CHAPTER TEN
RADIOACTIVITY

Introduction: What is radioactivity?

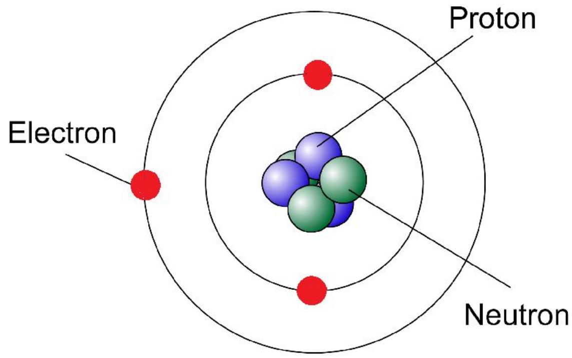
Radioactivity is the process in which unstable atomic nuclei spontaneously decompose to form nuclei with a higher stability by the release of energetic sub atomic particles. *Unstable nuclides continue to disintegrate until a stable atom is formed.*

In order to understand radioactivity, the structure of atoms needs to be understood.

Atomic Structure

Atoms are made up of protons, neutrons and electrons each with their own properties.

- Protons have a positive (+) charge
- Electrons have a negative (-) charge
- Neutrons have no charge (Neutral)



The protons and neutrons lie in the nucleus at the centre of the atom and the electrons orbit round the nucleus. The proton and neutron are equal in number and approximately equal in mass

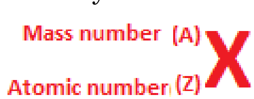
Atomic Number and Atomic Mass

- ✓ The **atomic number** of an element is the number of protons that lie in the nucleus. It is denoted by the symbol Z
- ✓ The number of neutrons is denoted by the symbol **N**. Protons and neutrons are called **nucleons** since they form the nucleus of an atom.
- ✓ The **atomic mass** or **mass number** of an element is the total number of protons and neutrons that lie in the nucleus of an atom. Is it denoted by symbol **A**

Mass number = atomic number + number of neutrons

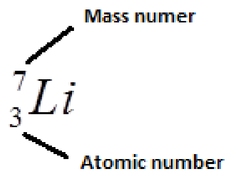
$$\mathbf{A = Z + N}$$

The chemical symbol of an element is written as

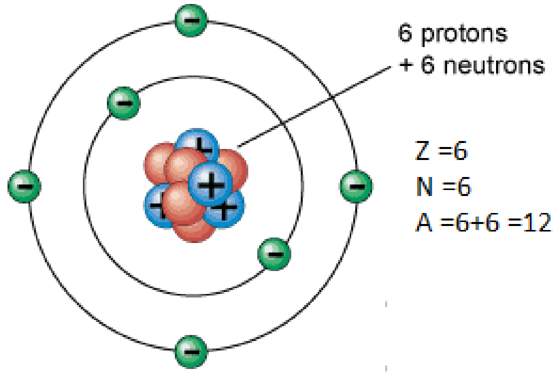


Example:

1. If we take the example of the Lithium atom it contains 3 protons and 4 neutrons in its nucleus.
   Therefore, it's:
   Atomic number = number of protons = 3
   Mass number = number of protons + number of neutron = 3 + 4 = 7
   Elements are normally represented by their chemical symbols along with their atomic and mass number, as:



2. For a stable carbon atom;



Carbon atom

$^{12}_{6}\mathbf{C}$

Radioactive isotopes

All the atoms of a particular element have the same number of protons. It is the number of protons which determine the chemical properties of an atom. The number of neutrons however can vary.

Or in other words, elements with the same atomic number but different mass number are called isotopes of that element.

For, example carbon- 12 and carbon-14 are isotopes of carbon. They are represented as $^{12}_{6}C$ and $^{14}_{6}C$ respectively.

Stable and Unstable Nuclei

A stable atom is an atom that has enough nuclear force to hold the nucleus together permanently.

Most atoms are stable and do not change from one element to another. An oxygen atom, for example, will normally stay an oxygen atom forever. In such an atom, the strong nuclear force holding the nucleus together is much stronger than the electric force pushing the protons away.

In unstable nuclei the strong nuclear forces are not sufficient enough to hold the nucleus together permanently. Such a nucleus tries to achieve a balanced state by giving off a neutron or proton through a process called radioactive decay.

Types of radiations

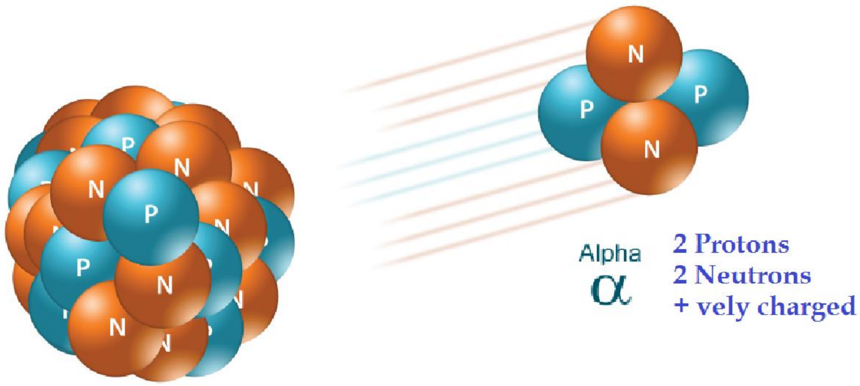
Radioactivity is the process in which unstable atomic nuclei spontaneously decompose to form nuclei with a higher stability by releasing atomic particles. **It** occurs naturally and only in unstable atoms.

The sub atomic particles and their associated energy that are released during the decomposition of the unstable nuclei are referred to as radiation. There are 3 main types of radiations:

i. Alpha decay (radiation)
ii. Beta decay (radiation)
iii. Gamma radiation

Alpha Particles (α)

These particles are made up of 2 protons and 2 neutrons: the helium nucleus. They are represented as ^4_2He. Often, large atoms decay by emitting an energetic alpha particle. These particles are relatively large and positively charged with a charge of +2. Named alpha because they were the first to be discovered.



Properties of alpha particles

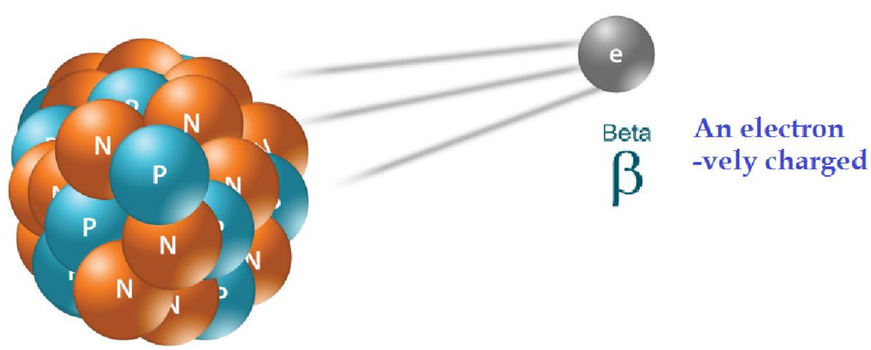
1. They are positively charged
2. They ionize the gas through which they travel
3. They travel in a straight line in free space
4. They can be stopped by a thin sheet of paper
5. They can be affected by photographic plates
6. They are slightly deflected by both magnetic and electric fields
7. They have large kinetic energy as they are relatively heavy.

Alpha particles have the least penetration power. They have the greatest ionization power. They cannot penetrate the skin but they are still dangerous. Since they have a great ionization power, so if they get into the body they can cause serious damage. They have the ability of ionizing numerous atoms, and for this reason, radioactive substances releasing alpha particles needs to be handled with rubber gloves. It should not be inhaled, eaten or allowed near open cuts.

Beta (β) particles

Beta particles are emitted by neutron rich unstable nuclei. Beta particles are high energy and are negatively charged.

They are represented by $_{-1}^{0}e$ meaning that they have no mass but a charge of -1.



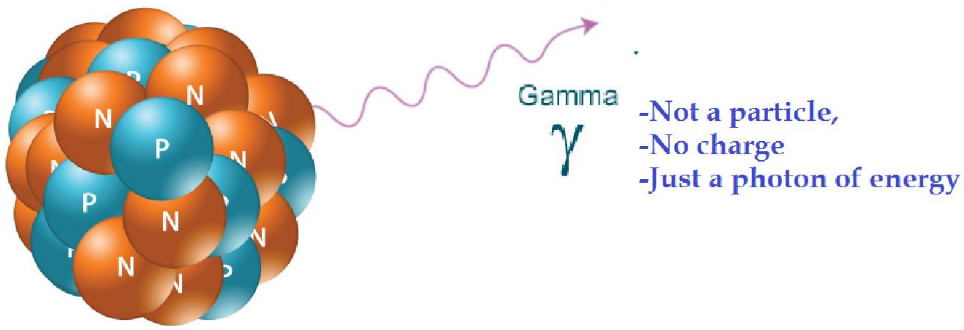
***Properties of* Beta (β) particles**

1. Their speeds are as high as 99.9% or more the speed of light
2. They are deflected by electric and magnetic fields but in a direction opposite to that of alpha particles.

3. They have a higher penetrative rate than alpha particles
4. Their ionization power is much less than that of alpha particles.
5. They can be affected by photographic plates but less than alpha particles

Gamma (Υ) particles

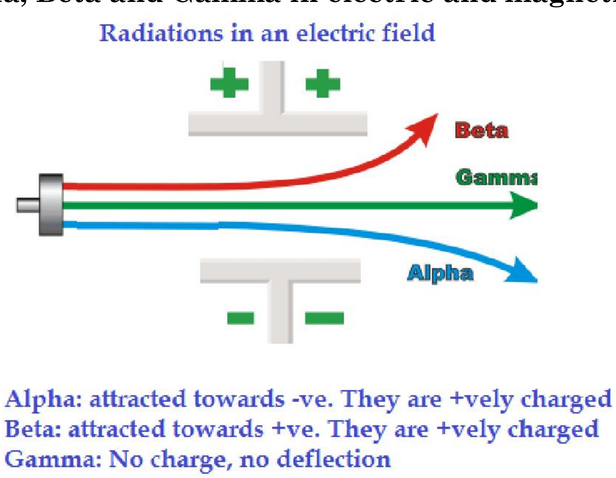
Gamma, unlike alpha or beta, does not consist of any particles, it is instead a ray. They have no mass or charge. Gamma rays are electromagnetic waves of very short wavelength and high frequency.

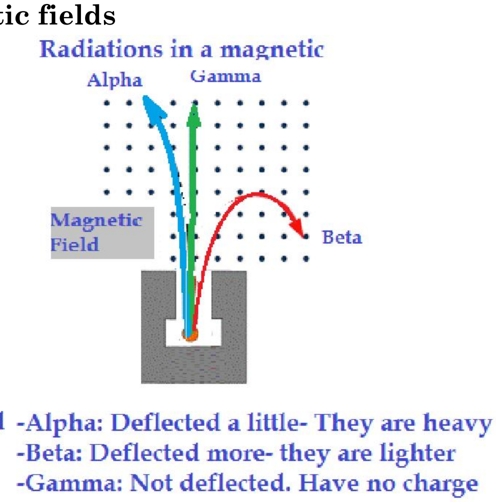


Properties of Gamma (Υ) particles

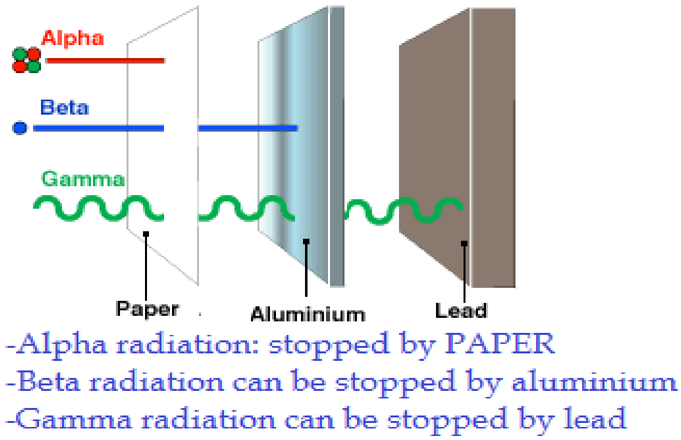
1. They travel at the speed of light.
2. They have less ionization power than that of both alpha and beta particles
3. They accompany the emission of alpha and beta particles
4. They carry no electric charge hence they are not deflected by both electric and magnetic fields.
5. They have more penetrating power than X-rays.

Alpha, Beta and Gamma in electric and magnetic fields





Penetration power of Alpha, Beta and Gamma



Differences between Alpha Beta and Gamma Radiation – Summary

	Alpha	Beta particle	Gamma
Nature of the radiation	A helium nucleus	An electron	A photon
Charge	Positive	negative	No charge
Penetrating power	Least penetration power	Moderate penetration power	Very high penetration power
Ionizing power	Very high ionization power	Moderated ionization power	Very low ionization power
Stopped	Stopped by a thin sheet of paper	Stopped by an aluminum sheet	Stopped by a lead block
Motion in magnetic field	Slightly deflected	Highly deflected since they are light	Not deflected
Motion in electric field	Attracted towards a negative plate	Attracted towards a positive plate	Not deflected

What is ionizing; how does the radiation cause ionization?

When a neutral atom or molecule loses or gain electrons, a charged particles called an ion is formed. When alpha particles or beta particles or gamma photons hit atoms they knock off negative electrons causing ionization, that is, in this case, the formation of positive ions. These atomic or molecular ions are very reactive and can bring about chemical changes

Effects of radioactive decay on the nucleus

Alpha decay

A nucleus emitting an alpha particle reduces its mass number by 4 units and its proton number by 2. The equation can be written as follows,

$$^{A}_{Z}X \xrightarrow{\alpha} {}^{4}_{2}He + {}^{A-4}_{Z-2}Y$$

$^{A}_{Z}X$ is called the parent nuclide while $^{A-4}_{Z-2}Y$ is the daughter nuclide. $^{4}_{2}He$ is an alpha particle

Example

1. Uranium- 235 $^{235}_{92}U$ changes to Thorium $^{231}_{90}Th$ by emitting an alpha particle. Write a nuclear equation to represent the decay.

Solution

$$^{235}_{92}U \xrightarrow{\alpha} {}^{4}_{2}He + {}^{231}_{90}Th$$

2. Thorium - 231 undergoes a decay by emitting two alpha particles to become lead. Write a nuclear equation to represent the decay.

Solution

$$ {}^{231}_{92}U \xrightarrow{\alpha} 2\left({}^{4}_{2}He\right) + {}^{223}_{88}Pb $$

Beta decay

When a nuclide undergoes a Beta decay, an electron is ejected from the nucleus and the number of protons increases by 1 while the mass number remains the same. Therefore, the atomic number increases by one.

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

Examples

1. Thorium ${}^{231}_{90}Th$ changes to Proctanium (P_o) with the emission of a beta particle. Show the decay using nuclear equation.

   Solution

$$ {}^{231}_{90}Th \xrightarrow{\beta} {}^{0}_{-1}e + {}^{231}_{91}Po $$

2. A radioactive carbon-14 decays to nitrogen by emitting a beta particle as shown. Determine the values of x, y and z in the equation below.

$$ {}^{231}_{6}C \xrightarrow{\beta} {}^{x}_{y}N + {}^{0}_{z}e $$

Solution

x: mass number does not change $\Rightarrow x = 231$

y: atomic increase by 1 $\Rightarrow y = 7$

z: an electron with -1 charge $\Rightarrow z = -1$

Gamma radiation

This a radiation in which unstable nuclides attains stability by only emitting energy. No new nuclide is produced. For example;

- Cobalt-60

$$ {}^{60}_{27}Co \longrightarrow {}^{60}_{27}Co + \gamma $$

- Thorium -230

$$ {}^{230}_{90}Th \longrightarrow {}^{230}_{90}Th + \gamma $$

More Examples

1. Write an equation to show how a radioactive isotope of cobalt ${}^{231}_{90}Co$ undergoes an alpha decay followed by the emission of gamma rays to form a new nuclide X.

   Solution

$$ {}^{60}_{27}Co \xrightarrow{\alpha} {}^{4}_{2}He + {}^{56}_{25}X + \gamma $$

2. Complete the decay series when Uranium-238 decays to Thorium-230. Indicate the type of decay with a letter.

$$ {}^{238}_{92}U \longrightarrow {}^{234}_{90}Th \longrightarrow {}^{234}_{91}Pa \longrightarrow {}^{234}_{92}U \longrightarrow {}^{230}_{90}Th $$

Solution

For;

α – the atomic number reduces by 2

β – the atomic number increases by 1

γ – the atomic number remains the same

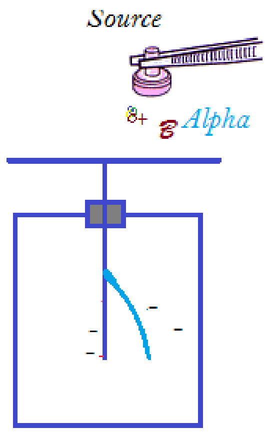
$$^{238}_{92}U \xrightarrow{\alpha} {}^{234}_{90}Th \xrightarrow{\beta} {}^{234}_{91}Pa \xrightarrow{\beta} {}^{234}_{92}U \xrightarrow{\alpha} {}^{230}_{90}Th$$

Detection of nuclear radiation

Gold leaf electroscope

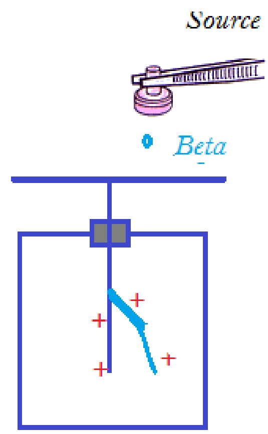
When an electroscope is charged, the gold leaf diverges, because the charges on the gold repel the charges on the metal plate. When a radioactive source is brought near the electroscope, the air around is ionized, and starts to conduct electricity. This means that the charge can "leak" away, the electroscope discharges and the gold leaf falls.

Beta particles are negatively charged and thus discharges a positively charged electroscope Alpha particles would similarly discharge a negatively charged electroscope.



Negative electroscope

Alpha particles discharges a negatively charged electroscope

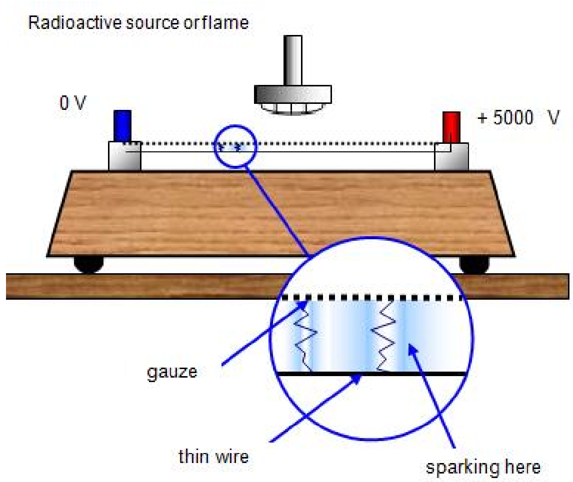


Positive electroscope

Beta particles discharges a positively charged electroscope

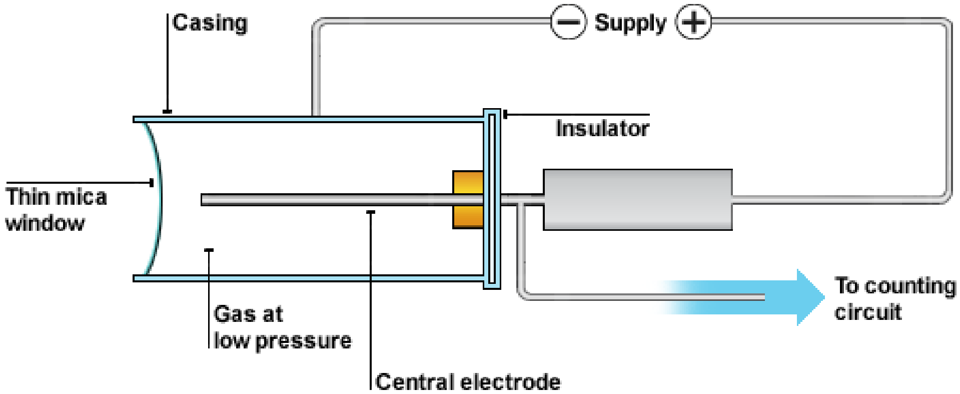
However, use of a charged electroscope may not be suitable because their ionization in air may not be sufficient to cause significant discharge.

The spark counter



This detector is suitable for alpha sources due to the inadequacy of the ionization by both beta and gamma radiations. By putting the source away from the gauze or placing a sheet of paper between the two one can determine the range and penetration of the alpha particles.

Geiger Muller (GM) tube



The mica window allows passage of alpha, beta and gamma radiations. When an alpha or beta or gamma radiation enters the tube it produces ions in the gas. The ions created in the gas enable the tube to conduct. A current is produced in the tube for a short time. The current produces a voltage pulse. Each voltage pulse corresponds to one ionising radiation entering the GM tube. The voltage pulse is amplified and counted.

Activity and half-life of elements

Decay law

Radioactive decay is a random process and is impossible to predict exactly when a particular atom will decay.

The law of radioactive decay states that "the rate of decay of a sample at a given time is directly proportional to the number of nuclides present in the sample".

Let N represent the present number of nuclides.

The rate of change of the nuclides; $\frac{dN}{dt}$

$$\therefore \frac{dN}{t} \alpha N$$

Since the number of nuclides reduces with time, N is negative

$$\frac{dN}{t} \alpha -N$$

$$\frac{dN}{t} = -\lambda N \quad \Rightarrow \lambda \text{ is a constant; decay constant}$$

Half-life

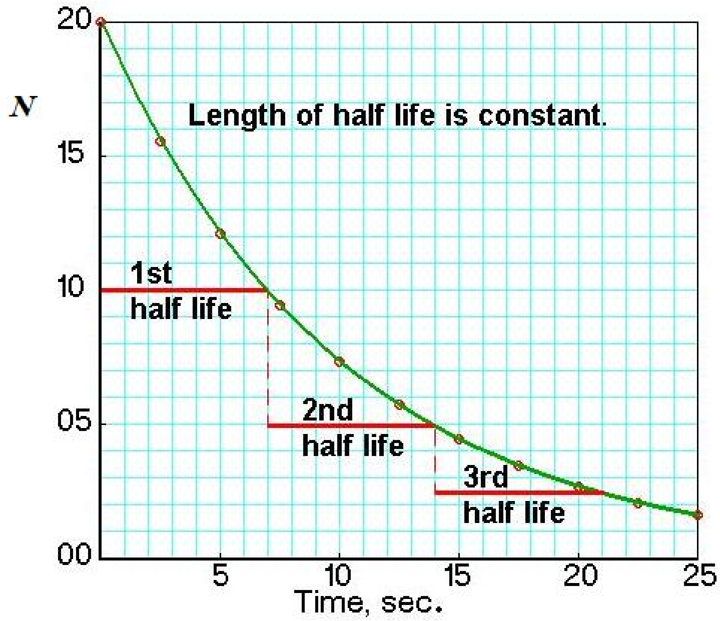
The half-life of a radioactive element is the time required for its one-half of the sample to decay. It is important to note that although the activity approaches zero, it never goes to zero. It is exponential.

Consider a radioactive sample with 20 nuclides initially and a half-life of 7 seconds. The decay process will be as shown below,

No of half-lives	Time in seconds	Decayed nuclides	Remaining nuclides
0	0	0	20
1	7	10	10
2	14	15	5
3	21	17.5	2.5
4	28	18.75	1.25

This process goes on and on as it approaches zero but never get to zero.

The above information can be illustrated on a graph as shown below



Given that the half-life of a sample is *t,* the number of nuclides remaining, after time T is given by;

$N = N_0\left(\frac{1}{2}\right)^{\frac{T}{t}}$ Where N_0 is the original number of nuclides

NOTE: while filling the table for half-lives, the number of nuclides reduces by half but time increases by half-life time; **not multiplied but added**.

Examples

1. The half-life of a sample of a radioactive substance is 98 minutes. How long does it take for the activity of the sample to reduce to 1/16th of the original value?

Solution

$$N = \frac{1}{16}N_0$$
$$t = 98$$
$$N = N_0\left(\frac{1}{2}\right)^{\frac{T}{t}}$$
$$\frac{1}{16}N_0 = N_0\left(\frac{1}{2}\right)^{\frac{T}{98}}$$
$$\left(\frac{1}{2}\right)^4 = \left(\frac{1}{2}\right)^{\frac{T}{98}}$$
$$4 = \frac{T}{98}$$
$$T = 4 \times 98 = 392 \text{ minutes}$$

Alternatively

N	Half-life	Time
1	0	0
$\frac{1}{2}$	1	98
$\frac{1}{2}\times\frac{1}{2}=\frac{1}{4}$	2	196
$\frac{1}{2}\times\frac{1}{4}=\frac{1}{8}$	3	294
$\frac{1}{2}\times\frac{1}{8}=\frac{1}{16}$	4	392

2. What is the half-life of element X if it takes 36 days to decay from 50 grams to 12.5 grams?

$$N_0 = 50g; \quad N = 12.5g$$
$$T = 36$$
$$N = N_0\left(\frac{1}{2}\right)^{\frac{T}{t}}$$
$$12.5 = 50\left(\frac{1}{2}\right)^{\frac{36}{t}}$$
$$\frac{12.5}{50} = \left(\frac{1}{2}\right)^{\frac{36}{t}}$$

$$\frac{1}{4}=\left(\frac{1}{2}\right)^{\frac{36}{t}}$$
$$\left(\frac{1}{2}\right)^{2}=\left(\frac{1}{2}\right)^{\frac{36}{t}}$$
$$2t=36$$
$$t=18\ days$$

Alternatively

N	Half-life	Time
50	0	0
25	1	t=36/2 =18 days
12.5	2	36

3. The initial number of atoms in a sample is 5.12×10^{20}. If the half-life of the sample is 3.0 seconds, determine the number of atoms that will have decayed after six seconds.

Solution

N	Half-life	Time
5.12×10^{20}	0	0
2.56×10^{20}	1	3
1.28×10^{20}	2	6

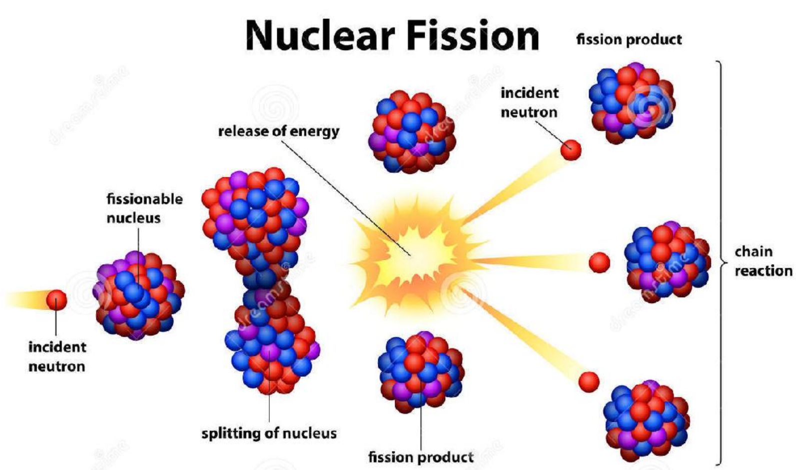
$$Decayed\ =5.12\times10^{20}-1.28\times10^{20}=3.84\times10^{20}$$

Alternatively

$$N=5.12\times10^{20}\left(\frac{1}{2}\right)^{\frac{6}{3}}$$
$$N=1.28\times10^{20}$$
$$Decayed\ =5.12\times10^{20}-1.28\times10^{20}=3.84\times10^{20}$$

Nuclear fission

When an atom splits into two parts, it releases energy. This process is known as fission. Nuclear fission is a process in which a nucleus splits into two or more lighter nuclei. It has great potential as a source of power.



Uranium or plutonium isotopes are normally used in nuclear fission, because their atoms have relatively large nuclei that are easy to split when hit by neutrons. For instance, when a uranium-235 or plutonium-239 nucleus is hit by a neutron, the following happens:

- ✓ the nucleus splits into two smaller nuclei, which are radioactive
- ✓ two or three more neutrons are released
- ✓ some energy is released

The additional neutrons released may also hit other nuclei and cause them to split. This produces even more neutrons, which in turn can split more nuclei. This is called a chain reaction. The chain reaction in nuclear reactors is controlled to stop it going too fast.

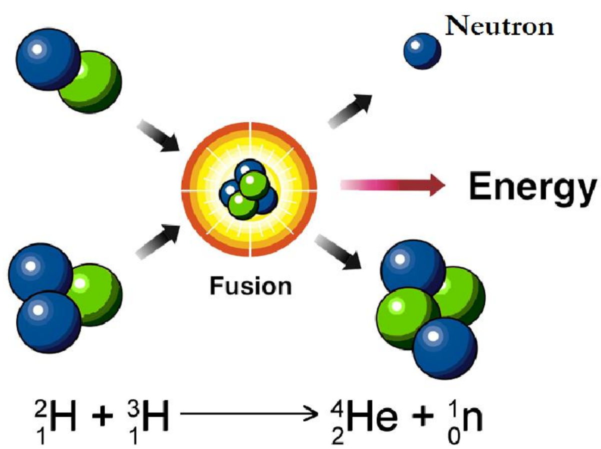
Applications of nuclear fission

1. They are used in the manufacture of atomic bombs. Vast amounts of energy is released within a very short time leading to an explosion.
2. In nuclear reactors, the release of nuclear fission energy is controlled and converted into electrical energy.

Nuclear fusion

Nuclear fusion is a process in which two atomic nuclei join to form a large nucleus. Energy and neutrons are released when this happens.

The Sun and other stars, for example, use nuclear fusion to release energy. In reactors, a hydrogen nuclei isotopes fuse to form helium nuclei, releasing energy and neutrons



$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n \quad + \quad Energy$$

Nuclear fusion is used in the production of hydrogen bombs.

Hazards of radioactivity and their precautions

1. Due to the ionizing radiation emitted by radiation materials, they affect living cells leading to serious illnesses. They may lead to skin burns, blisters, cancer and hereditary defects.
2. Their exposure to the environment through leaks may lead to environmental pollution leading to poor crop growth and destruction of marine life.

Applications of radioactivity

1. Carbon dating –identification of carbon-14 and carbon-12 absorbed by dead plants and animals, the ages of early life can be estimated
2. Medicine- treatment of cancer and sterilization of surgical instruments.
3. Biology and agriculture – radioactive sources are used to generate different species of plants with new characteristics that can withstand diseases and drought. Insects are

sterilized through radiation to prevent the spread of pests and diseases. Potatoes exposed to radiation can be stored for a long time without perishing.

4. Determining thickness of metal sheets
5. Source of electrical energy – in controlled nuclear reactors are used to generate electricity.

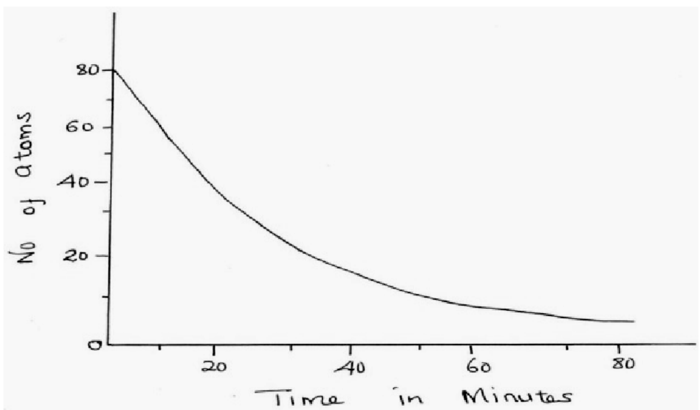
Topical Questions

1. A radioactive carbon 14 decay to Nitrogen by beta emission as below

$$^{14}_{6}C \longrightarrow \ ^{x}_{7}N + \ ^{0}_{y}e$$

Determine the values of x and y in the equation

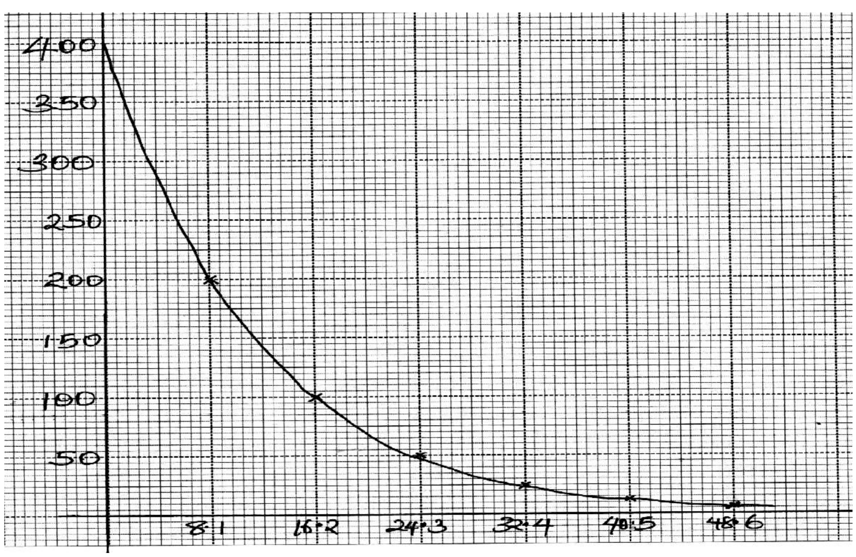
2. The initial mass of a radioactive element is 80g. The mass remaining after 20 years is 5g. Determine the half-life of the substance.
3. Alpha particles are more ionizing than beta particles. Give one reason for this
4. In a sample there are 5.12×10^{-20} atoms of krypton-92 initially. If the half-life of krypton-92 is 3.0s determine the number of atoms that will have decayed after 6s.
5. The activity of a radioactive substance, initially at 400 counts per second reduces to 50 counts per second in 72 minutes. Determine the half – life of the substance.
6. The figure below shows a decay of a certain element. The diagram is drawn to scale.



From the graph find:

a. Half-life of the element.
b. Number of half-lives undergone when the count rate is 10 atoms.

7. Define half-life of a radioactive material.
8. The initial mass of a radioactive substance is 20g. The substance has a half-life of 5 years. Determine the mass remaining after 20 years.
9. Figure 6 shows a graph of the variation of the number of atoms of a certain radioactive material with time.



Determine the half – life of the material

10. The following reaction is part of a radioactive series: Identify the radiation r and determine the values of **b** and **c**

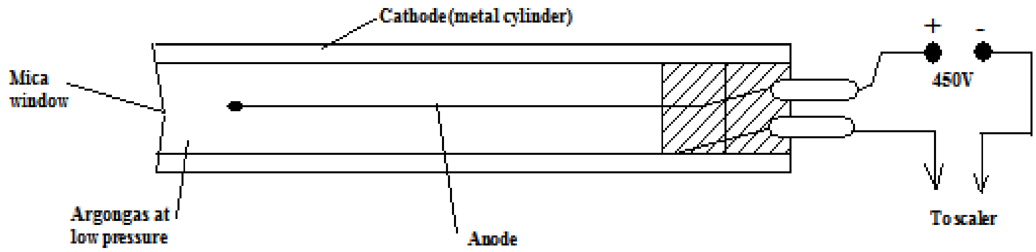
$$^{210}_{83}X \xrightarrow{r} {}^{210}_{84}Y \xrightarrow{\alpha} {}^{c}_{b}Z$$

11. Cobalt 60 is a radio isotope that has a half – life of 5.25 years. What fraction of the original atoms in a sample will remain after 21 years?
12. A radioactive sample of half-life 130 days initially has 1.0x 1020 radioactive atoms. Determine the number of radioactive atoms that would have decayed after 390 days.
13. A nucleus is represents by $^{107}_{42}\mathbf{X}$ State the number of neutrons in the nucleus.
14. Below is a nuclear reaction

$$^{232}_{90}A \xrightarrow{k} {}^{228}_{88}B \xrightarrow{gamma} {}^{y}_{x}C$$

   a. Identify radiation K
   b. Determine the values of X and Y.

15. **Figure 4** shows a Geiger muller (GM) tube



   a. Give the reason why the mica window is made thin.
   b. Explain how the radiation entering the tube through the window is detected by the tube.
   c. What is the purpose of the halogen vapour

16. The following represents a nuclear reaction involving the nuclide polonium Po

$$^{218}_{84}Po \xrightarrow{m} {}^{214}_{82}Pb \xrightarrow{n} {}^{214}_{83}Bi \xrightarrow{x} {}^{214}_{84}F$$

Identify m, n and x (3 marks)

17. **Figure 6,** shows a narrow beam of radiation from a radioactive source, incident to a postcard. The emergent radiation passes through a magnetic field which is perpendicular to the plane of the paper, and into the paper.

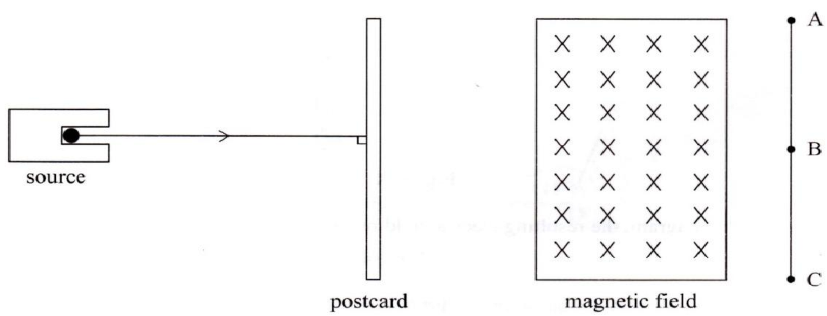


Figure 6

A detector moved along line AC detects radiations only at points B and C. state the two types of radiations detected

18. Complete the nuclear equation below by inserting the values of a and b.

$$^{14}_{6}C \longrightarrow {}^{b}_{a}X + {}^{14}_{7}N$$

19. Explain why carbon-14, $^{14}_{6}C$ is radioactive while carbon-12, $^{12}_{6}C$ is not.

20. Figure 12 shows a diffusion cloud chamber for detecting radioactivity.

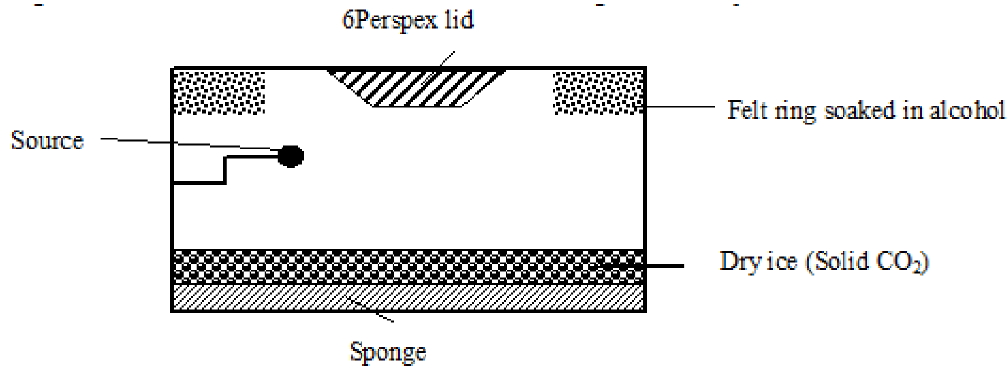


Fig. 12

(a)State the function of the following.
  i. Alcohol
  ii. Solid CO_2

(b) When radiation from the source enters the chamber, some white traces are observed.
  i. Explain how the traces are formed.
  ii. State how the radiation is identified

(c) A leaf electroscope can be used as a detector of radiation. State two advantages of the diffusion cloud chamber over the leaf electroscope.

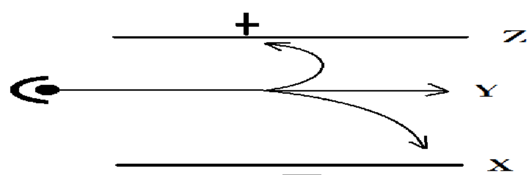
21. Below is radioactive decay.

$$^{232}_{90}X \xrightarrow{k} {}^{232}_{91}Y \xrightarrow{\alpha} {}^{y}_{x}Z$$

  a. Identify radiation K

  b. Determine the values of x and y

22. a) The diagram below shows the path taken by three radiations X, Y and Z from a radioactive source, through an electric field.



  a. Identify X, Y and Z.
  b. Give a reason for the differences in deviation shown by X and Z.

23. A radioactive source infront of a Geiger-muller tube shows a high count rate. The count rates are then taken from the source after placing a thin paper, then a thin aluminium foil and finally a thick lead slab, one at a time between the source and the G - M tube. It was observed that the paper had no effect on the count rate, aluminium had a small effect while the count rate was reduced greatly with lead.
  a. Give reasons for the three observations.
  b. Deduce the possible radiations from the source.
  c. State any two applications for the radiations entitled.

CHAPTER ELEVEN

ELECTRONICS

Introduction

Electrical conduction is the movement of electric charge through a transmission medium. The movement can form an electric current in response to an electric field. This charge movement depends on the material.

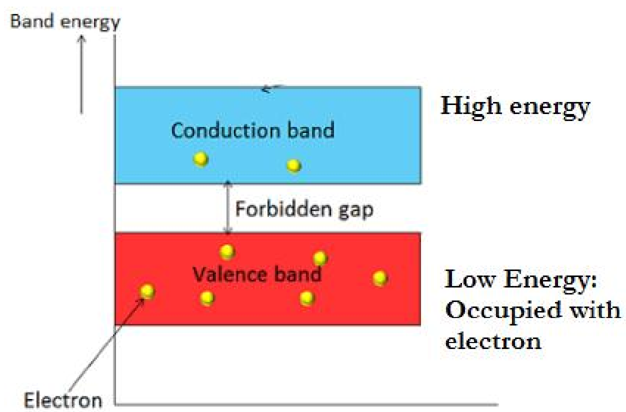
Conduction, under normal conditions, depends on the availability of free and mobile electrons. This explains why metals which have free electrons are very good conductors while such materials as plastic with no free electrons are poor conductors.

For conduction to be achieved, a material should have these free electrons, and if not, they must be made available through increasing temperature or even introducing them through such processes as doping.

Conduction in metals and resistors is well described by Ohm's Law, which states that the current is proportional to the applied electric field.

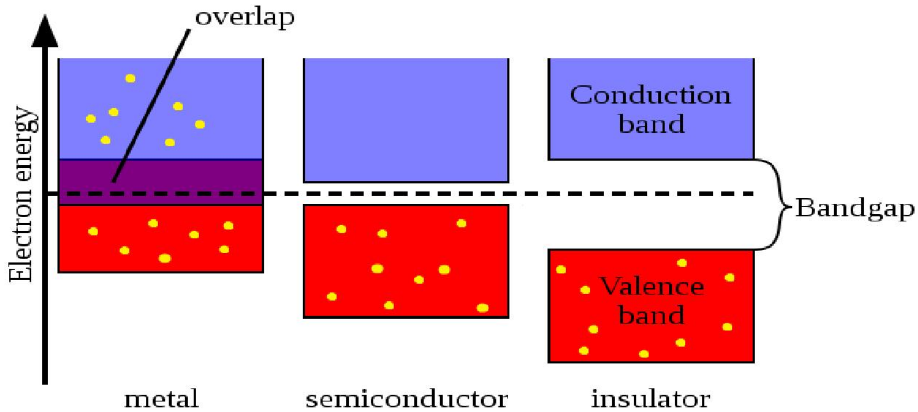
Band Theory of Conduction in Solids

In this theory, all materials have two bands, the valence band and the conduction band separated by a gap called the forbidden gap. The conduction band is a high energy band while the valence band is a low energy band. Electrons are easily found in the low energy band, the valence band. As the name suggests, the forbidden gap cannot have electrons. Electrons can only be found in the valence or conduction band.



The conductivity of a material depends on the availability of electrons in the conduction band. This means that a material only conducts if there are electrons in the conduction band. Electrons occupy the valence band naturally.

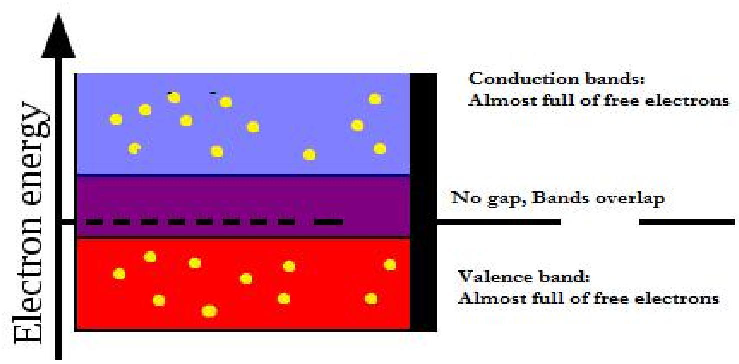
Therefore, materials can be classified as conductors, insulators and semiconductors depending on the distance separating the bands (the forbidden gap) and the possibility of getting free electron in the conduction band.



In insulators the electrons in the valence band are separated by a large gap from the conduction band, in conductors like metals the valence band overlaps the conduction band, and in semiconductors there is a small enough gap between the valence and conduction bands that thermal or other excitations can bridge the gap. With such a small gap, the presence of a small percentage of a doping material can increase conductivity dramatically.

Band theory in Conductors

In conductors, the forbidden gap is so small that the bands overlap. Since the gaps overlap, the electron in the valence band can easily move into the conduction band and are free and mobile to conduct electric current. No energy is required to overcome the forbidden gap. Hence, in terms of the band theory of solids, metals are unique as good conductors of electricity.



One unique property of conductors is that their conductivity decreases with increase in temperature. When conductors are heated, the present free electrons gain more kinetic energy increasing their collision with each other. These collisions instead increase the material's resistance to electric current flow which requires that the available free electron flow in one specific direction.

Band theory: Insulators

In insulators, there is a large forbidden gap between the valence band and the conduction band. All electrons are in the valence band. A lot of energy would be required to move electrons past the forbidden gap into the conduction band. This way, insulators cannot conduct electric current.