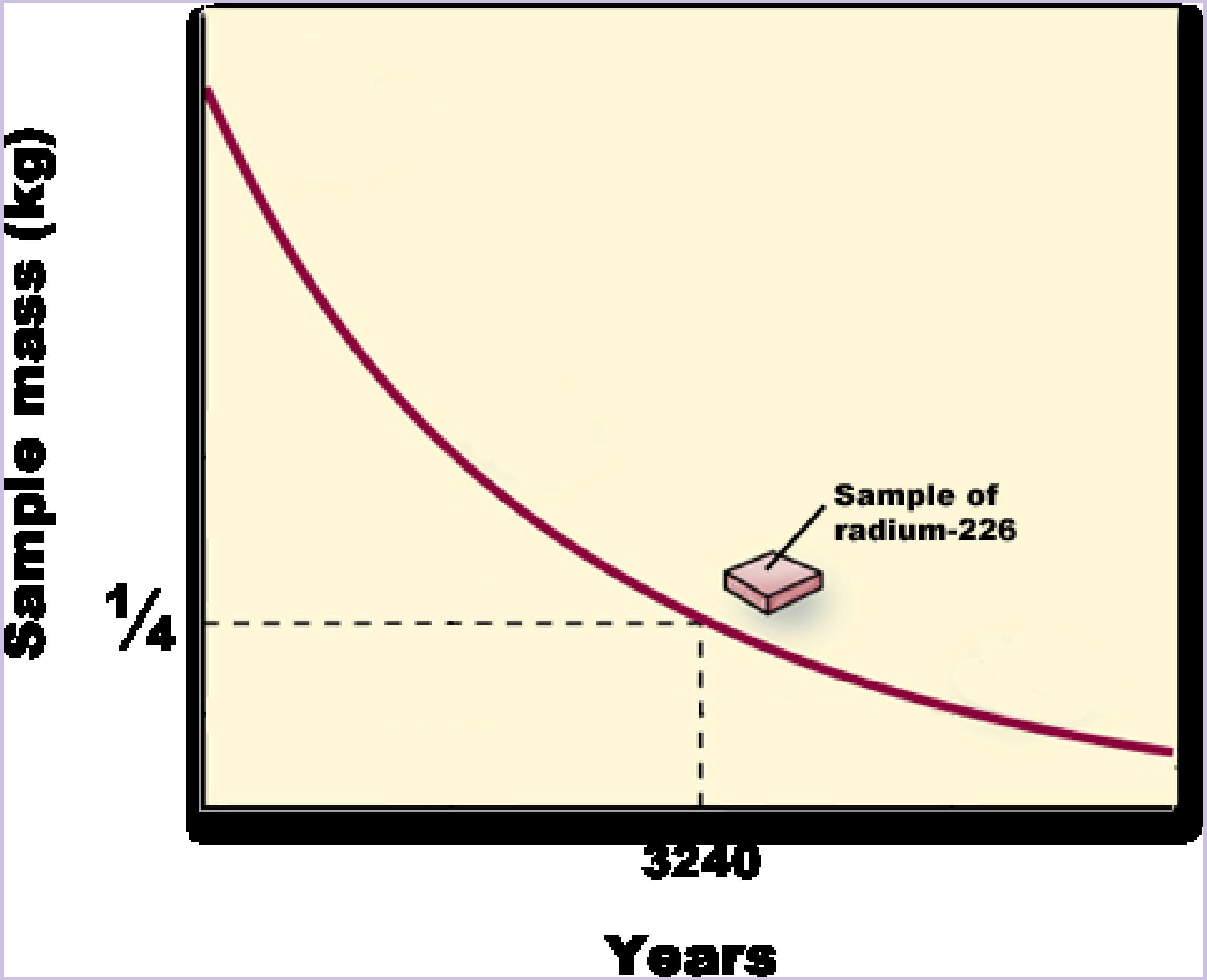


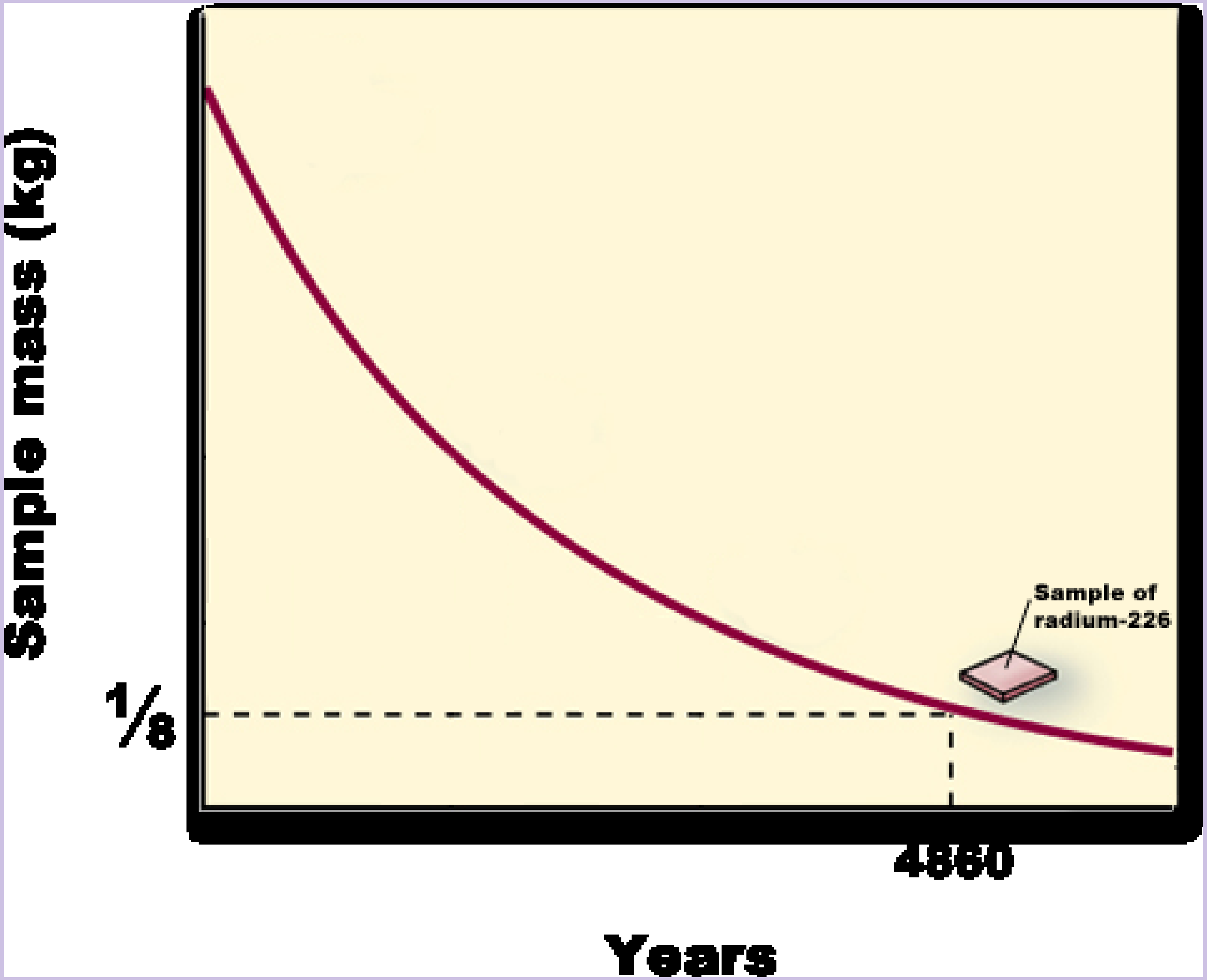
Alta Chemistry

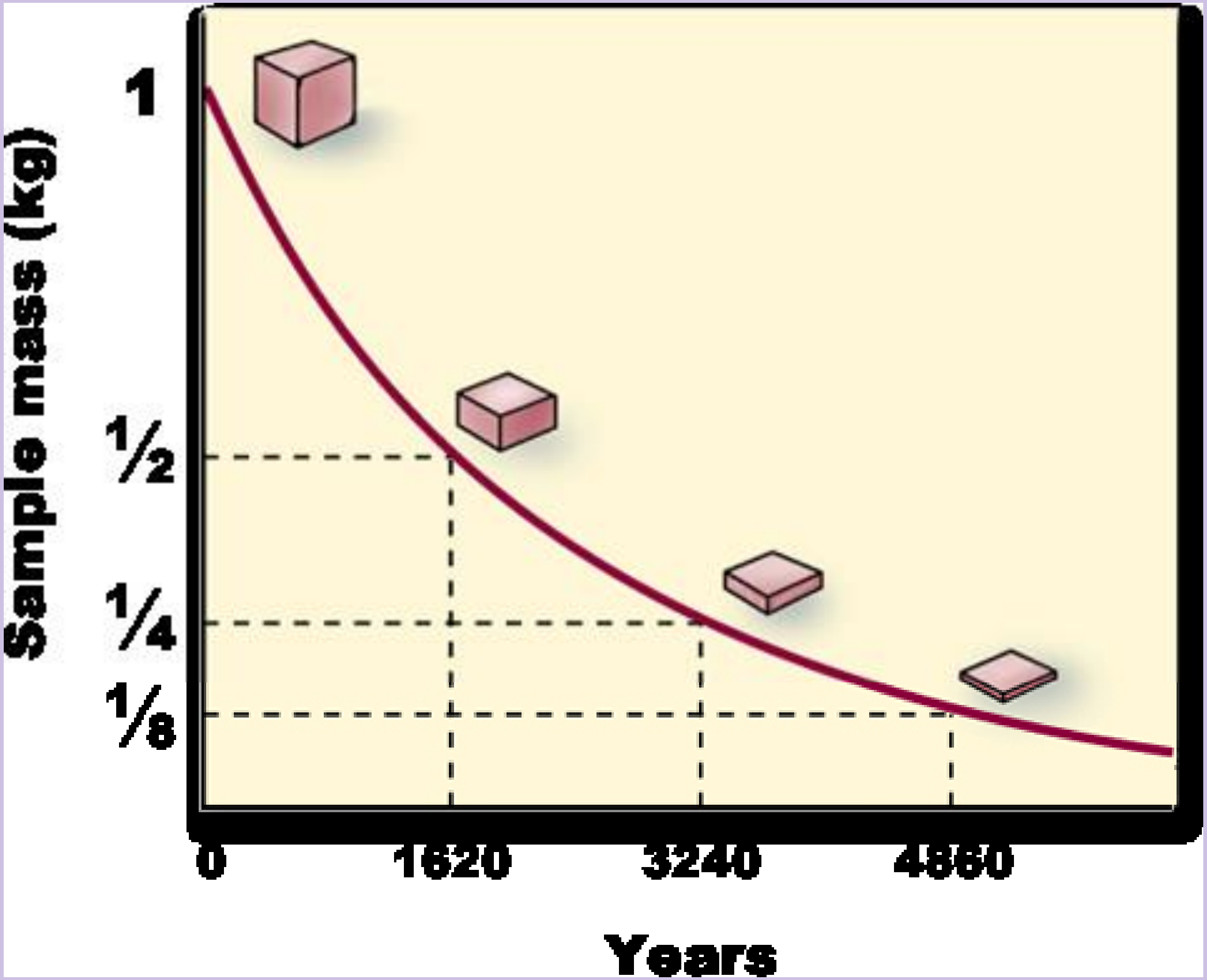

1
Sample of
radium-226
Sample mass (kg)
0
Years



Sample mass (kg)
½
Sample of radium-226
1620
Years

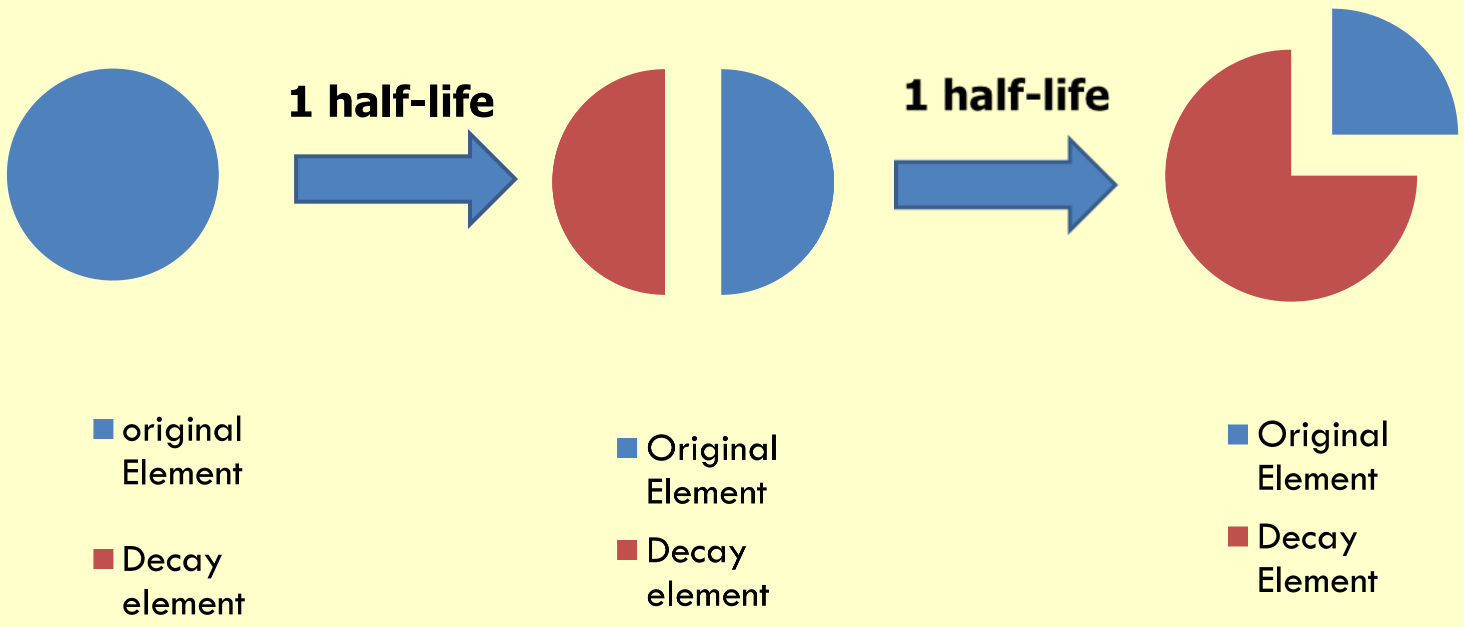

Sample mass (kg)
¼
Sample of
radium-226
3240
Years


Sample mass (kg)
1/8
Sample of
radium-226
4860
Years


Sample mass (kg)
1
½
¼
⅛
0
1620
3240
4860
Years

Counting Half-Lives

- Ex: If, after some time, ¼ of a sample of a radioactive element has not decayed, how many half-lives has it gone through?



Sample Problem

Carbon-14, a radioactive isotope of carbon, has a half life of 5730 years. If a 20 gram sample of carbon-14 is allowed to decay for 11,460 years, how much remains at the end of this period?

Solution

- Start by Figuring out how many half lives have passed.

11,460 yrs/5730 yrs= 2 half lives

- Started with 20 grams

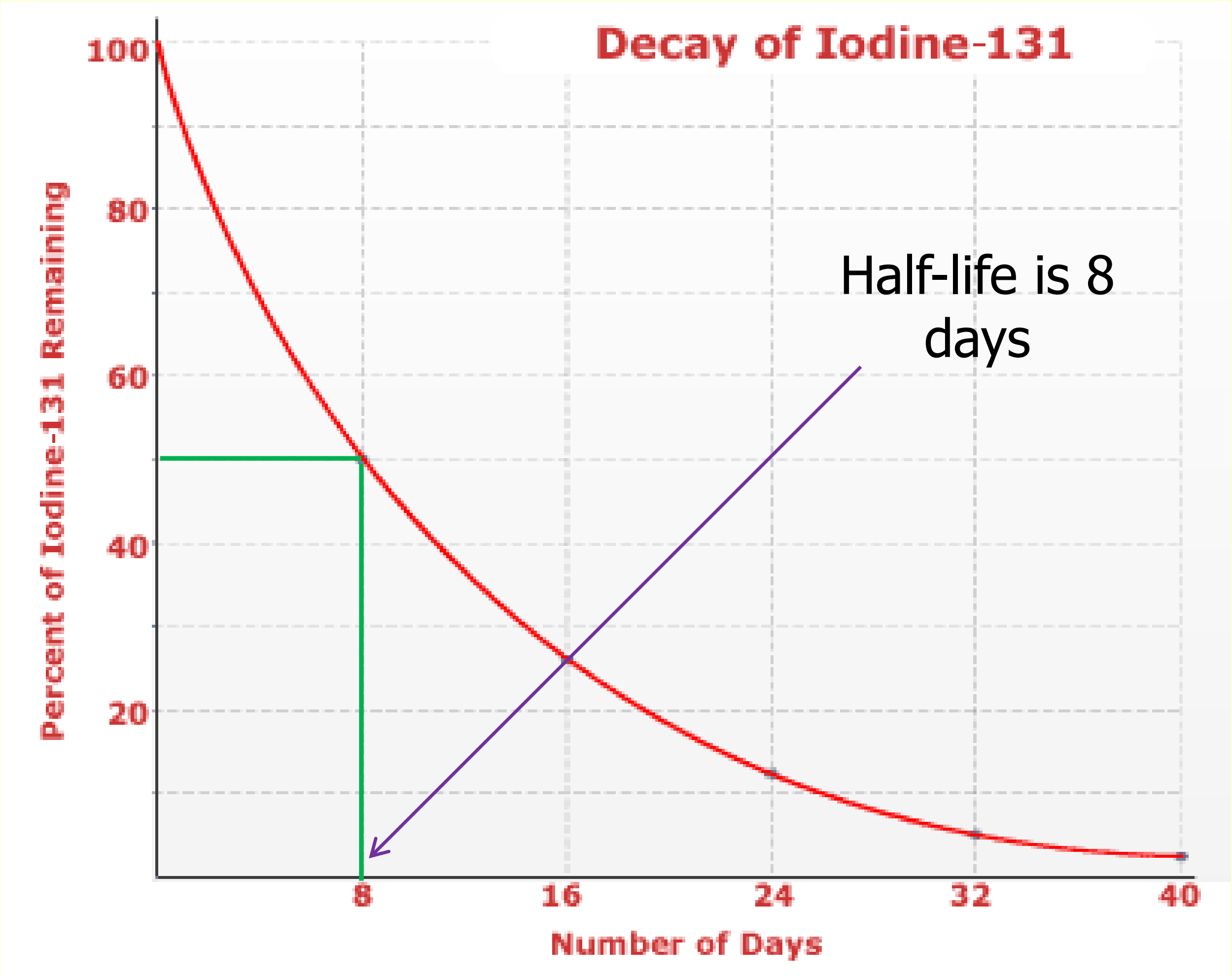
20/2 = 10 grams after 1 half life

10/2 = 5 grams after 2 half lives

5 grams left after 11,460 years

Half Life Graphs

What is the half life of Iodine 1-31 from this graph?



Nuclear Reactions

- Two Types of Nuclear reactions produce extremely large amounts of energy according to Einstein's famous equation

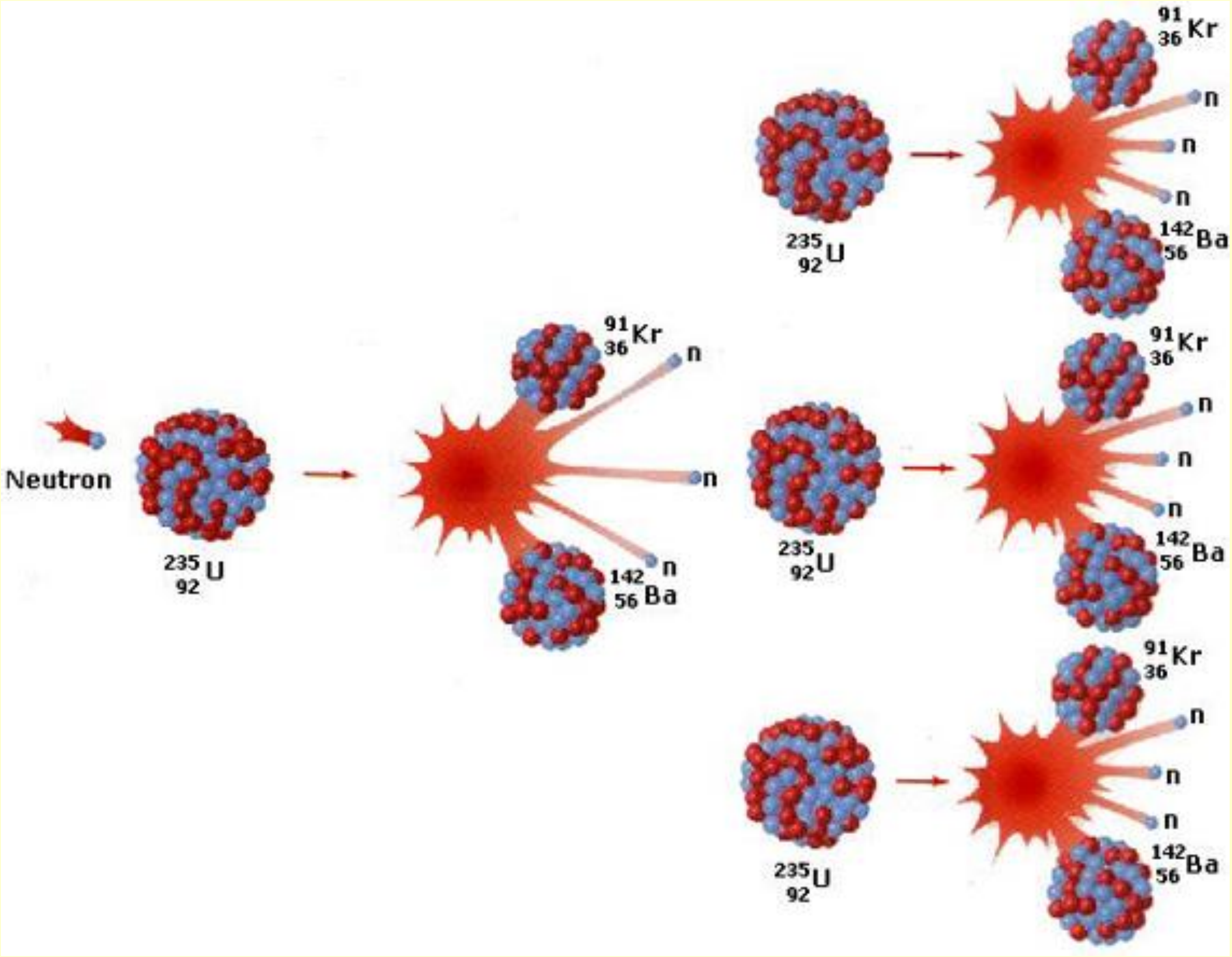
$$E = mc^2$$

  - **Fission** – the splitting of an atom into smaller parts
  - **Fusion**- the joining of two small nuclei to produce one larger nucleus

Fission

- Usually caused by **neutron bombardment** of a large nucleus, causing the nucleus to split into two smaller nuclei and some single neutrons.
- The resulting pieces fly into other nuclei causing them to split as well = **Chain Reaction!**

Fission


Neutron
235 92 U
91 36 Kr
142 56 Ba
n
n
n
235 92 U
91 36 Kr
142 56 Ba
n
n
n
235 92 U
91 36 Kr
142 56 Ba
n
n
n
235 92 U
91 36 Kr
142 56 Ba
n
n
n

Fission cont…

Nuclear Equation for Fission:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{90}_{37}Rb + ^{143}_{55}Cs + 3^{1}_{0}n$$

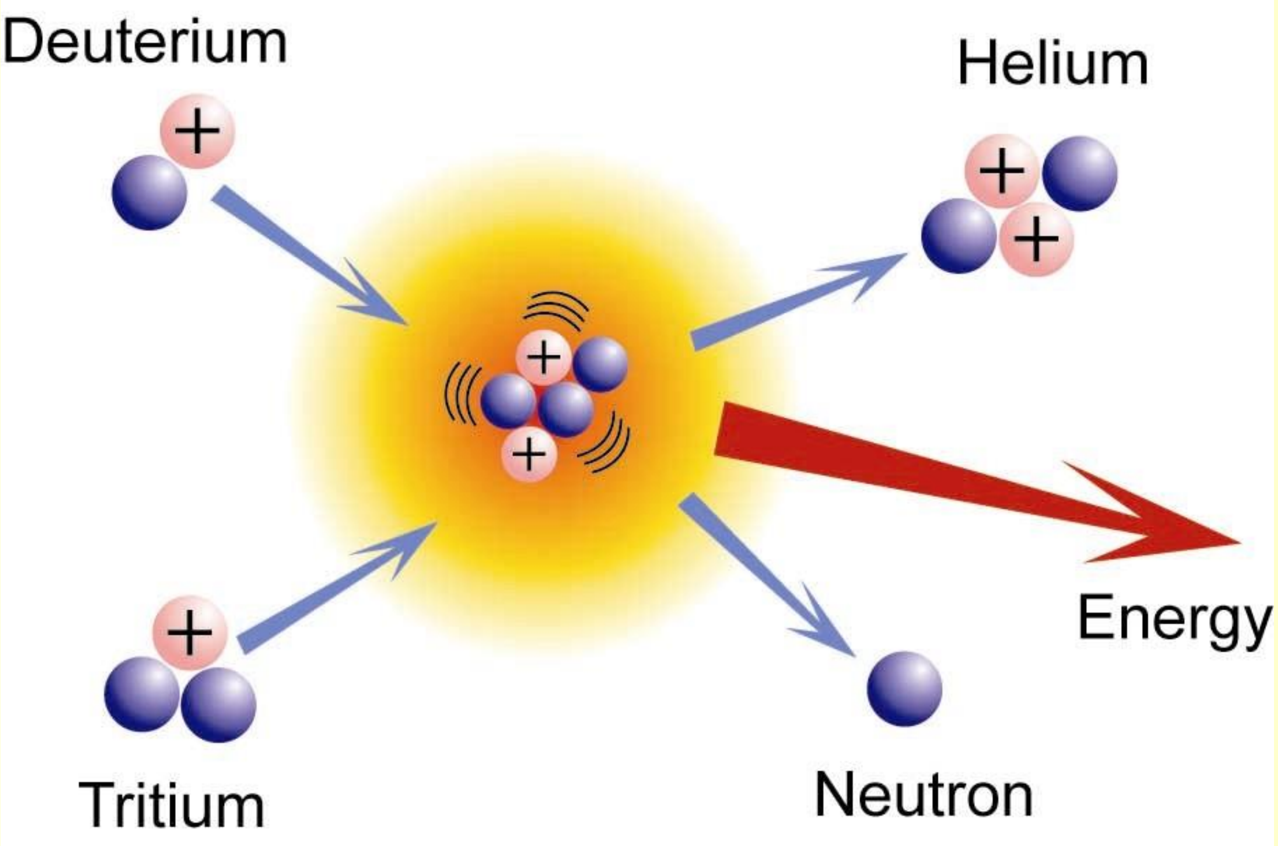
Nuclear Fission continued…

- The only two fissionable isotopes are **U-235** and **Pu-239**
- Mass is converted into energy when the nucleus splits.
  - **$E=mc^2$**
- All current nuclear reactor technology uses fission
- **Atom bombs** use fission reactions

Fusion

- Fusion reactions take lighter nuclei, like H and He, and **fuse** them together to make a heavier nucleus.
  - This is done by bringing the nuclei so close together that the nuclear forces “glue” the nuclei together.
- Mass is converted into energy when small nuclei join
  - $\mathbf{E=mc^2}$

Fusion



Fusion cont…

Nuclear Equation for Fusion:

$$ {}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n $$

Fusion continued…

- Fusion can only occur at **extremely high temperatures** and is very difficult to produce under laboratory conditions
  - Fusion reactions start at 1,000,000 °C
  - Currently no workable fusion reactor has been produced on earth
- The sun and stars all produce energy due to nuclear fusion
- Fusion reactions are often called THERMONUCLEAR REACTIONS
- Hydrogen bombs use fusion reactions

Origins of Elements

- All atoms started out as hydrogen, 90% of universe is still hydrogen
- Over time heavier nuclei, such as iron were formed due to FUSION:

Hydrogen →

helium →

carbon and oxygen→

iron and other elements

Elements on earth are heavier elements which have undergone this process.

Quiz

- What is fusion? (2pts)
- What is fission? (2 pts)
- What are the only fissionable isotopes? (2 pts)
- What nuclear reaction created the elements? (1 pt)
- What isotope of hydrogen is used in a H-bomb? (1 pts)
- Why don't we use fusion in nuclear reactors? (2 pt)