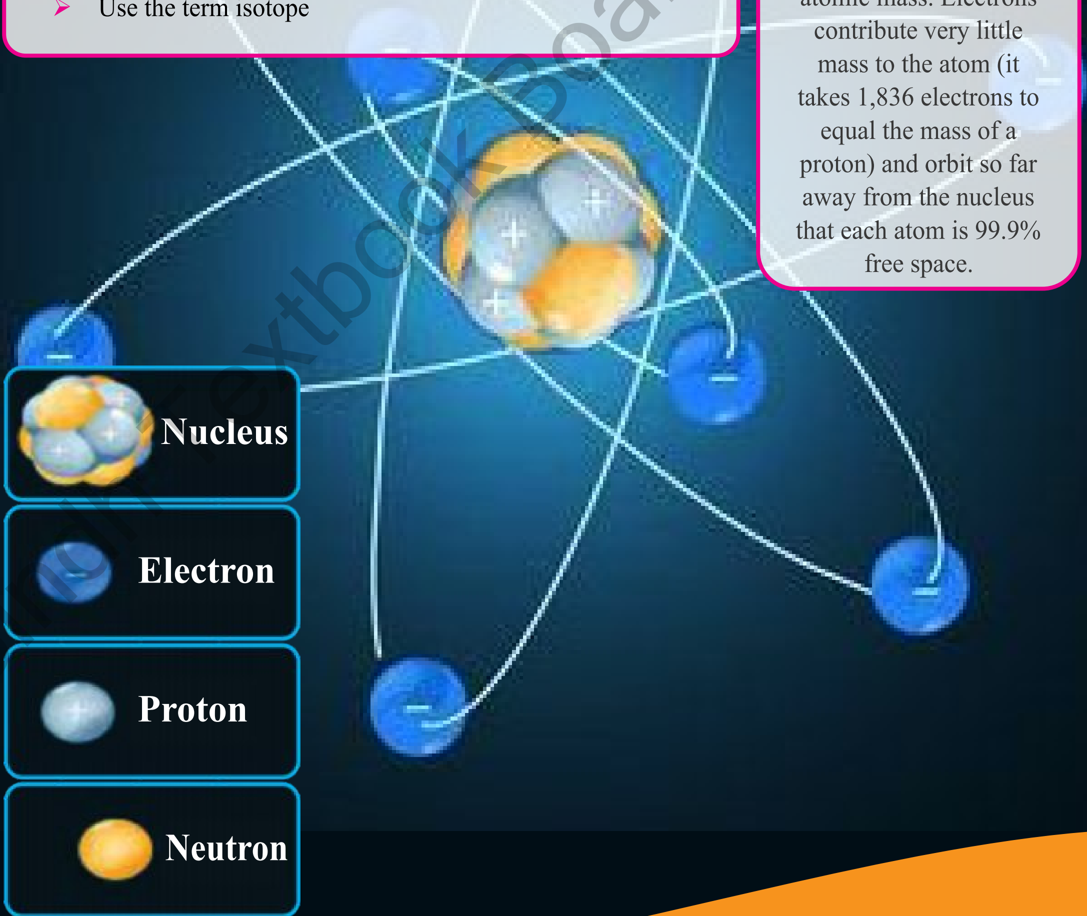
Unit - 19
Atomic Structure

Students Learning Outcomes (SLOs)
After learning this unit students should be able to

- Describe the structure of an atom in terms of a nucleus and electrons
- Describe the evidence for the nuclear model of the atom
- Describe the composition of the nucleus in terms of protons and neutrons
- Explain that number of protons in a nucleus distinguishes one element from the other.
- Represent various nuclides by using the symbol of proton number Z, nucleon number A and the nuclide notion $_{Z}X^{A}$
- Use the term isotope

There are over 100 different kinds of atoms. Among 92 of them occur naturally, while the remainder is manufactured. Atoms are mostly empty spaces. The nucleus of an atom is dense and contains nearly all of the atomic mass. Electrons contribute very little mass to the atom (it takes 1,836 electrons to equal the mass of a proton) and orbit so far away from the nucleus that each atom is 99.9% free space.



Matter composes everything such as bacteria, animals, and plants as well as non-living things such as tables, water, planets, and stars. But the building blocks of matter are atoms. Thus, the composition of everything, living or non-living, atoms.

What the exactly atom is? What is it composed of? Let us study atoms and the structure of atoms in detail in this unit.

19.1 ATOM AND ATOMIC NUCLEUS

The structure of an atom in terms of a nucleus and electrons

Atom is the smallest unit into which matter can be divided without releasing electrically charged particles. This is too small to be seen with any ordinary microscope. However, by shooting tiny atomic particles through atoms, scientists have developed a structure model. The simple Rutherford's atomic model given below; Fig 19.1 is often used to explain the basic structure of an atom.

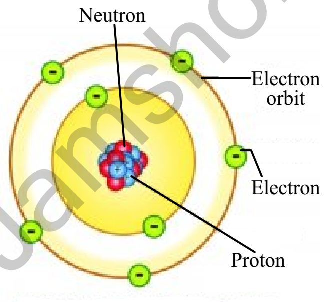


Fig: 19.1
The structure of an atom

Every atom is composed of two parts;

- The central hard-core of an atom is the nucleus which is the small, dense region consisting of closely packed protons and neutrons.
- Around the nucleus, electrons revolve at high speed. The number of particles (electrons and protons) depends on the type of atom.

Most of the atom is empty space. The rest comprise a positively charged nucleus surrounded by negatively charged orbiting electrons. The nucleus is tiny and dense compared with the electrons. Electrons are bound by a positively charged nucleus with the electrostatic force.

Do You Know!

The word "atom" comes from the Greek word "undivided." The name comes from the 5th century BCE Greek philosopher Democritus, who believed matter consisted of particles that could not be divided into smaller particles. For a long time, people believed atoms were the fundamental "undividable" unit of matter.

Nuclear Model of the Atom

Nobody has seen an atom. To visualize the processes in the atom, various models have been proposed. Rutherford put forward one of the earliest model of the nucleus, which he derived from experiments carried out by Geiger and Marsden. Let us discuss this experiment and its results in detail.

Geiger and Marsden α- scattering Experiment

Geiger and Marsden, the two scientists, used a beam of positively charged α- particles to bombard a thin gold

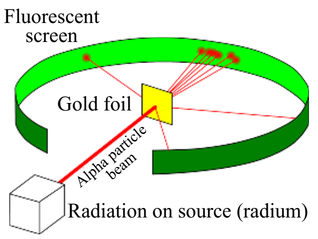


Fig: 19.2 Experimental arrangement of Geiger and Marsden α- scattering

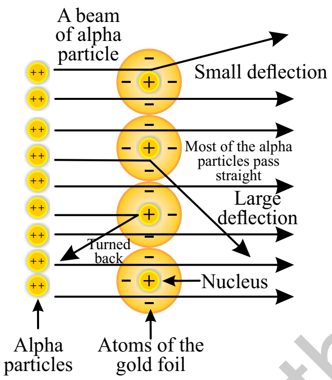


Fig: 19.3. Scattering of α-particles by a nucleus

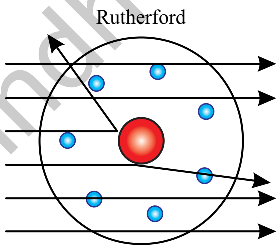


Fig: 19.4 Close up view of scattering of α-particles by a nucleus

foil placed in a vacuum surrounded by a ring-shaped fluorescent screen. After bombarding the foil, the scattered α- particles were detected using a rotating detector. When α- particles hit the screen of light was observed through the detector; Fig 19.2.

Geiger and Marsden found quite unpredicted experimental results that most of the α- particles were not deflected or only a few deflected through small angles. The unexpected result was that a small number of the α-particles were deflected through considerable large angles of more than 90^0, and a few of the α- particles were even deflected back through nearly 180^0.

To explain these observations, Rutherford postulated an atomic model. The nucleus carries all the positive charge of atom and nearly all its mass, as a large number of α- particles passing through the foil un-deflected suggest that there exit large empty spaces in an atom and those positively charged α- particles that deflected through large angles had come very close to the positively charged nucleus. However, a few were repelled so strongly that they bounced back or deflected through large angles, as shown in figures 19.3 and 19.4.

Self-Assessment Questions:

Q1: What the center of an atom is called?

Q2: Where are the electrons found inside an atom?

19.2 PROTONS, NEUTRONS

The composition of the atom

We studied in previous classes that atoms consist of three elemental particles: electrons, protons, and neutrons. The outermost region of the nucleus is called electron shell. It contains electrons. Electrons have a negative (-) charge. The nucleus contains the neutrons and the protons bound tightly together by the nuclear forces (gluons) as shown in figure 19.5. Neutrons carries no charge. The mass of a neutron is slightly larger than that of a proton. Proton have an equal positive (+) charge that of an electron in magnitude. An atom usually has an equal number of protons as electrons, so its net charge is zero. Therefore atom is considered neutral. Atoms have different properties depending upon the arrangement and number of their elemental particles;

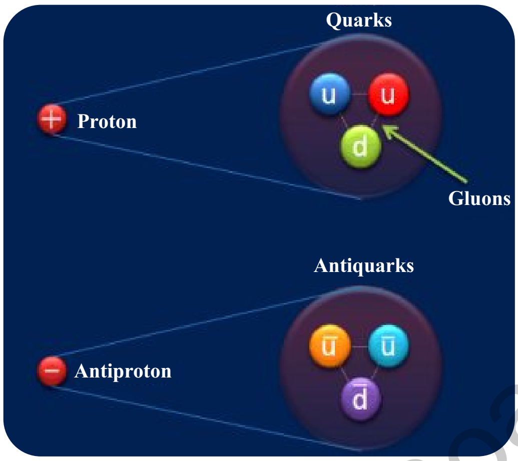


Fig: 19.5
The strong force binds quarks together in clusters to make more-familiar subatomic particles, such as protons and neutrons. It also holds together the atomic nucleus and underlies interactions between all particles containing quarks.

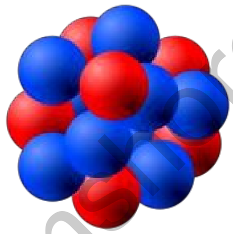


Fig: 19.6
A model of the atomic nucleus showing it as a compact bundle of the two types of particles: protons (red) and neutrons (blue)

Table 19.1
The relative masses and charges of particles in an atom

Name of Particle	Relative Mass	Relative Charge
Proton	1	+1
Neutron	1	0
Electron	1/1836	-1

The branch of physics concerned with the study and understanding of the atomic nucleus, including its composition and the forces which bind it together, is called nuclear physics.

Weblinks

Encourage students to visit below link for Atom and its composition
https://www.youtube.com/watch?v=pNroKeV2fgk&ab_channel=FuseSchool-GlobalEducation

Self Assessment Questions:

Q1: An atom consists of electrons revolving around the nucleus made of neutrons and protons. State which of these particles have
(i) An equal and opposite charge
(ii) Almost equal mass.

19.3 ELEMENTS

All materials are made from about 100 essential substances known as elements. The smallest part of an element is an atom. How is it possible to find the characteristics that differ between each element and distinguish one element from another? Each element have a unique number of protons.

Do You Know!

Only electron is fundamental particle

The number of protons in the nucleus of an atom in an element is called atomic number (Z).

The atomic number distinguishes one element from another. For example, the atomic number (Z) of carbon is six because it has 6 protons, and the atomic number (Z) of nitrogen is seven because it has 7 protons. There are some other examples given in table 19.2. The atomic number also tells you the number of electrons in that atom.

Do You Know!

If the atom is the size of a football ground, the nucleus would be the size of a pea. Although the nucleus is much denser than the rest of the atom.

Table 19.2.
Atoms of the first eight elements of the periodic table

Name of Element	Protons P = Z	Neutrons N = A – Z	Electrons $\bar{e}$	Atomic Number $Z = P^+$	Atomic Mass (A)
Hydrogen	1	0	1	1	1
Helium	2	2	2	2	4
Lithium	3	4	3	3	7
Beryllium	4	5	4	4	9
Boron	5	6	5	5	11
Carbon	6	6	6	6	12
Nitrogen	7	7	7	7	14
Oxygen	8	8	8	8	16

Weblinks

Encourage students to visit below link for Atomic Number

https://www.youtube.com/watch?v=D3GR6thtApI&ab_channel=Don%27tMemorise

Nuclides

An atom of an element has all the characteristics of that element. The nucleus is at the center of the atom and contains the protons and neutrons, which are collectively called nucleons. The number of protons in an atom of an element is called the atomic number, **(Z)**. The number of neutrons in the nucleus is the neutron number, **(N)**.

The number of protons and neutrons is collectively known as nucleon number (A) or atomic mass (A).

The total number of nucleons is the atomic mass, **A**. Table 19.2. These numbers are related by the symbol A.

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

A nucleus is represented symbolically by:

$$_{Z}\mathbf{X}^{A}$$

Where **X** represents the nuclide of a chemical element, **A** is the nucleon number, and **Z** is the atomic number.

For example, $_{6}\mathbf{C}^{12}$ represents the carbon nucleus with six protons and twelve nucleons. Thus, the total orbiting electrons are also six, and the neutron number is:

$$A = Z + N$$
$$N = A - Z$$
$$N = 12 - 6$$
$$N = 6$$

Self-Assessment Questions:

Q1: The nuclide notation for the uranium-235 is $_{92}U^{235}$. Determine the proton number, electron number, neutron number, and nucleon number of the uranium.

19.4 ELEMENTS AND ISOTOPES

Isotopes

The atoms of an element are not exactly alike. Some may have more neutrons than others. These different variants of the elements are called isotopes.

Two or more species of atoms of an element with the same atomic number, (Z) have different atomic mass, (A) is called Isotopes.

Most elements have mixture of two or more isotopes. For example, the hydrogen atom (atomic number 1) has three isotopes with atomic masses 1, 2, and 3. You can see how to represent an atom of Hydrogen using symbols and numbers in the table19.3 given below.

Table 19.3. Isotopes of the Hydrogen atom

Name of Isotope	Proton number, Z	Neutron Number, N	Atomic Mass, A	Symbol
Protium	1	0	1	$_{1}H^{1}$
Deuterium	1	1	2	$_{1}H^{2}$
Tritium	1	2	3	$_{1}H^{3}$

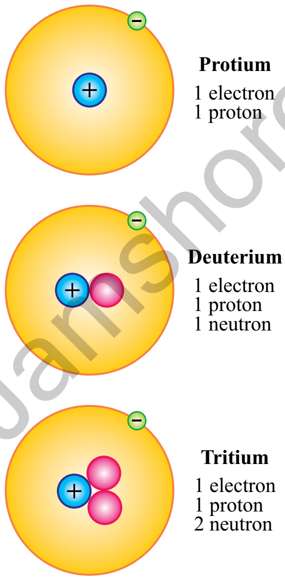


Fig: 19.7.
Isotopes of hydrogen

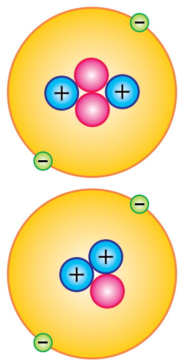


Fig: 19.8.
Isotopes of helium

Do You Know!

The elements with the most isotopes are Cesium and Xenon with 36 known isotopes.

Do You Know!

The term isotope is formed from the Greek roots isos "equal" and topos "place", meaning "the same place"; thus, the meaning behind the name is that different isotopes of a single element occupy the same position on the periodic table.

Every element has a specific position in the periodic table and nearly identical chemical behavior or properties with the same number of electrons.

Many other essential properties of an isotope depend on its mass. The total number of neutrons and protons in the nucleus of mass number (symbol A) gives it different physical properties, i.e. mass, surface area, volume, and density.

Isotopes are two or more species of atoms of an element with identical chemical properties that have different physical properties.

CONCEPT MAP

Atomic Structure
↓
Discovery of nucleus
↓
Rutherford atomic model
↓
Elements
↓
Isotopes
↓
Nuclide
→ Nucleon number
→ Atomic number

SUMMARY

- Everything around us is made up of atoms.
- Atom is the smallest unit of matter.
- Every atom is composed of two parts; the nucleus and the shell.
- The nucleus is a central small and dense part of the atom that contains protons and neutrons.
- The shell part of the atom contains electrons that orbit at high speed around the nucleus.
- Most of the atom is an empty space.
- In an atom, electric forces bind the electrons to the nucleus.
- An atom consists of three elemental particles: electrons, protons, and neutrons.
- Each element, however, does have a unique number of protons in its nucleus.
- The number of protons in an atom of an element is called the atomic number.
- The number of protons and neutrons in an atom is known as nucleons.
- The total number of nucleons in an atom is called the mass number.
- Isotope has the same atomic number but a different mass number.

Section (A) Multiple Choice Questions (MCQs)

Choose the correct answer from the following choices:

1. $^{2}_{1}H$ and $^{3}_{1}H$ are:

a) Isotopes b) Isobars
c) Isotones d) Isochores

2. The neutral atoms of all of the isotopes of the same element have
a) different numbers of protons.
b) exact numbers of neutrons.
c) An exact number of protons.
d) An exact number of nucleons.

3. Consider the species $_{17}\mathbf{Cl}^{35}$, and $_{17}\mathbf{Cl}^{37}$. These species have:
a) the exact number of nucleons
b) the exact number of protons
c) the exact number of neutrons.
d) the exact mass number.

4. Atomic mass of an element is equal to
a) Mass of protons and neutrons
b) Mass of protons and electrons
c) Mass of electrons and neutrons
d) Mass of protons only

5. The maximum mass of an atom is concentrated in:
   a) nucleus b) neutrons
   c) protons d) electrons
6. Consider isotope $_{92}\mathbf{U}^{237}$ of uranium. The number of neutrons in it is:
   a) 92 b) 237
   c) 145 d) 329
7. The symbol denotes the proton number is:
   a) P b) A
   c) N d) Z
8. The number of neutron(s) in Protium is:
   a) no b) one
   c) two d) three
9. In an atom, the nucleus when compared to the extra-nuclear part, is
   a) More significant in volume and heavier in mass
   b) smaller in volume but heavier in mass
   c) More significant in volume but lighter in mass
   d) Smaller in volume and lighter in mass
10. If an element B has five protons and six neutrons what will be the symbol of element B
   a) 11_6B b) 11B
   c) 11_5B d) $^{5}_{11}B$

Section (B) Structured Questions

1. (a) Which particles are found in the nucleus of an atom?
   (b) Describe the structure of an atom.
   (c) How does the number of protons in a nucleus distinguish one element from the other?
2. (a) Cite the Geiger Marsden experiment with the help of a diagram.
   (b) Give the Rutherford model of an atom.
   (c) Why it was proposed that most atoms possess an empty space.
3. (a) Define Atomic number (Z)
   (b) Explain the symbolic representation of an atom of an element. Give an example.
4. (a) What is the isotope?
   (b) Explain the isotope with an example.
   (c) Why are the chemical properties of an element's different isotopes identical?
   (d) List the physical properties of different isotopes of an element that are different.

KUNUPP
Karachi Nuclear Power Plant

Unit - 20

Nuclear Structure

Students' Learning Outcomes (SLOs)

After learning this unit, students should be able to

- Explain that some nuclei are unstable, give out radiation to eliminate excess energy, and are said to be radioactive.
- Describe that the three types of radiation are α, β & γ.
- State radioactive emissions and their:
  - nature
  - relative ionizing effects.
  - relative penetrating abilities
- Explain that an element may change into another element when radioactivity occurs.
- Represent changes in the composition of the nucleus by symbolic equation when alpha or beta particles are emitted.
- Describe sources of background radiations and artificial radiations.
- Describe that radioactive emissions occur randomly over space and time.
- Explain the meaning of the half-life of radioactive material.
- Make calculations based on the half f-life, which might involve information in tables or shown by decay curves.
- Determine the half-life of a sample of radioactive material by using a graph of the number of radioactive nuclei of activity versus time.
- Estimate the age of ancient objects by the process of carbon dating.
- Describe what radio-isotopes are. What makes them useful for various applications?
- Describe the application of radioisotopes in medicine, agriculture, and industrial fields.
- Describe the process of fission and fusion briefly.
- Describe how radioactive materials are handled, used, stored, and disposed of safely.

Nuclear Power Plant K-2 & K-3Karachi Nuclear Power Project Unit-2 (K-2) & Unit-3 (K-3)In the vicinity of KANUPP, construction work on two nuclear power reactors i.e., K-2 and K-3, was started in August, 2015 and in May, 2016 respectively. These units are based upon Chinese ACP1000 design, that is a Generation-III version of the PWR nuclear reactor technology. In this design, apart from other features, safety is significantly enhanced by using passive safety systems (no need of human action or input power for operation). On 23rd March of the year 2021, K-2 was connected to the national grid and successfully started commercial operation on 21 May, 2021. K-3 also achieved the milestone of grid connection on 4th March, 2022 and its commercial operation is expected very soon i.e., in a few weeks.

KUNUPP - Karachi Nuclear Power Plant

The nuclear structure is the area of physics that studies the nuclei of atoms. It is about far more than just nuclear power. Nuclear scientists are studying everything from the shapes of nuclei to cancer treatments and medical imaging, from highly unstable nuclei that only exist for fractions of a second to nuclear detectors. However, upon understanding the nuclear structure and nuclear radiation, we will appreciate that this radiation has peaceful and beneficial applications to our daily lives. Let us study this all in this unit in detail.

Do You Know!

Binding energy is amount of energy required to separate a particle from a system of particles or to disperse all the particles of the system.

20.1 NATURAL RADIOACTIVITY

Atomic nuclei consist of protons and neutrons, whereby protons repel each other through electrostatic force due to their positive charges. In contrast, nuclei bind the nucleons through another specific binding energy**.** These two forces compete with each other, leading to various nuclei stability. There are only certain neutron-proton pairings that form stable nuclei. As a result, an increasing ratio of neutrons to protons is required to form a stable nucleus.

Some proportions of neutrons to protons are more stable than others in a nucleus if the neutron number, **N,** is plotted against the proton number, **Z**; figure 20.1, for all different isotopes of all the elements.

Do You Know!

Higgs Bosons
(force carrier)
It is a type of boson which carries mass as well and known as god particle.

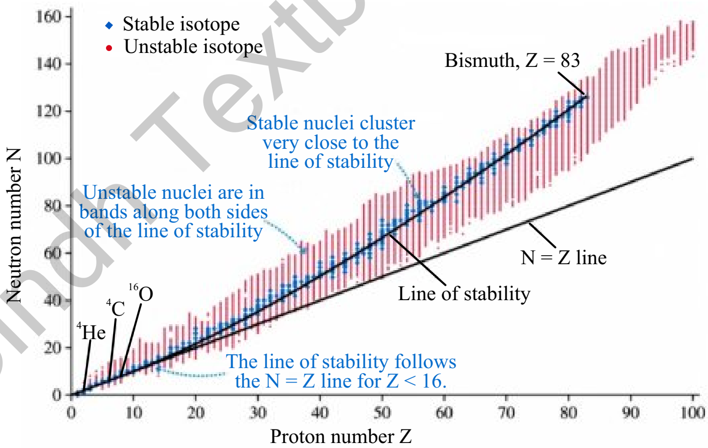


Fig: 20.1. Nuclear stability curve of all isotope

There are too many or few neutrons for a given number of protons. In that case, the resulting nucleus is unstable, and it undergoes radioactive decay to get rid of excess energy.

If an isotope undergoes radioactive decay is called radio-isotope or radioactive element.

The emission of ∝, β and γ radiation with the release of energy is known as radioactivity.

Do You Know!

Gluon

It is a type of boson (force carrier) is an exchanging particle of strong nuclear force

Types of radiation α, β & γ

To explain the graph of unstable nuclei with the varying number of neutrons as discussed above. It has these salient features as given below.

i. Stable isotopes lie along with the stability line.

ii. Isotopes above the stability line have too many neutrons to be stable. The decay for β^- (electron) emission reduces the number of neutrons.

iii. Isotopes below the line of stability have few neutrons to be stable. The decay for β^+ (positron) emissions increases the number of neutrons

iv. The heaviest isotopes (proton number, **Z > 83**) decay by ∝ emissions.

Many other infrequent types of decay, such as spontaneous fission or neutron emission, are also observed.

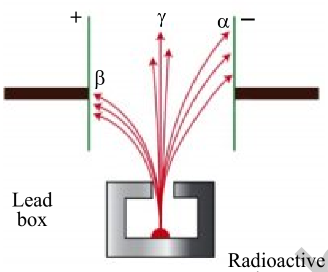


Fig: 20.2 Three types of radiations can be distinguished from their path followed in an external electric field

Nature of radioactive emission

To describe the nature of three types of radiation ∝, β, and γ, the radioactive source is placed inside the electric field. The radiation emitted from the source breaks down into three components: **α** and **β** -radiations bend in the opposite direction in the electric field, while γ -radiation does not change its direction; Figure 20.2.

This result describes that.

- **α** deflected towards a negatively charged while the plate is positively charged,
- **β** deflected towards a positive plate that is negatively charged. It is deflected more in the field, thus, much lighter than α particles.
- γ rays are not deflected by the field and carry no electric charge.

Further, it was found by further explorations that an alpha particle is a helium nucleus comprising two protons and two neutrons with a charge of +2e. Beta radiation is a streamlet of high-energy electrons. Gamma radiations are photons that are electromagnetic radiations of ultra-high frequency.

Do You Know!

The **α** and **β** –radiations are affected by a magnetic force that acts if they pass through opposite poles of a magnet.

Relative ionizing effects of radioactive emission

Ions are charged atoms or charged molecules.

Atoms become ions when they lose or gain electrons. Nuclear radiations, i.e., alpha, beta, and gamma, can knock out electrons from atoms in their paths, resulting in an ionizing effect. However, alpha particles have the most significant ionization power than beta particles and gamma rays. It is due to the large positive charge and large mass of alpha particles. Beta particles ionize a gas much less than alpha particles. The ionization power of gamma rays is even less than that of beta particles. The ionization of alpha particles in a gas is given in figure 20.3.

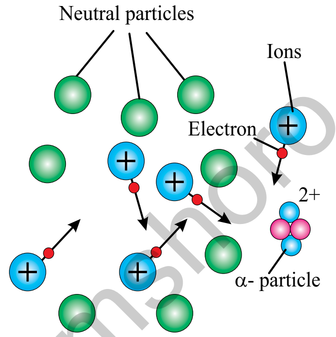


Fig: 20.3. Ionization of alpha particles in a gas

The phenomenon by which radiations split matter into positive and negative ions is called ionization.

Relative penetrating abilities of radioactive emission

An alpha particle has the shortest penetrating ability because of its strong interacting or ionizing power. Alpha particle has a penetrating range of only a few centimeters in the air; they can be stopped by a thick sheet of paper or by the skin. The beta radiation interacts with the matter due to its charge and has a high penetrating range compared to alpha particles. Beta particles have a range of several meters in the air. They can penetrate through thick paper but are stopped by a few millimeters of aluminum. However, gamma rays range several hundreds of meters in the air. The gamma rays are very penetrating, never completely stopped through lead, and thick concrete will reduce their intensity. It is due to their high speed and neutral nature. Fig. 20.4 shows the relative penetrating abilities of three kinds of radiations.

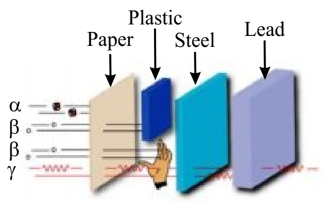


Fig: 20.4. Relative penetrating abilities of three kinds of radiations.

The strength of radiations to penetrate a certain material is called penetrating power.

Self Assessment Questions:

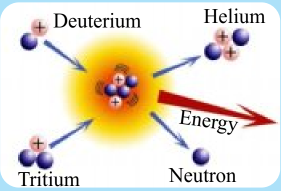
Q1: Which force is responsible for binding protons in the nucleus?

Q2: What is the nature of alpha radiations?

Q3: Define the penetrating power?

Do You Know!

In the core of the Sun hydrogen is being converted into helium. This is called nuclear fusion. It takes four hydrogen atoms to fuse into each helium atom. During the process some of the mass is converted into energy



Q4: Why do gamma radiations have a high penetrating ability?

Q5: Iron-59 emits beta and gamma radiations simultaneously. Explain how the gamma radiation could be separated from beta radiations emitted?

20.2 NUCLEAR TRANSMUTATIONS

We know that if an isotope is radioactive, it has an unstable arrangement of neutrons and protons. The emission of alpha or beta particles makes the nucleus more stable, whereas it changes the number of protons and neutrons. So it transmutes to the nucleus of a different element.

The original nucleus before decay is called the **parent nucleus**.

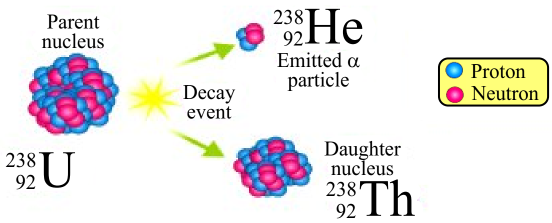
The nucleus formed after decay is called the **daughter nucleus.**

Radioactive disintegration causes nuclear transmutation and converts one chemical element or isotope into another chemical element or isotope.

Now we can represent changes in the composition of the nucleus using a nuclear equation in which an unstable parent nuclide X decays into a daughter nuclide *Y* by the emission of alpha, beta, and gamma decay products with the release of energy.

Alpha (α)-decay

In alpha decay, the proton number or atomic number, *Z* of the parent nuclide reduces by 2, while its atomic mass or nucleon number, *A,* decreases by 4.



Do You Know!

Helium nuclei is also known as **α.**

Its general equation

$$_{Z}X^{A} \longrightarrow {}_{Z-2}Y^{A-4} + \alpha + \text{energy}$$

Parent nuclide → daughter nuclide + alpha particle

Example:

When radium $_{88}Ra^{226}$ decays by alpha emission. The alpha decay leaves the nucleus with 2 protons and two neutrons less than before. So the atomic number drops to 86 and the atomic mass to 222. Radon has the atomic number of 86, so radon is the new element formed. Its decay process can be written as,

$$_{88}Ra^{226} \longrightarrow {}_{86}Rn^{222} + \alpha + \text{energy}$$

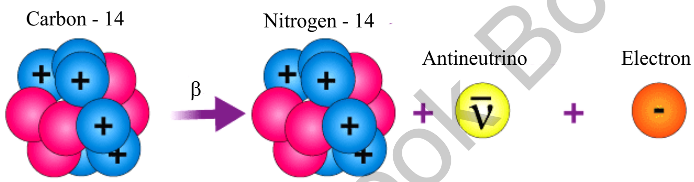
Beta (β)-decay

In beta decay, the atomic number Z of the parent nuclide increases by one, and its atomic mass or nucleon number remains unchanged.

Its general equation is

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

Parent nuclide → daughter nuclide + beta particle



Beta-minus Decay

Example:

When carbon $_{6}C^{14}$ decays by beta emission. The beta decay leaves the nucleus with one more proton and one neutron less than before. So the atomic number increases to 7, and the mass number remains unchanged. Nitrogen has the atomic number of 7, so nitrogen is the new element formed. Its decay process can be written as,

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

Beta (β)+ decay

In positron emission/positive beta decay (β^{+}-decay),

A proton in the parent nucleus decays into a neutron that remains in the daughter nucleus and the nucleus emits a neutrino and a positron, which is a positive particle like an ordinary electron in mass but of opposite charge.

Weblinks

Encourage students to visit below link for Radioactivity: Expect the unexpected

https://www.youtube.com/watch?v=TJgc28csgV0&ab_channel=TED-Ed

Weblinks

Encourage students to visit below link for Alpha and Beta decay

https://www.youtube.com/watch?v=UtZw9jfIxXM&ab_channel=FuseSchool-GlobalEducation

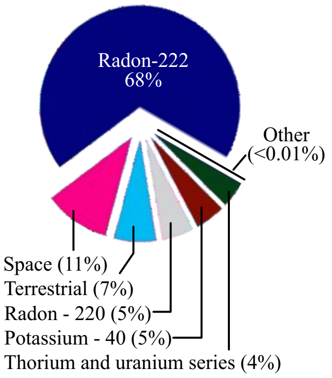


Fig: 20.5.
Sources of background radiations

Do You Know!

When cosmic rays enter the atmosphere, they undergo various transmutations, including the production of neutrons. When nitrogen-14 atoms absorb these thermal neutrons, radio-carbon-14 is produced in the upper layers of the atmosphere.

$${}_0n^1 + {}_7N^{14} \rightarrow {}_6C^{14} + {}_1p^1$$

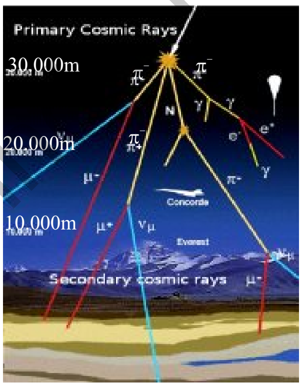
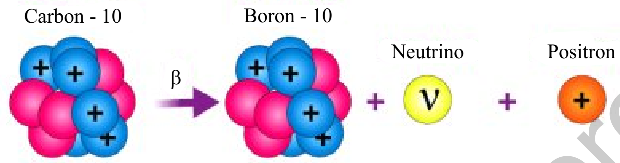


Fig: 20.6.
Shower of radiation



Beta-plus Decay

Self-Assessment Questions:

Q1: Define Nuclear Transmutation.

Q2: What nuclear changes take place in gamma emission?

Q3: When a nuclide of Strontium-90 (${}_{38}Sr^{90}$) decays by the emission of **β** particle, it becomes the nucleus of the Yttrium; symbol Y. Complete the nuclear equation.

20.3 BACKGROUND RADIATION

We are surrounded by the atmosphere on the surface of the Earth. There are a small number of radiations around us due to the radioactive elements present in the surroundings. These radiations mainly originate from various natural sources such as soil, rocks, air, building materials, food and drinks, and even from space.

These natural radiations that come from the surroundings are called background radiations.

In some areas, over half of these radiations come from radioactive radon ${}_{86}Rn^{222}$ gas, rocks seeping, and some types of granite; Figure 20.5.

Our planet Earth is also exposed to radiation from outer space called cosmic radiations, consisting of electrons, protons, alpha particles, and larger nuclei. The cosmic radiation interacts with atoms in the atmosphere to create a shower of radiation; figure 20.6, including X-rays, muons, protons, alpha particles, electrons, and neutrons.

Radioactive emissions occur randomly over space and time

Spontaneous decay is a process in which environmental factors cannot influence.

Radioactive decay takes place naturally (all by itself). There is no way of predicting when a particular nucleus will disintegrate, and the process is unaffected by pressure, temperature, chemical conditions, and other physical conditions. However, some nuclei undergo nuclear disintegration at different rates.

A random decay is a process in which the exact time of decay of a nucleus cannot be predicted.

A detector like a Geiger-Muller (GM) tube can demonstrate the random nature by observing the count rate of radioactive disintegration. When a GM tube is placed near a radioactive source, the counts are irregular. Each count represents a decay of an unstable nucleus. The variation of count rate over time of a sample radioactive source is plotted on the graph. You can see the fluctuations in count rate against time; figure 20.7 on the graph that provides evidence for the random nature of radioactive decay over space and time. It can be concluded from the experiment that

- The time of each decay cannot be predicted
- The direction in which radiation is emitted is not possible to determine.

20.4. Half-Life

Explain the meaning of the half-life of radioactive material.

The radioactive decay process is random, and the rate of radioactive decay is proportional to the number of unstable nuclei present. In the decay process, a constant fraction of many unstable radioactive nuclei disintegrates at a certain time. The lifespan of the unstable nuclei is indefinite and is challenging to measure. We can think of about decay rate by another term, half-life.

The half-life of a radioactive isotope is the time taken for half of the nuclei present in any given sample to decay.

Iodine-131 is a radioactive isotope of iodine. Iodine-131 has an eight-day half-life, which means that half of an iodine-131 sample will be converted to other elements within 8 days; Fig. 20.8. Half of the remaining iodine will decay in the next eight days, leaving eight only one-fourth

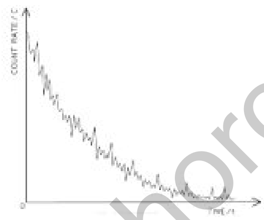


Fig: 20.7.
The fluctuation show the random nature of radioactive decay

Do You Know!

We all receive exposure to man-made radiation, such as X-rays, radiation used to diagnose diseases, and cancer therapy. The fallout from nuclear explosives testing and also small amounts of radioactive materials released to the surroundings from coal and nuclear power plants are also sources of manufactured background radiation.

of the original amount of radium, and so on, the decaying process continues.

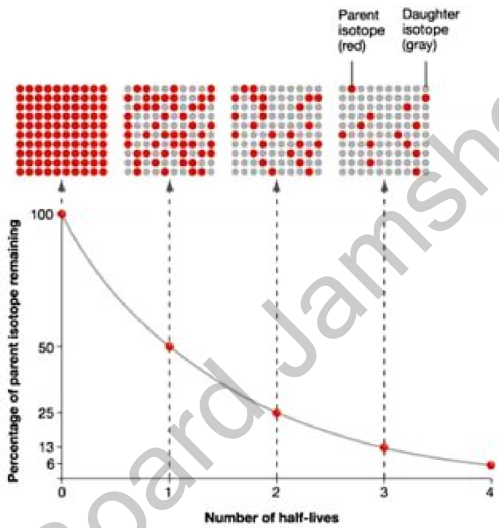


Fig: 20.8 Radioactivity of iodine

Every radioactive element has its characteristic half-life. The half-lives of some radioactive isotopes are given in the table below. It might seem strange that some isotopes have short half-lives while others have long half-lives.

Do You Know!

Experts have used scientific dating techniques to verify the historical chronology of ancient Egypt. Radiocarbon dating was used to show that the chronology of Egypt's Old, Middle and New Kingdoms is indeed accurate. The researchers dated seeds found in pharaohs' tombs, including some from the tomb of the King Tutankhamun.

Table 20.1 Half-lives of some radioactive nuclides

Radioactive isotope	Half-life
Boron-12	0.02 seconds
Radon-220	52 seconds
Iodine-128	25 minutes
Radon-222	3.8 days
Iridium-192	74 days
Cobalt-60	5.27 years
Strontium-90	28 years
Radium-226	1602 years
Carbon-14	5730 years
Plutonium-239	24400 years
Uranium-235	7.1×10^8 years
Uranium-238	5×10^9 years

If the radioactive element is $T_{½}$, then the number of nuclei in the sample will become half at the end. After a time of $2T_{1/2}$, i.e., after the second half-life period, the number of remaining nuclei will become 1/2.1/2 $=1/2^2$ =1/4; after a time of 3 $T_{1/2}$, the number of remaining nuclei left will be1/2.1/2.1/2 $=1/2^3$ =1/8, and at the end of '*n,*' half-lives number of atoms that remain will bet $1/2^n$. Thus, using the equation below, we can determine how much of the original amount of sample remains after a certain interval of time,

The remaining amount of sample = $1/2^n$ × the original amount of the sample

Where n is the number of half-lives.

Worked Example 1

If there are 96 grams of radioactive element Neptunium-240 present, how much Np-240 will remain after 6 hours? (Neptunium-240 has a half-life of 1 hour)

Solution:

Step 1: Write down the known quantities and quantities to be found.

Mass of the sample, m= 96 grams

Half-life of the sample, $T_{½}$ = 1 hour

Time, t= 6 hours

Number of half-lives, n = time interval/half-life

= 6 hours/ 1 hour

n = 6

Step 2: Write down the formula and rearrange if necessary

Remaining mass of the sample = $1/2^n$ × Mass of the sample

Step 3: Put the values and calculate.

Remaining mass of Neptunium-240 = $1/2^6$ × 96 grams

= 1/64 × 96 grams

= 1.5 grams

After 6 hours, only 1.5 grams of the original 96 grams sample would remain in the radioactive isotope of Neptunium -240.

Do You Know!

"Many scholars were not satisfied with these relative dating methods [of the Indus civilization by John Marshall and Sir Mortimer Wheeler from 1930s-50s], which relied on distant Mesopotamian chronologies, but it was not until after the introduction of the radiocarbon dating technique in the 1950s that the situation began to change. During his excavations at Mohen-jo-daro in 1964-65, George F. Dales collected the first series of samples for radiocarbon dating from the latest levels of the city.

Weblinks

Encourage students to visit below link for What is Radioactivity and Is It Always Harmful

https://www.youtube.com/watch?v=M0uw4ZNpqcI&ab_channel=ScienceABC

Worked Example 2

A sample of Ac-225 originally contained 8.0×10^{24} nuclei. After 960 hours, how much of the original sample remains un-decayed. The half-life of the isotope is ten days.

Solution:

Step 1: Given data and find unknown

Original number of nuclei, $N = 8.0 \times 10^{24}$ nuclei

Given time, t = 960 hours

= 960/24 days

= 40 days

Number of half-lives, n = time interval / half life

= 40 days/ 10 days

n = 4

Step 2: Write Remaining number of nuclei $=1/2^n \times$ the original number of nuclei

Step 3: Put the values and calculate.

Remaining number of Ac-225 nuclei $= 1/2^4 \times 8.0 \times 10^{24}$ nuclei

$= 1/16 \times 8.0 \times 10^{24}$ nuclei

$= 5.0 \times 10^{23}$ nuclei

After 960 hours, only 5.0×10^{23} nuclei of the original 8.0×10^{24} nuclei sample would remain the radioactive isotope of Ac-225.

Weblinks

Encourage students to visit below link for Half life of radioactive material

https://www.youtube.com/watch?v=IDkNlU7zKYU&ab_channel=FuseSchool-GlobalEducation

Worked Example 3

How long will it take to decay for 36.0 mg of Ra-226 to leave 4.5 mg? The half-life of the isotope is 1600 years.

Solution:

Step 1: Given data and find unknown.

Mass of original sample = 36.0 mg.

Mass of remaining sample = 4.5 mg

The half-life of the sample = 1600 years

Number of half-lives = $1/2^3$ (36 mg) = 4.5 mg.

Step 2: Write down the formula and rearrange if necessary

The required time = number of half-lives × half-life

Step 3: Put the values and calculate.

The required time = 3 × 1600 years

= 4800 years

This decay process requires 4800 years.

Radio activity

To determine the half-life of a sampling of radioactive element for some given data showing how the activity (or the number of nuclei) changes over time: Plot a graph of this data, activity or number of nuclei changes on the y-axis with time on the x-axis. Draw a smooth best fit curve closer to the x-axis.

Now, look at the original activity (where the line crosses the y-axis) and halve it. Move from the halved value (on the y-axis) to the best fit curve, and straight down to the x-axis. The point where you reach the x-axis should be the half-life of the sample radioactive element. Repeat it to take second and third half-lives and get an average to avoid any possible error.

Example:

Iodine-131 is a radioisotope. It undergoes decay by beta particle emission into xenon-131. From the graph, its initial percentage activity is 100%. After eight days have passed, half of the atoms of the sampling of iodine-131 will have decayed, and the sample will now be 50% iodine-131. After the next eight days pass (a total of 16 days or two half-lives), the sample will be 25% iodine-131. This decaying continues until the entire sample of iodine=131 has completely decayed; Fig. 20.9.

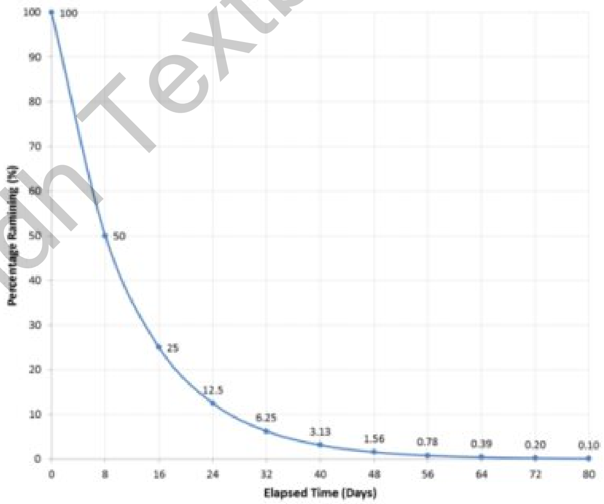


Fig: 20.9. Decay curve of Iodine-131

Do You Know!

Units of Radiation and Radioactivity

Becquerel (Bq)
Unit for intensity of radiation:
One nucleus decay (degenerates) per second = 1 becquerel

Sievert (Sv)
Unit of radiation exposure does which a person receives:
Associated with radiation effects

Estimate the age of ancient objects by the process of carbon dating.

Radioactive dating is a process by which the approximate age of an object is determined by using certain radioactive nuclides.

For example, radioisotope carbon-14 is found in a small amount in the atmosphere and is used to measure the age of organic material. Living plants and animals use carbon dioxide and become slightly radioactive accordingly. While an organism is alive, the amount of carbon-14 remains constant because fresh carbon-14 enters whenever the organism consumes nutrients; Fig. 20.10.

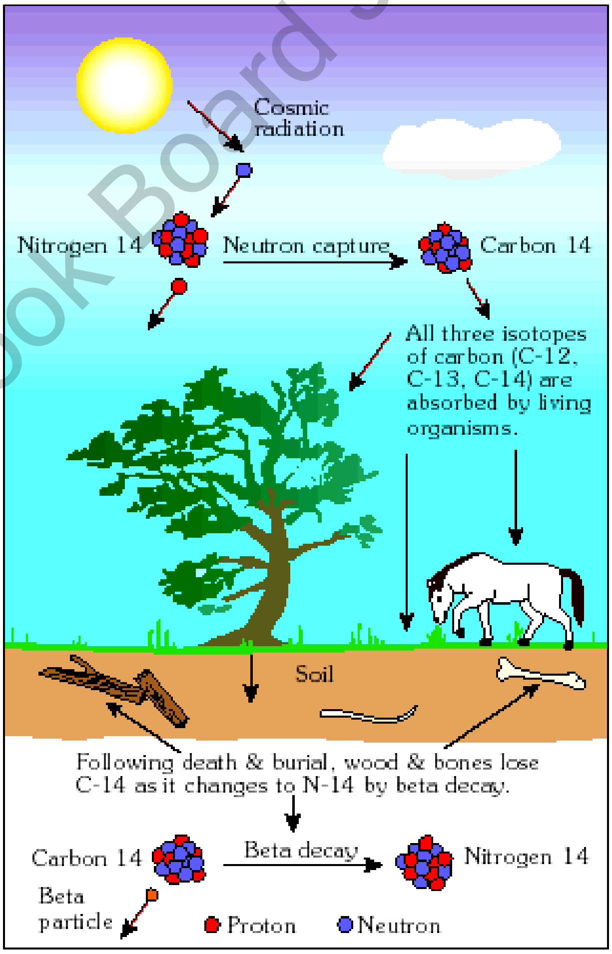


Fig: 20.10 Cycle of Radio Carbon-14

Do You Know!

Activity in radioactive-decay processes, the number of disintegrations per second, or the number of unstable nuclei that decay per second in a given sampling. Activity is expressed in the International S.I. Units by the Becquerel, **Bq** is exactly equal to one disintegration per second.

When an animal die, no more carbon is absorbed, and the radio carbon-14 present inside the animal starts decaying to nitrogen-14. Since the half-life of carbon-14 is 5730 years, archeologists can estimate the age of remains by computing the activity of carbon-14 in the live and dead animals.

Self Assessment Questions

Q1: Can the decay half-life of radioactive material be changed?

Q2: Why the radioisotopes of greater half-lives are used in radioactive dating of archeological relics?

20.5. Radio Isotopes

Radio-isotopes

The radioisotope is also **a radioactive isotope, radionuclide,** or **radioactive nuclide**. A radioisotope is a kind of the same element with different masses. It undergoes decay spontaneously and emits radiation to dissipate excess energy.

We have learned that every element has one or more isotopes. For example, hydrogen, the lightest element, has three isotopes H^1. H^2 and H^3. Only H^3 (tritium) is unstable. However, it is a radioactive isotope and undergoes nuclear decay.

The stable and non-radioactive elements can also be transmuted into radioactive elements by exposing them to neutrons, or alpha particles. Such artificially produced radioactive elements are also called radioisotopes. Here are some examples of the production of radioisotopes:

$_0n^1$	+	$_{16}S^{32}$	→	$_{15}P^{32}$	+	$_1H^1$
Neutron		Stable Sulphur Nuclide		Unstable phosphorus Nuclide		Proton
$_2He^4$	+	$_{13}Al^{27}$	→	$_{15}P^{30}$	+	$_0n^1$
Alpha particle		Stable aluminum Nuclide		Unstable phosphorus Nuclide		Neutron

In these examples, P^{32} and P^{30} produced are artificial radioisotopes.

Do You Know!

Radioisotope potassium-40 is used for dating rocks to estimate the age of the geological specimen. The unstable K-40 is trapped when molten material cools to form igneous rock. This K-40 decays to the stable argon nuclide *Ar*-40 with a half-life of 2.4×10^8 years. The age of the rock sample can be estimated by computing the concentrations of *K*-40 and *Ar*-40.

Do You Know!

Uranium-containing minerals that have been analyzed by radioactive dating have allowed scientists to determine that the Earth is over 4.5 billion years old.

Applications of radioisotopes in medicine, agriculture, and industrial fields.

The attributes of naturally and artificially decaying elements, radioisotopes, give rise to their multiple applications across many aspects of modern-day life. Radioisotopes are often used in medicine, industry, and agriculture for various beneficial purposes. Some practical applications of radioisotopes in different fields are given below.

1. Radiotracers

A radioactive tracer is a chemical compound in which a short-lived radioisotope has replaced a few atoms. Tracers monitor the metabolism of chemical reactions inside the human body, animals, or plants. Radioisotopes are used as tracers in medicine, industry, and agriculture.

In medicine, a patient drinks a liquid containing radio iodine-131, a gamma emitter, to check thyroid function. Over the next 24 hours, a detector measures the activity of the tracer to find out how quickly it becomes concentrated in the thyroid gland.

For the diagnosis of brain tumors, the phosphorous-32 isotope is used. The malignant part of the body absorbs more quantity, which helps trace the affected section of the body.

In industry, manufacturers use tracers to monitor flow and filtration to detect leaks in the equipment. A small amount of short-lived radioactive substances is used in various processes and scanned the flow rates of various materials, including liquids, powders, and gases, to locate leakages. Radiotracers are also used in the oil and gas industry to detect and estimate the extent of oil fields.

In agriculture, fertilizer uptake in the plant from root to leaves is traced by adding tracer phosphorus- 32 to the soil water.

Do You Know!

Radiations interact with matter to produce the excitation and ionization of an atom or molecule. As a result, physical and biological effects are produced. These physical and biological effects of radioisotopes produced are widely used in our daily life.

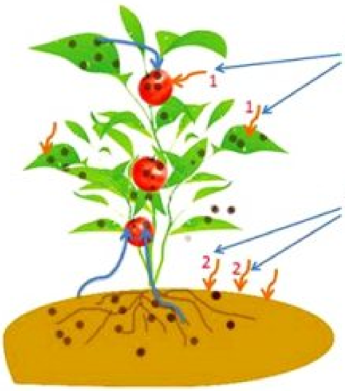


Fig: 20.11 Illustration of radionuclide transfer to plants

2. Medical treatment

In nuclear medicines, radioisotopes are used for curing various diseases. For example, cobalt-60 is a strong gamma emitter. These rays can penetrate in-depth into the body and kill the malignant tumor cells in the patient. Treatment like this is called radiosurgery.

3. Testing for cracks

Gamma rays have high penetrating power, so they can photograph metals to check cracks. A cobalt-60 is a natural gamma rays source and does not need electrical power like an x-ray tube.

Self-Assessment Questions

Q1: What is the main difference between stable and unstable nucleotides?

Q2: Why specific radioactive tracers are used orally in medical imaging?

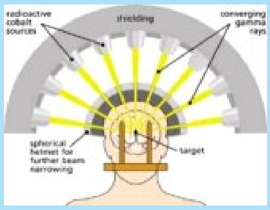
Q3: Why are the radioisotopes of shorter half-lives used in nuclear medicine?

20.6. Fission and Fusion

Nuclear reactions are processes in which one or more nuclides are produced from the collisions between two atomic nuclei. The nuclides produced from nuclear reactions are different from the interacting nuclei or parent nuclei. Two notable nuclear reactions are **nuclear fission reactions** and **nuclear fusion reactions**. Let us learn about these nuclear reactions.

Do You Know!

Gamma Knife radiosurgery is a radiation therapy used to treat tumors, malformations, and other abnormalities in the brain. Gamma Knife radiosurgery uses equipment to focus about 200 tiny radiation beams on a tumor. Each beam has a minimal effect it passes through. A strong dose of radiation is given to the tumor. This stereotype radiosurgery minimizes radiation risk to the target's healthy tissues.



Nuclear Fission

Nuclear fission occurs when a heavy nucleus, such as *U*-235 absorbing a slow-moving neutron, splits or fissions into two smaller nuclei with the release of energy.

For example:

When U-235 captures a neutron, an intermediate, highly unstable nucleus, *U*-236 is formed that disintegrates only for a fraction of a second into two smaller nuclei of nearly equal fragments, Kr-144 and Barium-89, called **fission fragments** accompanied by two or three neutrons.

$$_0n^1 + {}_{92}U^{235} \rightarrow {}_{92}U^{236} \rightarrow {}_{56}Kr^{144} + {}_{36}Ba^{89} + 3\,{}_0n^1$$

Measurements showed that about 200 MeV of energy is released in each fission event.

The schematic illustration; Fig. 20.12 represents the fission of $_{92}U^{235}$.

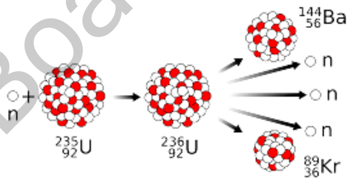


Fig: 20.12. Schematic illustration of nuclear fission

Chain Reaction:

In each nuclear fission, a few neutrons are emitted. These neutrons can, in turn, trigger further nuclei to undergo fission with the possibility of a chain reaction; Fig.20.13. Computations show that if the chain reaction is not controlled, it will explode, releasing massive energy.

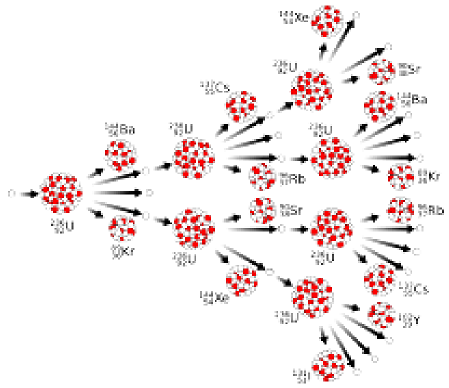


Fig: 20.13. The fission chain reaction in U-235

Do You Know!

In nuclear fission, the total mass of the products is less than the original mass of the heavy nucleus that is converted into energy.

Do You Know!

The fission of enriched uranium, U-235 of 1 Kg, can produce as much energy as 55 tons of burning coal.

This fission chain reaction is controlled in nuclear reactors. A nuclear reactor provides an enormous amount of energy for our valuable purposes.

Nuclear Fusion

Nuclear fusion occurs when two light nuclei combine to form a heavier nucleus with the release of energy.

For example: When a nucleus of Deuterium (H^2) is fused with a nucleus of Tritium (H^3), then a Helium nucleus or alpha particle is formed as represented by the equation,

$$_1H^2 + {}_1H^3 \rightarrow {}_2He^4 + {}_0n^1 + \text{energy}$$

A schematic illustration of the fusion reaction is shown in figure 20.14.

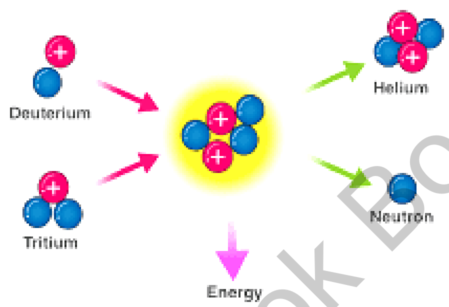


Fig: 20.14. Schematic illustration of nuclear fusion

The total mass of the final nuclei is always less than the mass of the original nuclei. This loss of mass produces nuclear energy.

Self-Assessment Questions

Q1: What is meant by

a) Nuclear fission b) Nuclear chain reaction

c) Nuclear fusion

Q2: Give an example of

a) Controlled chain reaction

b) Uncontrolled chain reaction

20.7 Hazards and safety measures

Describe how radioactive materials are handled, used, stored, and disposed of safely.

Radiation Hazards

All kinds of ionizing radiations such as **α, β**, γ, and X-rays can damage body cells when exposed to these radiations greater than the average level.

Do You Know!

Every star in the universe, including the sun, is alive due to the nuclear fusion of hydrogen nuclei into the helium nucleus. The stars use fusion to produce enormous heat and light energy.

Do You Know!

The International Atomic Energy Agency (IAEA) announced the ionizing radiation warning symbol. This symbol, to be used on sealed radiation sources, is aimed to alert anyone, anywhere, to the danger of a vital source of ionizing radiation.

Do You Know!

A **radiation dosimeter** is a scientific device that detects and measures dose uptake of external high energy ionizing beta, gamma, or X-ray radiation. This badge is lapelled by the people working with the radioactive materials being monitored, and it also records the radiation dose received.

The danger from **α** particles because of their lower penetration power is minimal. If sources of **α** particles are lodged into the body, through the air, or we eat, it can damage our body tissues.

The **β** particles are more penetrating and can damage the body surface tissues. Sources of these particles that enter the body can be quite damaging.

The γ rays are highly penetrating and the most dangerous of all other radioactive radiations.

The prolonged exposure to radioactive radiation can produce deep-sited burns, damage to cells or tissues, and the mutations of the cells that can lead to genetic changes. Radioactive exposure can also cause cancerous growth in specific body tissues.

Safety Measures

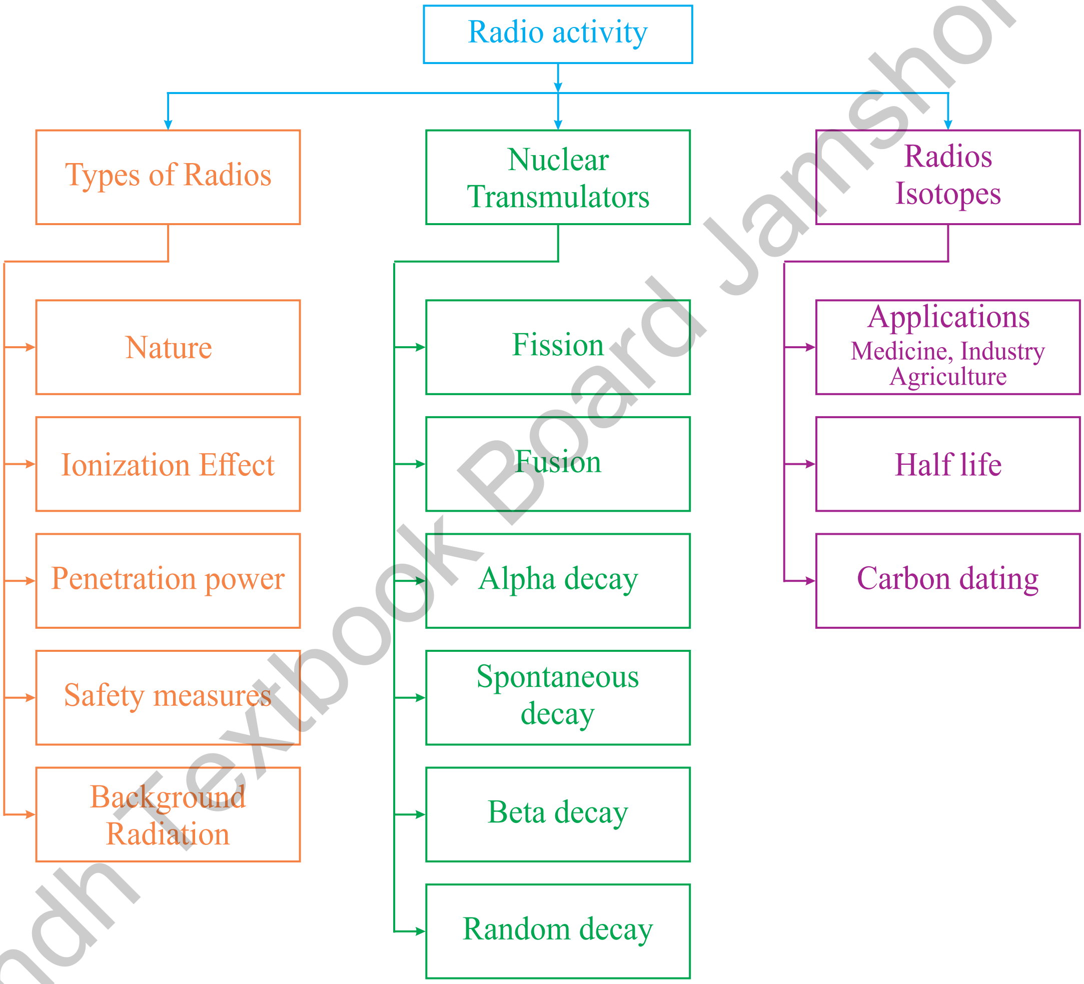
While working in the radiology department in hospitals, nuclear reactors, and research laboratories, should take the following safety measures to avoid any risk of radiation hazards:

i. Keep all radioactive sources at a safe distance from the body.
ii. Minimize the time spent near radioactive materials.
iii. Wear personal protective equipment, including a laboratory coat, gloves, safety glasses, and close-toed shoes.
iv. Lapel the dosimeter badge always and monitor regularly.
v. Do not eat, drink, smoke or touch exposed areas of skin while working in a room where radioisotopes are handled.
vi. Use tongs to handle radioactive sources.
vii. After use, must return the source immediately to its lead boxes.
viii. All radioactive sources should be kept in thick lead containers.
ix. Dispose of all radioactive waste under permitted regul ation or statutory control.

SUMMARY

- Atomic nucleus consists of protons and neutrons.
- Radio-isotope, an isotope that undergoes radioactive decay.
- Radioactivity is the emission of radioactive radiation elements with the release of energy.
- The **α** and **β** –radiations are affected by an electric field and a magnetic field.
- Ionization is a phenomenon by which radiations split matter into positive and negative ions.
- The alpha particle has the shortest penetrating ability.
- The gamma rays are very penetrating, stopped through lead and thick concrete.
- Penetrating power is the strength of radiations to penetrate a specific material.
- Nuclear transmutation is converting one chemical element into another element.
- In alpha decay, the proton number of the parent nuclide reduces by 2, and its atomic mass decreases by 4.
- In beta decay, the proton number of the parent nuclide increases by 1, and its atomic mass remains unchanged.
- Background radiations are natural radiations that come from the surroundings.
- Spontaneous decay is a process that environmental factors cannot influence.
- A random decay is a process in which the exact time of decay of a nucleus cannot be predicted.
- The half-life of a radioactive element is the time taken for half of the nuclei present in any given sample to decay.
- Radioactive dating *is when an object's approximate age is determined using radioactive nuclides.*
- Radioactive tracers monitor the metabolism of chemical reactions inside living objects.
- Nuclear fission is a process in which a heavy nucleus absorbs a slow neutron splits into two smaller nuclei with the release of energy
- Nuclear fusion is a process in which two light nuclei combine to form a heavier nucleus with the release of energy.

CONCEPT MAP


Radio activity
Types of Radios
Nuclear Transmulators
Radios Isotopes
Nature
Ionization Effect
Penetration power
Safety measures
Background Radiation
Fission
Fusion
Alpha decay
Spontaneous decay
Beta decay
Random decay
Applications
Medicine, Industry Agriculture
Half life
Carbon dating

Section (A) Multiple Choice Questions (MCQs)

Choose the correct answer from the following choices:

1. The α-radiation is
   (a) A stream of fast-moving electrons.
   (b) A form of electromagnetic radiation.
   (c) Highly ionizing than γ-radiation.
   (d) More penetrating than β-radiation.
2. A radioactive nuclide emits a β-particle. The atomic number (proton number) of the nucleus
   (a) Stays the same. (b) Increases by 1.
   (c) Decreases by 2. (d) Decreases by 4.
3. A radioactive element emits a particle from the nucleus of one of its atoms. The particle comprises two protons and two neutrons. The name of this process is called
   (a) α-emission (b) β-emission
   (c) γ-emission (d) Nuclear fission
4. A radioactive decay can be represented as shown. $_{91}Pa^{233} \rightarrow {}_{92}U^{233} + \ldots\ldots$
   The emitted particle is a/an
   (a) Gamma-ray. (b) Proton.
   (c) α-particle. (d) β-particle.
5. The type of radiation that travels in a straight line across an electric field is a/an
   (a) Proton (b) Electron
   (c) Alpha particle (d) Gamma-ray
6. A powder contains 100mg of a radioactive material that emits α-particles. The half-life of the isotope is five days. The mass of isotope that remains after ten days will be
   (a) 0mg (b) 25mg (c) 50mg (d) 75mg
7. The main source of energy in the stars is.
   (a) Chemical reaction (b) Nuclear fission
   (c) Nuclear fusion (d) Mechanical energy
8. The splitting of a heavy nucleus into smaller nuclei is called
   (a) Fusion (b) Fission
   (c) Half-life (d) Gamma decay
9. A process in which two light nuclei combine to form a heavier nucleus is called
   (a) Nuclear fusion (b) Nuclear fission
   (c) Beta-decay (d) Alpha-decay

10. Which row shows the nature and the penetrating ability of β-particles?

	Nature	Most are stopped by
a)	helium nucleus	a few mm of aluminum
b)	helium nucleus	a thin sheet of paper
c)	electron	a few mm of aluminum
d)	electron	a thin sheet of paper

11. Compared with α -particles and β – particles, γ- rays,
   (a) Are a type of radiation to carry a charge.
   (b) Have the most significant ionizing effect.
   (c) Have the most significant penetrating effect.
   (d) Have the most negligible mass.
12. The severe health hazards caused by radioactive emissions is/are.
   (a) Cancer
   (b) Genetic change
   (c) Deep-sited burns
   (d) All of these
13. Radioactive materials should be handled carefully. Which safety measure does not reduce the risk of using radioactive material?
   (a) Keeping the material a long distance
   (b) Keeping the material at a low temperature
   (c) Using lead screening
   (d) Using the material for a short time
14. A scientist experiments using a sealed source that emits β-particles. The range of the β-particles in the air is about 30cm. The precaution that is the most effective to protect the scientist from the radiation is,
   (a) Handling the source with long tongs
   (b) Keeping the temperature of the source low
   (c) Opening all windows in the laboratory
   (d) Washing his hands before leaving the laboratory
15. The safest way to dispose of a large quantity of radioactive waste is,
   (a) Burying it in a dry rock deep underground
   (b) Washing it in the drain
   (c) Burning it on a fire
   (d) Draining it into the sea

Section (B) Structured Questions

1. a) Define the term radioactivity.
   b) What do you mean by the term stable nucleus?
   c) Why are some elements radioactive, but some are not?

2. The uranium isotope $_{92}U^{238}$with atomic mass (nucleon number) 238 and atomic number 92.
   a) State the nucleon number.
   b) Uranium-238 nuclide decays to form a thorium nuclide (symbol Th) by emission of an alpha particle. State
      i. The proton number of an alpha particle,
      ii. The nucleon number of an alpha particle,
      iii. The proton number of thorium
      iv. The nucleon number of thorium isotopes formed.
   c) Complete the nuclear equation of the uranium decay
3. A radioactive rock emits gamma rays. A demonstrator plans to experiment to show that the emission of gamma rays is random.
   a) State the random nature of radioactive decay.
   b) Describe what is meant by a gamma-ray
      i. State two safety measures that the researcher must take.
      ii. Describe how the experiment is performed.
4. The nuclide notation for two isotopes of carbon is $_6C^{12}$ and $_6C^{14}$. Carbon-14 decays by beta emission to a stable isotope of nitrogen.
   a) Which nuclide of the carbon is? State with a reason.
      i. Stable isotope
      ii. Radioisotope
   b) What is meant by a beta particle?
   c) Write the nuclear equation of carbon-14 decay to a nitrogen -14 by beta decay.
5. When a slow-moving neutron hits a $_{92}U^{235}$ nucleus, it splits into the nucleus of barium $_{56}Ba^{141}$and the nucleus of krypton $_{36}Kr^{92}$ and emits three neutrons energy is released.

$$_0n^1 + _{92}U^{235} \rightarrow _{92}U^{236} \rightarrow _{56}Ba^{141} + _{36}Kr^{92} + 3\ _0n^1 + \text{energy}$$

   a) State name of the nuclear process.
   b) Which of the two isotopes of U-235 and U-236 have a shorter half-life.
   c) How can we make radioisotopes artificially? Describe a suitable example
   d) For the given process, state its one application in our daily lives.
6. The reaction that takes place at the center of the sun can be represented as

$$2\ _1P^1 + 2\ _0n^1 \rightarrow _2He^4 + \text{energy}$$

   a) State the name of this type of reaction.
   b) Also, define the reaction.
   c) A Nuclear fusion reaction is a more reliable and sustainable energy source than nuclear fission chain reaction. Justify this statement with suitable arguments
7. a) What do you understand by the half-life of a radioactive element?

b) When a Radium-226 undergoes alpha decay, Radon-222 is produced
$_{88}Ra^{226} \rightarrow {}_{86}Rn^{222} + {}_{2}He^{4}$ + energy
Which of the nuclide is a
i. Parent nuclide
ii. Daughter nuclide

c) Define the terms
i. Parent nuclide
ii. Ii. Daughter nuclide

8. Describe uses of radioisotopes in
a) medicine,
b) industry,
c) agriculture

9. a) What are the common radiation hazards?
b) Why is an alpha source more harmful when lodged into the body?
c) Which type of radiation is more hazardous than other radiations? Explain why?
d) Describe briefly the safety measures that are taken against them.

Section (C) Numericals

1. A living plant contains approximately the same isotopic abundance of C-14 as does atmospheric carbon dioxide. The observed rate of decay of C-14 from a living plant is 15.3 disintegrations per minute per gram of carbon. How much disintegration per minute per gram of carbon will be measured from a 12900-year-old sample? (The half-life of C-14 is 5730 years.) **(2.2513, 0.21, 3.2)**

2. The smallest C-14 activity that can be measured is about 0.20%. If C-14 is used to date an object, the object must have died within how many years? **(51374 yr)**

3. How long will it take for 25% of the C-14 atoms in a sample of C-14 to decay? **(2378 yr)**

4. The carbon-14 decay rate of a sample obtained from a young tree is 0.296 disintegration per second per gram of the sample. Another wood sample prepared from an object recovered at an archaeological excavation gives a decay rate of 0.109 disintegration per second per gram of the sample. What is the age of the object? **(8258 yr)**

Glossary

AC Generators machine that converts mechanical energy into electrical energy like AC current.

Alpha Rays is a positively charged nuclear particle identical to the nucleus of a helium atom that consists of two protons and two neutrons.

Alternating Current is a type of electrical current, in which the direction of the flow of electrons switches back and forth at regular intervals or cycles.

Ammeter is a measuring instrument used to find the strength of the current flowing around an electrical circuit when connected in series with the part of the circuit being measured. A modified form of a galvanometer, connecting shunt (very small) resistance parallel to a galvanometer to make it an ammeter.

Amplitude: The maximum displacement from the mean position

Analogue Electronics: Analog means continuous and real. *Analog electronics* is a branch of electronics that deals with a continuously variable signal. It's widely used in radio and audio equipment along with other applications. The Analog signal translates the information into electric pulses of varying amplitude,

Artificial Radioactivity is produced in a substance by bombardment with high-speed particles (such as protons or neutrons).

Atom is the smallest building block of a matter.

Background Radiation: The measure of the level of ionizing radiation present in the environment. Most of the *background radiation* occurs naturally from minerals and a small fraction comes from man-made elements.

Beta Rays: Beta particles (β) are high-energy, high-speed electrons (β^-) or positrons (β^+) that are ejected from the nucleus by some radionuclides during a form of radioactive decay called beta-decay

Browsers: Applications that are used to access and view websites.

Capacitance: The ability to store electric charges its unit is Farad. $Q = CV$ OR $C = Q/V$

Capacitor: The electronic device that stores electric charges.

Cathode Rays emitted high-speed electrons in a stream from the heated cathode of a vacuum tube.

Cell Phone: A portable telephone that can make and receive calls over a radio frequency link while the user is moving within a telephone service area.

Central Process Unit (CPU) or (brain) of the Computer and it performs all types of data processing operations.

Compound Microscope is a high resolution and uses two sets of lenses to provide a 2-dimensional image of the sample.

Compression is a region in a longitudinal wave where the particles are closest together.

Computer: An electronic, that processes data according to a set of instructions.

Concave Lens is a lens that diverges the straight light coming from the source to create a reduced, upright, or digital picture. It can generate real and virtual objects, depending on the light source.

Concave Mirror is a spherical mirrors whose inner side is reflecting or polished.

Convex Lens is (positive lens) is also known as a convergent lens. It can converge light rays passing parallel to its main axis.
Convex Mirror is a spherical mirrors whose outer side is reflecting or polished.
Coulomb is the SI unit of electric charge, equal to the quantity of electricity conveyed in one second by a current of one ampere.
Crest: is the highest surface part of a wave is called the crest,
Critical Angle: is the angle of incidence, for which the angle of refraction is 90°. If light enters a denser medium from a comparatively rarer medium.
Damped Oscillation is that fades away with time. OR. The motion of an oscillator reduces due to an external force, the oscillator and its motion are damped.
Data: Collection of given information.
DC Motor is an electrical machine that converts electrical energy into mechanical energy. In a *DC motor*, the input electrical energy is the direct current.
Dielectric is very poor conductor of electric current. Dielectric means an insulator like Distilled water, transformer oil, etc. are liquid dielectric materials
Diffraction of waves involves a change in direction of waves as they pass through an opening or around a barrier in their path.
Digital Electronics: The branch of electronics that deals with the study of digital signals, and the components that use or create them. The digital signal translates information into a binary format of 0 and 1, where each bit represents two distinct amplitudes.
Direct Current is the flow of electric charge that does not change direction, or it is a unidirectional current. DC is produced by generators with commutators.
Dispersion of Light is process of splitting white light into its constituent colors.
Dispersion of light through Water Droplets: A rainbow is produced by dispersion and internal reflection of light in water droplets in the atmosphere.
Echo is the repetition of sound caused by the reflection of sound.
Electric Charge is the physical property of matter that causes it to experience a force when placed in an electromagnetic field. The charge may be positive or negative.
Electric Current is basically the flow of the electron per unit of time. Its unit is Amp (A). $I = q/t$
Electric Field Intensity at a point is the force experienced by a unit positive charge placed at that point. Electric Field Intensity is a vector quantity. $E = F/q$
Electric Field: The region around an electric charge.
Electric Potential is the amount of work needed to move a unit charge from a reference point to a specific point against an electric field. The unit of electric potential is volt. $V = \Delta w/q$
Electric Power: The rate at which a device changes current to another form of energy. $P = E/t$
Electrical Energy is a type of kinetic energy caused by moving electric charges. The amount of energy depends on the speed of the charges – the faster they move, carry more electrical energy.
Electrical Resistance is the *resistance* force that counter-acts the flow of current. Its unit is ohm.

Electricity is the form of energy, s that we get from the conversion of other sources of energy, like coal, natural gas, oil, nuclear power, and other natural sources, which are called primary sources.
Electromagnetic Force is a fundamental force. It is an interaction between electrically charged particles. It acts between charged particles and is associated with electric and magnetic fields. The electromagnetic force can be attractive or repulsive. $F = q(V \times B)$ OR $F = BILSin\Theta$

Electromagnetic Induction: The creation of an electro-motive force (EMF) by way of a moving magnetic field around an electric conductor and conversely, the creation of current by moving an electrical conductor through a static magnetic field.
Electromagnetic waves are created by a fusion of electric and magnetic fields. The light you see, and the colors around you are visible because of electromagnetic waves. These waves travel with a speed equal to the speed of light, i-e., 3×10^8 m/s. Microwaves, X-rays, Radio waves, Ultraviolet waves, infrared, Visible rays, and Gamma rays.
Electromagnetism is a type of magnetism produced by an electric current or The branch of Physics deals with the electromagnetic force that occurs between electrically charged particles.
Electromotive Force (emf) is the amount of energy required to drive a unit positive charge through an external circuit connected to a cell. its**(emf)** unit is joule per coulomb or volt.
Electron Gun: An electrical instrument produces a beam of electrons.
Electron is elementary particle having a negative charge, moving around the nucleus.
Electronics: The branch of physics and electrical engineering that deals with the emission, behavior, and effects of electrons and with electronic devices.
Electroscope is instrument used for detecting the presence of an electric charge.
Electrostatic Induction: A redistribution of electric charge in an object, caused by the influence of nearby charges.
Elements: An element is a substance that cannot be broken down into any other substance. An element is uniquely determined by the number of protons in the nuclei of its atoms.
Fax Machine: A device that sends and receives printed pages or images over telephone lines.
Frequency: The number of cycles in one second. $F=1/T$
Gamma Rays: The part of the electromagnetic spectrum with the most energy and shortest wavelength. With no charge.
Glass Prism is a triangular object made up of a transparent material, like glass or plastic, that has at least two flat surfaces that form an acute angle
Half-life: The time needed for half of the material to decay. $T_{1/2} = \ln 2/\lambda$
Hard Disk: Hard disk drive or hard drive, magnetic storage medium for a computer.
Hardware: The tangible or physical elements of a computer.
Image: The collection rays at a focal point when light rays appear to converge or to diverge after reflection or refraction is known as the *image*.
Information and Communication Technology: (ICT) is defined as a diverse set of technological tools and resources used to transmit, store, create, share, or exchange information.
Isotopes are atoms with the same number of protons but differ in numbers of neutrons. Isotopes are different forms of a single element.

Lens is basically glasses that are thicker/thinner with curved sides. A lens is a piece of transparent glass that concentrates or disperses light rays when passes through them by refraction.
Logic Gates: A device that acts as a building block for digital circuits. The basic logic gates are classified into seven types: AND gate, OR gate, XOR gate, NAND gate, NOR gate, XNOR gate, and NOT gate.
Longitudinal waves: The movement of the particles is parallel to the motion of the energy, i.e., the displacement of the medium is in the same direction in which the wave is moving. Example – Sound Waves, Pressure Waves
Magnetic Field is a vector field; it is the region around a magnetic material or a moving electric charge within which the force of magnetism acts. The unit of the magnetic field is Tesla (T).
Mechanical waves are a wave that is an oscillation of matter and is responsible for the transfer of energy through a medium.
Microscopy is the technical field to view samples & objects that cannot be seen by naked eye.
Moving Coil Galvanometer is electrical instrument used to measure a small amount of current.
Musical Sound has a pleasant effect on the listener.
Mutual Induction is process in which a changing current in one coil induces emf in another coil,
Natural Radioactivity is a phenomenon of spontaneous and continuous and uncontrollable disintegration of an unstable nucleus accompanied by the emission of active radiations is called natural radioactivity.
Neutron: Elementary particle not having any charge also lay in the nucleus.
Noise Pollution is unwanted and disturbing sounds in our environment.
Nuclear Fission: A nuclear reaction in which the nucleus of an atom splits into two or more nuclei.
Nuclear Fusion: A Nuclear reaction through which two or more light nuclei collide to form a heavier nucleus
Nuclear Transmutation: Nuclear transmutation is a conversion of one chemical_element into another. A transmutation involves a change in the structure of atomic nuclei and hence may be brought by a nuclear_reaction
Nucleus is in the center of an atom, containing proton and neutron in it.
Ohm's Law: The potential difference across conductors is directly proportional to the electric current flowing through it provided physical conditions same.
Oscilloscope is an instrument used to display and analyze the waveform of electronic signals.
Periodic Motion: A motion that repeats itself in an equal period of time.
Photo Phone is a device that allows transmission of speech on a beam of light.
Photographic Enlarger is an optical instrument used to enlarger image on a Photographic plate.
Potential Difference: is the difference in the amount of energy that charge carriers have between two points in a circuit. $V = \Delta W/Q$
Power Transformer is an electrical instrument used in transferring electrical power from one circuit to another without changing the frequency.
Primary Memory: The component of the computer that holds data, programs, and instructions that are currently in use. Primary storage is located on the motherboard.

Production of Sound Waves: It is produced from vibrating particles, so when there are no particles (i.e., there is no medium), sound cannot be generated, e.g. in outer space.
Projector is an apparatus with a system of lenses for projecting slides or film onto a screen.
Proton: Elementary particle having a positive charge, and lay in the nucleus
Quality of Sound or "timbre" is describes those characteristics of sound which allow the ear to distinguish sounds that have the same pitch and loudness
Radio waves: The wireless transmission and reception of electric signals by means of electromagnetic waves.
Radioactive Dating or Radiometric is a way to find out how old something is.
Radioisotopes: An unstable combination of neutrons and protons, or excess energy in their nucleus. When it breaks down becomes more stable
Rarefaction is a region in a longitudinal wave where the particles are furthest apart.
Reflection of Light: The bouncing back of the light.
Reflection of waves involves a change in direction of waves when they bounce off a barrier.
Refraction of Light is the change in direction of a wave passing from one medium to another is caused by its change in speed.
Refractive Index: The ratio of the velocity of light in a vacuum to its velocity in a specified medium. OR The ratio of incident angle to the refracted angle.
Refraction of waves: involves a change in the direction of waves as they pass from one medium to another.
Resistivity: The resistance per unit length and cross-sectional area is called resistivity. $R = \rho l/g$
Resistor is an instrument that limits or regulates the flow of electrical current in an electronic circuit
Secondary Storage devices: Any non-volatile storage device that is internal or external to the computer, such as floppy, USBs, CDs, or DVDs.
Self-Induction is the phenomenon in which a changing current in a coil induces an emf in itself.
Simple Harmonic Motion is an oscillatory motion under a retarding force directly proportional to the amount of displacement from an equilibrium position. Obeys Hook's law $F \alpha -x$
Simple Microscope: it makes the image enlarged that cannot be seen by naked eyes.
Simple pendulum is an ideal pendulum consists of a point mass suspended by a weightless inextensible perfectly flexible thread and free to oscillate neglecting air resistance. $T = 2\Pi\sqrt{l/g}$
Software is the set of instructions, data, programs used to operate and execute specific tasks.
Sound Waves: longitudinal (mechanical) is a wave of compression and rarefaction by which sound is propagated in an elastic medium such as air.
Spectrum: The intensity of light as it varies with wavelength or frequency.
Speed of Sound in (Gas, Liquid and Solids) varies from substance to substance: typically, sound travels most slowly in gases as compare to liquids and fastest in solids. For example, sound travels at 343 m/s in air, it travels at 1,481 m/s in water (almost 4.3 times as fast) and at 5,120 m/s in iron (almost 15 times as fast)
Speed of Sound is the distance traveled by sound wave per unit of time as it propagates through an elastic medium. At 20 °C (68 °F). $V = \lambda f$

Spherical Mirror is a mirror that has the shape of a piece cut out of a spherical surface. There are two types of spherical mirrors: concave, and convex.

Storage Devices: Used to store data.

Telescope: An arrangement of lenses, mirrors, or both that collects visible light, allowing direct observation or photographic recording of distant objects.

The internet: The internet is a globally connected network system facilitating worldwide communication and access to data resources.

The Spectrum of White Light is consisting of seven basic colors arranged in a specific order: red, orange, yellow, green, blue, indigo, and violet.

Thermionic Emission: Discharge of electrons from heated materials.

Time-Period: Time is taken by a wave to complete its one cycle or one oscillation. $T=1/f$

to transmit or send data with the aid of an antenna.

Total Internal Reflection(TIR) is the complete reflection of a ray of light within a medium such as water or glass from the surrounding surfaces back into the medium. The phenomenon occurs if the angle of incidence is greater than the critical angle.

Transmitter: An electronic device used in telecommunications to produce radio waves

Transverse Waves- When the movement of the particles is at right angles or perpendicular to the motion of the energy, then this type of wave is known as a transverse wave. Light is an example of a transverse wave.

Trough is the lowest part is the trough.

Ultrasound is high-frequency wave. That a normal human ear cannot hear.

Voltmeter is an instrument used for measuring the potential difference between two points in an electrical circuit. A modified form of a galvanometer, connecting a large resistance in series with a galvanometer.

$V \alpha I$ OR $V = IR$ OR $I = V/R$

Wave front is a surface over which the phase of the wave is constant

Wavelength is the spatial period of a periodic wave—the distance over which the wave's shape repeats. $\lambda = v/f$

Waves is a dynamic disturbance of one or more quantities. Waves can be periodic. Waves transfer energy from one place to another, but they do not necessarily transfer any mass. Light, sound, and waves in the ocean are common examples of waves.

Wave-Speed: Distance travelled by wave travels in a unit time. $V = \lambda f$

•••••••