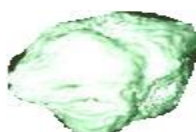


Chapter 10**Radioactivity****10.0: Introduction: history of radioactivity**

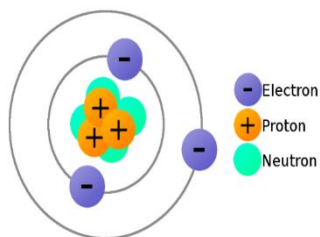
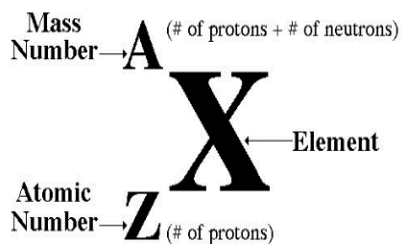
- In 1896, **Henri Becquerel** discovered almost by accident that some substance (like **uranium** and **radium**) can blacken a photographic film even in the dark. These substances are **radioactive material**.



- In 1898, **Marie Curie** and her husband (**Pierre Curie**) discovered two other radioactive elements namely **polonium** and **radium**.



- **Remember:** Matter is made up of **molecules**. The molecules are themselves made up of **atoms**. An **atom** can be **sub-divided** into **three sub-atomic particles** which are **protons** or **atomic number, neutrons** and **electrons**.



Subatomic Particles			
Particle	Symbol	Charge	Relative Mass (amu)
Electron	e^-	1-	0
Proton	p^+	1+	1
Neutron	n	0	1



$$A = Z + n \quad Z = A - n \quad n = A - Z \quad e = z \text{ in number but different charge}$$

♥ **Definition:** Radioactivity is the emission of sub-atomic particles and electromagnetic wave or rays from the unstable nucleus of an atom or Radioactivity is the process whereby unstable atomic nuclei release energetic subatomic particles or electromagnetic radiation (EMR).

- Elements which emit radiation from their nuclei are called **radioactive elements**.
- Radioactivity arises from unstable nuclei which may occur naturally (**natural radioactivity**) or be produced in **artificially** in nuclear reactors (**induced radioactivity**). Induced radioactivity can be done by forcing an extra neutron to the nucleus which disturbs the delicate balance of the neutrons and protons in the nucleus. The nucleus becomes unstable and the result is radioactive change.
- Most of the elements having atomic number greater than **82** emit invisible **radiation naturally**.

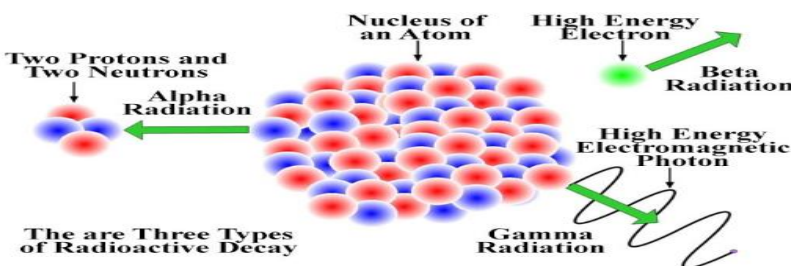
10.1 Characteristics of radioactive materials

- They are continually **decaying (breaking down)** or **disintegrate** into simpler atoms as a result of emitting radiations. The decay of radioactive materials is a **random process**.
- Radiations from radioactive elements **produce bright flashes** when they strike fluorescent compounds such as zinc Sulphate.
- Radiations from radioactive materials cause the ionization of air molecules.
- Radiations from radioactive element **penetrate** the photographic film and blacken it.
- Radiations from radioactive materials can **destroy** the germinating power of plant seeds and can kill bacteria.

10.2 Types of radiations

Whenever an unstable nuclide disintegrates it emit one or more of these three radiations or radioactive material.

1. Alpha (α) radiation
2. Beta (β) radiation.
3. Gamma (γ) radiation.



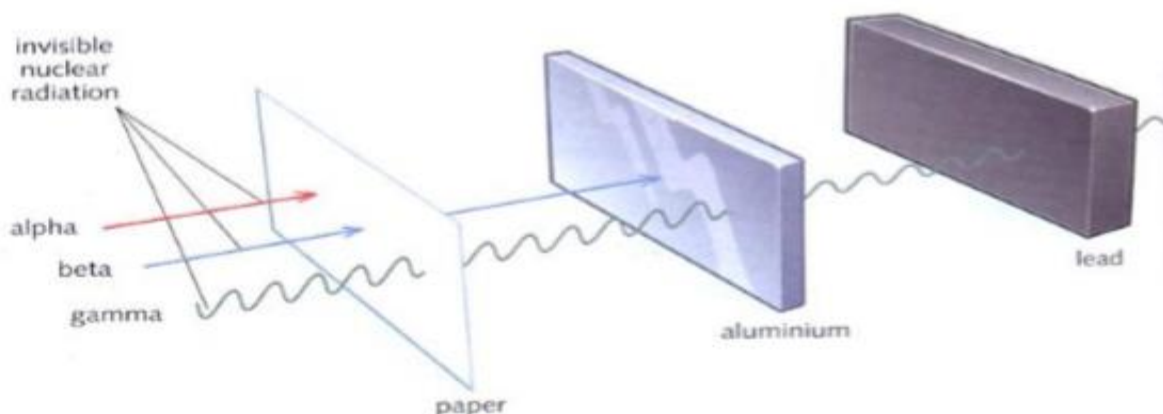
- ❖ Most radioactive substances emit **two kinds** of radiations simultaneously (usually **alpha** and **gamma** or **beta** and **gamma**).

The three main types of nuclear radiation **alpha**, **beta** and **gamma** which can be **identified** by their:

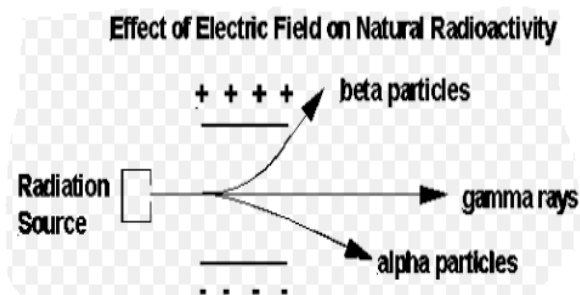
- | | |
|----------------------------|--|
| ✓ Penetrating power | ✓ Charge |
| ✓ Ionizing ability | ✓ Effects in an electric and magnetic fields. |
| ✓ Speed | |
| ✓ Mass | |



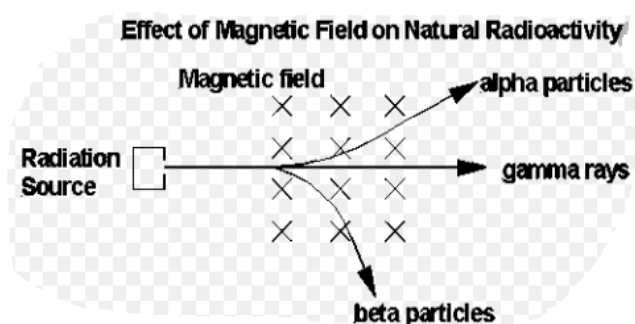
Penetrating power: The figure 5.1 below shows the penetrating power of these three types of radiations (Alpha, Beta and Gamma):



The passage of **alpha**, **beta** and **gamma** through a **magnetic field** and **electric field** is as shown figure 5.2 below:



- ✓ The **Alpha** radiation is **attracted** towards the **negative plate** of the electric field. This shows it has some kind of **positive charge**.
- ✓ The **Beta** particle is attracted towards the **positive plate** because it has a **negative charge**.
- ✓ The **Gamma radiation** is not affected by the **electric field** it passes straight through so it has **no charge**.



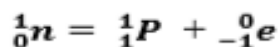
- **Beta** particle is **negatively charged** particle so it deflected in the opposite direction of Alpha.
- **Gamma** rays are not deflected by the magnetic field.
- The **Alpha** beam is a stream of **positive (+)** charged particle it **deflected by the magnetic field**.

Alpha radiation (α)

- It is positively charged particle from the nucleus of the radioactive elements.
- It is helium nucleus, this means its charge is +2 and its **mass is 4**. It can be denoted as ${}^4_2\alpha$ or ${}^4_2\text{He}$.
- It travels at about **10% of speed of light**.
- It has a high power of **ionization** of air molecules since it has **+2charge** it attracts electrons from nearby atoms in the gas.
- **Alpha** particles have a **least penetrating power**. It travels only a few centimeters in air and can be stopped by a thin sheet paper or the outer layer of the skin.
- Its ionization is concentrated in a small volume due to its **low speed** and **low penetrating power**.
- Alpha can be detected on a photographic film, in a cloud chamber (it is a straight thick tracks, all of about the same length).
- Examples of alpha emitters are radium, uranium, thorium and the good laboratory source of alpha radiations is americium-241

Beta radiation (β)

The term **beta** is referred to an **electron** from the nucleus of the atom. Electron do not exist in the nucleus but **one neutron** is changed into **proto-electron pair** as shown below then the electron can be lost from the nucleus.



- ✓ Beta particles are fast moving electrons and relatively charge of **-1**.
- ✓ They are much lighter than alpha and are usually more penetrating having ranges of several meters in air or they can be stopped by few centimeter of aluminum
- ✓ They travel about **90% of speed of light**.
- ✓ They are much less ionizing power than alpha but are more easily deviated by the field.
- ✓ Beta particles can be detected by Geiger-Muller (Gm) , cloud chamber or photographic film.
- ✓ Examples of some pure beta emitters: carbon-14, sulfur-35 and its good **laboratory source is strontium-90**.

Gamma radiation (γ)

- A gamma radiation is high-energy electromagnetic radiation emitted from the nucleus of an atom. It is not a stream of particles.
- It travels at about speed of light (**$C=3 \times 10^8 \text{ m/s}$**)
- It has no net charge.
- Gamma radiations have low ionizing power and have high penetrating power. They are never completely absorbed but their intensity can be reduced by several centimeters of lead.
- **Gamma emission** generally occurs after an **alpha** or **beta**.
- Gamma rays can be detected by a photographic film, cloud chamber and Geiger Muller counter.

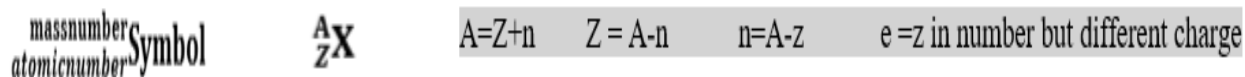
- Examples of some gamma emitters: iodine-131, cesium-137, radium-226, and technetium-99m. Its main **laboratory source is cobalt-60**.

Table: 10. 1 below summarizes the properties of the three types of radiations

Type of radiation	Alpha (α)	Beta (β)	Gamma (γ)
Nature of radiation	Nucleus of Helium	High speed of electron	Electromagnetic wave
Relative charge	+2	-1	0
Speed	Up to 10% of speed of light	Up to 90% of the speed of light	Speed of light
Ionizing effect	Strong	Weak	Very weak
Effects of fields	Deflected by fields	Deflected by fields	Not deflected
Penetrating power	Not very penetrating, stopped a thick sheet of paper	Penetrating, but stopped by few centimeters of aluminium	Very penetrating, never completely absorbed, through lead may reduce its density.

10.3-Nuclear Equations

In nuclear changes, just as a chemical change, nothing is very **lost** or **gained**. The **total mass number** and **total atomic number** remain the same. The mass number and atomic number of an atom can be written in the form of:



And $Z = n(P)$

✓ E.g. Carbon -14 is written as ${}^{14}_6\text{C}$; and uranium -328 is written as ${}^{238}_{92}\text{U}$.

A general atom X is written as ${}^A_Z\text{X}$ where $A = N + P$ and $Z = n(P)$

→ Neutron ... ${}^1_0\text{n}$;

→ Proton..... ${}^1_1\text{P}$;

→ Electron... ${}^0_{-1}\text{e}$

→ Alpha particle ${}^4_2\alpha$ or ${}^4_2\text{He}$

→ Beta particle ${}^0_{-1}\beta$

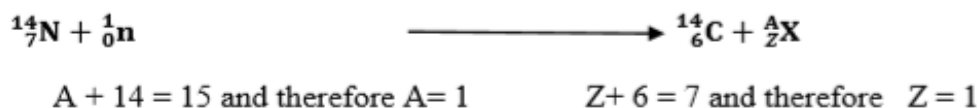


Remember:

In any nuclear equation, the **total mass number** and **atomic** on the **LHS** must equal to the **total mass number** and **atomic** on the **RHS**.

Examples

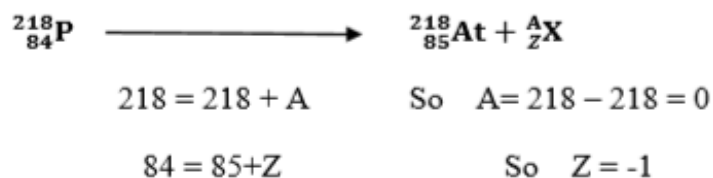
1) When a **neutron** bombards a **nitrogen atom**, **carbon -14** and other nuclide result. Identify the unknown nuclide?



So the unknown particle is hydrogen since it has a mass number of 1 and an atomic number of 1



2) What other product is formed when polonium -218 decay to Astatine?



The unknown particle is an electron



Exercise one

1. When two atoms of ${}^2_1\text{H}$ hydrogen are fused together they form a neutron and one new atom. What is that new atom?

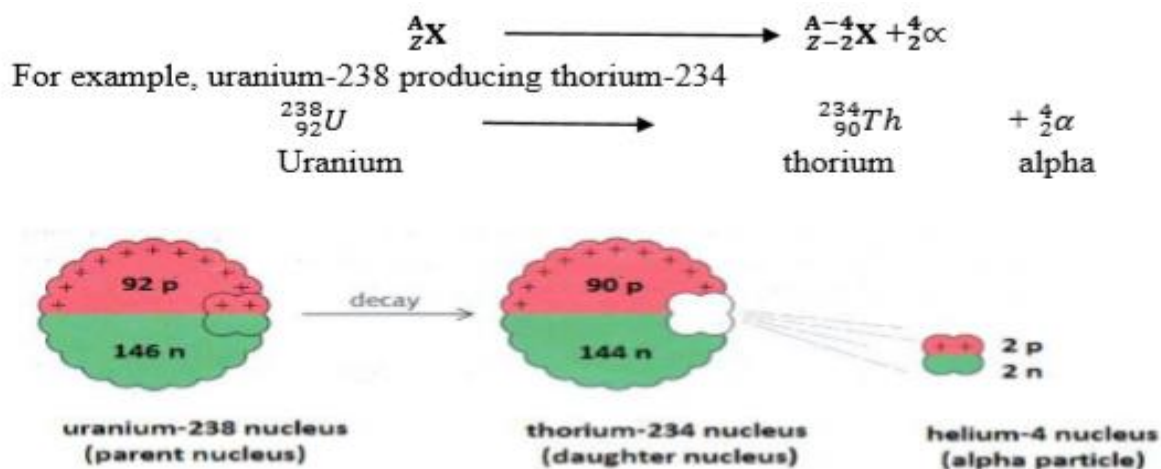


2. Which of these three types of radiation
 - i. Is form of electromagnetic radiation?
 - ii. Has no charge?
 - iii. Carries positive charge?
 - iv. Travel at the speed of light?
 - v. Is made up of electrons
 - vi. Has the most ionizing effect?
 - vii. Can be stopped few centimeters of aluminum?
 - viii. Can be penetrating a thick sheet of lead

10.4 Effects on the Nucleus

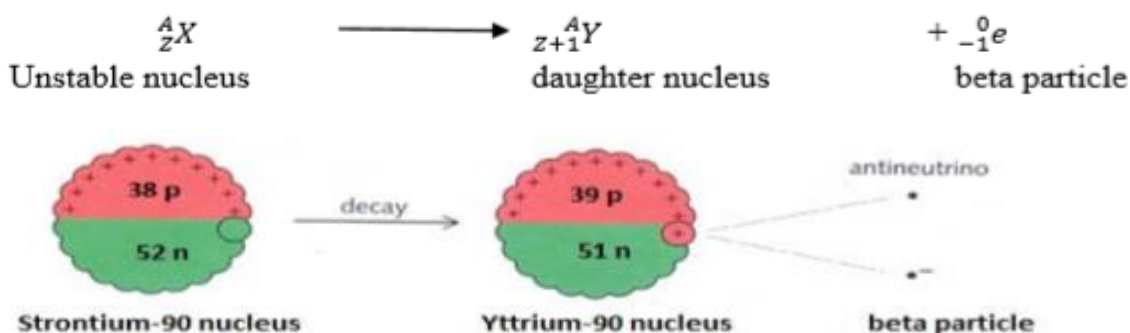
Alpha decay

In an alpha decay, the atomic number **Z** of the nucleus goes down by **2** and the mass number **A**, goes down by **4**, such a change is called a **nuclear transmutation**



Beta radiation

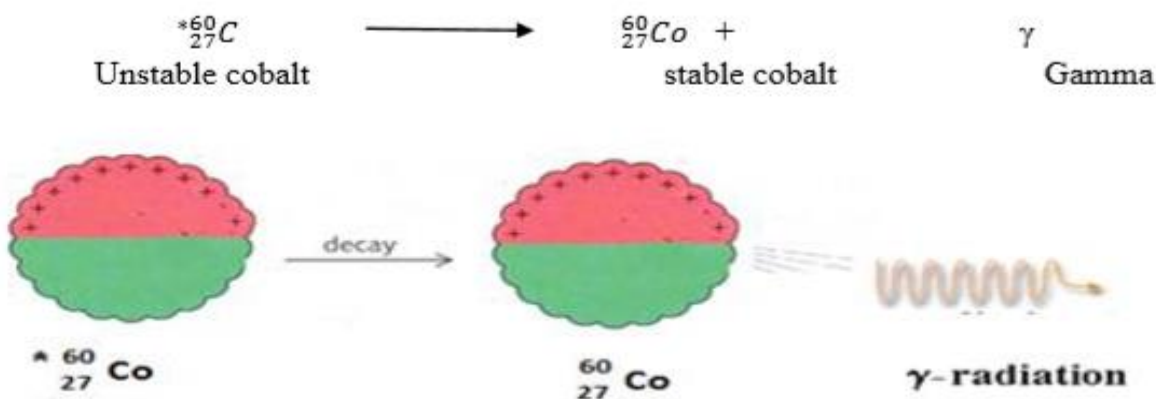
A **beta** particle is an **electron**. When an electron is ejected from the nucleus, the atomic number “Z” is **increased** by 1 (because a **new proton** has been **created**), but the **mass** number “A” remains **unchanged**.



Gamma emission

Gamma rays are **e.m radiation**, the emission of an alpha or beta particle from a nucleus leaves the protons and neutron in an “**exited**” **arrangement**. As the protons and neutrons **rearrange** to become more **stable**, they **lose energy**. This is carried as burst of **gamma radiation**. When a nucleus emits **gamma rays**, the nucleus keeps the same **atomic** and **mass number**.

For example: **cobalt-60** is a common gamma-emitting nuclide



Radioactive decay

Radioactive decay is the process by which unstable nucleus breaks down or disintegrate releasing radiation. Disintegration Series (Decay Series) When an **unstable nuclide** disintegrates, it forms a **new nuclide**. The new nuclide may also be unstable; hence it also decays to give a further nuclide. This process **continuous** until a **stable nuclide** is **formed** this process is called **decay series**. For example uranium decays:

“Heavy” atoms (greater than Bismuth, #83) naturally decay to smaller atoms along a consistent path, or series, of decays

Radioactive U-238 $\rightarrow$ Th-234 + α

Th-234 $\rightarrow$ Pa-234 + β

Pa-234 $\rightarrow$ U-234 + β

U-234 $\rightarrow$ Th-230 + α

Th-230 $\rightarrow$ Ra-226 + α

Ra-226 $\rightarrow$ Rn-222 + α

Rn-222 $\rightarrow$ Po-218 + α

Po-218 $\rightarrow$ Pb-214 + α

Pb-214 $\rightarrow$ Bi-214 + β

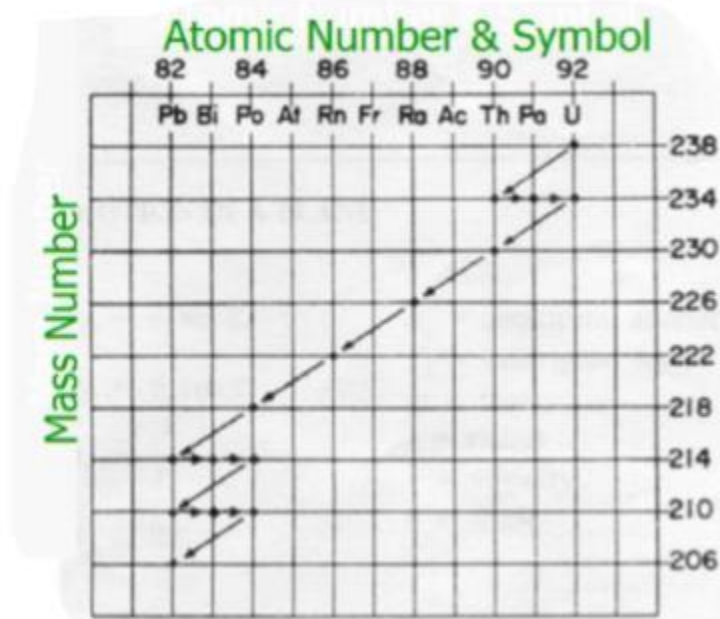
Bi-214 $\rightarrow$ Po-214 + β

Po-214 $\rightarrow$ Pb-210 + α

Pb-210 $\rightarrow$ Bi-210 + β

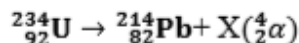
Bi-210 $\rightarrow$ Po-210 + β

Po-210 $\rightarrow$ **Stable Pb-206** + α



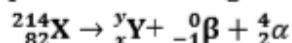
Exercise

1. How many alpha particles are emitted when uranium 234 decays to lead 214 as shown below?

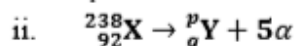
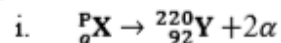


2. An isotope of uranium -235 can be written U. what is the significance of number of 235 and 92.

- a) Complete the following radioactive decay equation



- b) Find the values of P and q in the equations.



3. A radioactive nuclide emits an alpha particle followed by beta particle. The mass number and atomic number of the resulted nucleus respectively are.

- a) $A + 4, Z + 1$
 b) $A - 4, Z - 1$
 c) $A, Z + 1$
 d) $A - 4, Z - 2$

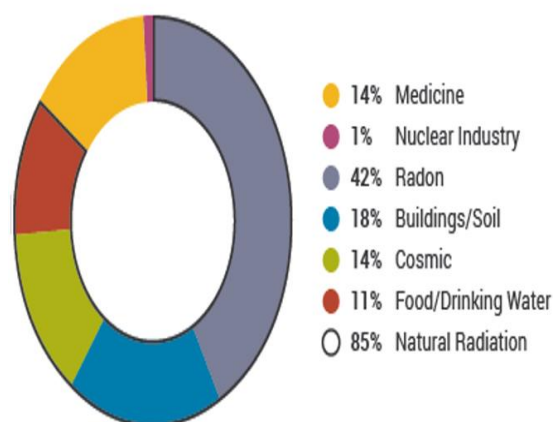
10.5 Isotopes, Isobars and Nuclides

- ✚ **Isotopes** are atoms of **same element** which have different **mass number** because they have different **number of neutrons** in their nuclei. E.g. Cl-35 Cl-37 and H-1, H-2 H-3.
- ✚ **Isobars** are atoms of **different elements** which have **same mass number**. E.g. Ra-288, Ac-288 and thallium-288.
- ✚ **Nuclides** are atoms which have **different nuclei**; whether the difference is the number of **protons**, the number of **neutrons** or **both**.

Background radiation

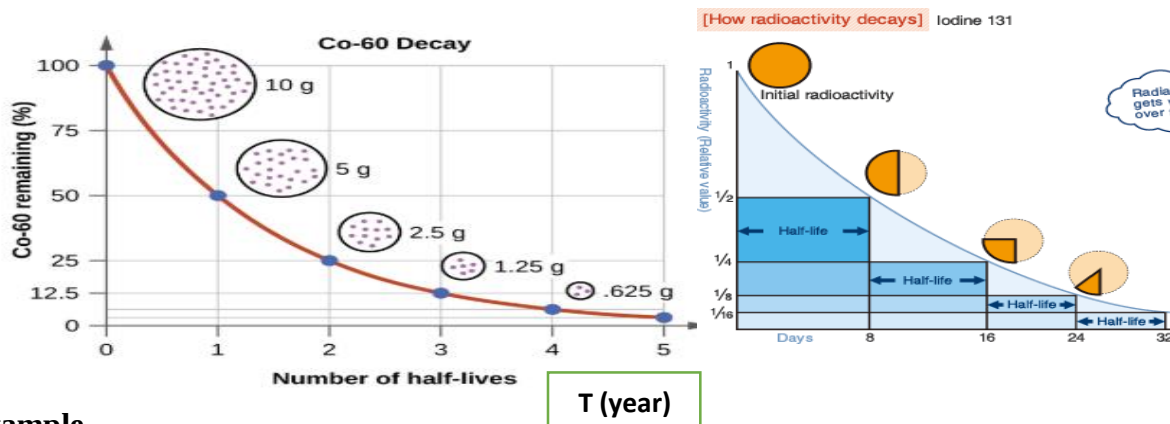
Nuclear radiations can **damage** or **destroy** living cells. It may upset the chemical instructions in cells so that cell may grow up abnormally and can cause **cancer**. However there is small amount of radiation around us all the time because of radioactive material in the environment. This is called **background radiation**. It mainly comes from natural source such as soil, rocks building materials, air, food, Drinks and cosmic rays from space. Nuclear power station and nuclear bombs also increase back ground radiation.

Sources of Radiation



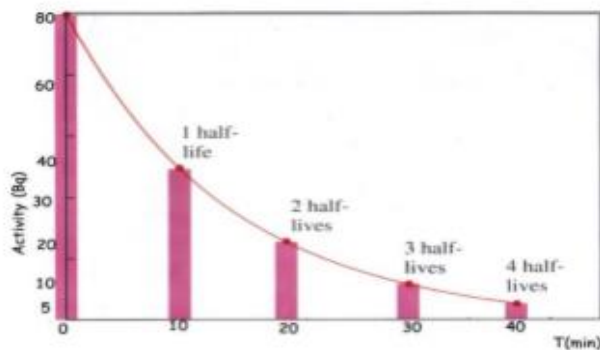
10.6 Rate of decay and half-life

- **Rate of decay:** A very unstable nuclide decays more frequently than with greater stability, but in every case the decay follows the same rule. “The rate of radioactive decay is directly proportional to the number of nuclei present” **Rate of decay $\propto N$** or **rate of decay $= \lambda N$** Where λ = constant of proportionality and each nuclide have different value for λ .
- **Half-life:** The average time for half of the atoms in a given sample to decay is called **half-life**. In other words it is the time taken for the activity of a given sample to fall to **half** the original value. It can be denoted as $t_{1/2}$. The decay curve of the figure below.



Example

Suppose you have **80grams** of reactive nucleus



The activity falls by **the same fraction** in **successive time intervals**. It falls from **80Bq to 40Bq in 10 minutes**; from **40Bq to 20Bq in the next 10 minutes**, from **20Bq to 10Bq in the third minutes** and so on. **The half-life of the sample is 10 minutes.**

Note: Radioactivity is measured in Becquerel's (Bq). 1 Bq = 1 nuclear disintegration per second the Becquerel is a very small unit. In elementary work, quantities of kBq to MBq range are common.

- The unit of radioactivity was the curie (Ci). Curie is a very large unit (1Ci = 3.7x10¹¹Bq) so quantities of μ Ci and mCi range are used.

- Different nuclides have different half-lives as shown in the table below.

Element	Half life
Uranium	4500×10^6 years
Plutonium	24000 years
Carbon	5600 years
Iodine	8 days
Sodium	15 hours
Polonium-218	3 minutes
Radon	54 second
Polonium-214	1.6×10^{-4} seconds

- **Half-life** of a nuclide is a characteristic of that nuclide; **it is governed** by the **structure** of the **nucleus**. It is not **affected** by the **temperature, pressure** and any other **physical condition**.
- The number of nuclides that is not decayed “N” after a time “T” is found by:

$$N = N_0 \left(\frac{1}{2}\right)^{T/t} \quad \text{where } N_0 = \text{original number of atoms,}$$

N = number of un-decayed atom or remain atom

t = half life

Or the activity of the nuclide “A” after a time “T” can be found by:

$$A = A_0 \left(\frac{1}{2}\right)^{T/t} \quad \text{where } A_0 = \text{original activity,}$$

t = half life.

Examples 1.

In a laboratory there are **12g** of radioactive nuclide, if the half live of the radioactive nuclide is **5 days**, how many atoms remain after **20 days**?

Given

$$N_0 = 12\text{g} \quad t = 5\text{days} \quad T = 20\text{days} \quad N = ?$$

Answer:

$$N = N_0 \left(\frac{1}{2}\right)^{T/t} = (12\text{g}) \left(\frac{1}{2}\right)^{20/5} = (12\text{g}) \left(\frac{1}{2}\right)^4 = 12\text{g}/16 = 0.75\text{g will remain.}$$

2. A radioactive nuclide has a half-life of **8 day**

- a. What fraction of the original number of atoms of the isotope will be left after **32 days**?
- b. If there are **10,000** atoms in the sample at present, how many atoms will remain after **32 days**?

Answer

$$\begin{aligned}
 \text{a) } N &= N_0 \left(\frac{1}{2}\right)^{T/t} \\
 &= (1) \left(\frac{1}{2}\right)^{32/8} \\
 &= \left(\frac{1}{2}\right)^4 = 1/16 \text{ of the original atom will be left after 32 days} \\
 \text{b) } N &= N_0 \left(\frac{1}{2}\right)^{T/t} \\
 &= (10,000) \left(\frac{1}{2}\right)^{32/8} \\
 &= (10,000) \left(\frac{1}{2}\right)^4 \\
 &= 625 \text{ atoms will remain}
 \end{aligned}$$

Exercise (check your answers from the exercise book)

1. A radioactive substance has decayed to 1/128 of its original activity after 49 days. What is its half-life?
2. 800g of radioactive nuclide has a half-life of two hours. Calculate How many grams will remain;
 - i. After 6 hours
 - ii. After 10 hours
3. In an experiment to find the half-life of radioactive nuclide the count rate falls from 120Bq to 15 Bq in 30 days. What is half-life?
4. 16000 of radioactive nuclide has a half-life of 20 days, how many grams will remain
 - a) After 60 days
 - b) After 100 days
5. A radioactive nuclide has a half-life of 20 minutes.
 - a) What fraction from the original nuclide will remain one hour?
 - b) If there are 8000 atoms in the sample at present how many un-decayed atoms will remain after one hour.
6. A bone of living human being contains 160 units of carbon 14 an identical bone was found ancient burial around, which contains 10 units of carbon 14. The half-life of carbon 14, is 5730 yrs. calculate the age of skeleton?
7. A radioactive isotope has a half-life of 2.5h
 - a) At what fraction from the original nuclide will remain after 20 hours?
 - b) If there are 4000g in the sample at present how many grams will remain after 20 hours?

Radiation detectors

1. **Photographic film** (Photographic plates can be used to detect radioactive rays, because such plates are blackened by the rays)
2. **Ionization detector** (is used to detect only **alpha** and **Beta particles**)
3. **Spark counter**
4. **Cloud chamber**
5. **Scintillation Detectors**
6. **Geiger-Muller tube (GM tube)**
7. **The gold leaf electroscope (alpha only)**

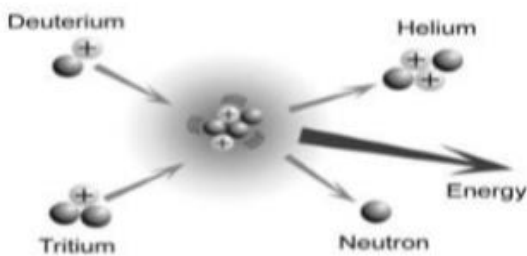
Types of Nuclear Reactions

There are **two** types of **nuclear reactions** and they are:

1. **Nuclear fusion (union)**
2. **Nuclear fission (division)**

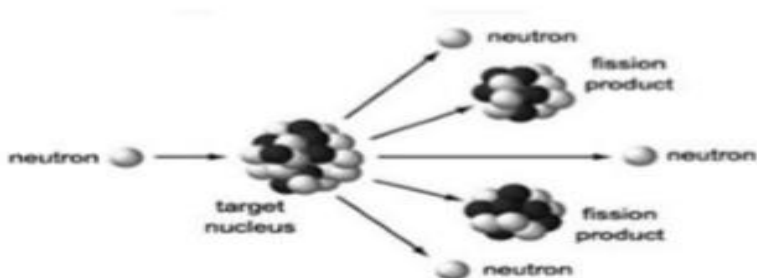
1. Nuclear fusion

The combination of two light nuclei to form a heavier nucleus is called nuclear fusion.



2. Nuclear fission (division)

The **splitting** of a **heavy nucleus** into nuclei with smaller masses is called nuclear fission.



10.7 Applications and Hazards of Radioactivity

Applications of radioactivity

1. **As a thickness gauge**(is used to check the thickness of a substance)
2. **As a Tracers**(Checking the function of body organs, underground pipes and Tracing the plants uptake of fertilizers)
3. **Radiotherapy** (is used to kill cancer cells)



4. **Radio dating (Archaeology)**
5. **As a sterilizing agent** (is used medical equipment and food)



Hazards of radioactivity

Radiation can affect the people in a number of ways:

- It can destroy cells and tissues
- It can also change the DNA, causing mutations and effecting the future generation if the sex cells are effected
- Radiation can cause skin burns and cancer

To reduce hazards from radioactive material

- People should be shielded from radioactive source by suitable absorber.
- There should be as large a distance as possible between person and radioactive source.
- People who work with radioactive material wear a badge containing photographic film that measure the amount of exposure to radiation.
- Radioactive substances should be kept in thick lead boxes.
- Minimize time spent near radiation source.
- Never eat or drink in the lab.

Do Exercise page 184----- page 188