ICSE
Living Science
Physics

Class 10

Chapter 12 Radioactivity and Nuclear Energy

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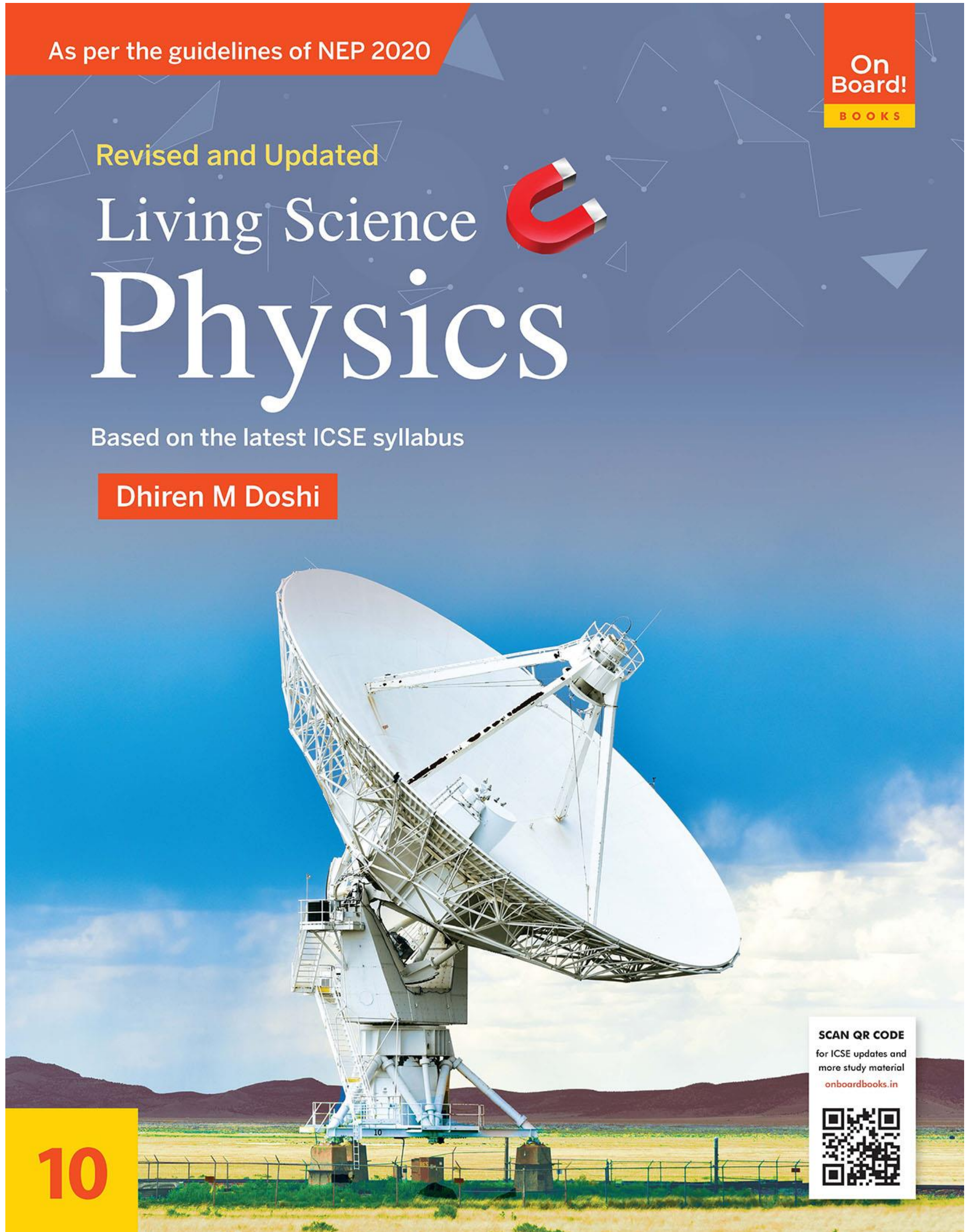


LEARNING OBJECTIVES

Atomic Structure and Radioactivity

- ❖ Structure of an Atom
- ❖ Atomic number and mass number
- ❖ Stability of atomic nucleus

Isotopes

Isobars

Isotones

Natural Radioactivity

Rutherford's Experiment to Study the Nature of Radiations Emitted by Radioactive Elements

- ❖ Cause of natural radioactivity
- ❖ Laws of radioactive decay
- ❖ Uses of radioactive isotopes

Discovery of X-ray

- ❖ What are X-rays?
- ❖ Uses of X-rays
- ❖ X-ray safety

Radiation Hazards

- ❖ Safety measures
- ❖ Radioactive fallout
- ❖ Background radiation

Nuclear Fission

- ❖ Chain reaction
- ❖ Conservation of energy

Nuclear Fusion

Structure of an Atom

1. Every atom is made up of three sub-particles: electrons, protons and neutrons.

2. It consists of a tiny central core called the nucleus. The protons and neutrons are located in the small nucleus.

3. Electrons are negatively charged, protons are positively charged and neutrons are neutral.

4. Most of the mass and all the positive charges (protons) of an atom are concentrated in the nucleus.

5. The size of the nucleus is extremely small (diameter = 10^{-15} m) as compared to the size of the atom (diameter = 10^{-10} m). So most of the space in an atom is **empty**.

6. The negatively charged particles known as electrons revolve around the nucleus in circular orbits called **energy levels** or **shells**.

7. The number of revolving electrons is equal to the number of protons in the nucleus, hence an atom is electrically neutral.

Electronic Configuration

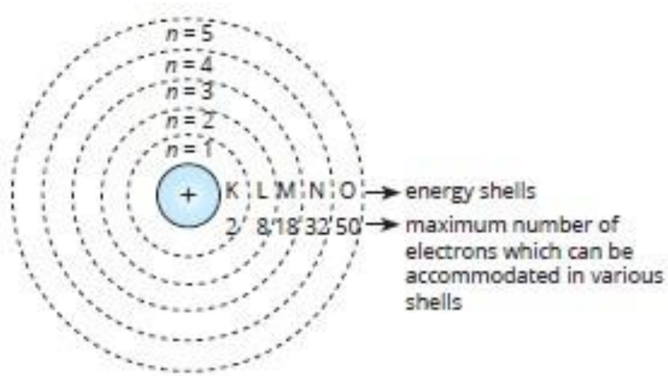
1. Energy levels are represented by letters K, L, M, N, O, P, etc. The first orbit (n = 1) is called the K shell, the second orbit (n = 2) is called the L shell and so on. 'n' is called the principal quantum number.

2. Each shell is associated with a definite amount of energy (hence they are known as energy levels). The energy of the electrons in the K shell is the least while those of L, M, N and O shells increase progressively.

3. The distribution of electrons in the various shells of an atom is known as **electronic configuration** and takes place in such a way so as to achieve maximum stability for the atom.

4. The maximum number of electrons that can be accommodated in a shell is given by $2n^{2}$, where n is the shell number.

Distribution of electrons



5. The outermost shell of an atom cannot accommodate more than 8 electrons, even though it has the capacity to hold more.

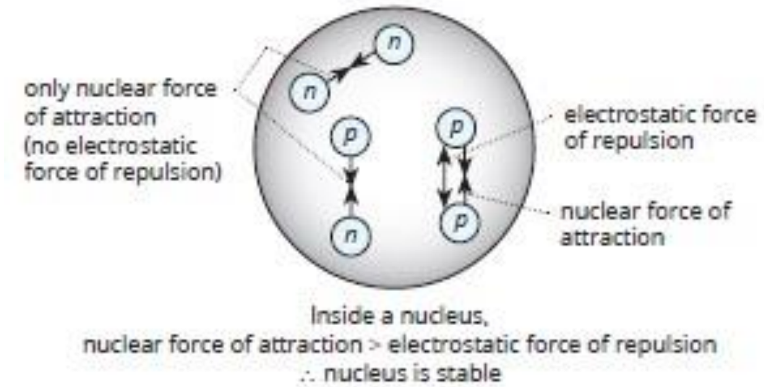
Atomic Number and Mass Number

The number of protons present in the nucleus of an atom is called the **atomic number**. It is usually denoted by *Z*.

The mass of an atom is represented by its mass number. The **mass number** is defined as the sum of the number of protons and neutrons in the nucleus of the atom. It is denoted by *A*.

Stability of Atomic Nucleus

The magnitude of nuclear forces (attractive forces) is much greater than the electrostatic forces of repulsion, the nucleons remain tightly held inside the nucleus and the **nucleus remains stable**



Isotopes

The atoms of an element having same atomic number (*Z*) but different mass numbers (*A*) are called **isotopes**. Isotopes have same number of electrons and protons but different number of neutrons. Example: ${}^{12}_{6}C$ and ${}^{14}_{6}C$

Isobars

The atoms of different elements having same mass number (*A*) but different atomic numbers (*Z*) are called **isobars**. $^{23}_{11}Na$ and $^{23}_{12}Mg$ are isobars.

Isotones

The atoms of different elements having different mass numbers (*A*) and different atomic numbers (*Z*) but have same number of neutrons (*A* – *Z*) are called **isotones**. $^{23}_{11}Na$ and $^{24}_{12}Mg$ are isobars.

Natural Radioactivity

The phenomenon of spontaneous emission of radiations by heavy elements is called **radioactivity**.

- The elements which show the phenomenon of spontaneous emission of high-energy radiations are called radioactive elements. Uranium, thorium, radium and polonium are examples of radioactive elements.

- All heavy elements (*Z* above 82) show the phenomenon of radioactivity. It is because the nuclei of these elements are unstable and they disintegrate (by emission of radiation) to acquire a more stable state.

- The emission of radiations continues till it transforms a heavy unstable radioactive element into a new stable element (like 208 82Pb). After this, the radioactivity stops.

Rutherford's Experiment to Study the Nature of Radiations

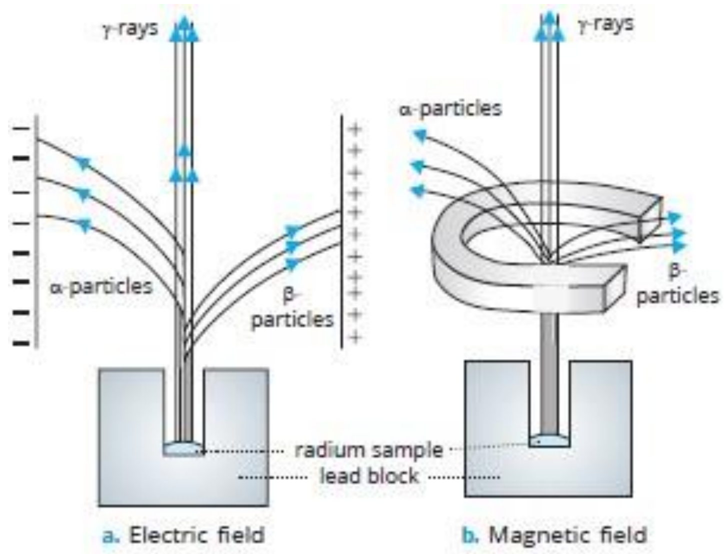
A small amount of some radioactive substance (radium) is placed at the bottom of a small hole made in a block of lead. A narrow beam of rays emerges from the top of the block.

When the radiations coming out of the hole are subjected to an electric field, it is observed that the radiations split into three parts.

•One part bends towards the negative plate. This part constitutes α-**particles**. The deflection of α-particles towards the negative plate shows that they are positively charged. α-particles bend towards the negative plate by a small amount showing that they are **heavy and positively charged particles**.

•The second part bends towards the positive plate. This part constitutes β-**particles**. The deflection of β-particles towards the positive plate shows that they are negatively charged. β-particles bend towards the positive plate by a large amount showing that they are **light and negatively charged particles**.

- The third part remains unaffected and goes straight without bending. This part constitutes γ**-rays**. This means γ-rays are uncharged. It has been found that γ-rays are electromagnetic waves (photons) of very short wavelengths. These are emitted from the nucleus that is in the excited state.



Cause of natural radioactivity

The nuclear force of attraction is less than the electrostatic force of repulsion, with the result, the nuclei of the atoms become unstable. Therefore, in order to stabilise itself, such a heavy unstable nucleus ejects particles out of it. It keeps on ejecting particles till it becomes stable. On emission of α-particles or β-particles, the new stable atom is formed.

Laws of radioactive decay (changes in the nucleus)

The nuclei of the radioactive atoms are in a highly excited state. They disintegrate to produce α-particles or β-particles along with γ-rays.

1. Alpha decay (α-decay)

The phenomenon of emission of α-particles from a radioactive nucleus is called α-decay.

When an atom emits an α-particle (i.e. 42He), its nucleus loses four nucleons – two protons and two neutrons. Therefore, its mass number (*A*) decreases by 4 and its atomic number (*Z*) decreases by 2.

2. Beta decay (β-decay)

The phenomenon of emission of an electron (β-particle) from a radioactive substance is called β-decay.

When there are too many neutrons relative to the number of protons in the nucleus, the electrostatic force of repulsion exceeds the nuclear forces between the nucleons and the nucleus becomes unstable. Such a nucleus becomes stable when one of its neutrons changes into a proton and an electron. As a result, an electron is emitted as a β-particle. The proton remains in the nucleus so that the nucleus has lost a neutron and gained a proton, i.e. it has become a different nucleus with a different atomic number.

3. Gamma decay γ-decay)

The phenomenon of emission of gamma ray (photons) from a radioactive nucleus is called gamma decay.

It has been found that the emission of alpha particle or beta particle is followed by the emission of gamma rays. This emission takes place because either the parent nucleus or the daughter nucleus is in excited state, i.e. they have excess energy than that required to hold the nucleons together.
When an atom emits γ-rays (photons), the γ-rays take no mass and no electric charge from the parent nucleus and hence the mass number and atomic number remain unchanged.

Note: Refer to Table 12.3 for Comparison of properties of α-particles, β-particles and **γ** -radiation

Uses of radioactive isotopes

Radioactive isotopes have extensive applications in several spheres of human life including Medical field, in agriculture, in industries and many other miscellaneous uses.

Note: Refer to Page 251 and 253 of the book for detailed uses of radioactive Isotopes

X-Rays

X-rays are a form of electromagnetic radiation. The discovery of X-rays was made by a German scientist W.K. Roentgen in 1895.

Like radio and light waves, X-rays are also electromagnetic waves. These rays travel at the speed of light. The wavelength of an X-ray, however, is one hundredth to that of the light rays that you can see, at around 10–10 m. This means that they have a lot more energy. X-ray fluorescence is the emission of X-rays from excited atoms produced by the impact of high-energy electrons, other particles or a primary beam of other X-rays.

Uses of X-rays

1. The main use of X-rays is in medicine. A common application is in the form of X-ray machines, which take photograph of a patient’s body.
2. X-rays are also used in security machines at airports to scan baggage.
3. Art historians use X-rays to check if a picture has been painted on top of an older one.
4. X-ray diffraction is also very important in spectroscopy and as a basis for X-ray crystallography.
5. In industry, X-ray photography is used to check welded joints.

X-ray safety

With other medical procedures, X-rays are safe when used with care. Radiologists and X-ray technologists have been trained to use the minimum amount of radiation necessary to obtain the needed results. Properly conducted imaging carries minimal risks and should be performed when clinically indicated.

Radiation Hazards

Radiation hazard means the risk to the living tissues xposed to the natural radioactivity, X-rays or nuclear radiations (α, β and γ-rays). The damage to the human body from nuclear radiations is caused due to the ionization of atoms in the living cells. The ionization of atoms completely destroys the living cells. Radiation hazards lead to disorders or diseases at the following two levels:

Somatic level: When the somatic cells of a person are exposed to the nuclear radiations, it causes irreversible damage to the somatic cells, thereby causing serious illness like leukemia, cancer and total blindness.

Genetic level: When the reproductive cells (present in the reproductive organs) are exposed to the nuclear radiations, this causes mutation in the chromosomes leading to various genetic disorders. The genetic disorders thus produced are passed on to the next generation.

Safety measures

People working in places like nuclear power plants and dealing with radioactive materials are constantly exposed to the harmful radiations coming from them. Such people are required to follow safety rules.

Radioactive fallout

The term radioactive fallout refers to the radioactive materials and debris that settle on the earth after the detonation of a nuclear weapon or after a nuclear accident that produces a cloud of airborne material.

The direction and distance the radioactive fallout travels depends largely on weather conditions like wind speed, wind direction and amount of rain.

The amount of contamination depends on the initial amount of radioactive material contained, for example, in a nuclear reactor.

Nuclear Disasters

When nuclear energy is used carelessly or when it is used for non-productive purposes, it leads to disasters. Radiation accidents are more common than nuclear disasters but they cause damage to a smaller area than nuclear disasters.

Management and mitigation of nuclear and radioactive disasters

- Countries should be careful when undertaking any nuclear activity.
- Nuclear testing areas should be kept away from populated regions.
- Companies should be careful when they conduct experiments with radioactive materials.

Nuclear Fission

The process of splitting of the nucleus of a heavy atom such as $^{235}_{92}U$ (by bombarding with slow neutrons) into two or more lighter nuclei with the release of tremendous amount of energy is called nuclear fission. For example, when uranium-235 atoms are bombarded with slow moving neutrons, the heavy uranium breaks up to produce two medium-weight atoms, barium-139 and krypton-94 with the emission of 3 neutrons. A large amount of energy is produced during the reaction.

Chain Reaction

A kind of reaction where the particle which initiates (starts) the reaction is also produced during the reaction and carries on the reaction further to make it self-propagating and continuous is called a **chain reaction**.

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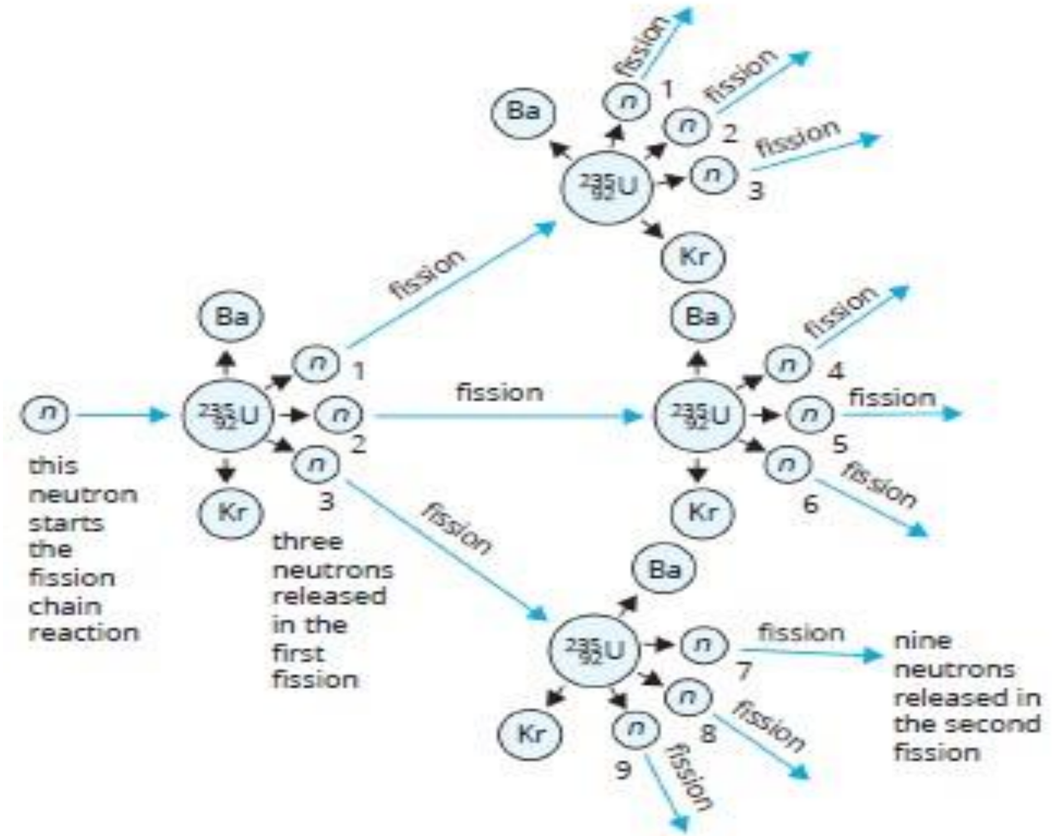
Uncontrolled chain reaction during the fission of U-235



Note: Refer to Table12.4 P 257 for Characteristics of controlled and uncontrolled chain reactions

Conservation of energy

The difference between the actual mass of the original nucleus and the sum of the masses of the individual product nucleons is called **mass defect** or **loss in mass**. It is represented by Δ*m*.

∴ Mass defect Δ*m* = *M* – *A*

where, *M* is the mass of the original nucleus, and *A* is the sum of the masses of individual nucleon product formed.

The amount of energy released during a nuclear reaction is calculated using mass-energy equivalence relation, first derived by Albert Einstein in 1905.

The loss in mass (mass defect) in a nuclear reaction gets converted into energy. The energy so obtained is called nuclear energy. If Δ*m* is the loss in mass, the nuclear energy released (*E*) according to Einstein's equation is

E = Δ*mc*2 where Δ*m* = mass defect or loss in mass, *c* = speed of light in vacuum (i.e. 3 × 108 m s–1)

The energy released in nuclear reactions is expressed in units of electron volt (eV) or million electron volt (MeV).

$$1 \text{ electron volt} = 1.602 \times 10^{-19} \text{ joules}$$

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$$

Nuclear Fusion

The process in which two lighter nuclei fuse to form a stable heavier nucleus with the liberation of enormous amount of energy is called nuclear fusion. For example, two deuterium atoms (heavy hydrogen atoms with mass number 2) combine to form a heavy nucleus of helium and a neutron is emitted. A large amount of energy is also produced during the reaction.

$$^{2}_{1}H + ^{2}_{1}H \xrightarrow{\text{Nuclear fusion}} ^{3}_{2}He + ^{1}_{0}n + \text{Large amount of energy}$$

Deuterium → Helium

Nuclear fusion releases a tremendous amount of energy according to the Einstein equation as the mass of the product nucleus is little less than the sum of the masses of the original individual nuclei. Such nuclear fusion reactions are the sources of energy in the sun and other stars.

Note: Refer to Table 12.5 P-252 for Comparison between nuclear fission and nuclear fusion

SUMMARY

1. **Atomic number:** The number of protons present in the nucleus of an atom is called the atomic number (*Z*).

2. **Mass number:** The sum of the numbers of protons and neutrons in the nucleus of the atom is called the mass number (*A*).

3. **Isotopes:** The atoms of an element having same atomic number (*Z*) but different mass numbers (*A*) are called isotopes.

4. **Isobars:** The atoms of different elements having same mass number (*A*) but different atomic numbers (*Z*) are called isobars.

5. **Radioactivity:** The phenomenon of spontaneous emission of radiations by heavy elements is called radioactivity.

6. **Alpha decay:** When an atom emits an α-particle, its nucleus loses four nucleons – two protons and two neutrons. Therefore, its mass number (*A*) decreases by 4 and its atomic number (*Z*) decreases by 2.

7. **Beta decay:** When an atom emits a β-particle, there is no change in the total number of nucleons. Therefore, its mass number does not change but its atomic number (*Z*) increases by 1.

8. Gamma decay: When an atom emits γ-rays, the mass number and atomic number remain unchanged.

9. Use of radioactive isotopes: a. Medical field **b.** In agriculture **c.** In industries **d.** General use.

10. Radiation hazards: It leads to disorders and diseases at the following two levels **a.** somatic level **b.** genetic level.

11. Background radiation: The radiation from all the sources whether they are a part of earth's radioactive substances or caused by man like in nuclear testing or use of nuclear weapons to which the man is exposed all times is called background radiation.

12. Nuclear fission: The process of splitting of the nucleus of a heavy atom such as 235 92U(by bombarding with slow neutrons) into two or more lighter nuclei with the liberation of enormous amount of energy is called nuclear fission.

13. Nuclear fusion: The process in which two lighter nuclei fuse to form a stable heavier nucleus with the liberation of enormous amount of energy is called nuclear fusion.