Nuclear chemistry and application of radioactivity

Nuclear chemistry is the branch of science that deals with the **study of nuclear composition, nuclear energy and different changes that occurs in the nucleus** of atoms and their uses is known as nuclear chemistry.

Radioactivity: The phenomenon of **spontaneous emission of invisible radiations** from the nucleus of an atom and transformation of the atom into atom of another element is known radioactivity.

The substances that emit invisible radiations like alpha (α), beta (β) and gamma (γ) are **radioactive substances** and the radiations emitted are called **radioactive rays.**

The phenomenon of spontaneous transformation of unstable element (radioactive element) into lighter atoms is known as **radioactive disintegration or decay.**

Natural and artificial radioactivity

The process of **spontaneous disintegration** of or decay of naturally unstable isotopes resulting in the formation of another element along with the emission of radiation is called **natural radioactivity.** Elements having atomic no. greater than 83 like uranium, thorium, polonium, radium etc. show natural radioactivity.

Artificial radioactivity: The process of **changing non radioactive element into radioactive element** by bombarding the element with high energy particles like α-particles, β-particles, protons, neutrons etc. is called **artificial radioactivity.** Example:

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

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

$$^{75}_{33}As + ^{4}_{2}He \rightarrow ^{78}_{35}Br + ^{1}_{0}n$$

$$^{37}_{17}Cl + ^{1}_{0}n \rightarrow ^{38}_{17}Cl$$

Units of radioactivity: **Becquerel, Curie and Rutherford** are units of radioactivity. The unit of radioactivity Curie (Ci) is defined as the quantity of any substance which produce 3.7×10^{10} disintegration per second (dps).

1 curie = 3.7×10^{10} dps

In **SI system** the unit of radioactivity is **Becquerel.**

1 Becquerel = 1 disintegration/sec.

Nuclear reaction

Nuclear reaction can be broadly classified into two types:

1. **Nuclear fission reaction:** The process of splitting a heavy nucleus (having mass number greater than 230) into lighter nuclei of comparable mass by heating the nuclei with suitable sub-atomic particles with the release of large energy is called **nuclear fission reaction**. During the process of fission reaction large amount of energy is released, this energy is called **fission energy**.

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

Nuclear chain reaction: During the fission reaction, the neutron emitted in the reaction will heat another uranium atom and cause fission of another uranium and produce more neutrons. Thus a chain of self sustaining nuclear reaction will set up and produce huge amount of energy. It is of two types:

a. Controlled fission reaction.

b. Uncontrolled fission reaction or explosive fission reaction.

2. Nuclear fusion reaction: The process of combining two or more light nuclei to form a stable heavier nucleus with the release of a large amount of large amount of energy is called **nuclear fusion reaction**. The sum of mass of nuclei after fusion is less than the mass before fusion. This decrease in mass is converted into a large amount of energy which is called **fusion energy.** The energy released by sun is due to fission reaction.

Nuclear fusion reaction **require high temperature** to overcome the electrostatic repulsive force between the combining nucleus. So nuclear fusion reaction is also known as **thermonuclear reaction.**

In the sun, deuterium and tritium combine to form a helium nucleus and neutron with the release of large amount of energy.

$$_1H^2 + {}_1H^3 \longrightarrow {}_2He^4 + {}_0n^1 + 17.6 \text{ MeV.}$$

deuterium **tritium** **helium**

Nuclear power and nuclear weapons

In nuclear fission reaction, when a neutron is bombarded to uranium($^{92}U_{235}$), a chain of reaction is set up with the release of large energy called **nuclear energy.** The energy obtained in the nuclear process can be used either as **nuclear power** or in the form of **nuclear weapon**. Uranium is the most common nuclear fuel.

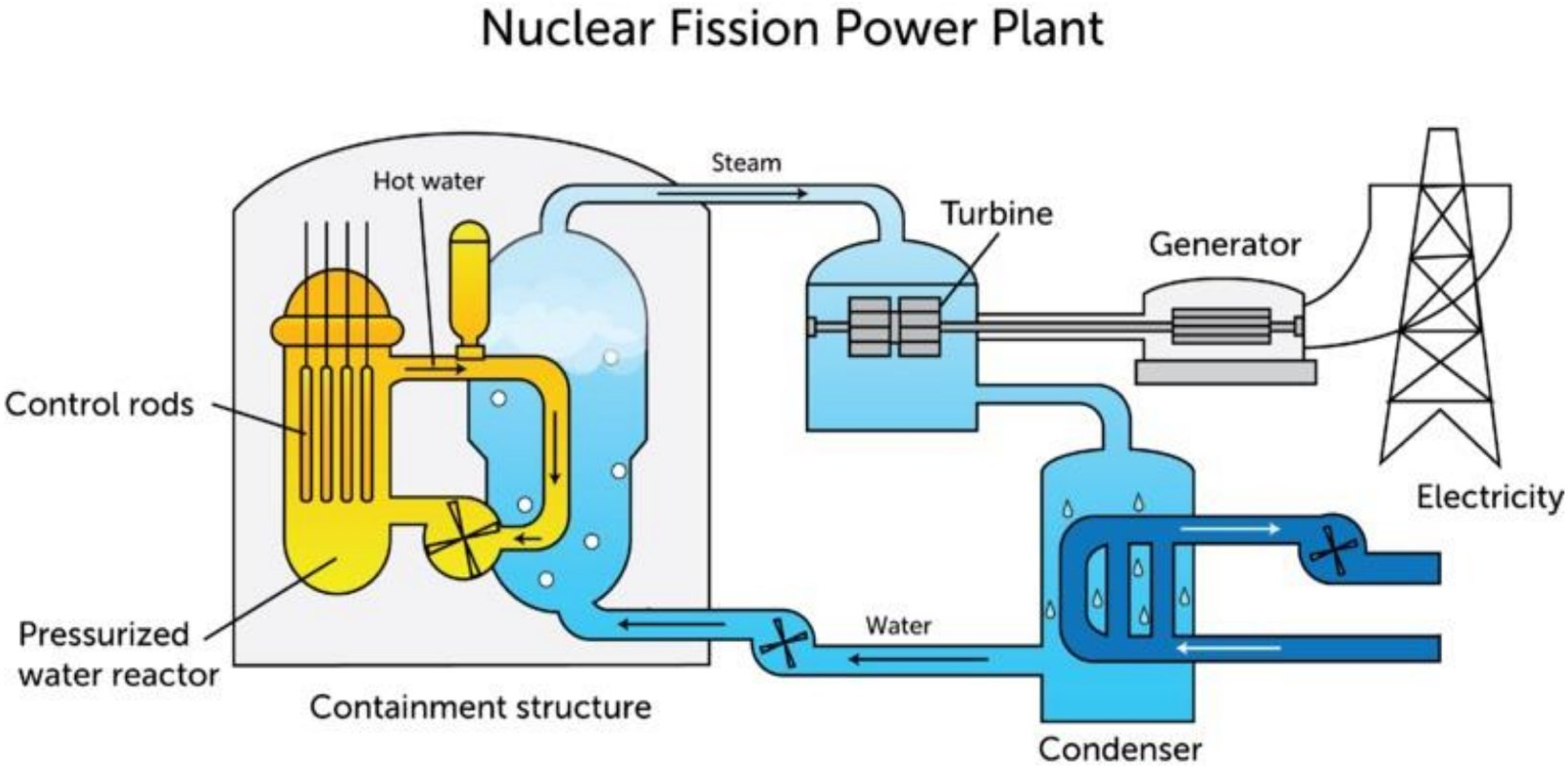
Nuclear power station(controlled nuclear fission reaction):

Fission reaction is a chain reaction which once started continues to propagate and repeat the process until all fissionable material is disintegrated.

In a controlled nuclear fission reaction, the number of fission reaction is controlled by absorbing the desired number of neutrons with the help of moderator and control rods.

The equipment used to carry out fission reactions under controlled conditions is called a **nuclear reactor.**

The energy produced in a nuclear reactor can be used to produce steam which can run turbine and produce electricity.



Uncontrolled nuclear fission (nuclear weapon)

A nuclear weapon is an explosive device that generate large amount of energy from nuclear reactions causing massive death and destruction.

Atomic bomb: If chain reactions of fission reaction is not controlled then powerful explosion occurs with a release of tremendous amount of energy. This is the working principle of atomic bomb. The atomic bomb explosion causes sudden rise in temperature of air, combustion of surrounding materials, emerging of shock wave, production of intense radiation and other radioactive side products.

Two nuclear weapons (bomb) named little boy and fat man were dropped over two Japanese cities, Hiroshima and Nagasaki in 1945 during second world war where 129000 to 226000 people were dead.

Hydrogen bomb: Hydrogen bomb is a thermonuclear weapon, fusion weapon where hydrogen nuclei are fused to produce helium atom along with tremendous amount of heat. First, a fission reaction occurs with the release of large amount of heat, the heat generated result in the fusion of nuclei of hydrogen to form helium along with the release of large amount of heat.

$$_1H^2 + {}_1H^3 \longrightarrow {}_2H^4 + {}_0n^1 + 17.6MeV$$

Nuclear isotopes: The isotopes of an element which is radio active in nature is called radio active isotopes or nuclear isotopes. Chemical properties of radio active isotopes of an atom is same as the normal isotopes. Some common radio active isotopes are iodine-131, phosphorous-32, carbon-14, sodium-24, titanium etc.

Application of radioactive isotopes:

Radioisotopes are widely used in the field of medicine, chemistry, agriculture, biology, engineering, industry, and research. Some of the important uses of radioactivity and radioactive isotopes are as follows:

1. Used to sterilize hospital equipment by exposing through γ radiation.
2. Used to study to study the wearing and tearing of piston ring, gears in engines.
3. Used to monitor fluid flow and in the detection of leakage in petrolium pipe and others.

4. Medical application: In medical, radioactive isotopes are mainly used for two purpose. In medical diagnosis and in medical therapy.

a. **In medical diagnosis:**

- Iron-59 is used to study the deficiency of RBC I blood.
- Iodine-131 is used to detect disorder in thyroid glands and to locate the position of tumors.
- Sodium-23 is used to study the pumping action of heart.
- Iodine-131 is used to examine the function of organs like kidney, liver.

b. **In Medical therapy:**

- Iodine-131 is used in treatment of thyroid.
- Cobalt-60 is used in treatment of various form of cancer by irradiation therapy.
- Gold-198 is used in treatment of blood cancer.
- Phosphorous-32 is used in the treatment of skin disease and leukemia.

5. Prediction of age:

a. **In predicting the age of earth and rocks:** In the natural disintegration series, the end product of the uranium present in rocks, minerals is an isotope of lead (Pb-206) and each series has certain decay constant. By knowing the amount of parent radioactive uranium (U-238), isotope of lead (Pb-206) in the sample of rock and the decay constant of series, the age of rock can be estimated by using first order rate kinetics.

b. **Determination of age of dead animals and trees by radio carbon dating:** All plants use CO_2 from atmosphere for growth, so certain amount of ^{14}C will be present in plant. There is one atom of ^{14}C for every 7.49 x 1011 carbon atom in the $^{12}CO_2$ of air in plants and animals. This ratio of $^{14}C/^{12}C$ remains constant. When plant or animals dies, no additional C-14 is taken in, and that C-14 in the body begins to decay. If we know the concentration of C-14 in a living object, and its concentration in a dead piece at any particular time then the material age can be calculated as.

$$\text{Age of dead sample} = \frac{2.303}{\lambda} \log_{10} \frac{\frac{[{}_6C^{14}]}{[{}_6C^{12}]}\ living\ body}{\frac{[{}_6C^{14}]}{[{}_6C^{12}]}\ deadbody}$$

6. Agricultural application:

- The radioactive isotopes are used to study the function and physiology of fertilizers in plant.
- Radioactive isotopes is used for developing new species of plant by causing mutations.
- Large dose of radiation can kill bacteria and insects, this can be used to preserve foodstuffs, seeds, vegetable for longer time.

7. Tracer techniques:

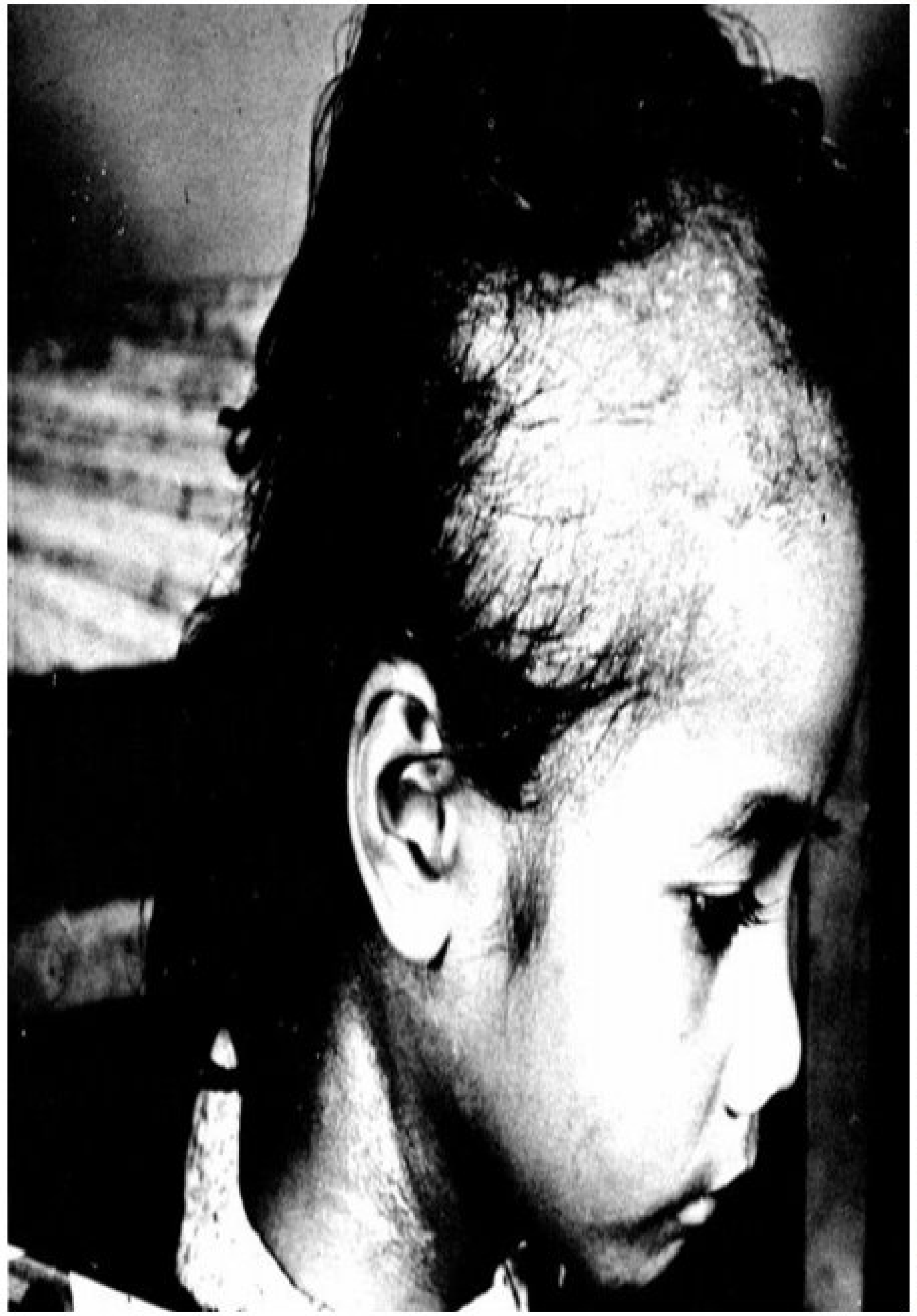
- Radio isotopes is used in the study of reaction mechanism of various chemical reaction by using tracer technique.
- Using tracer technique, radio isotopes is allowed to enter the organism and then its absorption, functioning, and distribution to different part of the plants or animals are studied by detecting radiation emitted by radio isotope.

Harmful effect of nuclear radiation

Long and continuous exposure of a person to a radiation may damage cell and tissue leading to death of the person. The adverse effect of radiation on living being is known as radiation hazard. Exposure to high amount of nuclear radiation affect plants, soil, and animals including human.

- α and β particles emitted from radioactive substance have high ionization power, so when these radiations are inhaled, swallowed, absorbed or injected into a body can damage organs and tissues.
- γ radiation has high penetration power, so it can easily penetrate the skin and damage skin and other part of our body.
- Excessive exposure to the nuclear radiation can cause loss of hair, can damage brain, nerves and blood vessels.
- Excessive exposure to radioactive iodine can effect thyroid gland.

The **Chernobyl disaster** was caused by a nuclear accident that occurred on 26 April 1986, in the Chernobyl Nuclear Power Plant, in the north of the Ukrainian. It is considered the worst nuclear disaster in history. The area covered by 30km of radius is evacuated and about 3,50,000 people evacuated from their homes. It is estimated that it may take 20 years to several hundred years for Chernobyl to be safe for living.



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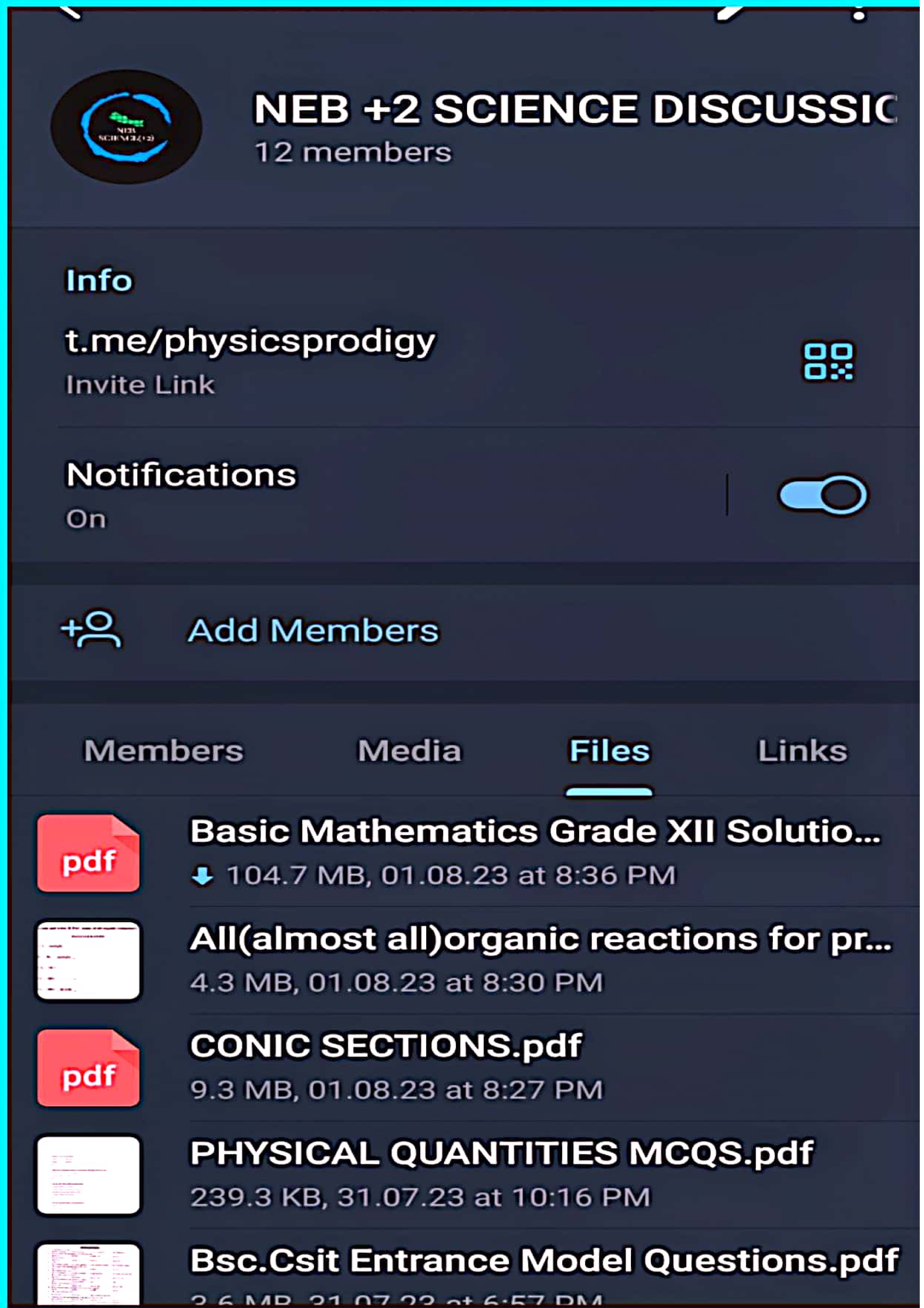

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