**Dep. of Chem.- Fac. of Science.** **South Valley University**

# Course of:

# Nuclear Chemistry

**A part of:**

**Physical Chemistry (IV) (Chm 455) course.**

**For B.Sc Science students (Zoology group)**

Prepared by:


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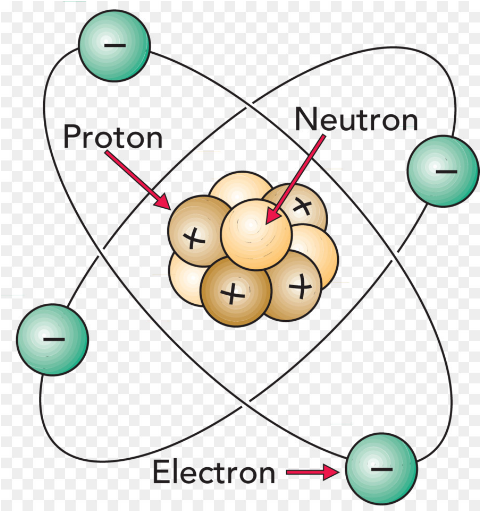


# Nuclear Chemistry

$4^{th}$ Year Zoology

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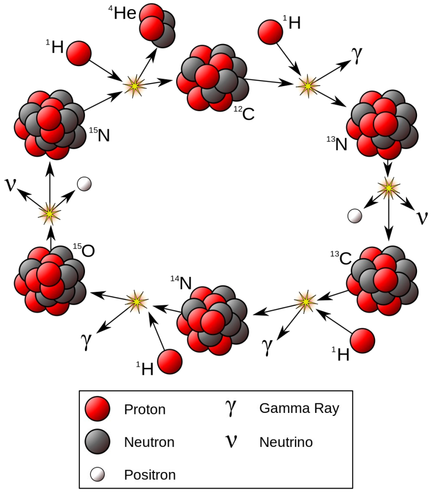
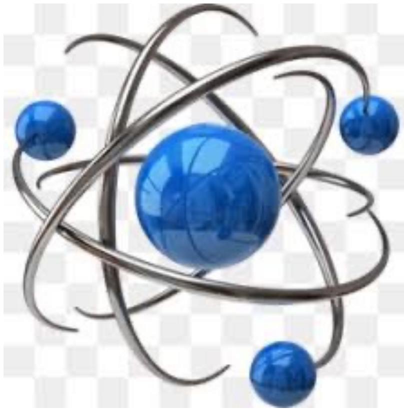
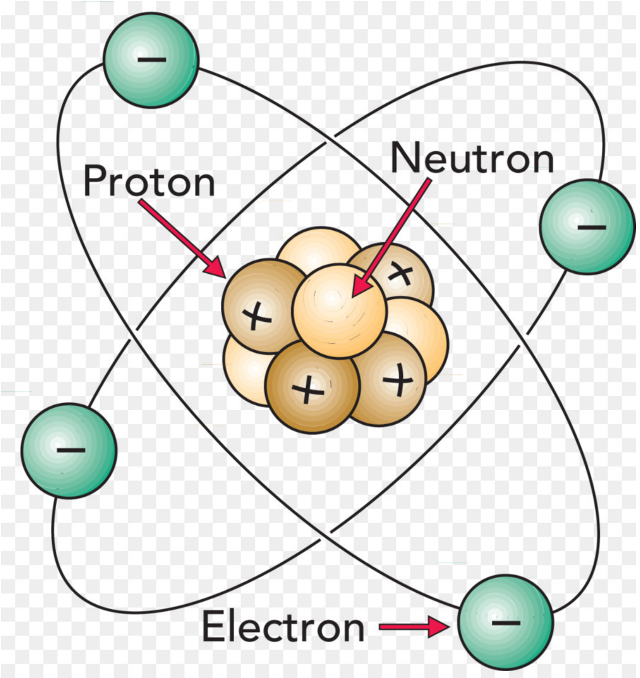
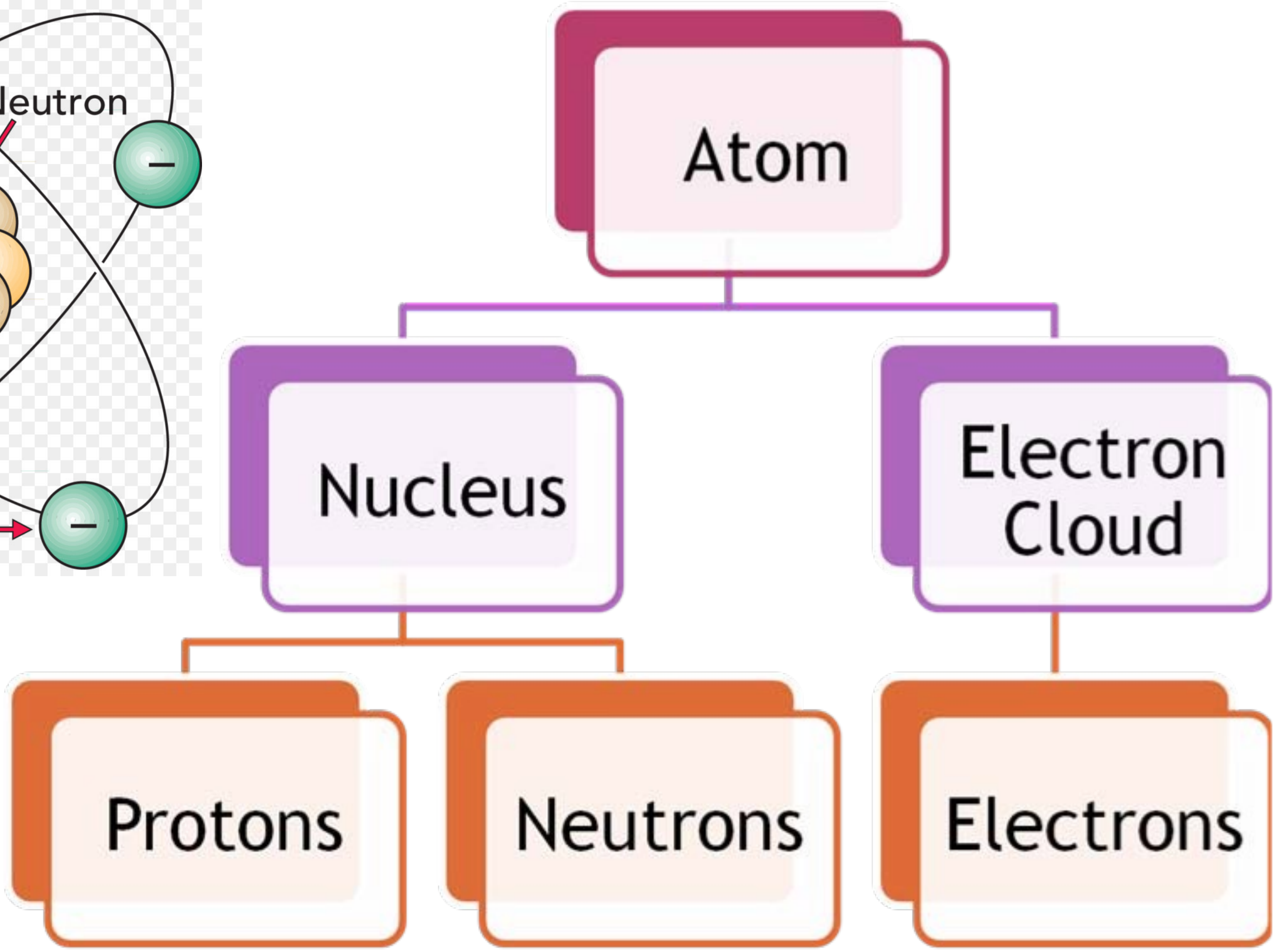



# Basics of Nuclear Chemistry

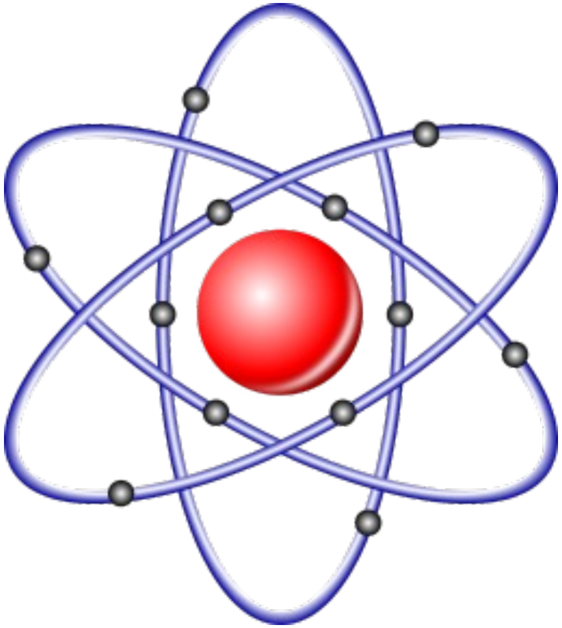


# BASICS OF NUCLEAR CHEMISTRY


Proton
Neutron
Electron


Atom
Nucleus
Electron Cloud
Protons
Neutrons
Electrons

# THE ATOM



- **Very basic structure.**
- **Mostly empty space.**
- **Atomic Radius measured in picometer ($10^{-12}$ m).**
- **Radius of nucleus measured in femtometer ($10^{-15}$ m)**

# HELIUM ATOM

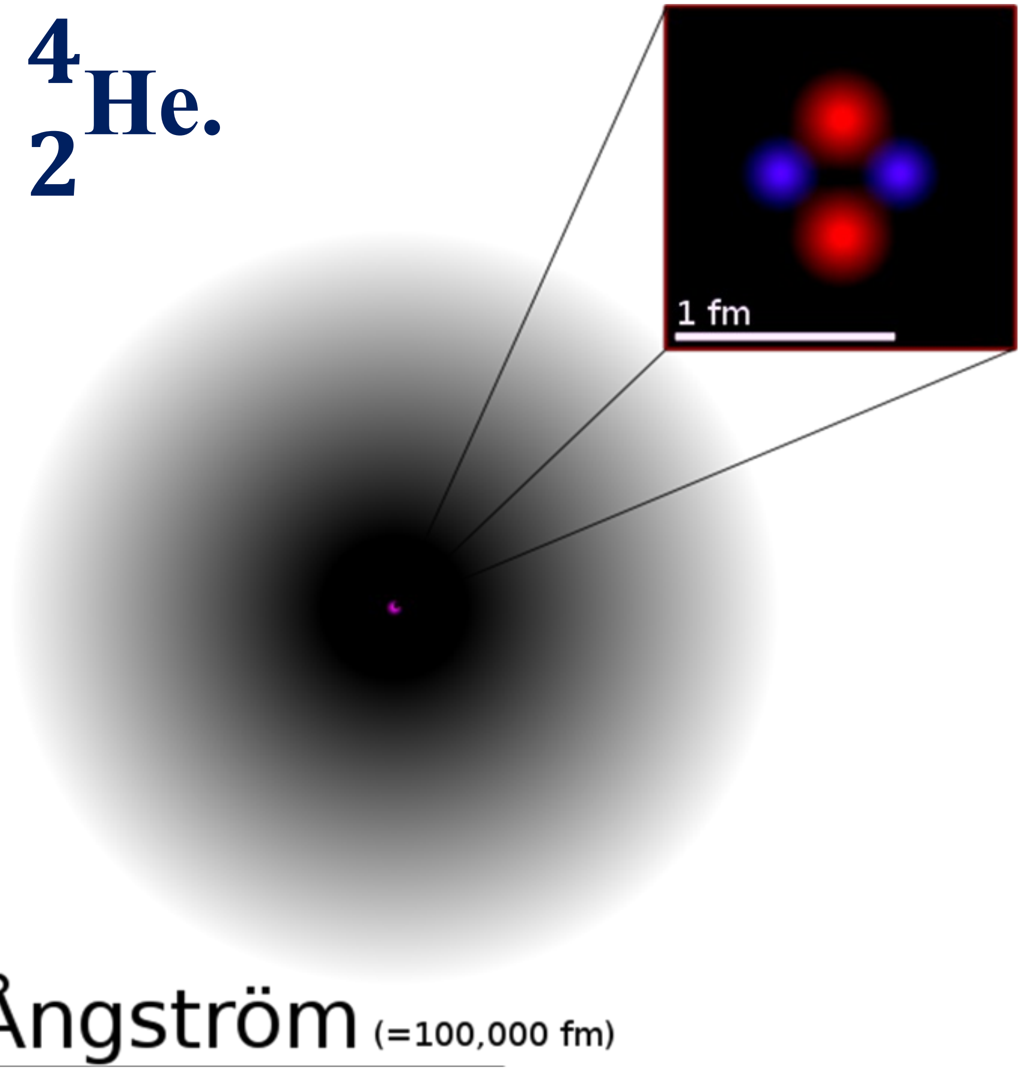
$^{4}_{2}\mathrm{He}$.

1 femtometer = $10^{-15}$ m

1 picometer = $10^{-12}$ m

1 Å = $10^{-10}$ m

1 nanometer = $10^{-9}$ m



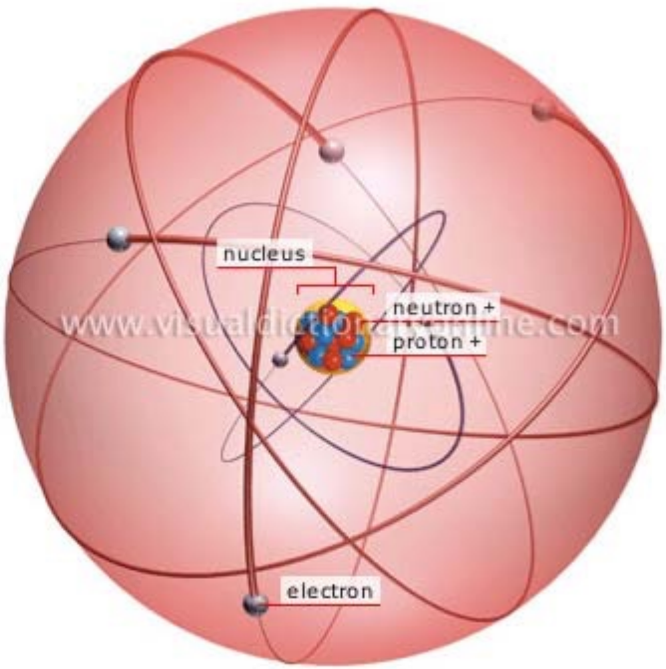
# SUBATOMIC PARTICLES

## Protons
- Symbol
  - $p^+$
- Charge
  - +1
- Relative Mass
  - 1
- Actual Mass
  - $1.67 \times 10^{-24}$

## Neutrons
- Symbol
  - $n^0$
- Charge
  - 0
- Relative Mass
  - 1
- Actual Mass
  - $1.67 \times 10^{-24}$

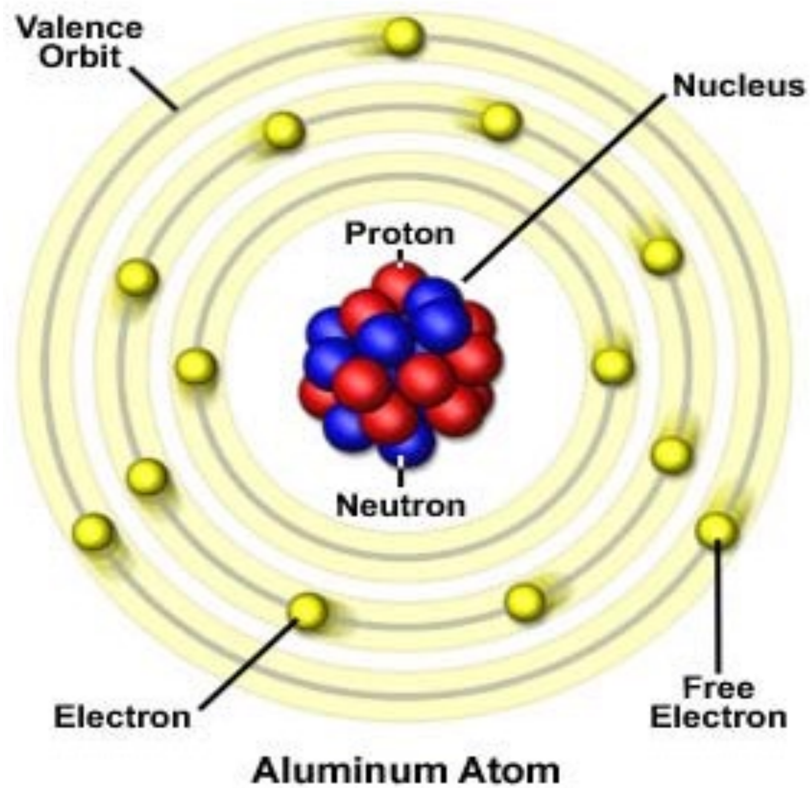
## Electrons
- Symbol
  - $e^-$
- Charge
  - -1
- Relative Mass
  - 1/1840
- Actual Mass
  - $9.11 \times 10^{-28}$

# CARBON ATOM




6 electrons,
6 protons,
6 neutrons

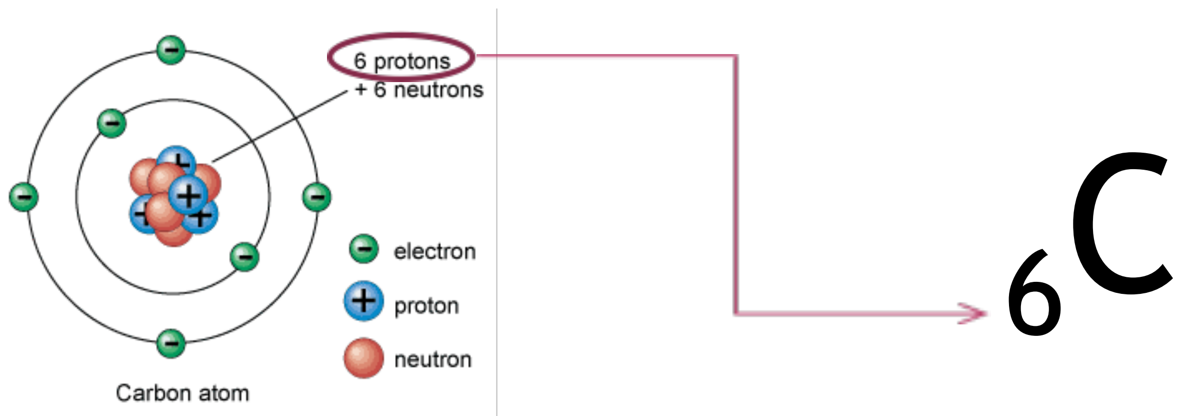
# ALUMINUM ATOM




13 electrons,
13 protons,
14 neutrons

# HOW WE TELL ATOMS APART

- Atoms differ depending upon the number of protons in the nucleus and as they are discovered, they are named and become **elements.**
- Each element is given an **atomic number** which corresponds with its proton number
- They are now organized by increasing atomic number in the **Periodic Table of Elements.**



# Periodic Table of Elements

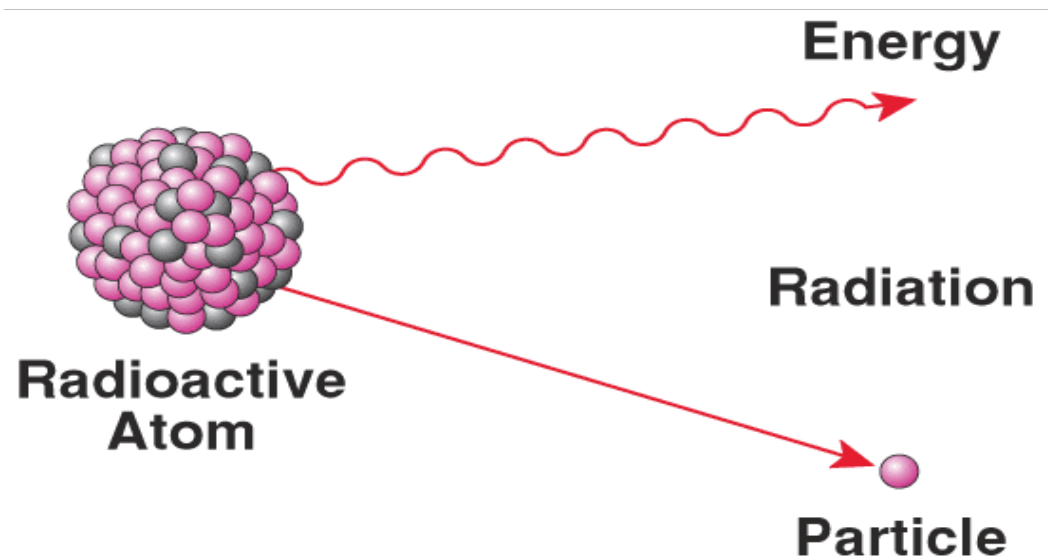
| | IA | IIA | IIIB | IVB | VB | VIB | VIIB | VII | VII | VII | IB | IB | IIIA | IVA | VA | VIA | VIIA | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 H | | | | | | | | | | | | | | | | | 2 He |
| 2 | 3 Li | 4 Be | | | | | | | | | | | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne |
| 3 | 11 Na | 12 Mg | | | | | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | 18 Ar |
| 4 | 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr |
| 5 | 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 Tc | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe |
| 6 | 55 Cs | 56 Ba | 57 *La | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 Po | 85 At | 86 Rn |
| 7 | 87 Fr | 88 Ra | 89 +Ac | 104 Rf | 105 Ha | 106 106 | 107 107 | 108 108 | 109 109 | 110 110 | | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * Lanthanide Series | 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu |
| + Actinide Series | 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr |

# WHAT IS NUCLEAR CHEMISTRY?

- ✓ Nuclear Chemistry is the division dealing with the atomic nucleus, radioactivity, and nuclear reactions
- ✓ **Radioactivity** - the spontaneous emission of a stream of particles or electromagnetic rays in nuclear decay

Any atom with 84 or more protons is radioactive.



# ISOTOPES

Atoms of the same element may have different neutron numbers, thus different mass numbers

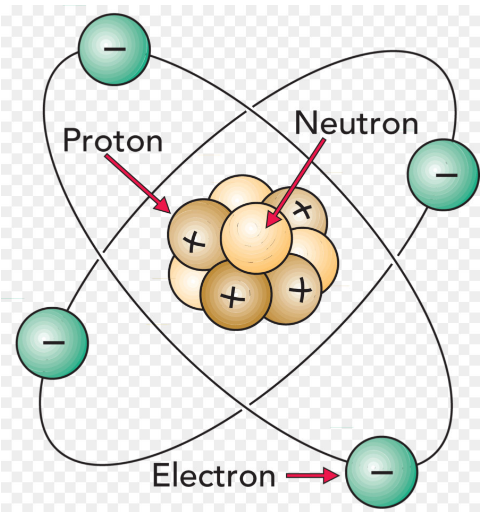
$_{6}^{12}C$ Carbon-12

6 electrons, 6 protons, 6 neutrons

$_{6}^{14}C$ Carbon-14

6 electrons, 6 protons, 8 neutrons

# Any Questions?




# Nuclear Chemistry

$4^{th}$ Year Zoology & Entomology

2020-2021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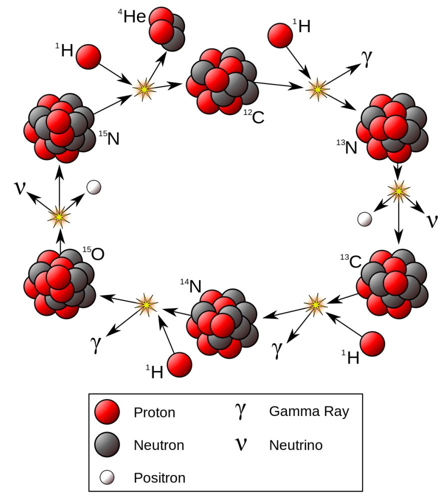


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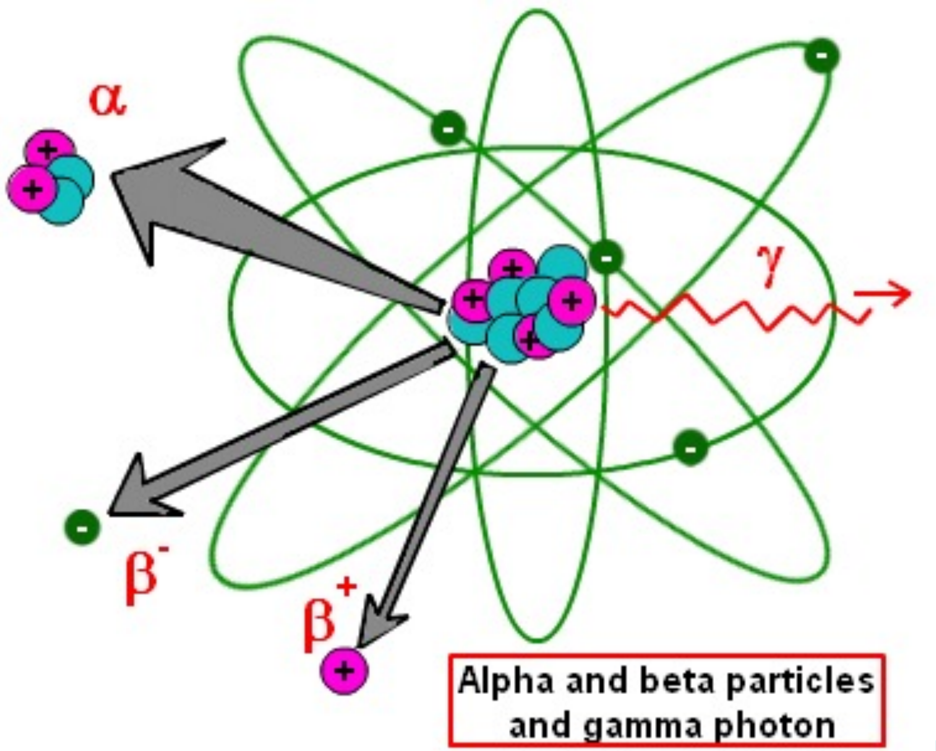
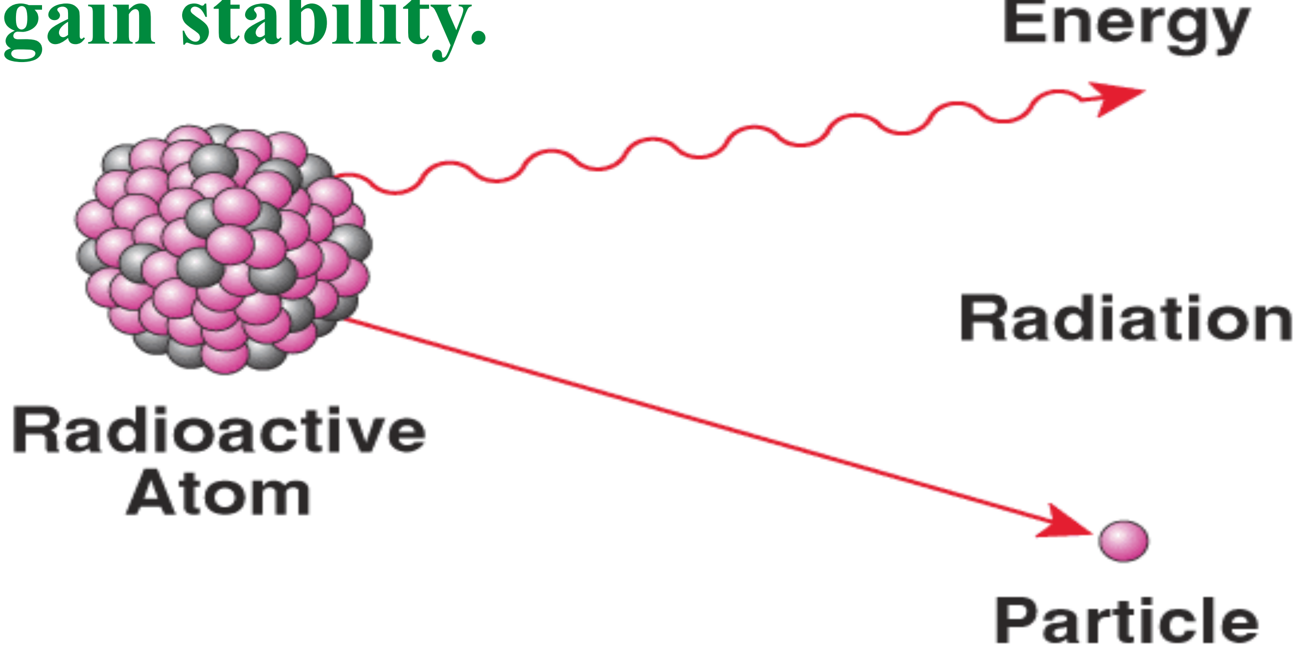
# Radioactivity

# What is Radioactivity?



# Radioactivity

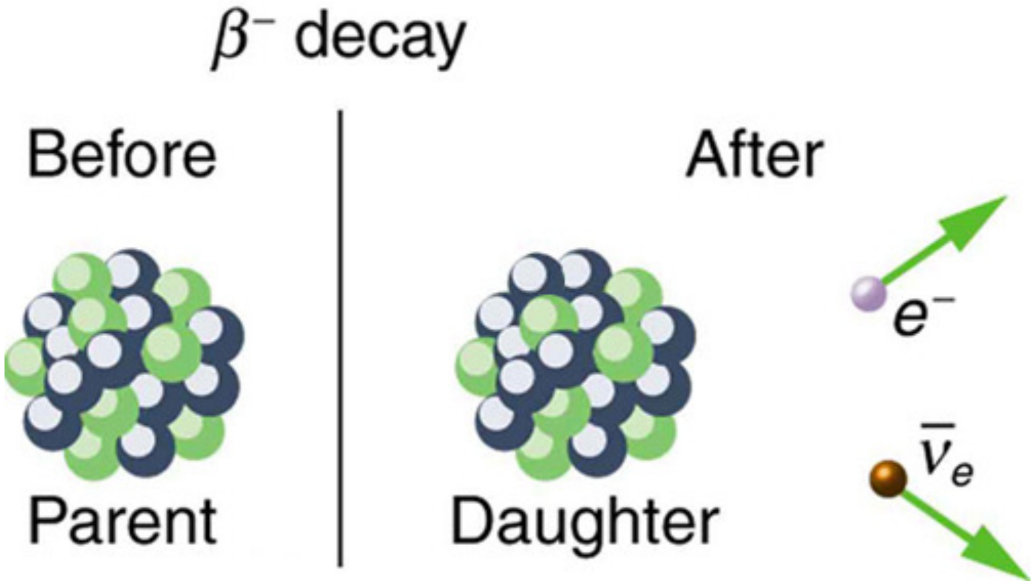
Is the spontaneous emission of a stream of particles or electromagnetic rays in nuclear decay to gain stability.



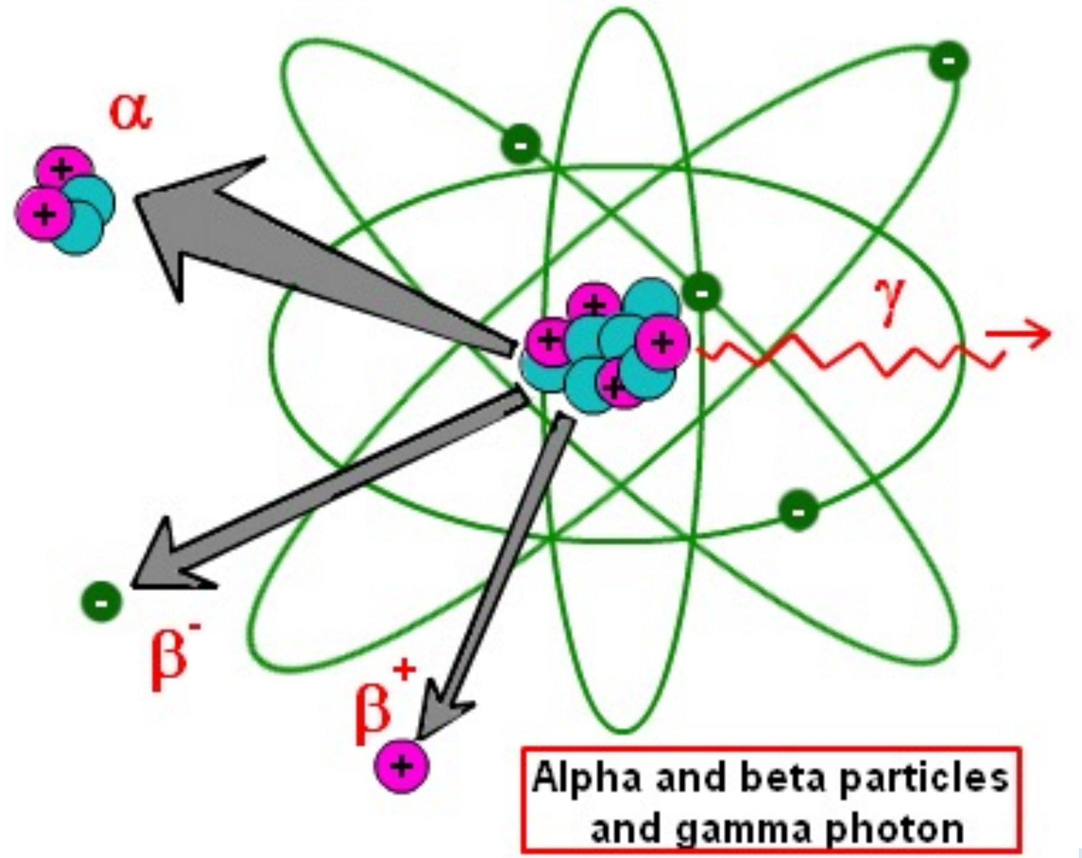
# Radioactivity

**Parent nuclide:** the original nuclide undergoing decay.

**Daughter nuclide:** the nuclide formed from the decay.



# Types of Radioactive Emissions:



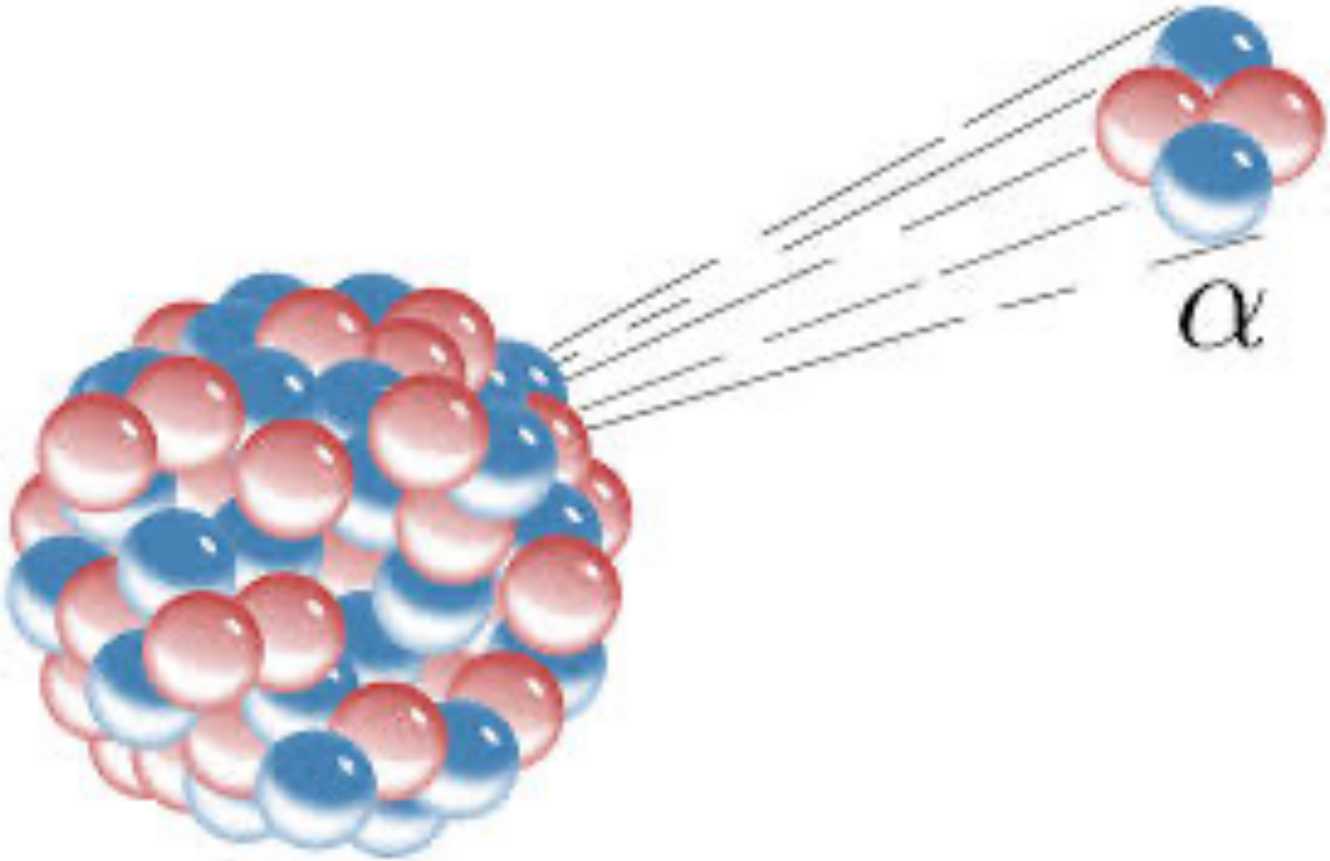
# Types of Radioactive Emissions

Nuclides with more than 83 protons change to reach the band of stability by releasing one or more of the following:

1. **Alpha particle ( $^{4}_{2}He$ or $\alpha$ ).**
2. **Beta ( $^{0}_{-1}e$ ) or $\mathcal{B}^-$**
3. **Gamma rays ( $^{0}_{0}\gamma$ ) or $\gamma$**
4. **Positron emission ( $^{0}_{+1}e$ ) or $\mathcal{B}^+$**

# Types of Radioactive Emissions

1. **Alpha radiation**

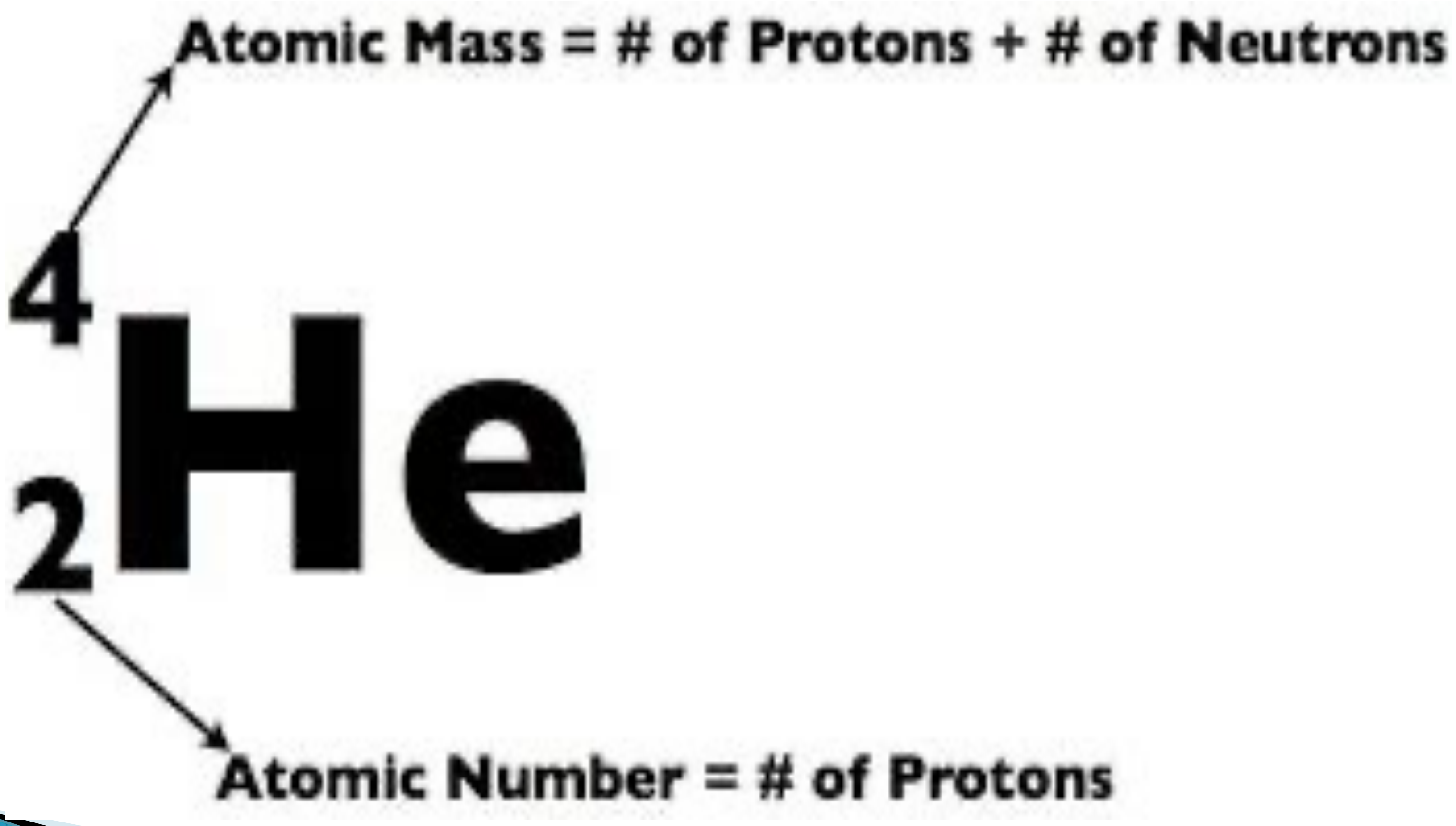


# Types of Radioactive Emissions

1. **Alpha radiation**

# Types of Radioactive Emissions

1. **Alpha radiation**



## Types of Radioactive Emissions

### 1. Alpha radiation

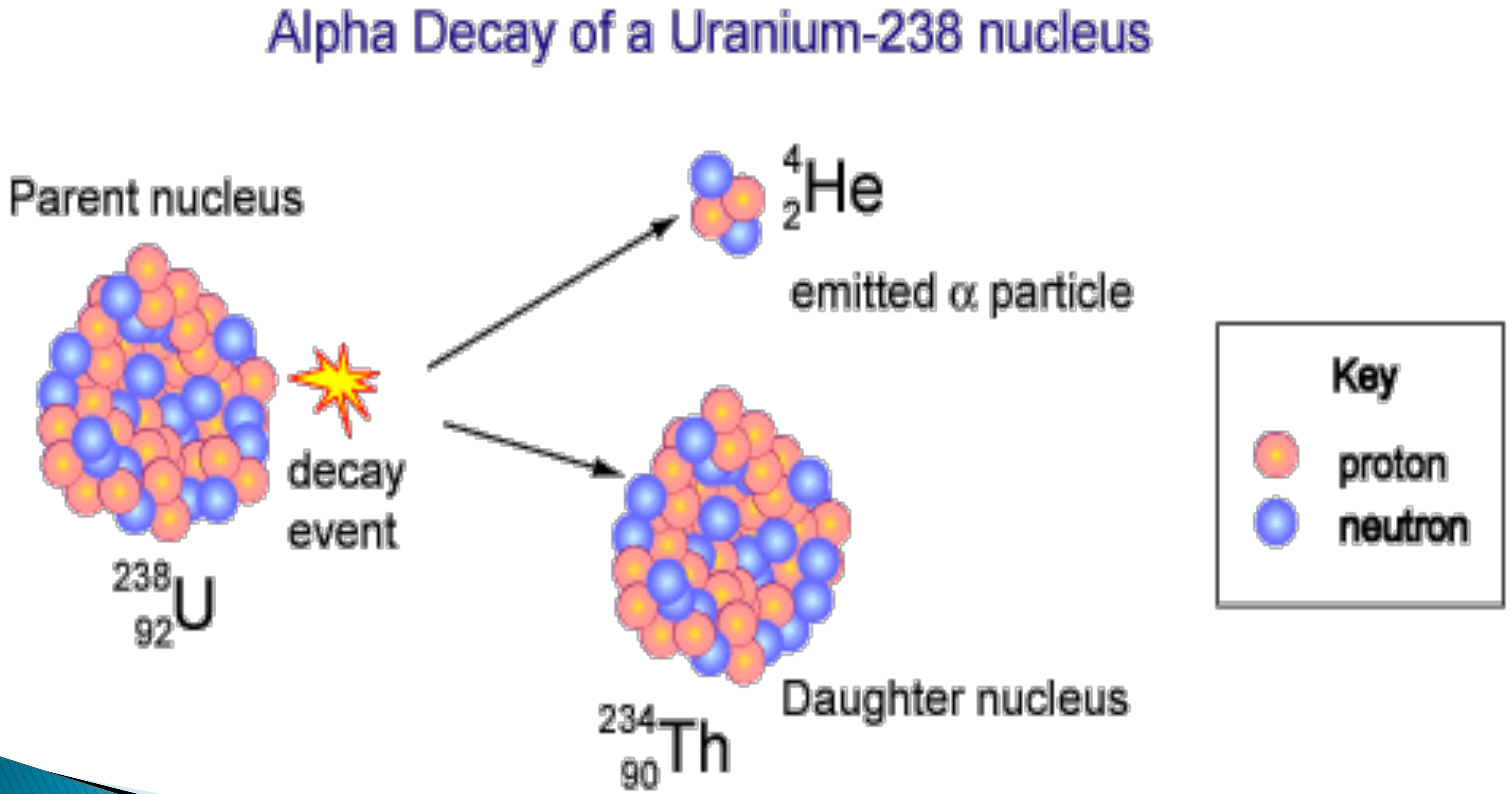
Two protons and two neutrons in the form of a helium nucleus: $\alpha$ or $^{4}_{2}He$

$$^{235}_{92}U \longrightarrow \underbrace{^{4}_{2}He}_{\alpha \text{ particle}} + ^{231}_{90}Th$$

**Uranium** **Thorium**

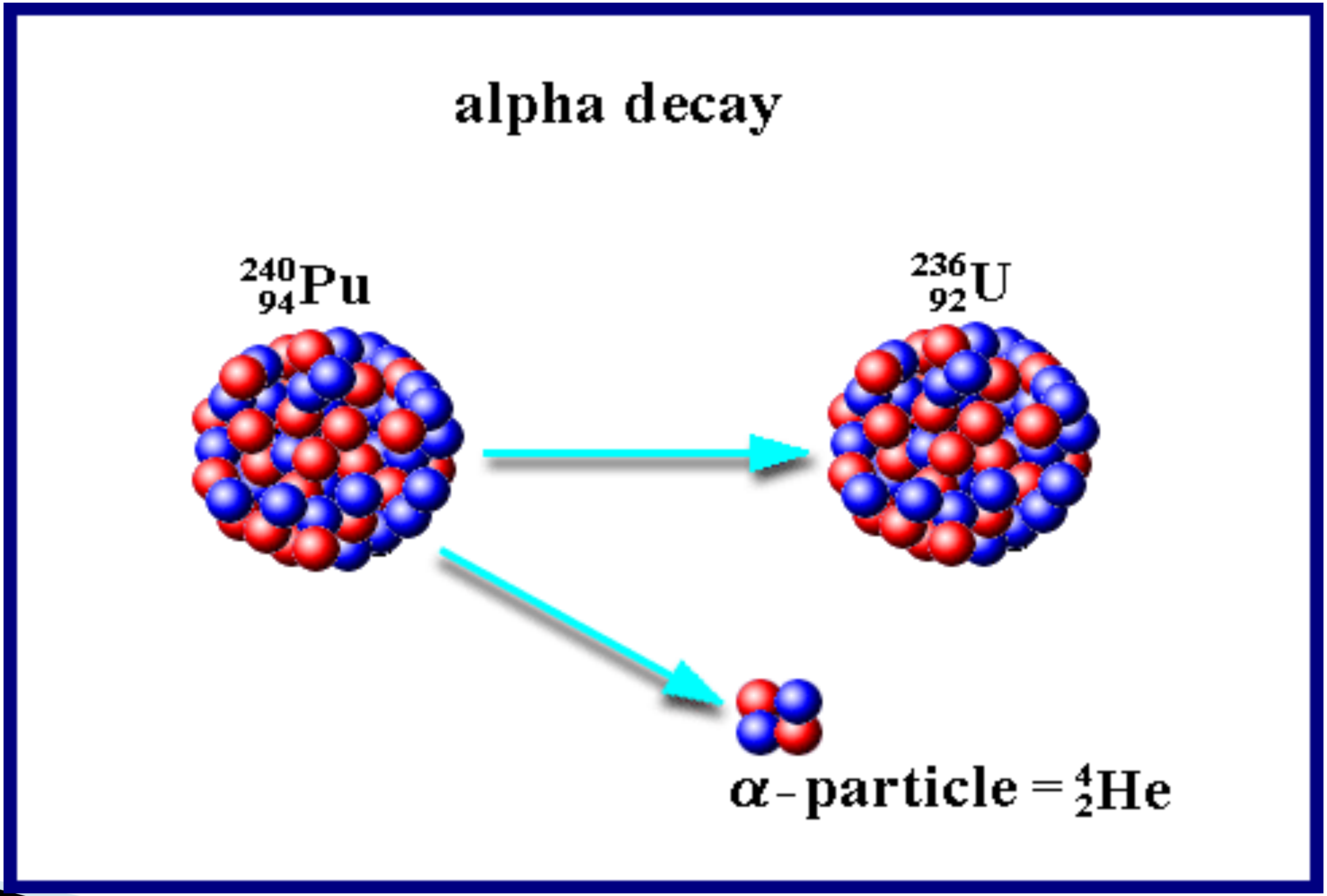
## Types of Radioactive Emissions

1. **Alpha radiation**



## Types of Radioactive Emissions

1. **Alpha radiation**



## Types of Radioactive Emissions

1. **Alpha radiation**

$$^{241}_{95}Am \rightarrow \, ^{4}_{2}He + \, ^{237}_{93}Np$$

**Americium** **Neptunium**

## Types of Radioactive Emissions

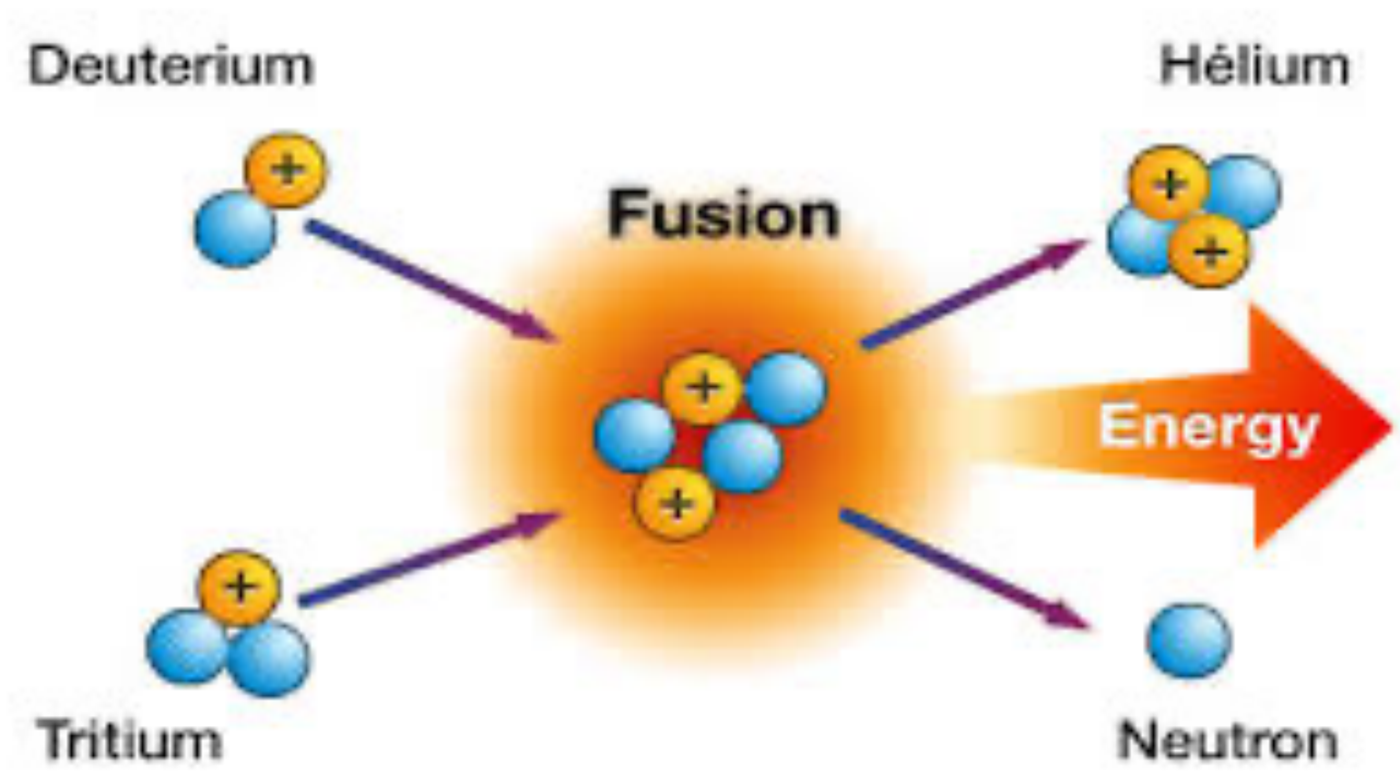
1. **Alpha radiation**

$$^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He} + {}^{0}_{0}\gamma$$

radium-226 radon-222 alpha particle energy

## Types of Radioactive Emissions

1. **Alpha radiation**



# Types of Radioactive Emissions

## 1. Alpha radiation Reactions

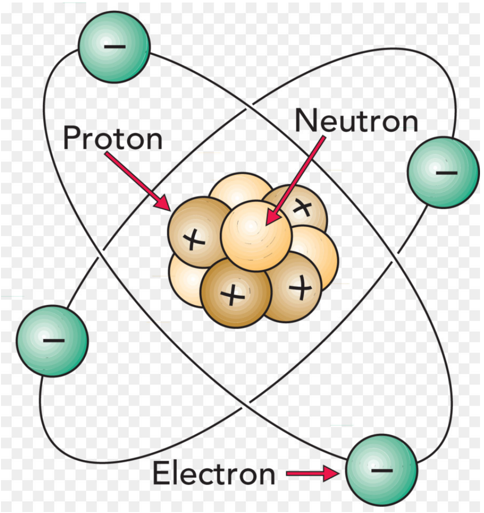
$$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{18}_{9}F$$

# Types of Radioactive Emissions

1. **Alpha radiation Reactions**

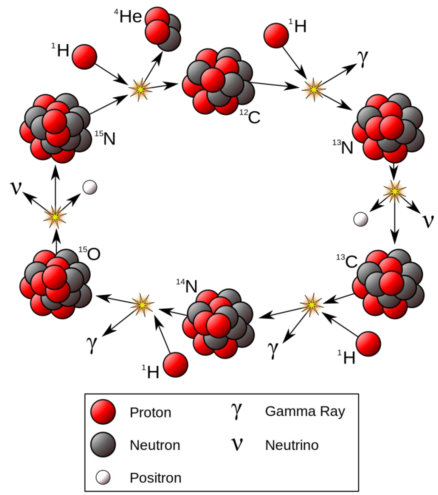
$$ {}^{14}_{7}N + {}^{4}_{2}He \longrightarrow {}^{17}_{8}O + {}^{1}_{1}H $$

Any Questions?




# Nuclear Chemistry

4th Year Zoology & Entomology





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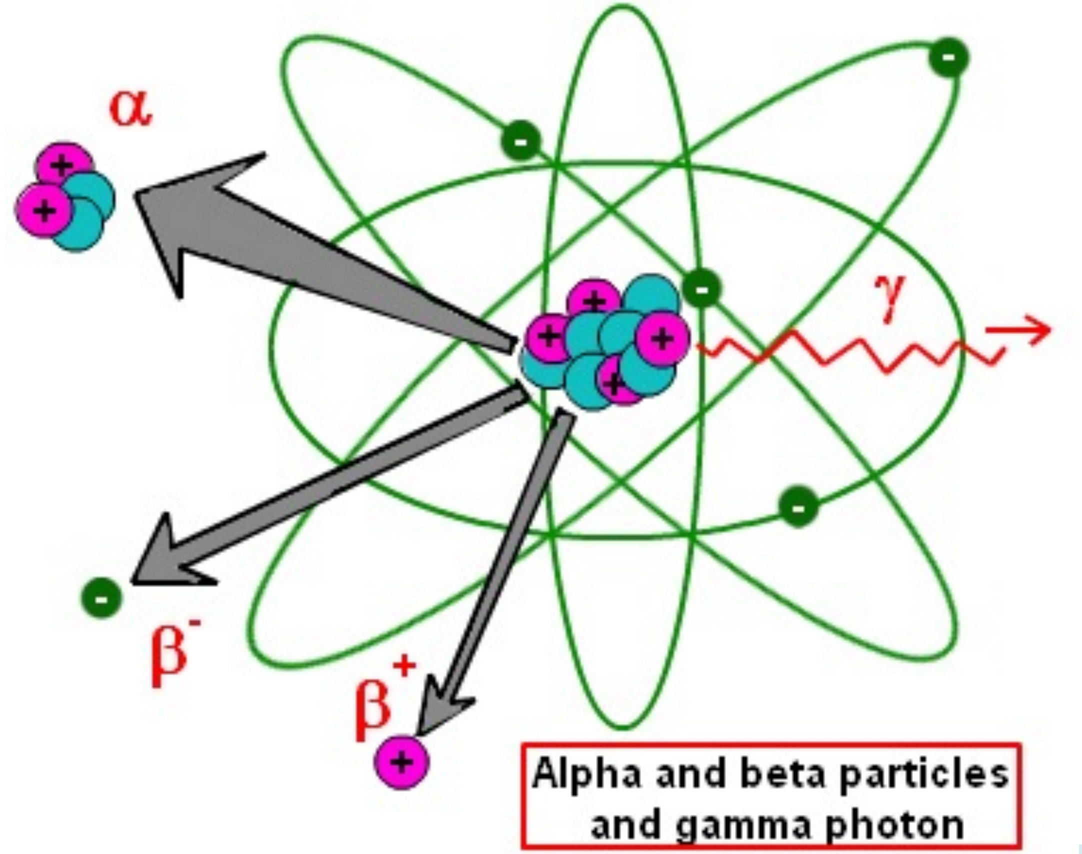
# Types of Radioactive Emissions

# Types of Radioactive Emissions:



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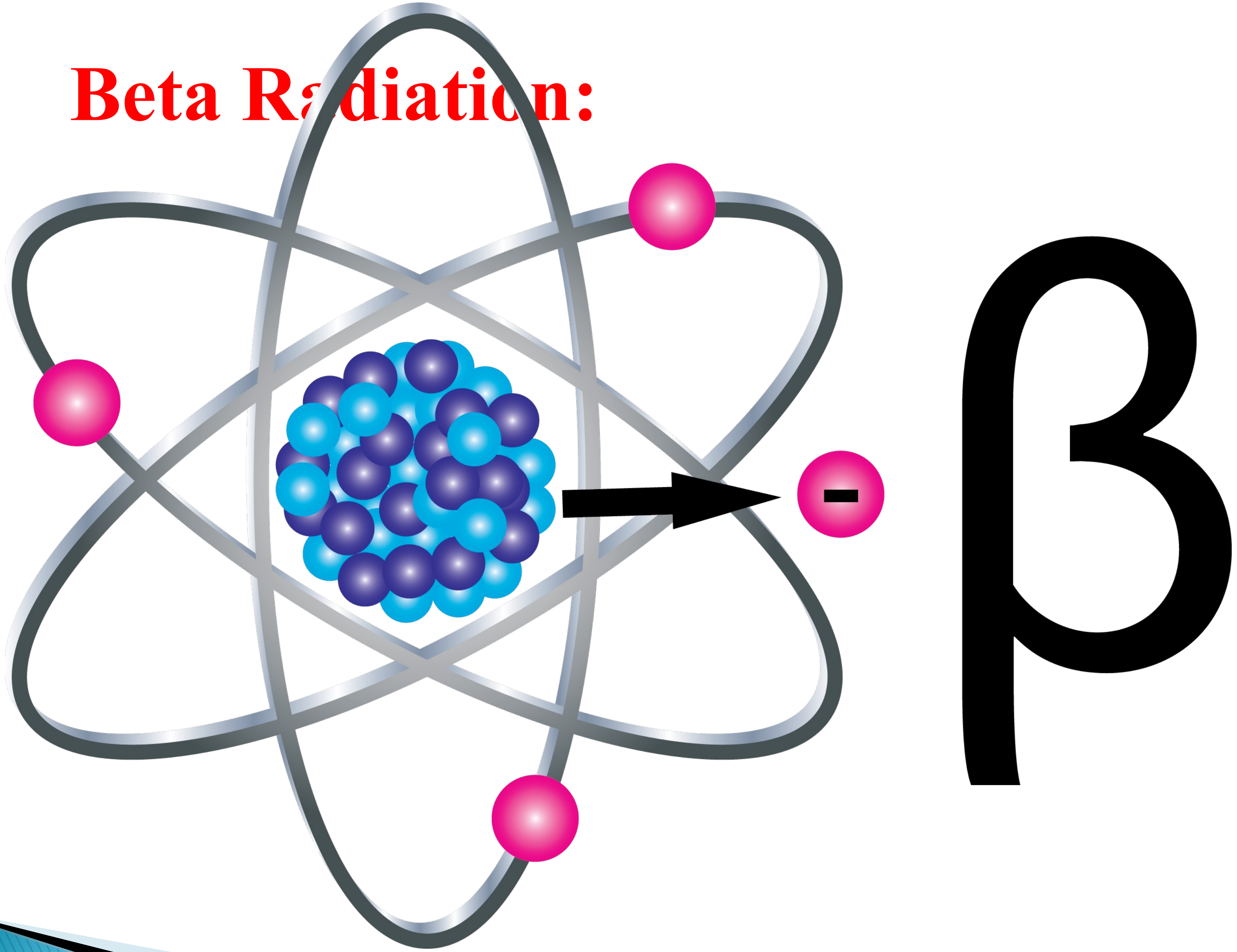
4. **Gamma rays ( $^{0}_{0}\gamma$ ) or $\gamma$**

# Types of Radioactive Emissions

2. **Beta Radiation:**



## 2. Beta Radiation β:

Is a high-energy, high-speed electron (**$\beta^-$**) or positron (**$\beta^+$**) emitted by the radioactive decay of nucleus during the process of Beta decay.

So, there are two forms of beta decay:-

A. **$\beta^-$ decay, which produces electrons.**

B. **$\beta^+$ decay or Positrons emission .**

Types of Radioactive Emissions

2. **Beta Radiation:**

A. **$\beta^-$ decay, which produces electrons.**

Consists of a stream of beta particles which are high speed electrons.

Represented by the symbol ( $^{0}_{-1}e$ ) or $\mathcal{B}^-$

## Types of Radioactive Emissions

2. **Beta Radiation:**

A. **$\beta^-$ decay, which produces electrons.**

- **As a result of $\beta^-$ decay, the atomic number increases.**
- **Beta emission results in the conversion of a neutron ($^{1}_{0}n$) to a proton ($^{1}_{+1}p$).**

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

# Types of Radioactive Emissions

2. **Beta Radiation:**

A. **$\beta^-$ decay, which produces electrons.**

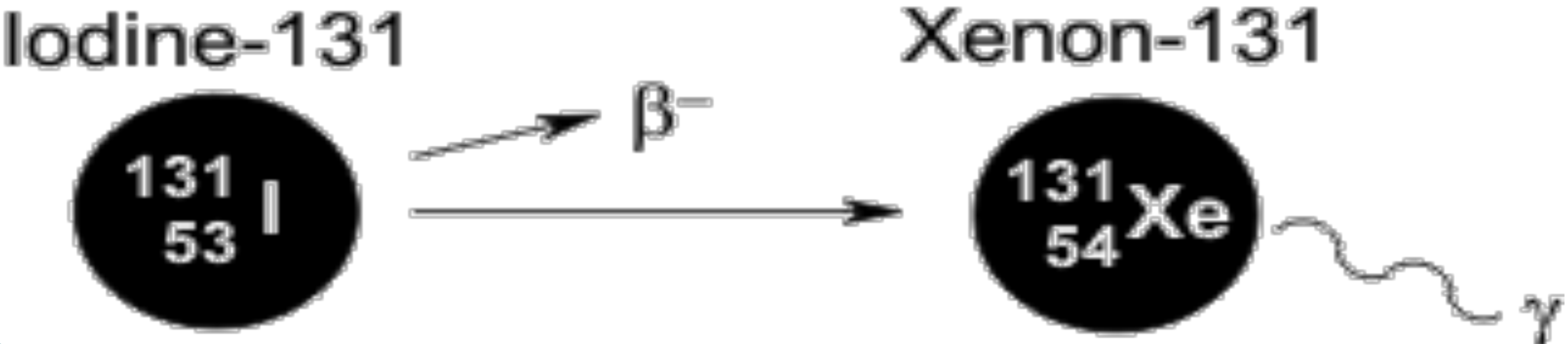
**The electron comes from the neutron being converted NOT from the electron cloud.**

# Types of Radioactive Emissions

2. **Beta Radiation:**

A. **$\beta^-$ decay, which produces electrons.**

Iodine-131 is an example of a radioactive isotope that undergoes Beta emission.



## Types of Radioactive Emissions

2. **Beta Radiation:**

A. $\beta^-$ decay, which produces electrons.

$$ {}^{46}_{20}Ca \longrightarrow {}^{46}_{21}Sc + \beta^- $$

## Types of Radioactive Emissions

2. **Beta Radiation:**

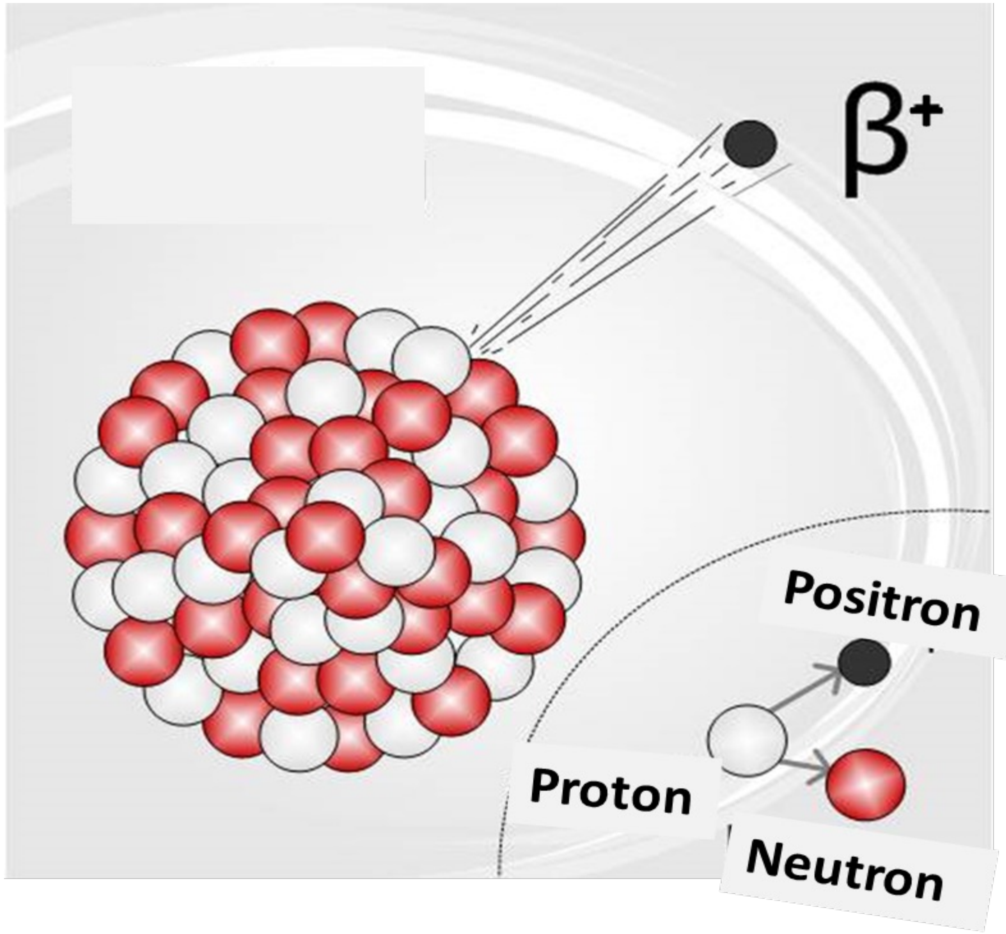
A. **$\beta^-$ decay, which produces electrons.**

$$^{14}_{6}C \longrightarrow {}^{14}_{7}N + \underbrace{{}^{0}_{-1}e}_{\beta\ \text{Particle}}$$

## Types of Radioactive Emissions

2. **Beta Radiation:**

B. **$\beta^+$ decay, which produces Positron**



## Types of Radioactive Emissions

# 2. Beta Radiation:

## B. $\beta^+$ decay, which produces Positron

- A positron is a particle that has the same mass as an electron but opposite charge.

- The positron is represented as $^{0}_{+1}e$ or $\mathcal{B}^+$.

## Types of Radioactive Emissions

2. **Beta Radiation:**

B. **$\beta^+$ decay, which produces Positron**

Carbon-11 is an example of a particle that undergoes positron emission.

$$ {}^{11}_{6}\mathrm{C} \rightarrow {}^{11}_{5}\mathrm{B} + {}^{0}_{+1}\mathrm{e} $$

- Notice the atomic number goes down.

# Types of Radioactive Emissions

2. **Beta Radiation:**

B. **$\beta^+$ decay, which produces Positron**

- Positron emission is the effect of converting a proton to a neutron:

$$ {}^{1}_{+1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e $$

# Types of Radioactive Emissions

3. **Gamma radiation**

- High energy photons (electromagnetic radiation of a short wavelength).
- Gamma radiation does not change the mass or atomic number and is represented as $^{0}_{0}\gamma$

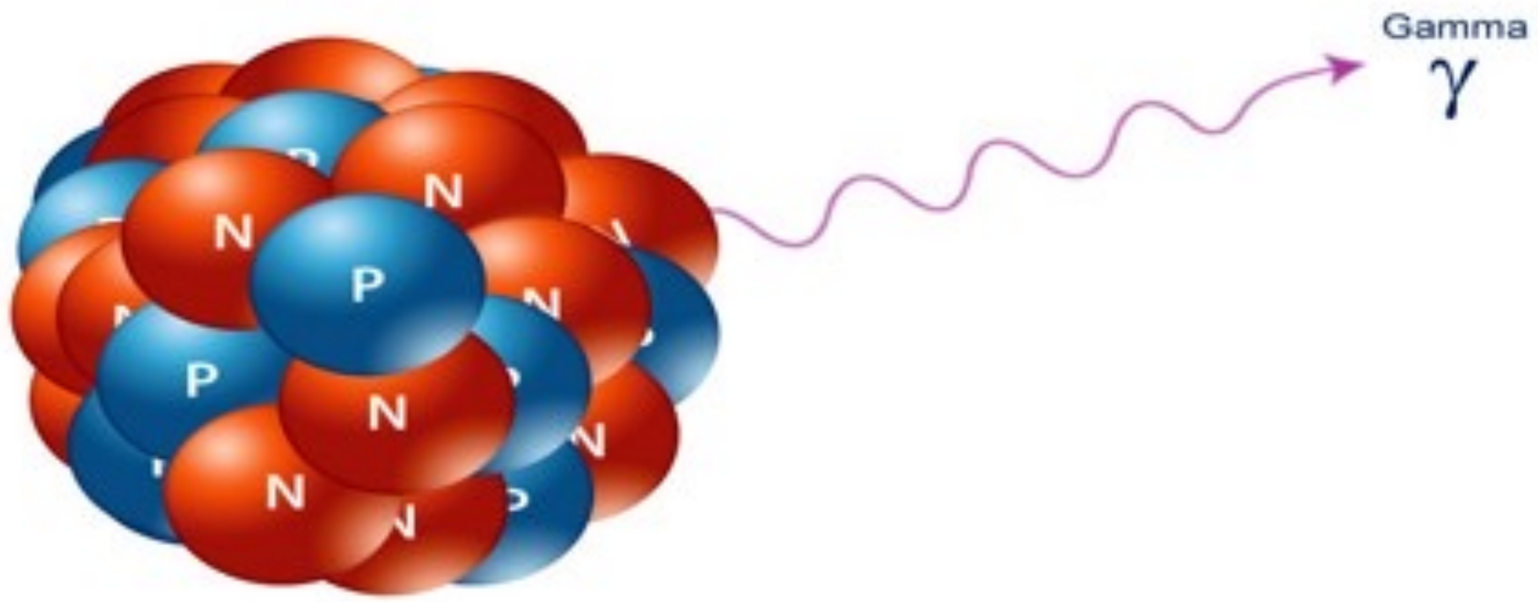
## Types of Radioactive Emissions

3. **Gamma radiation**

- It almost always accompanies other radioactive emission because it represents the energy lost when the remaining nucleons reorganize into more stable arrangements.
- Generally you do not show gamma rays when writing nuclear equations

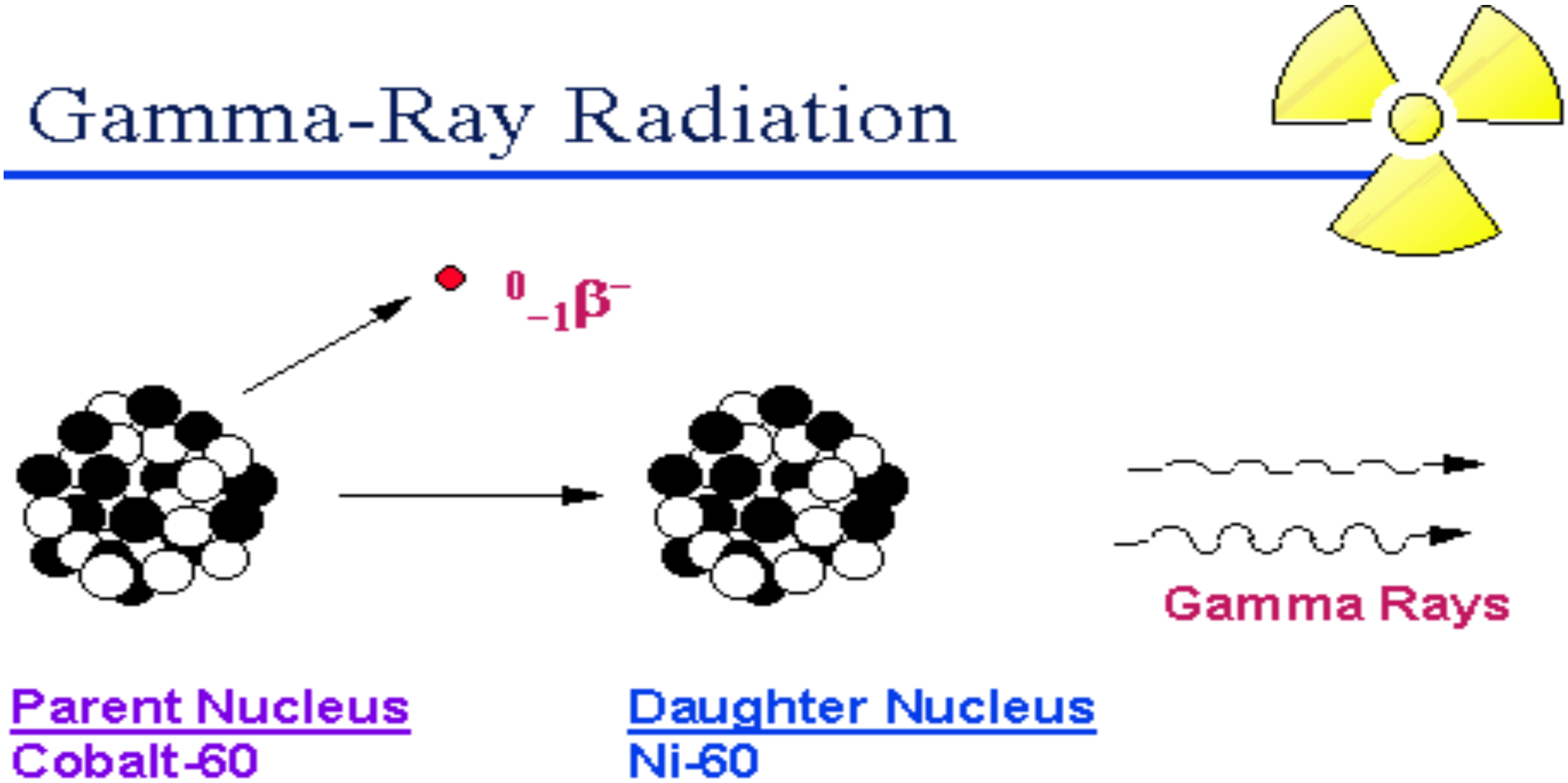
## Types of Radioactive Emissions

3. # Gamma radiation



# Types of Radioactive Emissions

## 3. Gamma radiation




$_{60}Co^{27}$ $_{60}Ni^{28}$

## Types of Radioactive Emissions

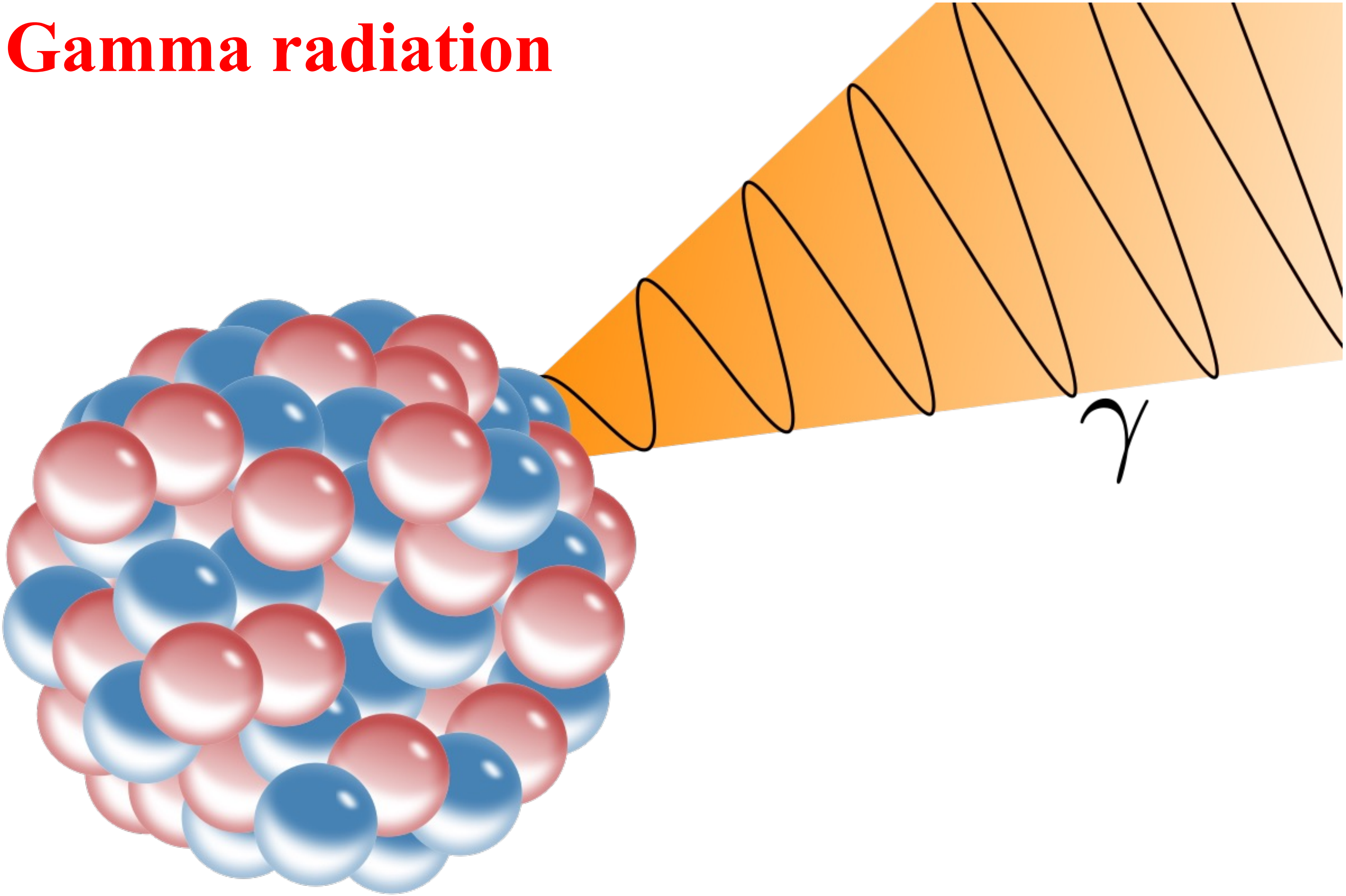
3. **Gamma radiation**

$$^{226}_{88}Ra \longrightarrow \, ^{222}_{86}Rn + \, ^{4}_{2}He + \, ^{0}_{0}\gamma$$

radium-226 — radon-222 — alpha particle — energy

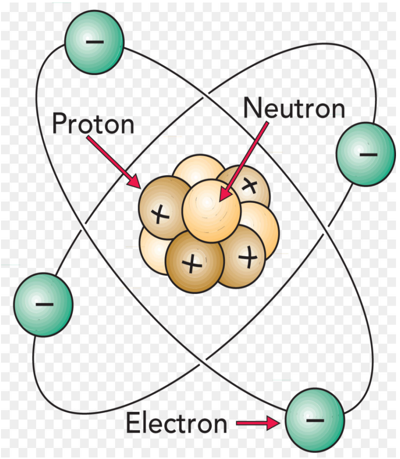
## Types of Radioactive Emissions

3. **Gamma radiation**



Any Questions?

# Nuclear Chemistry





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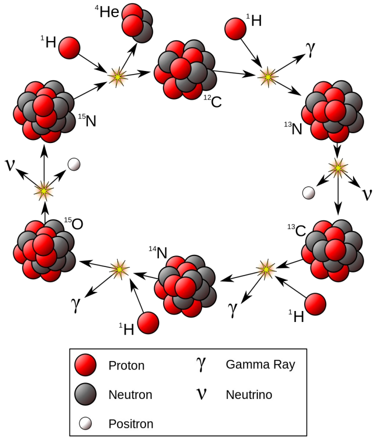


# Radioactive Emissions Penetration and Electron Capture

# Types of Radioactive Emissions

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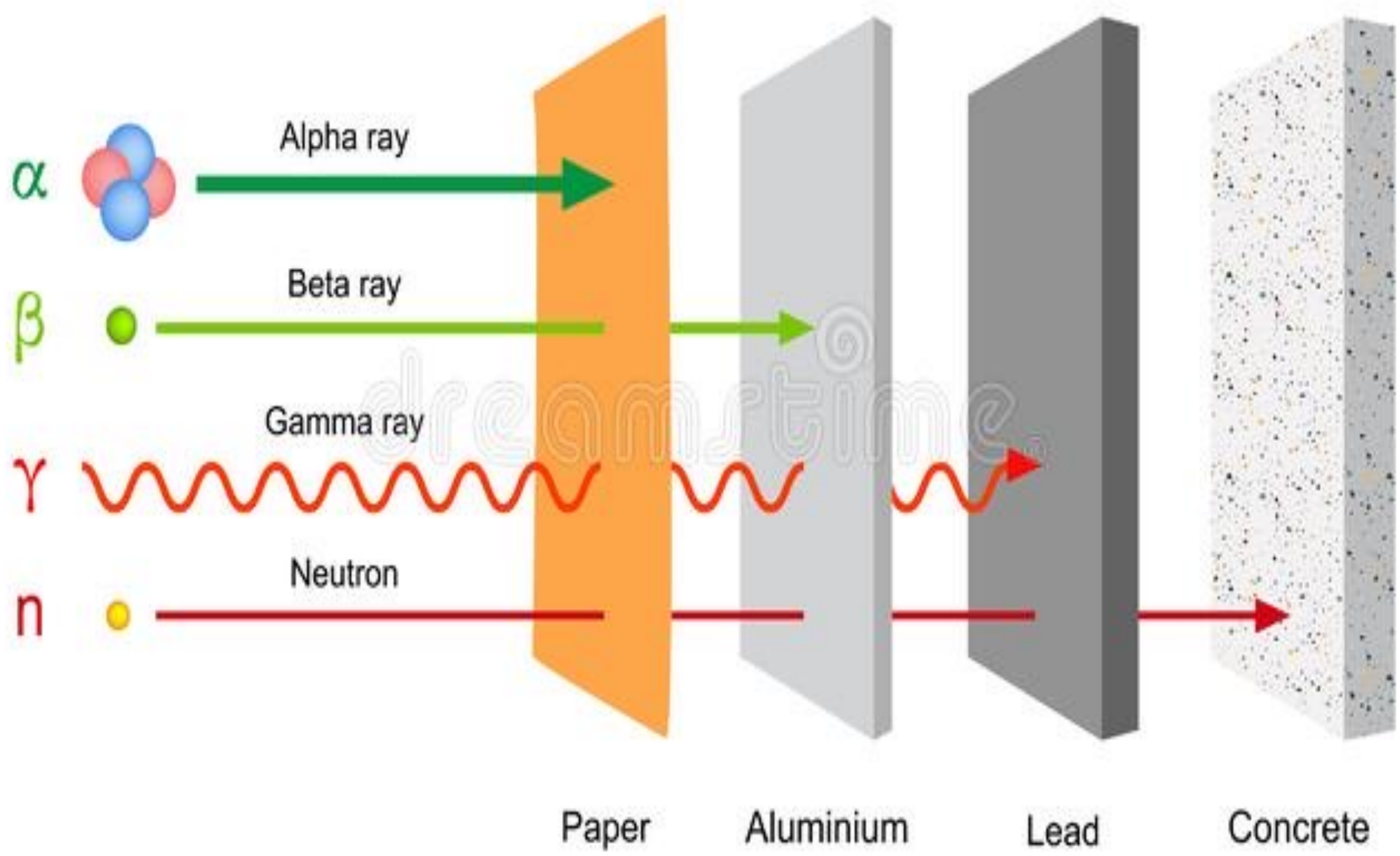
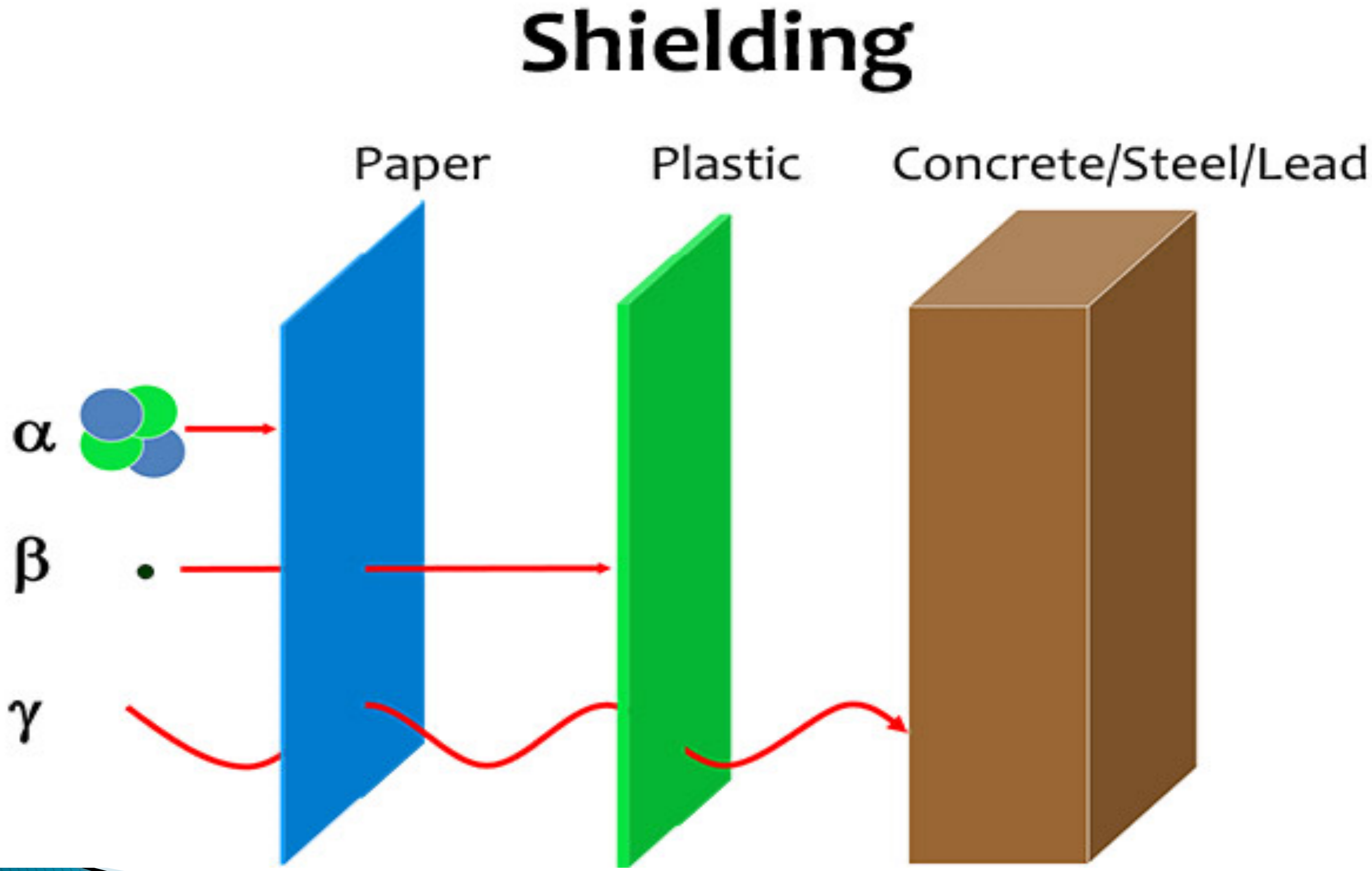
# Radioactive Emissions Penetration

# Radioactive Emissions Penetration

Penetrating power of Alpha, Beta and Gamma ray through Paper, Aluminium, Led and Concrete



# Radioactive Emissions Penetration



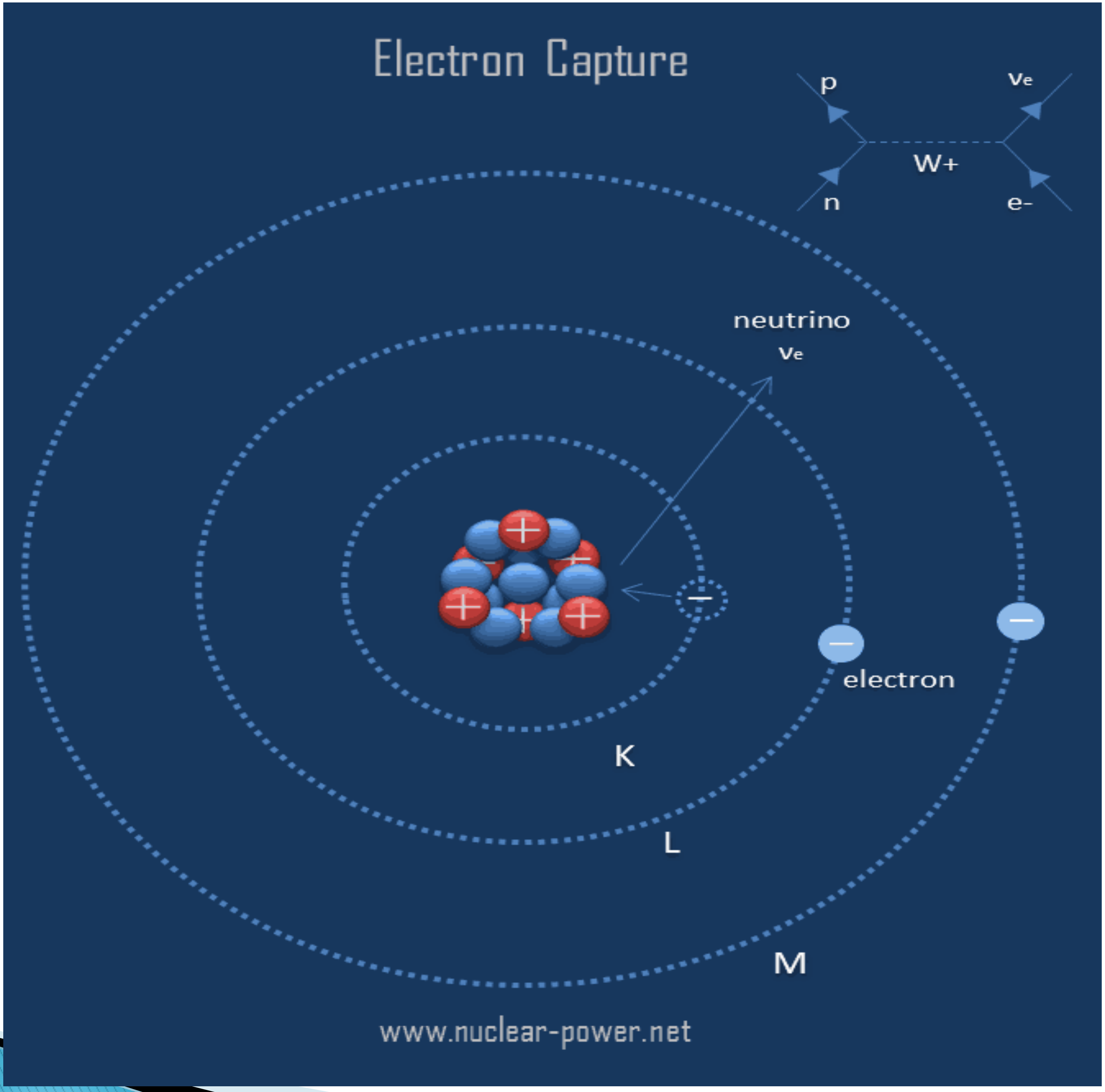
# Electron Capture

## Electron capture

Capture by the nucleus on an inner shell electron of the electron cloud.

Rubidium-81 does this:

$$^{81}_{37}\mathbf{Rb} + {}^{0}_{-1}\mathbf{e} \rightarrow {}^{81}_{36}\mathbf{Kr}$$


Electron Capture
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n
e-
neutrino
νe
electron
K
L
M
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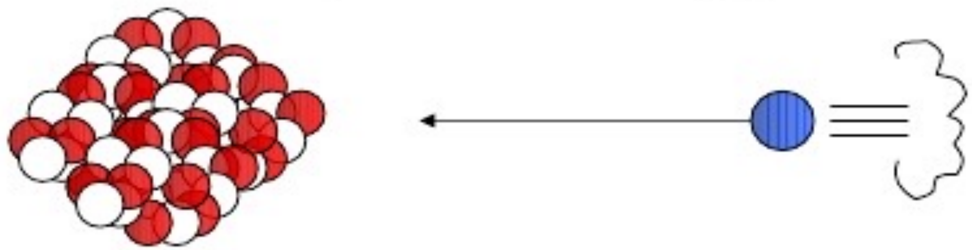
# Electron capture

Electron capture has the effect of positron emission, converting a proton to a neutron

$$^{1}_{+1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e$$

# Electron Capture

Electron Capture is the opposite of Beta Emission

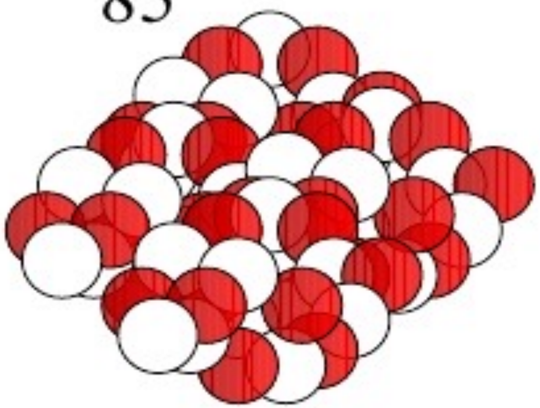


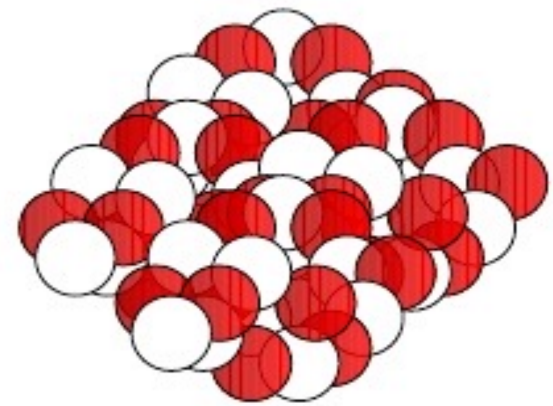
The capture of the electron allows a **proton to turn into a neutron**

$$^{A}_{Z}X + {}^{0}_{-1}e \longrightarrow {}^{A}_{Z-1}Y$$

# Electron Capture

$$^{218}_{85}\mathrm{At} + {}^{0}_{-1}\mathrm{e} \longrightarrow {}^{218}_{84}\mathrm{Po}$$





Capture negative particle,
forming a neutron from a proton

- Atomic # decreases by 1
- Mass # stays the same
  (electrons have no mass)

# Electron capture

$$^{7}_{4}\mathrm{Be} \xrightarrow{\text{Electron Capture}} {}^{7}_{3}\mathrm{Li}$$

# Electron capture

$$^{40}_{19}K + ^{0}_{-1}e \longrightarrow ^{40}_{18}Ar$$

# Electron capture

$$^{40}_{19}K + ^{0}_{-1}e \longrightarrow ^{40}_{18}Ar$$

# Which is like positron emission:

$$^{40}_{19}K \longrightarrow ^{40}_{18}Ar + \beta^{+}$$

# Which is like positron emission:

$$^{15}_{8}O \longrightarrow ^{15}_{7}N + ^{0}_{+1}e$$

# Electron Capture

**Electron capture: (inner-orbital electron is captured by the nucleus)**

$$^{201}_{80}Hg + \ ^{0}_{-1}e \rightarrow \ ^{201}_{79}Au + \ ^{0}_{0}\gamma$$

Electron capture converts a proton to a neutron

# Write your own Electron Capture

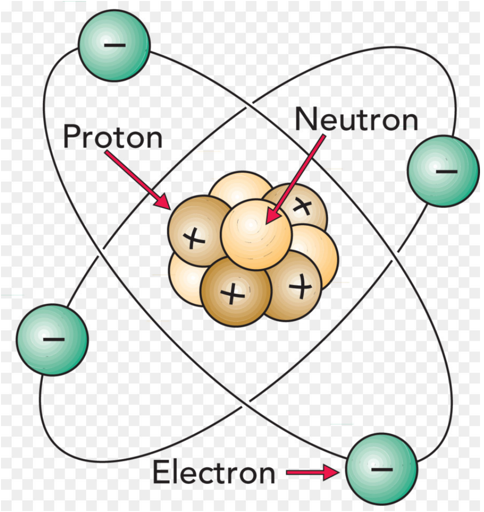
$$^{A}_{Z}X + ^{0}_{-1}e \longrightarrow ^{A}_{Z-1}Y$$

What is Y?

$$^{37}_{18}Ar + ^{0}_{-1}e \longrightarrow ^{A}_{Z-1}Y$$

$$^{37}_{18}Ar + ^{0}_{-1}e \longrightarrow ^{37}_{17}Cl$$

Any Questions?




# Nuclear Chemistry

4th Year Zoology & Entomology

2020-2021

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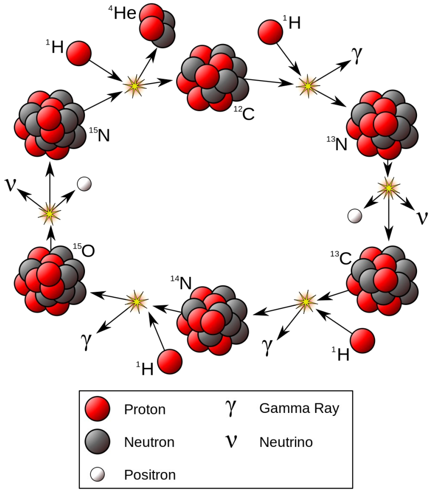



# Nuclear Stability

## Binding energy:

**It was found that the atomic weight of an element is less than the sum of weights of nucleons (Protons and Neutrons).**

# Atomic Mass Unit

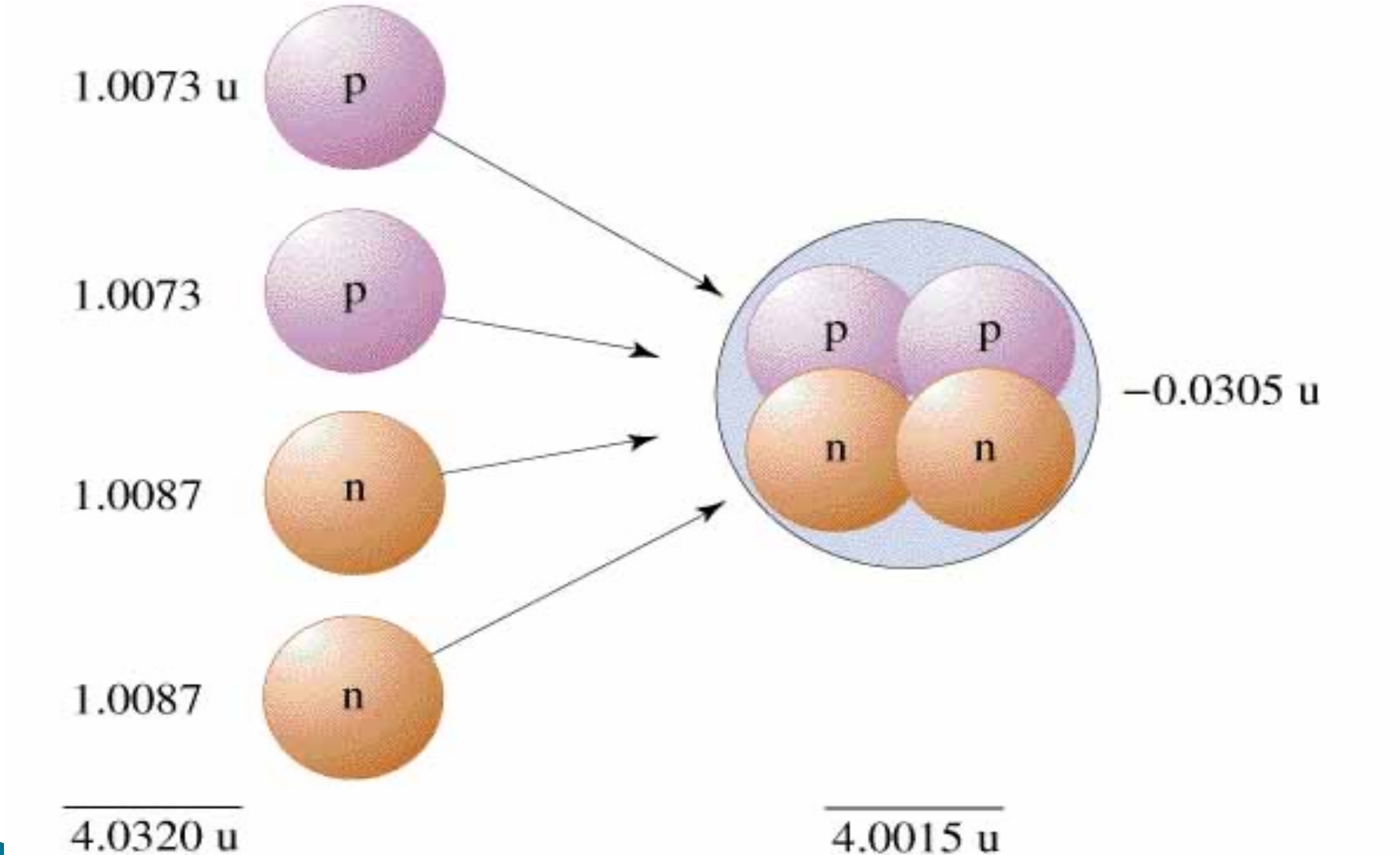
**Atomic Mass Unit (a.m.u) = 1/12 of the mass of $^{12}_{6}C$**

**or = 1.6605 x $10^{-24}$ gm.**

**1 Proton = 1.0073 a.m.u**

**1 Neutron = 1.0087 a.m.u**

# Binding energy in Helium



# Binding energy in Helium

2 protons = 2 x 1.00728 u = 2.01456 u

+

2 neutrons = 2 x 1.00728 u = 2.01732 u

Total mass of individual particles = 4.03188 u

−

$\alpha$ particle mass = 4.00153 u

Extra mass = 0.03035 u

# Binding energy

- At. Wts. Of Hg = 199.9683 a.m.u, while the sum of nucleons weights = 201.628 a.m.u,
- So the atomic weight of Hg is less with 1.66 a.m.u than the sum weights of nucleons?

**Where did the weight difference go?**

# Binding energy

**Weight loss converted into energy which consumed in binding the nucleus components and it called Binding Energy which can be defined as:**

**"The required energy to build the atoms nuclei through binding their components”**

# Calculation of Binding energy

**Binding energy can be calculated by using Albert Einstein's equation of the relationship between mass and energy:**

$$E = mc^2$$

**E = Energy (Erg)** **m = mass (gm)**

**c = Speed of light ($2.998 \times 10^{10}$ cm $sec^{-1}$)**

# Calculation of Binding energy

**The energy produced by consuming one atomic mass unit can be calculated as the following:**

$$E = (1.6605 \times 10^{-24}) \times (2.998 \times 10^{10})^2 = 1.49 \times 10^{-3}\ gm\ cm^2\ Sec^{-2}$$

**As: (1 a.m.u = 1.6605 x $10^{-24}$ gm)**

$$E = 1.49 \times 10^{-3} \times (6.242 \times 10^{11}) = 9.3 \times 10^{8}\ eV$$

**As: (1gm $cm^2$ $Sec^{-2}$ = 6.242 x $10^{11}$ eV)**

**That's means; the energy produced by consuming one atomic mass unit = 930 million electron volts.**

# Calculation of Binding energy

**Calculation of Binding energy for Helium nucleus:**

**Binding Energy =**

**$0.0305 \times 9.30 \times 10^8 = 0.28 \times 10^8$ eV = 28 MeV**

**So, the binding energy for each nucleon at the Helium nucleus = the whole binding energy divided by the number of nucleons (4):**

**Binding energy for each nucleon = 28/4 = 7 MeV**

# Calculation of Binding energy

**Calculation of Binding energy for Mercury nucleus:**

**Binding Energy =**

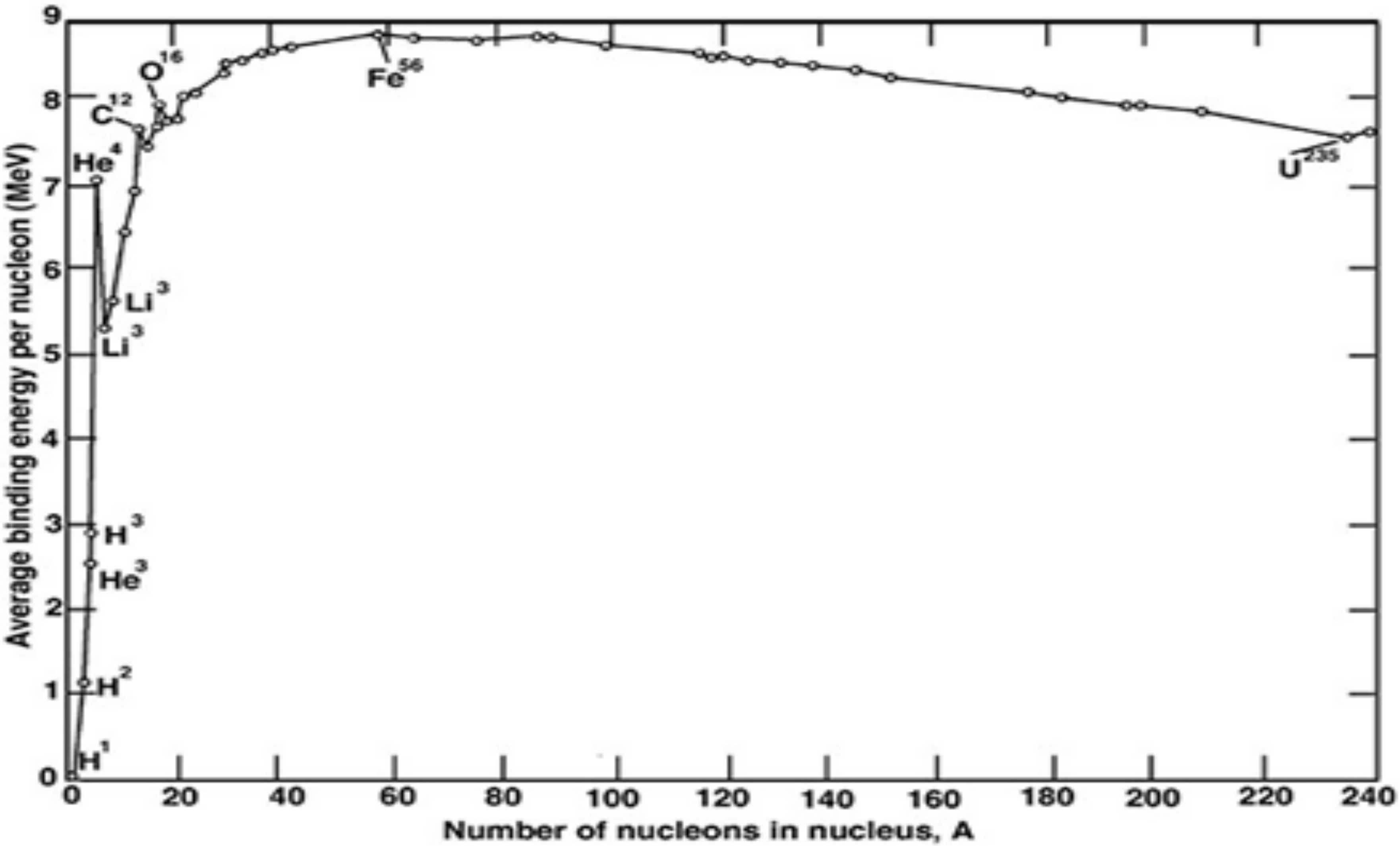
**$1.66 \times 9.30 \times 10^{8} = 15.44 \times 10^{8}$ eV = 1544 MeV**

**Binding energy for each nucleon = 1544 / 200 = 7.72 MeV.**

## Binding energy

**So, by plotting the relationship between the binding energy for each nucleon of the element and the Mass number; it was found that the binding energy increases starting from Hydrogen to the maximum amount at Iron nucleus, then starts to decrease until it reaches to the lowest value at Uranium 235.**

# The relationship between the binding energy of each nucleon and the atomic mass number.



# Nuclear Stability

## What makes a nucleus stable?

- **The number of neutrons needed to create a stable nucleus increases more than the number of protons.**

# Nuclear Stability

## What makes a nucleus stable?

- **It depends on a variety of factors.**
- **No single rule allows us to predict whether a nucleus is radioactive and might decay unless we observe it.**
- **There are some observations that have been made to help us make predictions.**

# Nuclear Stability

## What makes a nucleus stable?

*Neutron to proton ratio*

- **Strong nuclear force exists between nucleons.**
- **The more protons packed together the more neutrons are needed to bind the nucleus together.**

# Nuclear Stability

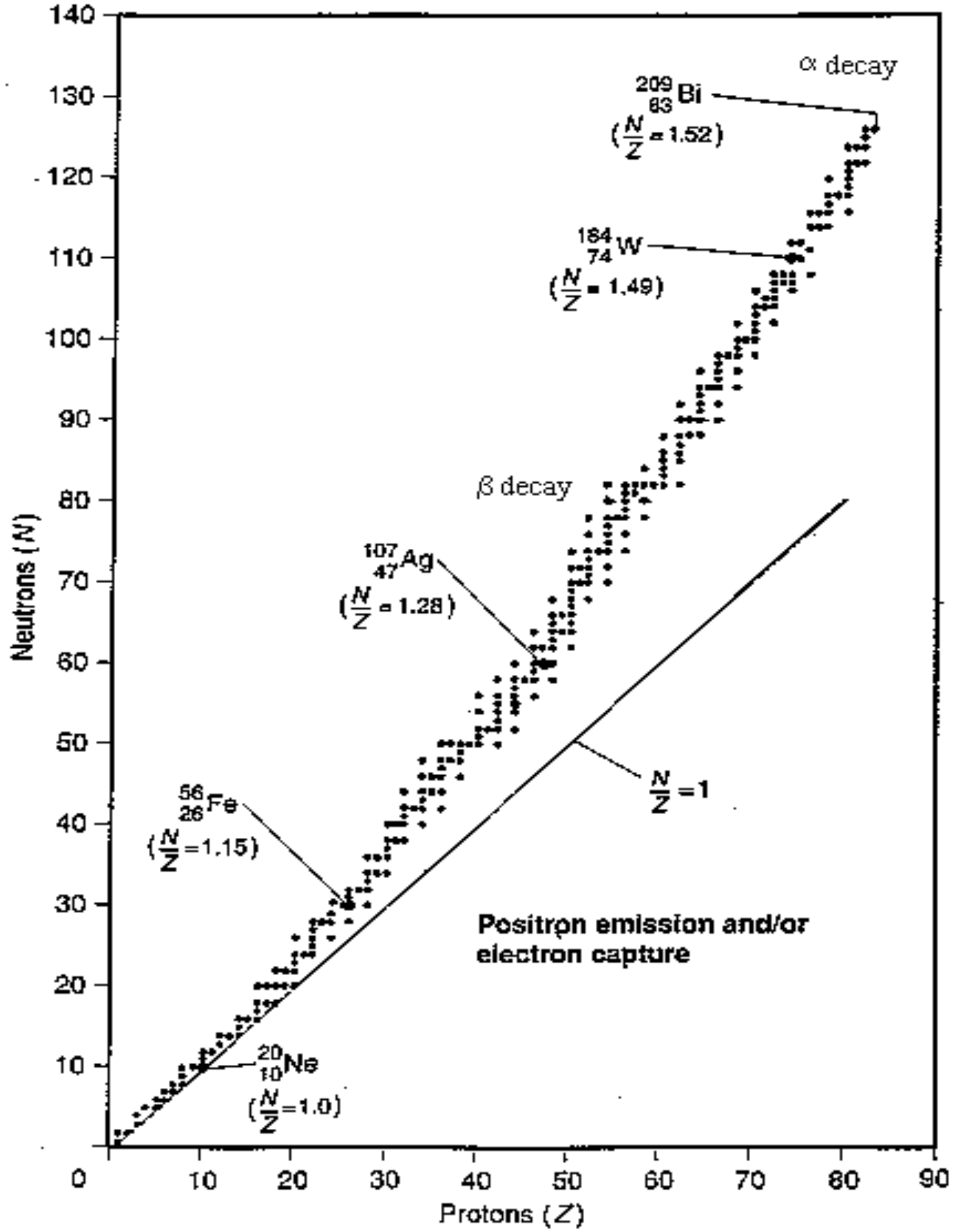
## What makes a nucleus stable?

- **Atomic nucleus with an atomic number up to twenty has almost equal number of protons and neutrons.**
- **Nuclei with higher atomic numbers have more neutrons to protons.**

# Nuclear Stability

## Belt of stability

- All nuclei with 84 or more protons are radioactive.



140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
Neutrons (N)
Protons (Z)
α decay
$^{209}_{83}$Bi
($\frac{N}{Z}$ = 1.52)
$^{184}_{74}$W
($\frac{N}{Z}$ = 1.49)
β decay
$^{107}_{47}$Ag
($\frac{N}{Z}$ = 1.28)
$^{56}_{26}$Fe
($\frac{N}{Z}$ = 1.15)
$^{20}_{10}$Ne
($\frac{N}{Z}$ = 1.0)
$\frac{N}{Z}$ = 1
Positron emission and/or
electron capture

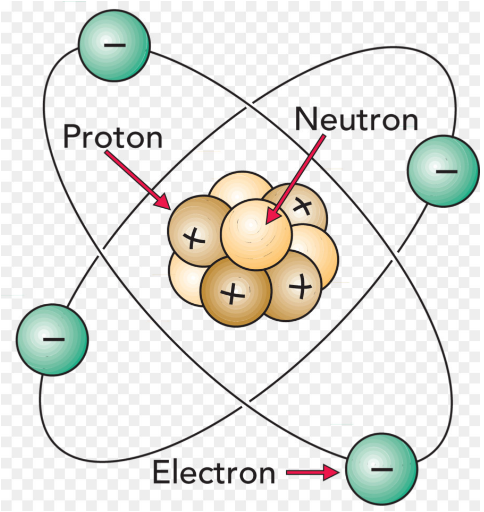
# Nuclear Stability

## Belt of stability

- **Nuclei above the belt of stability are rich isotopes can lower their ratio and move to the belt of stability by emitting a beta particle. This increases number of protons and decreases neutrons.**

Any Questions?

# Nuclear Chemistry

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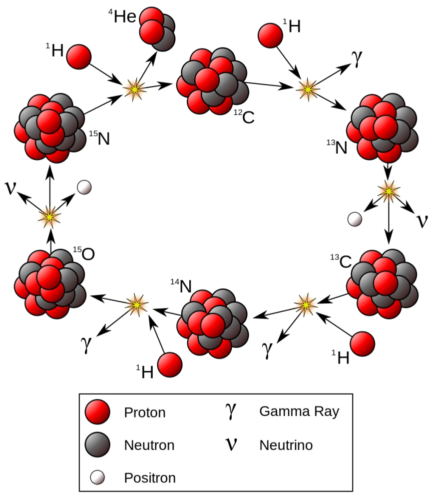


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# Isotopes

# Isotopes

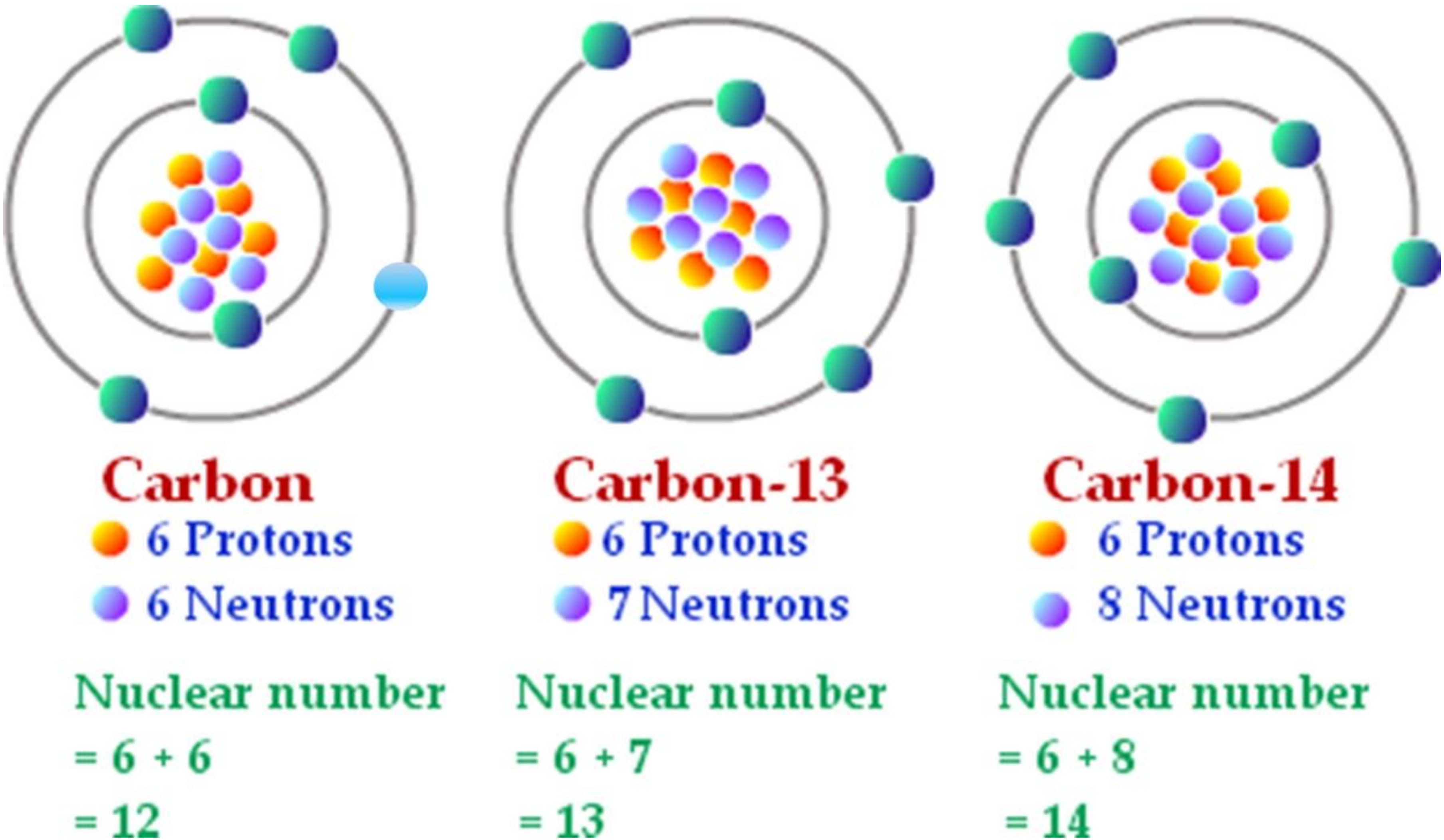
# Isotopes

- **Isotopes Differ in number of neutrons only.**
- **They are distinguished by their mass numbers.**

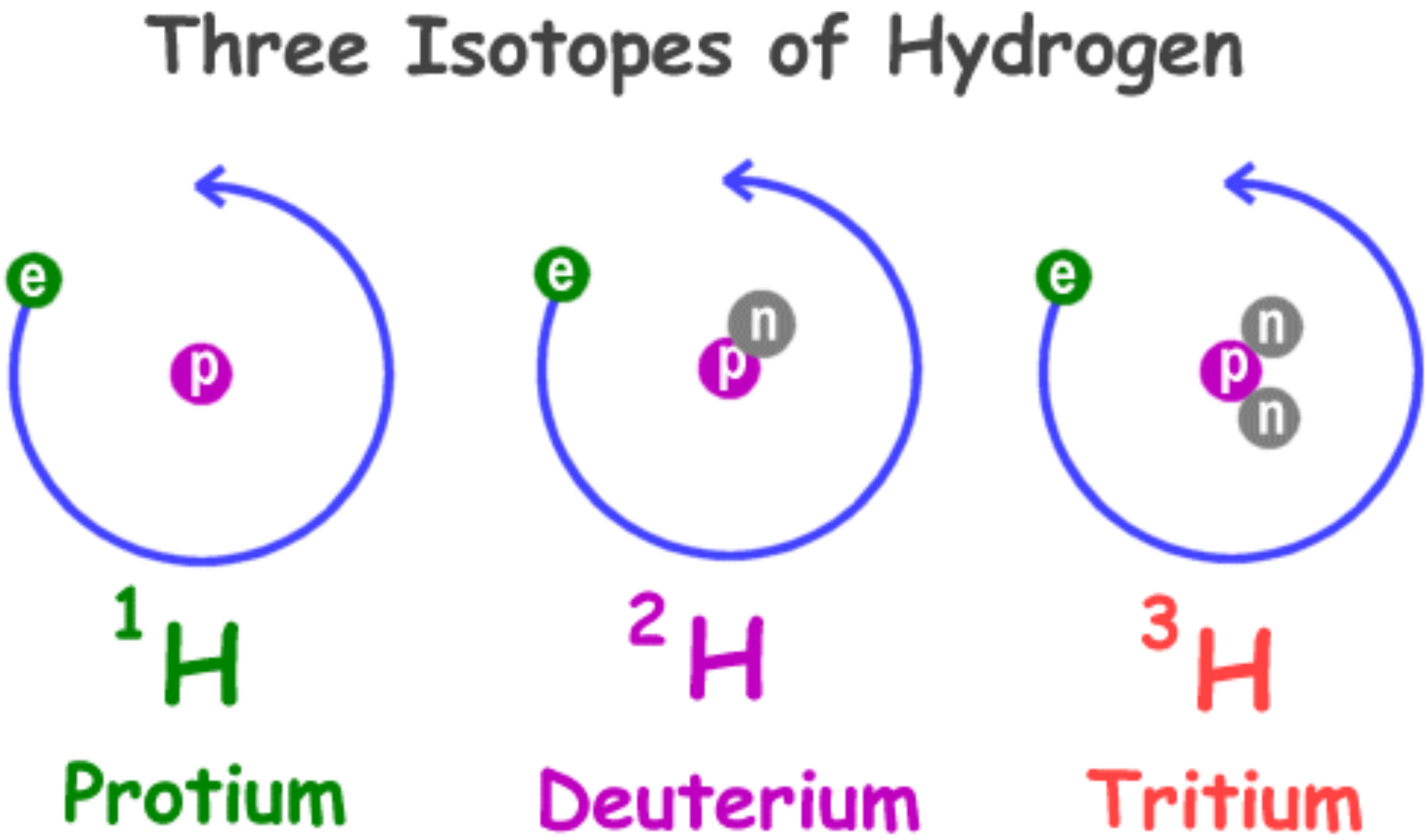
# Isotopes

- Isotopes are Nuclei with the same *atomic number* but different *atomic weights*.
- For many elements, several different isotopes exist in nature.
- Different isotopes of the same element have the same atomic number but different mass numbers.

# Isotopes

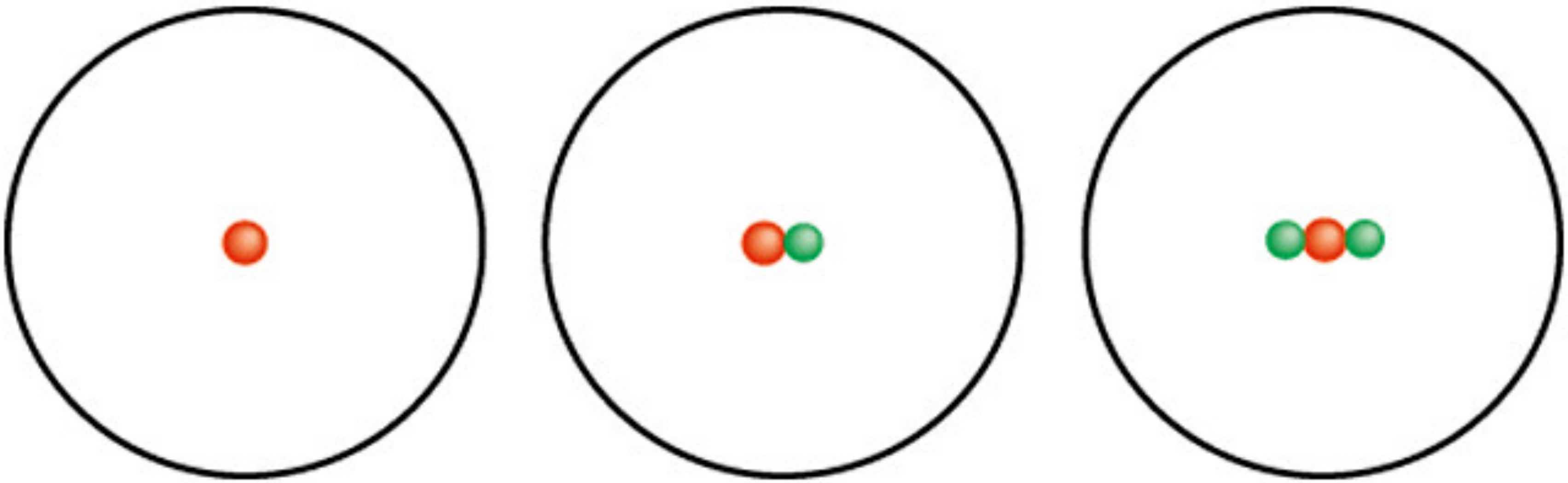

Carbon
6 Protons
6 Neutrons
Nuclear number
= 6 + 6
= 12
Carbon-13
6 Protons
7 Neutrons
Nuclear number
= 6 + 7
= 13
Carbon-14
6 Protons
8 Neutrons
Nuclear number
= 6 + 8
= 14

# Isotopes



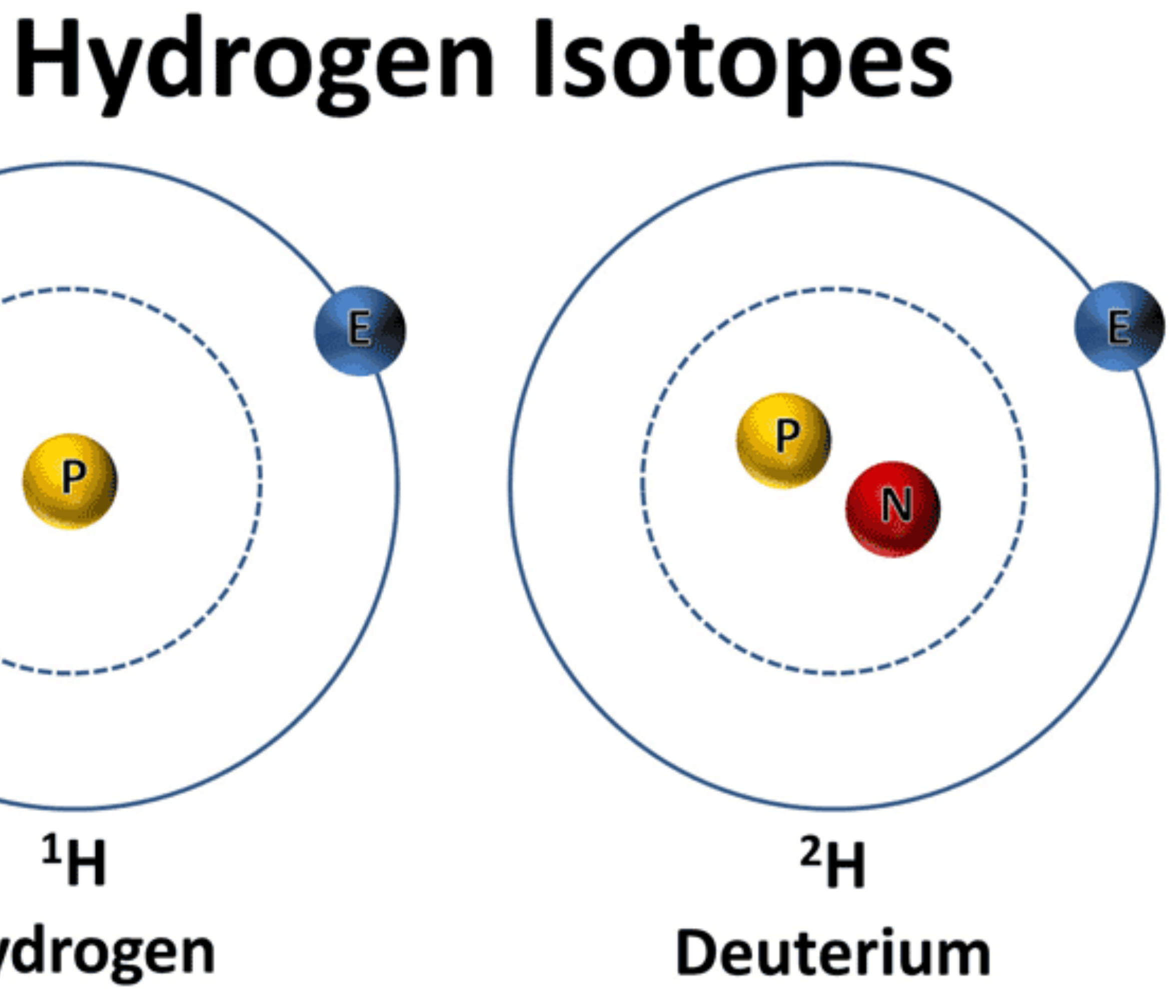
Three Isotopes of Hydrogen
e
p
e
n
p
e
n
p
n
$^1H$
Protium
$^2H$
Deuterium
$^3H$
Tritium

# Isotopes



$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

# Isotopes



# Isotopes

- Natural Uranium, which is found in many rock formations on earth, has three isotopes that all experience alpha emission, the release of alpha particles.

# Isotopes

- $^{233}_{92}U$ Is Uranium with an atomic mass of 233 and atomic number of 92.
- The number of neutrons is found by subtraction of the two numbers :

233 – 92 (protons) = 141 neutrons.

# Isotopes

- **The isotope composition of natural Uranium is:**
  - **99.27% Uranium-238,**
  - **0.72% Uranium-235,**
  - **A trace of Uranium-234.**

# Are all isotopes radioactive?

**According to the theory, If the ratio of neutrons to protons (n/p or N/Z) more than one, or becomes too large, the isotope is radioactive or the atomic number is above 83, the isotope will be radioactive.**

Any Questions?