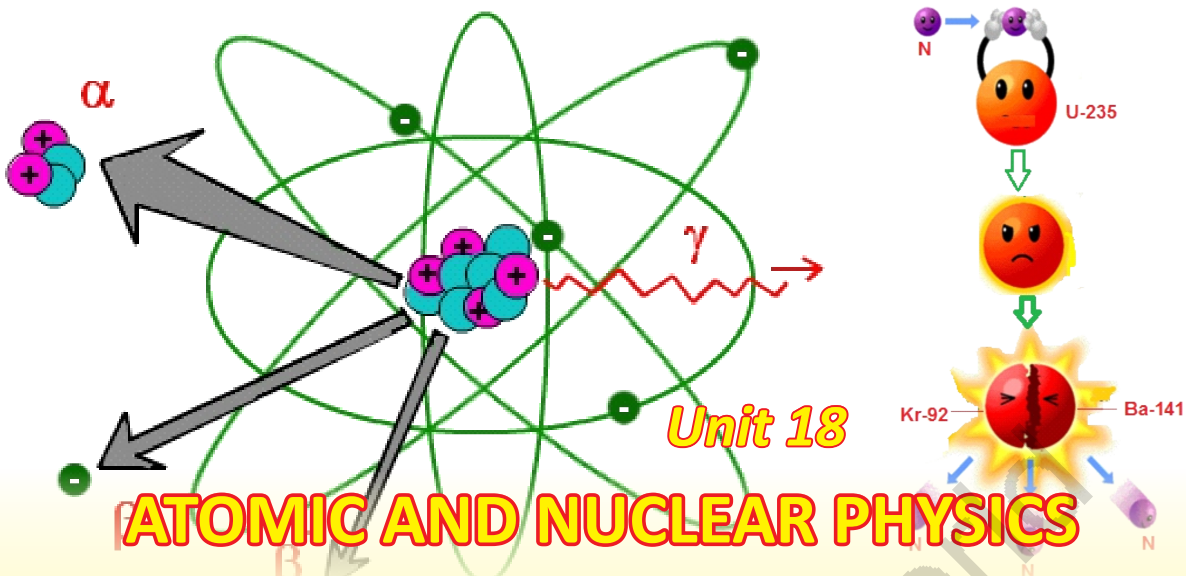


Unit 18

ATOMIC AND NUCLEAR PHYSICS

After studying this unit, students will be able to:

- describe the structure of an atom in terms of a nucleus and electrons.
- 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 notation *X*.
- explain that some nuclei are unstable, give out radiation to get rid of excess energy and are said to be radioactive.
- describe that the three types of radiation are α, β & γ.
- state, for radioactive emissions:
  - their nature
  - their relative ionizing effects
  - their 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 equations when alpha or beta particles are emitted.
- describe that radioactive emissions occur randomly over space and time.
- explain the meaning of hal-life of a radioactive material.
- describe what are radioisotopes. What makes them useful for various applications?
- describe briefly the processes of fission and fusion.
- show an awareness of the existence of background radiation and its sources.
- describe the process of carbon dating to estimate the age of ancient objects.
- describe hazards of radioactive materials.

Science, Technology and Society Connections

The students will be able to:

- describe how radioactive materials are handled, used, stored and disposed of, in a safe way.
- make a list of some applications of radioisotopes in medical, agriculture and industrial fields.
- make estimation of age of ancient objects by the process of carbon dating.

ATOMIC AND NUCLEAR PHYSICS

Scientists were always interested to know the smallest particle of matter. Greek Philosopher Democritus in 585 BC postulated that matter is built from small particles called atoms. The atom means indivisible in Greek language. Rutherford in 1911, discovered that atom had a central part called the nucleus. In this unit, we will describe different aspects of atomic and nuclear physics such as radioactivity, half-life, nuclear reactions, fission and fusion.

For your information

The word atom is derived from the Greek word "otomos", meaning "indivisible." At one time, atoms were thought to be the smallest particles of matter. Today we know that atoms are composite systems and contain even smaller particles: protons, neutrons and electrons.

18.1 ATOM AND ATOMIC NUCLEUS

Rutherford discovered that the positive charge in an atom was concentrated in a small region called nucleus. The nucleus contains protons and neutrons which are collectively called nucleons. Atom also contains electrons which revolve in nearly circular orbits about the positively charged nucleus (Fig. 18.1). The simplest atom is that of hydrogen, nucleus of which is a single proton. We describe an element with respect to its nucleus and use the following quantities:

The **atomic number** Z is equal to the number of protons in the nucleus.

The **neutron number** N is equal to the number of neutrons in the nucleus.

The **atomic mass number** A is equal to the number of nucleons (protons + neutrons) in the nucleus i.e., $A = Z + N$.

The mass of neutron is nearly equal to that of proton. But proton is about 1836 times heavier than an electron. So the mass of an atom is nearly equal to the sum of masses of protons and neutrons.

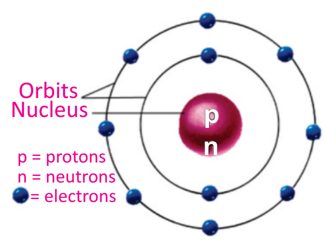


Fig.18.1: The nucleus of an atom consists of protons and neutrons

Generally, an atom is represented by the symbol $^{A}_{Z}X$. For example, nuclide of hydrogen atom having only one proton is $^{1}_{1}H$.

Example 18.1: Find the number of protons and neutrons in the nuclide defined by $^{13}_{6}X$.

Solution: From the symbol, we have

Atomic number Z = number of protons = 6

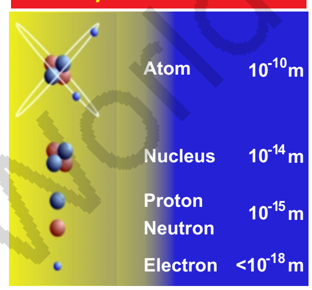
Atomic mass A = number of protons + number of neutrons = 13
But number of protons are 6, so number of neutrons will be 7. So the element is an isotope of carbon-6, and is written as $^{13}_{6}C$.

ISOTOPES

Isotopes are atoms of an element which have same number of protons but different number of neutrons in their nuclie. Three isotopes of Hydrogen are shown in Fig.18.2. Protium (^1_1H) contains one proton in the nucleus and one electron that revolves round the nucleus. Deuterium (^2_1H) contains one proton, one neutron and one electron. Tritium (^3_1H) contains one proton, two neutrons and one electron.

Fig.18.2: Three isotopes of hydrogen Protium (^1_1H), Deutrium (^2_1H) and Tritium (^3_1H).

For your information



Size of atom and its constituents.

18.2 NATURAL RADIOACTIVITY

In 1896, Becquerel accidentally discovered that uranium salt crystals emit an invisible radiation that can darken a photographic plate. He also observed that the radiation had the ability to ionize a gas. Subsequent experiments by other scientists showed that other substances also emited radiations. The most significant investigations of this type were conducted by Marie Curie and her husband Pierre. They discovered two new elements which emitted radiations. These were named polonium and radium. This process of emission of radiations by some elements was called natural radioactivity by Marie Curie.
Subsequent experiments performed by Henrey Becquerel suggested that radioactivity was the result of the decay or disintegration of unstable nuclei.

The spontaneous emission of radiation by unstable nuclei is called natural radioactivity. And the elements which emit such radiations are called radioactive elements.

Three types of radiation are usually emitted by a radioactive

Do you know?

The positively charged protons in a nucleus have huge electrical forces of repulsion between them. Why do not they fly apart in response to this force? Because there is an attractive force between the nucleons called the strong force. This force acts over only a very short distance. Without this strong nuclear force, there would be no atoms beyond hydrogen.

substance. They are: alpha (α) particles; beta (β) particles; and gamma (γ) rays. These three forms of radiations were studied by using the scheme shown in Fig. 18.3. The radioactive source is placed inside the magnetic field. The radiation emitted from the source splits into three components: α and β-radiations bend in opposite direction in the magnetic field while γ-radiation does not change its direction.

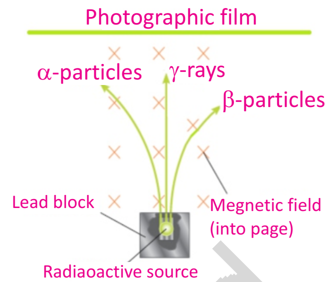


Fig.18.3: Three types of radiations can be distinguished from their path followed in an external magnetic field

18.3 BACKGROUND RADIATIONS

Radiations present in atmosphere due to different radioactive substances are called background radiations (Fig.18.4). Everywhere in rocks, soil, water, and air of our planet are traces of radioactive elements. This natural radiation is called the background radiation. It is as much part of our environment as sunshine and rain. Fortunately, our bodies can tolerate it. Only places where radiation is very high can be injurious to health.

The Earth, and all living things on it also receive radiation from outer space. This radiation is called cosmic radiation which primarily consists of protons, electrons, alpha particles and larger nuclei. The cosmic radiation interacts with atoms in the atmosphere to create a shower of secondary radiation, including X-rays, muons, protons, alpha particles, electrons, and neutrons.

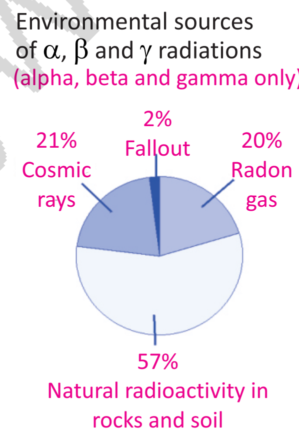


Fig.18.4: The sources of background radiation from the environment

18.4 NUCLEAR TRANSMUTATIONS

We know that during natural radioactivity, an unstable nucleus of radioactive element disintegrates to become more stable.

The spontaneous process in which a parent unstable nuclide changes into a more stable daughter nuclide with the emission of radiations is called nuclear transmutation

Now we represent radioactive decay by means of a nuclear equation in which an unstable parent nuclide *X* changes into a daughter nuclide *Y* with the emission of an alpha particle, beta particle or gamma particle.

1. Alpha (α)-decay

General Equation:

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

parent nuclide — daughter nuclide — α-particle

Example: $${}^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He + \text{Energy}$$

radium — radon — α-particle

It means in alpha decay, the proton number or atomic number Z of the parent nuclide reduces by 2 and its mass number or nucleon number A decreases by 4.

For your information

The SI unit for radioactivity is the becquerel, Bq. In SI base units, 1 Bq = 1disintegration per second (dps). This is a very small unit. For example, 1.0 g of radium has an activity of 3.7 3 × 10^{10} Bq. Therefore, the kilobecquerel (kBq) and the megabecquerel (MBq) are commonly used. The activity of 1.0 g of radium is 3.73×10^{4}MBq.

2. Beta (β)-decay

General Equation:

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

parent nuclide — daughter nuclide — β-particle

Example: $${}^{14}_{6}C \longrightarrow {}^{14}_{6}N + {}^{0}_{-1}e + \text{Energy}$$

carbon — nitrogen — β-particle

In beta (β)-decay, the parent nuclide has its proton number Z increased by 1 but its mass number or nucleon number A remains unchanged.

3. Gamma (γ)-decay

General Equation:

$${}^{A}_{Z}X^{*} \longrightarrow {}^{Z}_{6}X + \gamma$$

parent nuclide — daughter nuclide — gamma rays

Example: $${}^{60}_{27}Co^{*} \longrightarrow {}^{60}_{27}Co + {}^{0}_{0}\gamma + \text{Energy}$$

cobalt — cobalt — γ-rays

Gamma rays are usually emitted alongwith either an alpha or a beta particle.

Physics Insight

when alpha and beta particles are slowed down by collisions, they become harmless. in fact, they combine to form neutral helium atoms.

Nature and Properties of Radiations

Alpha particle is a helium nucleus comprising of two protons and two neutrons with a charge of 2e. An unstable nucleus with large protons and neutrons may decay by emitting alpha radiations. . Beta radiation is a stream of high-energy electrons. An unstable nuclei with excess of neutrons may eject beta radiations. Gamma radiations are fast moving light photons. They are electromagnetic radiations of very high frequency (short wavelength) emitted by the unstable excited nuclie.

Ionizing Effect

The phenomenon by which radiations split matter into positive and negative ions is called ionization. All three kinds of radiations i.e., alpha, beta and gamma can ionize the matter. However, alpha particles have the greatest power of ionization as compared to beta particles and gamma rays. It is due to 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. Ionization of three radiations in a gas is shown in Fig. 18.5.

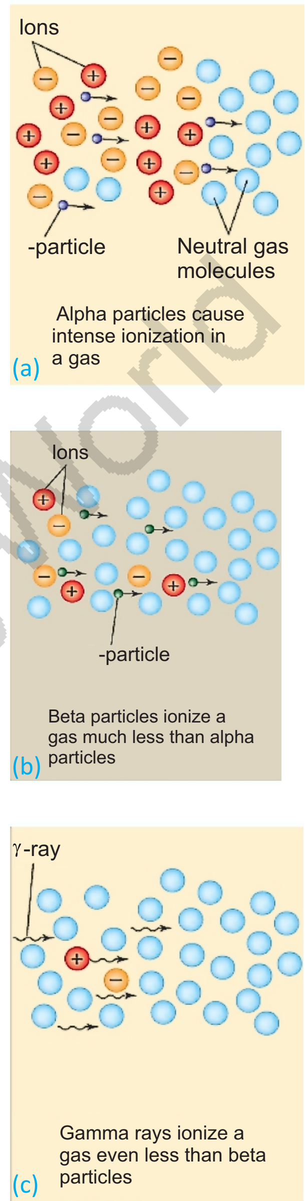


Fig. 18.5: Ionization effect of radiations in a gas

Penetrating Ability

The strength of radiations to penetrate a certain material is called penetrating power. The alpha particle has the shortest range because of its strong interacting or ionizing power. The gamma rays can penetrate a considerable thickness of concrete. It is due to their large speed and neutral nature.

The beta radiation strongly interacts with matter due to its charge and has a short range as compared to gamma radiations. Fig. 18.6 shows the relative penetrating abilities of three kinds of radiations.

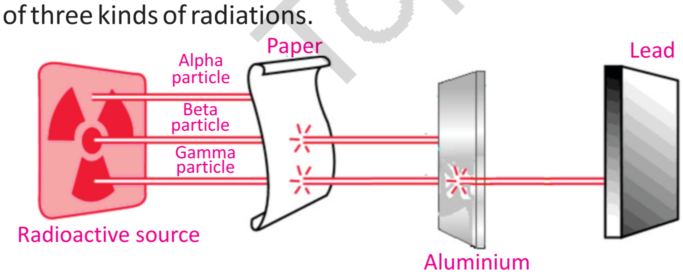


Fig.18.6: Penetrating power of radiations in different materials

Alpha particle has a range of only a few centimetres in air. Beta particles have range of several metres in air. However, gamma rays have a range of several hundreds metres in air.

18.5 HALF-LIFE AND ITS MEASUREMENT

Process of radioactivity is random and the rate of radioactive decay is proportional to the number of unstable nuclei present. In the process, a constant fraction of large number of unstable radioactive nuclei decays in a certain time. So the life time of the unstable nuclei is unlimited and is difficult to measure. We can get the idea about decay rate by the term half-life.

Remember

Three types of Radiations

Alpha Particle	Beta Particle	Gamma Ray
Charge +2	Charge − 1	No charge
Least penetration	Moderate penetration	Highest penetration
Transmutes nucleus: $A \rightarrow A - 4$, $Z \rightarrow Z - 2$, $N \rightarrow N - 2$	Transmutes nucleus: $A \rightarrow A$, $Z \rightarrow Z + 1$, $N \rightarrow N - 1$	Changes only energy $A \rightarrow A$, $Z \rightarrow Z$, $N \rightarrow N$

Half-Life

The time during which half of the unstable radioactive nuclei disintegrate is called the half-life of the sample of radioactive element.

Every radioactive element has its own characteristic half-life. For example, radium-226 has a half-life of 1620 years, which means that half of a radium-226 sample will be converted to other elements by the end of 1620 years (Fig.18.7). In the next 1620 years, half of the remaining radium will decay, leaving only one-fourth the original amount of radium, and so on.

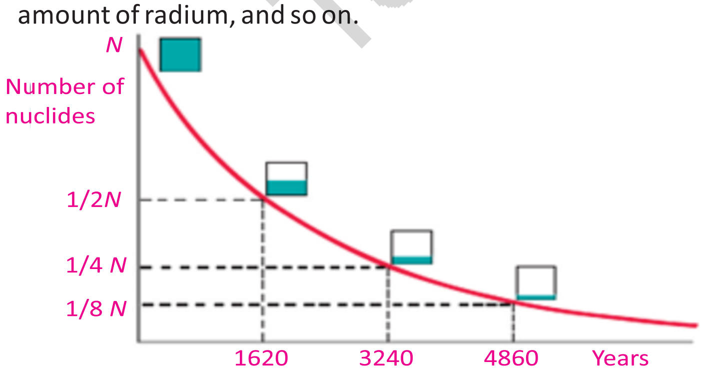


Fig.18.7: Radioactivity of radium

Alpha (α) Particles
Positively charged particles (helium nuclei), ejected at high speed with a range of only a few centimetres in air. They can be stopped by an ordinary sheet of thin aluminium foil.

Beta (β) Particles
Streams of high-energy electrons, ejected at various speeds as high as close to the speed of light. Beta particles may be able to penetrate several millimetres of aluminium.

Gamma (γ) Rays
Electromagnetic radiation of very short wavelenght. Their wavelengths and energies can vary. High-energy gamma rays can penetrate at least 30 cm of lead or 2 km of air.

For your information

i. Nuclear radiation is measured in units of roentgen equivalent man (rem), a unit of equivalent dose.
ii. Patient should be exposed to X-rays with the limit of 0.1 to 1.0 rem.
iii. Safe limit of radiation exposure is 5.0 rem per year.

Physics insight

A half-life is the time a radioactive element takes for half of a given number of nuclei to decay. During a second half-life, half of the remaining nuclei decay, so in two half-lives, three-quarters of the original material has decayed, not all of it.

If the half-life of the radioactive element is $T_{1/2}$, then at the end of this time the number of atoms in the sample will become half i.e., 1/2. After a time $2T_{1/2}$, i.e., after second half-life period, the number of remaining atoms will become $1/2.1/2 = 1/2^2 = 1/4$, after a time 3 $T_{1/2}$, the number of remaining atoms left will be $1/2.1/2.1/2 = 1/2^3 = 1/8$, and at the end of '*t*' half lives number of atoms that remain will be $1/2^t$. It means that if N_o is the original number of atoms in the sample of radioactive element, then after '*t*' half-lives number of atoms left in the sample can be determined by using the relation,

$$\text{Remaining atoms} = \text{Original atoms } 1/2^t$$

$$\text{or} \quad N = N_o \times 1/2^t$$

The process of radioactivity does not depend upon the chemical combinations or reactions. It is also not affected by any change in physical conditions like temperature, pressure, electric or magnetic fields.

Be careful !

International symbol that indicates an area where radioactive material is being handled or produced.

Example 18.2: The activity of a sample of a radioactive bismuth decreases to one-eight of its original activity in 15 days. Calculate the half-life of the sample.

Solution: Let $T_{½}$ is the half-life and A_o is the original activity of the sample. After time $T_{½}$ activity will be $A_o/2$. After $2T_{½}$ activity will become $1/2. A_o/2 = A_o/4$. While after time $3T_{½}$, i.e., after three half-lives, the activity will drop to $A_o/8$. It means activity drops to one-eighth of original activity in a time of $3T_{½}$.

Therefore, $3T_{½} = 15$. This means half-life $T_{½}$ of the sample will be 5 days.

Example 18.3: A radioactive element has a half-life of 40 minutes. The initial count rate was 1000 per minute. How long will it take for the count rate to drop to (a) 250 per minutes (b) 125 per minutes (c) Plot a graph of the radioactive decay of the element.

Solution: The initial count rate is 1000, therefore,

$$1000 \xrightarrow{40 \text{ min.}} 500 \xrightarrow{40 \text{ min.}} 250 \xrightarrow{40 \text{ min.}} 125$$

(a) As clear from above, it takes 2 half-lives for the count rate

Radiation Treatment

Gamma radiations destroy both cancerous cells and healthy cells. Therefore, the beam of radiation must be directed only at cancerous cells.

to decrease from 1000 to 250 per min, hence

Time taken = 2×40 min. = 80 min.

(b) It takes 3 half-lives for the count rate to decrease from 1000 to 125 per min, hence

Time taken = 3×40 min. = 120 min = 2 h

(c) Graph is shown in Fig 18.8.

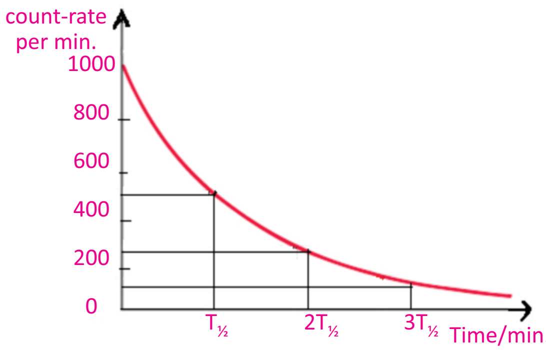


Fig. 18.8: Decay of unstable element

For your information

During brain radiotherapy, patient is carefully positioned in the helmet to ensure that the *gamma* rays converge at the desired point in the brain. A lead apron protects the body from exposure to radiation.

18.6 RADIOISOTOPES AND THEIR USES

Nuclei which do not emit radiations naturally are called stable nuclei. In general, most of the nuclei with atomic number 1 to 82 are stable nuclei. While the elements whose atomic number is greater than 82 are naturally unstable. They emit different types of radiations, all the time, and hence continuously change from one type of element to another.

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

1. $^{1}_{0}n + ^{23}_{11}Na \longrightarrow ^{24}_{11}Na +$ gamma (γ)-rays

neutron — stable sodium nuclide — a sodium radioisotope

2. $^{4}_{2}He + ^{27}_{13}Al \longrightarrow ^{30}_{15}P + ^{1}_{0}n$

alpha particle — stable aluminium nuclide — a phosphorous radioisotope

Uses of Radioisotopes

Radioisotopes are frequently used in medicine, industry and agriculture for variety of useful purposes. Following are few applications of radioisotopes in different fields.

1. Tracers

Radioactive tracers are chemical compounds containing some quantity of radioisotope. They can be used to explore the metabolism of chemical reactions inside the human body, animals or plants. Radioisotopes are used as tracers in medicine, industry and agriculture. For example, radio iodine-131 readily accumulates in the thyroid gland and can be used for the monitoring of thyroid functioning. For the diagnosis of brain tumor phosphorous-32 is used. The malignant part of the body absorbs more quantity of isotopes, and this helps in tracing the affected part of the body.

In industry tracers can be used to locate the wear and tear of the moving parts of the machinery. They can be used for the location of leaks in underground pipes. By introducing a suitable radioactive tracer into the pipe, the leak can be conveniently traced from higher activity in the region of crack in the pipe.

In agriculture, radio phosphorous-32 is used as a tracer to find out how well the plants are absorbing the phosphate fertilizer which are crucial to their growth (Fig.18.9).

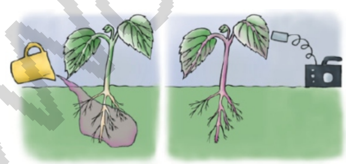


Fig.18.9: To check the action of a fertilizer, researchers combine a small amount of radioactive material with the fertilizer and then apply the combination to a few plants. The amount of radioactive fertilizer taken up by the plants can be easily measured with radiation detectors.

2. Medical Treatment

Radioisotopes are also used in nuclear medicines for curing various diseases. For example, radioactive cobalt-60 is used for curing cancerous tumors and cells. The radiations kill the cells of the malignant tumor in the patient.

3. Carbon Dating

Radioactive carbon-14 is present in small amount in the atmosphere. Live plants use carbon dioxide and therefore become slightly radioactive (Fig. 18.10).

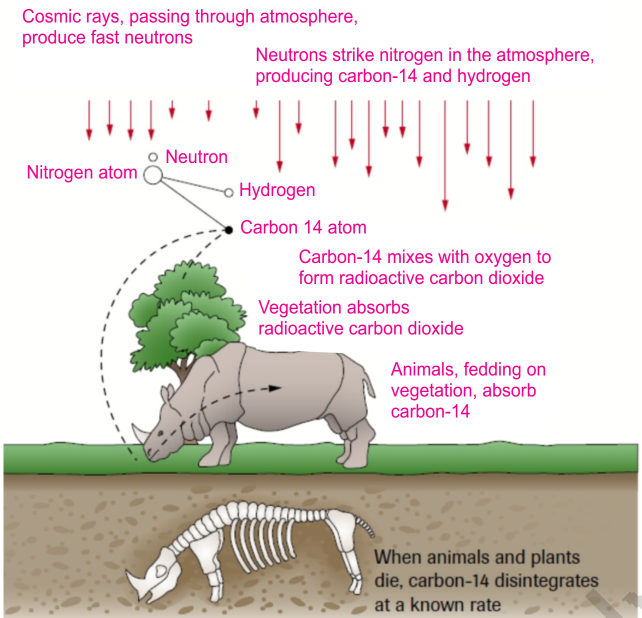


Fig. 18.10: Radiocarbon dating is possible because plants and animals absorb radioactive carbon-14 through their intake of Co_2

When a tree dies, the radio carbon-14 present inside the plant starts decaying. Since the half-life of carbon-14 is 5730 years, the age of a dead tree can be calculated by comparing the activity of carbon-14 in the live and dead tree. The activity of the live tree remains almost constant as the carbon-14 is being replenished while the carbon-14 in the dead tree is no more replenished. Therefore, by measuring the activity in the ancient relic, scientists can estimate its age.

Other radioisotopes are also used to estimate the age of geological specimens. For example, some rocks contain the unstable potassium isotope *K*-40. This decays to the stable argon nuclide *Ar*-40 with half-life of 2.4×10^8 years. The age of rock sample can be estimated by comparing the concentrations of *K*-40 and *Ar*-40.

Example 18.4: The *C*-14: *C*-12 ratio in a fossil bone is found to be $1/4^{th}$ that of the ratio in the bone of a living animal. The half- life of *C*-14 is 5730 years what is the approximate age of the fossil?

Solution: Since the ratio has been reduced by factor of 4 therefore, two half-lives have passed.

Therefore age of the fossil is given by: 2 x 5730 = 11460 years

18.7 FISSION REACTION

Nuclear fission takes place when a heavy nucleus, such as *U*-235, splits, or fissions, into two smaller nuclei by absorbing a slow moving (low-energy) neutron (Fig. 18.11) as represented by the equation:

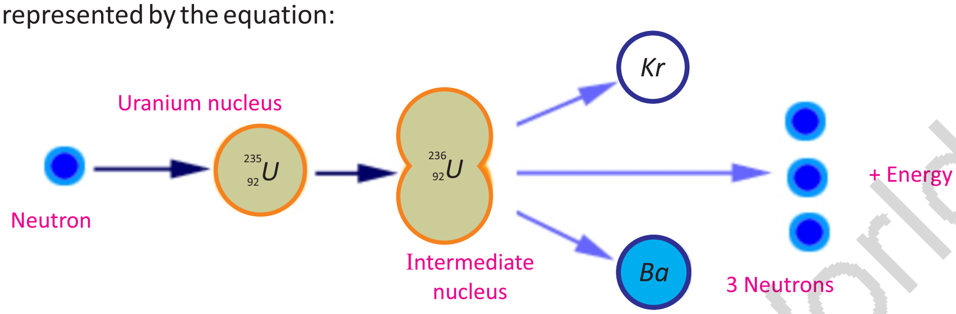


Fig. 18.11: Nuclear fission reaction

$$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{236}_{92}U^{*} \longrightarrow X + Y + neutron$$

where *U**-236 is an intermediate state that lasts only for a fraction of second before splitting into nuclei *X* and *Y*, called **fission fragments**. Nuclear fission was first observed in 1939 by Otto Hahn and Fritz Strassman. The uranium nucleus was split into two nearly equal fragments after absorbing a slow moving (low-energy) neutron. The process also resulted in the production of typically two or three neutrons per fission event. On the average, 2.47 neutrons are released per event as represented by the expression

$$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{141}_{56}Ba \longrightarrow ^{92}_{36}Kr + 3\,^{1}_{0}n$$

In nuclear fission, the total mass of the products is less than the original mass of the heavy nucleus. Measurements showed that about 200 MeV of energy is released in each fission event. This is a large amount of energy relative to the amount released in chemical processes. For example, If we burn 1 tonne of coal, then about 3.6×10^{10} J of energy is released. But, during the fission of 1 kg of Uranium-235 about 6.7×10^{11} J of energy is released.

We have seen that neutrons are emitted when *U*-235 undergoes fission. These neutrons can in turn trigger other nuclei to undergo fission with the possibility of a chain reaction (Fig.18.12). Calculations show that if the chain

For your information

Electron volt is also a unit of energy used in atomic and nearly physics:

$1 eV = 1.6 \times 10^{-19}$ J

reaction is not controlled, it will proceed too rapidly and possibly results in the sudden release of an enormous amount of energy (an explosion).

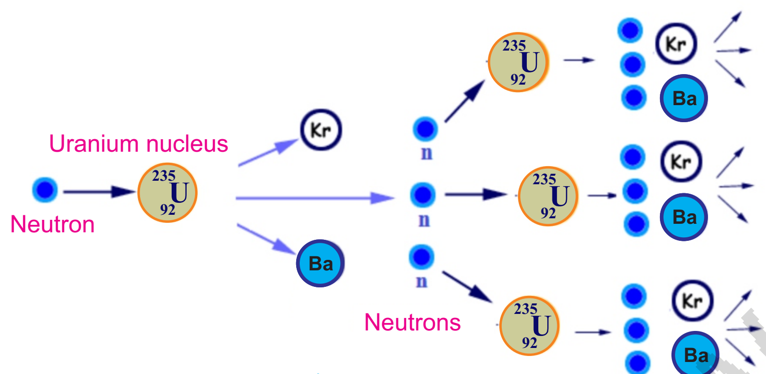


Fig. 18.12: Fission Chain reaction in *U*-235

This fission chain reaction is controlled in nuclear reactors. A nuclear reactor provides energy for useful purposes. In this sort of self sustained reaction, extra neutrons liberated in fission reactions are absorbed using some material to slow down the chain reaction.

Half-lives of Selected Isotopes

Element	Isotope	Half-Life	Radiation Produced
Hydrogen	$^{1}_{0}H$	12.3 years	β
Carbon	$^{14}_{6}C$	5730 years	β
Cobalt	$^{14}_{6}Co$	30 years	β, γ
Lodine	$^{131}_{53}I$	8.07 days	β, γ
Lead	$^{212}_{82}Pb$	10.6 hours	β
Polonium	$^{194}_{84}Po$	0.7 seconds	α
Polonium	$^{210}_{84}Po$	138 days	α, γ
Uranium	$^{235}_{92}U$	7.1×10^{8} years	α, γ
Uranium	$^{238}_{92}U$	4.51×10^{9} years	α, γ
Plutonium	$^{236}_{94}Pu$	2.85 years	α
Plutonium	$^{242}_{94}Pu$	3.79×10^{5} years	α, γ

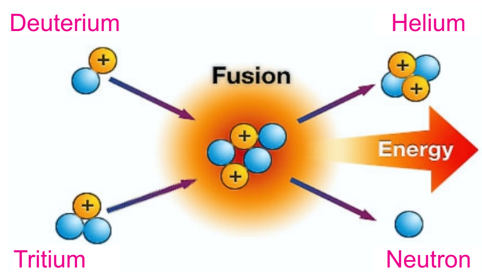
18.8 NUCLEAR FUSION

When two light nuclei combine to form a heavier nucleus, the process is called nuclear fusion.

The mass of the final nucleus is always less than the masses of the original nuclei. According to mass-energy relation this loss of mass converts into energy. If an atom of Deuterium is fused with an atom of Tritium, then a Helium nucleus or alpha particle is formed as given by

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

Pictorally fusion reaction is shown in the following figure:



Energy coming from the Sun and stars is supposed to be the result of fusion of hydrogen nuclei into Helium nucleus with release of energy. The temperature at the centre of the Sun is nearly 20 million kelvin which makes the fusion favourable. According to this reaction, four hydrogen nuclei fuse together to form a helium nucleus alongwith 25.7 MeV of energy.

18.9 HAZARDS OF RADIATIONS AND SAFETY MEASURES

Although, radiations are very useful in medicine, agriculture and industry, they can also cause considerable damage if not used with precautions. Radioactive, nuclear materials are now widely used in nuclear power plants, nuclear-powered submarines, intercontinental ballistic missiles etc. Some of the harmful effects on human beings due to large doses or prolonged small doses of radiations are:

1. Radiation burns, mainly due to beta and gamma radiations, which may cause redness and sores on the skin.
2. Sterility (i.e., inability to produce children).

3. Genetic mutations in both human and plants. Some children are born with serious deformities.
4. Leukemia (cancer of the blood cells).
5. Blindness or formation of cataract in the eye.

During the nuclear accident at Chernobyl, Russia, the explosion of the nuclear reactors melted through a few metres thick concrete housing. This caused a massive destruction of local community and also contaminated vegetation and livestock in the large surrounding area. Millions of dollars were lost as the contaminated vegetable and livestock had to be destroyed.

Because we cannot detect radiations directly, we should strictly follow safety precautions, even when the radioactive sources are very weak.

1. The sources should only be handled with tongs and forceps.
2. The user should use rubber gloves and hands should be washed carefully after the experiment.
3. All radioactive sources should be stored in thick lead containers.
4. Never point a radioactive source towards a person.
5. Frequent visits to the radiation sensitive areas should be avoided.

SUMMARY

- There are two parts of an atom. Its central part is called the nucleus which contains neutrons and protons called nucleons. The nucleus is positively charged and electrons revolve around it in nearly circular orbits.
- The number of protons present inside a nucleus is called the charge number or the atomic number and is denoted by the letter Z.
- The sum of neutrons and protons present in a nucleus is called its atomic mass number. It is denoted by the letter A.
- The atoms of same element with same atomic number but different atomic mass number are called isotopes.
- The elements whose atomic number is greater than 82 are unstable. The process of decaying such elements into daughter elements is called natural radioactivity and such elements are called radioactive elements.
- Radioactivity is a random process which does not depend on space and time.

- The time during which the atoms of a radioactive element are reduced to one half is called the half-life of that element.
- Background radiations are caused by some radioactive elements present in rocks, soil and water.
- A process in which nucleus of an unstable heavy element breaks into two nuclei of lighter elements with the emission of radiation is called nuclear transmutation.
- The isotopes which emit radiations are called radioactive isotopes. They are used in medicine, agriculture and industry for a variety of purposes.
- The age of a dead human, animal or tree can be estimated by comparing the activity of carbon-14 in the live and dead tree. The technique is called carbon dating.
- A process in which a heavy nucleus breaks into two nearly equal parts with the release of large energy is called nuclear fission.
- A process in which two light nuclei diffuse to form a heavier nucleus with release of enormous amount of energy is called fusion reaction.

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the following choices:

i. Isotopes are atoms of same element with different
   (a) atomic mass (b) atomic number
   (c) number of protons (d) number of electrons

ii. One of the isotopes of uranium is $^{238}_{92}U$. The number of neutrons in this isotope is
   (a) 92 (b) 146
   © 238 (d) 330

iii. Which among the following radiations has more penetrating power?
   (a) a beta particle (b) a gamma ray
   (c) an alpha particle (d) all have the same penetrating ability

iv. What happens to the atomic number of an element which emits one alpha particle?
   (a) increases by 1 (b) stays the same
   (c) decreases by 2 (d) decreases by 1

v. The half-life of a certain isotope is 1 day. What is the quantity of the isotope after 2 days?
   (a) one-half (b) one-quarter
   (c) one-eighth (d) none of these

vi. When Uranium (92 protons) ejects a beta particle, how many protons will be in the remaining nucleus?
   (a) 89 protons (b) 90 protons
   © 91 protons (d) 93 protons

vii. Release of energy by the Sun is due to
(a) nuclear fission (b) nuclear fusion
(c) burning of gases (d) chemical reaction

viii. When a heavy nucleus splits into two lighter nuclei, the process would
(a) release nuclear energy (b) absorb nuclear energy
(c) release chemical energy (d) absorb chemical energy

ix. The reason carbon-dating works is that
(a) plants and animals are such strong emitters of carbon-14
(b) after a plant or animal dies, it stops taking in fresh carbon-14
(c) there is so much non-radioactive carbon dioxide in the air
(d) when plants or animals die. they absorb fresh carbon -14

REVIEW QUESTIONS

18.1. What is difference between atomic number and atomic mass number? Give a symbolical representation of a nuclide.

18.2. What do you mean by the term radioactivity? Why some elements are radioactive but some are not?

18.3. How can we make radioactive elements artificially? Describe with a suitable example.

18.4. What are the three basic radioactive decay processes and how do they differ from each other?

18.5. Write the alpha decay process for $^{234}_{91}Pa$. Identify the parent and daughter nuclei in this decay.

18.6. Explain whether the atomic number can increase during nuclear decay. Support your answer with an example.

18.7. What do you understand by half-life of a radioactive element?

18.8. Is radioactivity a spontaneous process? Elaborate your answer with a simple experiment.

18.9. What is meant by background radiations? Enlist some sources of background radiations.

18.10. Describe two uses of radioisotopes in medicine, industry or research.

18.11. What are two common radiation hazards? Briefly describe the precautions that are taken against them.

18.12. Complete this nuclear reaction: $^{235}_{92}U \longrightarrow {}^{140}_{54}X + ? + 2\,{}^{1}_{0}n$. Does this reaction involve fission or fusion? Justify your answer.

18.13. Nuclear fusion reaction is more reliable and sustainable source of energy than nuclear fission chain reaction. Justify this statement with plausible arguments.

18.14. A nitrogen nuclide $^{14}_{7}N$ decays to become an oxygen nuclide by emitting an electron. Show this process with an equation.

18.15. Determine which of these radioactive decay processes are possible:

(a) ${}^{214}_{84}Po \longrightarrow {}^{214}_{84}Po + {}^{4}_{2}He$ (b) ${}^{230}_{90}Th \longrightarrow {}^{226}_{88}Ra + {}^{4}_{2}He$

(c) ${}^{233}_{91}Pa \longrightarrow {}^{233}_{92}U + {}^{0}_{-1}\beta$ (d) ${}^{12}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta$

CONCEPTUAL QUESTIONS

18.1. Is it possible for an element to have different types of atoms? Explain.

18.2. What nuclear reaction would release more energy, the fission reaction or the fusion reaction? Explain.

18.3. Which has more penetrating power, an alpha particle or a gamma ray photon?

18.4. What is the difference between natural and artificial radioactivity?

18.5. How long would you likely have to wait to watch any sample of radioactive atoms completely decay?

18.6. Which type of natural radioactivity leaves the number of protons and the number of neutrons in the nucleus unchanged?

18.7. How much of a 1 g sample of pure radioactive substance would be left undecayed after four half-lives?

18.8. Tritium, ${}^{3}_{1}H$ is radioactive isotope of hydrogen. It decays by emitting an electron. What is the daughter nucleus?

18.9. What information about the structure of the nitrogen atom can be obtained from its nuclide ${}^{14}_{7}N$? In what way atom in ${}^{14}_{7}N$ is different from the atom in ${}^{16}_{7}N$?

NUMERICAL PROBLEMS

18.1. The half-life of ${}^{16}_{7}N$ is 7.3 s. A sample of this nuclide of nitrogen is observed for 29.2 s. Calculate the fraction of the original radioactive isotope remaining after this time.

Ans. (1/16)

18.2. Cobalt-60 is a radioactive element with half-life of 5.25 years. What fraction of the original sample will be left after 26 years? **Ans. (1/32)**

18.3. Carbon-14 has a half-life of 5730 years. How long will it take for the quantity of carbon-14 in a sample to drop to one-eighth of the initial quantity?

Ans. (1.72×10^4 years)

18.4. Technetium-99 m is a radioactive element and is used to diagnose brain, thyroid, liver and kidney diseases. This element has half-life of 6 hours. If there is 200 mg of this technetium present, how much will be left in 36 hours. **Ans.(3.12 mg)**

18.5. Half-life of a radioactive element is 10 minutes. If the initial count rate is 368 counts per minute, find the time for which count rates reaches 23 counts per minute.

Ans. (40 minutes)

18.6. In an experiment to measure the half-life of a radioactive element, the following results were obtained:

Count rate / minute	400	200	100	50	25
Time (in minutes)	0	2	4	6	8

Plot a graph between the count rate and time in minutes. Measure the value for the half-life of the element from the graph. **Ans. (half-life is 2 minutes)**

18.7. A sample of certain radioactive element has a half-life of 1500 years. If it has an activity of 32000 counts per hour at the present time, then plot a graph of the activity of this sample over the period in which it will reduce to 1/16 of its present value.

18.8. Half-life of a radioactive element was found to be 4000 years. The count rates per minute for 8 successive hours were found to be 270, 280, 300, 310, 285, 290, 305, 312. What does the variation in count rates show? Plot a graph between the count rates and time in hours. Why the graph is a straight line rather than an exponential?
Ans. (Variation in count rate shows the random nature of radiactive decay, graph is almost horizontal line rather than exponential curve which is due to long half-life as compared to period of 8 hours)

18.9. Ashes from a campfire deep in a cave show carbon-14 activity of only one-eighth the activity of fresh wood. How long ago was that campfire made?

Ans. (17190 years)

GLOSSARY

AMMETER: An instrument which measures larger current.
AMPERE: If one coulomb of charge passes through any cross section in one second, then current will be equal to one ampere.
AMPLITUDE: The maximum displacement below or above the mean position of a vibrating body.
ANALOGUE ELECTRONICS: The branch of electronics which processes in the form of analogue quantities.
ANALOGUE QUANTITIES: Those quantities which change continuously with time or remain constant.
APERTURE: The line joining the end points of a spherical mirror.
ATOMIC MASS NUMBER: The sum of neutrons and protons present in a nucleus.
BOOLEAN ALGEBRA: The branch of mathematics which deals with the relationships of logic variables.
BOOLEAN VARIABLES: Such things which have only two possible states.
CAPACITANCE: The ability of the capacitor to store charge.
CAPACITOR: A device used to store electric charge.
CAPACITORS IN SERIES: In this combination, the capacitors are connected side by side.
CATHODE-RAY OSCILLOSCOPE: An instrument be used to display the magnitudes of rapidly changing electric current or potential as a function of time.
CATHODE-RAY TUBE: A vacuum tube used to accelerate electrons which emit from the cathode by applying high voltage between cathode and anode.
CENTRE OF CURVATURE: The centre of the hollow sphere of which a spherical mirror is a part.
ATOMIC Number: The number of protons present in a nucleus.
CLADDING: The inner part of the fibre optics.
COMMUNICATION TECHNOLOGY: An electronic based system of information transmission, reception, processing and retrieval.
COMPACT DISC: A molded plastic disc containing digital data that is scanned by a laser beam for the reproduction of recorded sound or other information.
COMPOUND MICROSCOPE: A light microscope used to investigate small objetcs.
COMPRESSIONAL WAVES: The longitudinal waves comprising series of compressions and rarefactions.
COMPUTER: An electronic device used to perform mathematical and logical operations at high speed.
CONCAVE MIRROR: A spherical mirror whose inner curved surface is reflecting.
CONVEX MIRROR: A spherical mirror whose outer curved surface is reflecting.
CONVEX LENS: A lens that causes incident parallel rays to converge at the focal point.
CONCAVE LENS: A Lens which diverges the parallel rays of light from its surface.
COULOMB'S LAW: The force of attraction or repulsion between two charged bodies is

directly proportional to the product of the quantity of charges and inversely proportional to the square of the distance between their centres.

CRESTS AND TROUGHS: In transverse waves, the highest points and the lowest points of the particles of the medium from the mean position.

CYCLE: One complete vibration of a wave.

DATA MANAGING: To collect information for a special purpose and to store it in a computer in a file form.

DATA: Facts and figures that are used by programs to produce useful information.

DIFFRACTION OF WAVES: The bending of waves around obstacles or sharp edges.

DIGITAL ELECTRONICS: The branch of electronics which processes data in the form of digits.

DIGITAL QUANTITIES: The quantities which change in non continuous steps.

ELECTRIC CURRENT: The time rate of flow of electric charge through any cross section.

ELECTRIC POTENTIAL: The amount of work done in bringing a unit positive charge from infinity to a particular point in an electric field.

ELECTRIC POWER: The amount of energy supplied by current in a unit time.

ELECTROMAGNET: The type of magnet which is created when current flows through a coil.

ELECTROMAGNETIC INDUCTION: The production of an electric current across a conductor moving through a magnetic field.

ELECTRON VOLT: The kinetic energy that an electron gains when accelerated between two points with a potential difference of 1 V. $1eV = 1.6 \times 10^{-19}$ J

ELECTRONICS: The branch of applied physics which discusses those principles and ways by means of which we control the flow of electrons using different devices.

ELECTROSTATIC INDUCTION: In the presence of a charged body, an insulated conductor having positive charges at one end and negative charges at the other end.

EMF: The total amount of energy supplied by the battery or the cell in moving one coulomb of positive charge from the positive to the negative terminal of the battery.

ENDOSCOPE: A medical instrument used for exploratory, diagnostic, and surgical purposes.

FARSIGHTEDNESS (HYPERMETROPIA): The disability of the eye to form distinct images of nearby objects on its retina.

FAX MACHINE: A mean to send the documents from one place to another through telephone lines.

RIGHT HAND RULE: Grasp a length of wire with your right hand such that your thumb points in the direction of the current. Then fingers of your right hand circling the wire will point in the direction of the magnetic field.

FISSION REACTION: The process of splitting up a heavy nucleus into two smaller nuclei with release of large amount energy.

FLASH DRIVE: A small storage device that can be used to transport files from one computer to another.

FLEMING'S LEFT HAND RULE: Stretch the thumb, forefinger and the middle finger of the left hand are mutually perpendicular to each other. If the forefinger points in the direction of the magnetic field, the middle finger in the direction of the current, then the thumb

would indicate the direction of the force acting on the conductor.
FLOW OF INFORMATION: The transfer of information from one place to another through different electronic and optical equipments.
FOCAL LENGTH: The distance between the principal focus and the pole.
FREE ELECTRONS: Loosely bound electrons in metals which can move from one point to another inside the metals.
FREQUENCY: The number of cycles or vibrations of a vibrating body in one second.
FUSE: A short piece of metal that melts when excessive current passes through it.
FUSION REACTION: A process in which two light nuclei diffuse to form a heavier nucleus with release of enormous amount of energy.
GALVANOMETER: A sensitive electrical instrument which detects current in a circuit.
GENERATOR: A machine that converts mechanical energy into electrical energy.
GOLD LEAF ELECTROSCOPE: A sensitive instrument used to detect electric charge.
GROUNDED: An object connected to a conducting wire or copper pipe buried in the Earth.
HALF-LIFE: The time during which half of the unstable radioactive nuclei disintegrate.
HARDWARE: The parts of a computer that we can see and touch.
LENZ'S LAW: The direction of the induced current is always such that it opposes the cause that produces it.
INFORMATION AND COMMUNICATION TECHNOLOGY (ICT): It is concerned with the scientific methods and means to store and process vast amounts of information instantly.
INFORMATION STORING DEVICES: Devices used to store information for later use and benefits.
INFORMATION TECHNOLOGY: The scientific method used to store information to arrange them for proper use and to communicate them to others.
INTERNET: A computer networks which spreads all across the globe.
ISOTOPES: The elements with same atomic number but different atomic mass number.
KILOWATT-HOUR: The amount of energy obtained by a power of one kilowatt in one hour.
LIGHT PIPE: A bundle of fibre optics bonded together.
LOGIC GATES: The digital circuits which implement the various logic operations.
LONGITUDINAL WAVES: The sound waves in which particles of the medium vibrate along the direction of propagation of the waves.
LOUDNESS: A feature of sound by which a loud and a faint sound can be distinguished.
MAGNIFICATION: The ratio of the image height to the object height.
MECHANICAL WAVES: Those waves which require some medium for their propagation.
MOBILE PHONE: An electronic device with two-way communication. It sends and receives the message in the form of radiowaves.
MUSICAL SOUND: Sound having pleasant effect on our ears.
MUTUAL INDUCTION: The phenomenon of production of induced emf in one coil due to change of current in a neighbouring coil.
NEARSIGHTED (MYOPIA): The defect of eye due to which people cannot see distant objects clearly without the aid of spectacles.

GLOSSARY

OHM'S LAW: The current passing through a conductor is directly proportional to the potential difference applied across its ends, provided the temperature and physical state of the conductor do not change.
OPTICAL CENTRE: A point on the principal axis at the centre of a lens.
PARALLEL CIRCUIT: A circuit in which voltage remains the same across each resistor.
PERIODIC MOTION: The regular motion of a body which repeats itself in equal intervals of time.
PITCH: The characteristics of sound by which a shrill sound can be distinguished from a grave one.
POLE: The mid-point of the aperture of the spherical mirror.
POWER OF ACCOMMODATION: The ability of the eye to change the focal length of its lens so as to form clear image of an object on its retina.
PRINCIPAL AXIS: The straight line passing through the pole and the centre of curvature of a spherical mirror.
PRINCIPAL FOCUS: A point on the principal axis of mirror/lens where a beam of light parallel to the principal axis converges to or appears to diverge after reflection from the spherical mirror/lens.
PRISM: A transparent triangular piece of glass with at least two polished plane faces inclined towards each other from which light is reflected or refracted.
QUALITY OF SOUND: The characteristics of sound by which two sound waves of same loudness and pitch are distinguished from each other.
RADIOACTIVITY: A phenomenon in which radioactive element emits radioactive rays.
RADIUS OF CURVATURE: The radius of the hollow sphere of which a spherical mirror is a part.
REFLECTION OF LIGHT: When light travelling in a certain medium falls on the surface of another medium, a part of it returns back in the same medium.
REFRACTION: The change of path of waves/light while passing from one medium into another medium due to change in speed.
REFRACTIVE INDEX: The ratio of the speed of light in air to the speed of light in a material:
RESISTANCE: The measure of opposition to the flow of current through a conductor.
RIPPLE TANK: A device used to produce and manipulate water waves.
S.H.M: To and fro oscillatory motion in which acceleration of the body is directly proportional to the displacement of the body from the mean position and is always directed towards the mean position.
SERIES CIRCUIT: A circuit in which current remains the same across each resistor.
SIMPLE MICROSCOPE: A convex lens of short focal length which is used to produce magnified images of small objects.
SOFTWARE: It refers to computer programs and the manuals that support them.
SOLENOID: A coil of wire consisting of many loops.
SOUND: A form of energy that is passed from one point to another in the form of waves.
SPHERICAL MIRROR: A mirror whose polished, reflecting surface is a part of a hollow

sphere of glass or plastic.

THERMIONIC EMISSION: The process of emitting of electrons from hot cathode.

TRANSFORMER: An electrical device which is used to increase or decrease the value of an alternating voltage.

TRANSVERSE WAVES: The mechanical waves in which particles of the medium vibrate about their mean position perpendicular to the direction of propagation of the waves.

TRUTH TABLES: The truth tables are tables which give the values of the inputs and outputs of the basic types of logic gates or combination of such gates.

ULTRASONICS: Sound waves of frequency higher than 20, 000 Hz.

WAVE: A disturbance in a medium which travels from one place to another.

WAVELENGTH: The distance between two consecutive crests or troughs.

WORD PROCESSING: Such a use of computer through which we can write a letter, prepare reports and books, etc.

Electromagnetic

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