The binding energy per nucleon in light nuclei such ^2_1H, ^3_1H, ^6_3Li and ^7_3Li is rather small. However there is a general increase in the binding energy per nucleon as the mass number of the nucleus increases. Thus we can expect that the fusion of these light nuclei to form a heavier nucleus will be accompanied by release of energy. As important examples, we have the fusion reactions of neutron - deuteron and deuteron –tritron

$$^2_1H + ^2_1H \longrightarrow ^3_2He + ^1_0n + 3.27\text{MeV}$$
$$^2_1H + ^2_1H \longrightarrow ^3_1H + ^1_1H + 4.02\text{MeV}$$
$$^2_1H + ^3_1H \longrightarrow ^4_2He + ^1_0n + 17.6\text{MeV}$$

The energy released in each of these fusion reactions is much smaller than the average of 200 MeV released by the fission of ^{235}U and ^{239}Pu. However, the abundance of deuterium is so great that controlled fusion could supply the energy needs of the Earth of many millions of years.

The fusion reactions are much more difficult to bring about as their nuclei repel one another due to their positive charges. They prevent the close contact required for nuclear fusion. The repulsive barrier could be overcome by increasing the kinetic energy on heating the mixture of light isotopes to a temperature of 100 million °C. At extremely high temperatures, 10^8 °C no atoms exist, and a system contains only a collection of nuclei and electrons called **plasma.** Efforts are being made to use strong magnetic fields to force the plasma into a narrow beam and away from the walls of a conventional container where the plasma would lose its energy. The sun and stars exist as plasma.

In a thermonuclear weapon a fission reaction is used to provide the high energies needed to initiate fusion. In one device an ordinary fission bomb (i.e., hydrogen bomb) is surrounded by a shell of lithium deuteride. Neutrons from the fission reaction are captured by lithium nuclei,

$$^6_3Li + ^1_0n \longrightarrow ^4_2He + ^3_1H + \text{tremendous energy}$$

and under high energy conditions supplied by the fission reaction the tritium (^3_1H) undergoes fusion with deuterium:

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

In a hydrogen bomb so called fission-fusion-fusion bomb a shell of $^{239}_{92}U$ surrounds the fusion device. Normally, this isotope of uranium will not under go fission, but under energy rich conditions it will.

Difference between Nuclear Fission and Fusion Reactions

Nuclear Fission	Nuclear Fusion
1. A heavy nucleus is broken into two nuclei of intermediate.	1. Two higher nuclei fuse to form a single heavier nucleus.
2. Slow neutrons are required to produce fission.	2. Very high temperature is required to start fusion reaction.
3. Fission reaction is done artificially in the laboratory.	3. Fusion reaction is natural, it is source of solar energy and terrestrial energy.
4. Fusion chain reaction occurs.	4. Fusion reaction occurs as cyclic process, no chain reaction.
5. It produces less energy than fusion reaction.	5. It produces more energy than fission reaction.
6. Many techniques of fusion reactors are developed.	6. Fusion reactor construction is in process.
7. It can be used for peaceful purpose and is used for producing power electricity.	7. Uptil now the fusion reaction can be used only for the destruction purpose, i.e., producing hydrogen bomb.
8. Heavy nucleus is used as fuel. $^{235}_{92}U + ^{1}_{0}n \longrightarrow [^{236}_{92}U] \longrightarrow ^{139}_{56}Ba + ^{94}_{36}Kr + 3\,^{1}_{0}n$ $[^{236}_{92}U] \longrightarrow ^{90}_{38}Sr + ^{144}_{54}Xe + 2\,^{1}_{0}n$	8. Lighter nuclei are used as fuel. $^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n + 3.27 MeV$ $^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{1}H + ^{1}_{1}H + 4.02 MeV$ $^{2}_{1}He + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n + 17.6 MeV$
9. Atom bomb is based on the principle of nuclear fission.	9. Hydrogen bomb is based on the principle of nuclear fusion.

8.15 Uses of Radioisotopes

Some important uses of radioisotopes in various fields are given below:

1. Uses of radioisotopes as radioactive Tracers

A **radioactive tracer** *is a very small amount of radioactive isotope added to a chemical, biological, or physical system to study the system.* The advantage of a radioactive tracer is that it behaves chemically just as a nonradioactive isotope does, but it can be detected in exceedingly small amounts by measuring the radiations emitted.

(i) Uses of tracers in the diagnosis of diseases. Radioisotopes used for diagnostic purposes localize in specific organs or tissue within a body. This enables a specialist with a radiation detector computer system to generate a picture of the area being studied.

(a) Hemoglobin contains iron. The rate at which injected radioactive ^{59}Fe appears in the blood provides a measurement of the red blood cell production.

(b) Functioning of thyroid gland. Radioisotope of iodine, ^{131}I is given to a patient with thyroid disorders. It decays β-rays. Detection of these rays gives an information regarding the functioning of the thyroid gland.

(c) Test of cancer growth. ^{60}Co emits high energy γ-rays which are used for testing deeply seated cancer growth.

(d) Brain tumors can be located very accurately because of their greater tendency to absorb certain radioisotopes –such as ^{111}In and ^{64}Cu- from the blood stream.

(e) Circulation of blood. Radiosodium, Na^{24} (β-particle emitter) has been used to study cases of restricted circulation of blood. A small quantity of NaCl solution which contains labeled sodium (Na^{24}) is injected into the vein of a patient's forearm and a γ-ray detector is then placed in contact with one of his feet. If blood circulation is normal, the presence of radioactivity is soon discovered in the blood. It increases rapidly and becomes maximum within an hour. However, if there is any circulatory impairment, radioactivity will increase slowly showing that blood has some difficulty in reaching the foot. By moving the detector to different parts of the body, the position of restriction can be located and the necessary treatment applied.

2. Uses of radioactive tracers in Chemistry

(a) Rate of exchange reactions: The rate of some exchange reactions has been studied by using tracers. For examples, the electron interchange between Fe^{3+} and Fe^{2+} can be followed by mixing radioactive $^{55}Fe^{3+}$ ions with nonradioactive Fe^{2+} ions. The rate of the exchange

$$^{55}Fe^{3+} + Fe^{2+} \longrightarrow {}^{55}Fe^{2+} + Fe^{3+}$$

is determined by taking periodic samples of the mixture, separating Fe^{2+} from Fe^{3+}, and determining how fast the radioactivity has decreased in the Fe(III) or increased in the Fe(II).

(b) Hydrolysis of esters. Mechanism of ester hydrolysis has been studied by using O^{18} isotope. It is observed that when an ester is hydrolysed by water containing O^{18} (i.e., H_2O^{18}), the alcohol formed does not have any O^{18} while the acid has the whole of it. The presence of O^{18} in the acid proves that the –OR′ group in the ester is wholly replaced by –O^{18}H group in H_2O^{18}.

$$R-\overset{\overset{\large O}{\|}}{C}-\boxed{OR' + H}O^{18}H \longrightarrow R-\overset{\overset{\large O}{\|}}{C}-O^{18}H + R'OH$$

(c) Photosynthesis. The mechanism of the process of photosynthesis taking place in plants has been studied by reacting CO_2 containing ^{18}O (CO_2^{18}) with H_2O. In this process the green plants take up CO_2 and H_2O in presence of sunlight and chlorophyll to form sugar, giving out O_2 gas.

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

It is observed that O^{18} present in CO_2^{18} goes to sugar and water while that of water is evolved as free oxygen. Thus O_2 evolved in the process of photosynthesis comes from H_2O and not from CO_2. The reaction shown above should be shown as

$$6CO_2^{18} + 12H_2O \longrightarrow C_6H_{12}O_6^{18} + 6H_2O^{18} + 6O_2$$

3. Uses of Tracers in Industry.

Radioactive isotopes have found many applications in industry both in research and in process control. Some of the applications are mentioned below:

(a) Self-diffusion of metals. The phenomenon of self-diffusion in metals i.e., the movement of the atoms of a metal within the crystal lattice has been studied with the help of isotopes.

(b) As catalyst. γ-rays obtained from Co^{60} have been used as catalyst in the manufacture C_2H_5Br from C_2H_4 and HBr.

(c) Mechanisms of reactions. Radioactive carbon, ^{12}C has been used as a tracers in studying mechanisms involved in many reactions of industrial importance such as polymerization, alkylation, catalytic synthesis, etc.

(d) Radioactive isotopes has been used in studying the mechanism of the effectiveness of various lubricants.

(e) Uniform mixing. Uniformity of mixing during the blending of petrols, lubricating oils and greases etc. has been achieved by labelling one of the constituents with a radioactive tracer.

(f) Determination of the wear of piston rings. The wear of piston rings and of gears in engines and its prevention by means of suitable lubricants have been studied by radioactivity. A steel piston ring is made radioactive by exposing it to neutrons in a nuclear reactor. The piston ring is then fitted into the cylinder of an internal combustion engine which is operated normally with a particular lubricating oil. By determining the radioactivity removed by the oil, the amount of piston wear can be determined.

4. Uses of Tracers in Agriculture

(a) Uptake of phosphorus by plants. When a plant grows, it absorbs phosphorus both from the soil and from the added phosphatic fertilizer. In order to check the usefulness of the fertilizer, it is important to know what proportion of phosphorus comes from each source. When radiophosphorus (P^{32}) is added in the phosphatic fertilizer, the exact proportion taken up by the plant can be determined accurately.

The efficiency of different phosphate fertilizers can be compared with the help of radioactive phosphorus being used as a tracer element. Fertilizer which is absorbed quickly is more efficient.

(b) Transporation of mineral in plants. The transporation of mineral from roots to leaves and its subsequent redistribution within the plants can be followed through the use of radioactive isotopes by means of radioatography. By this technique the distribution of S^{35}, supplied in the form of sulphate, in sugar beet plants has been followed.

5. Uses of Tracers in Analytical Techniques.

Radioisotopes have number of applications in chemical analysis

(a) Isotope dilution, *a technique to determine the quantity of a substance in a mixture or of the total volume of solution by adding a known amount of an isotope to it.* After removal of a portion of the mixture, the fraction by which the isotope has been diluted provides a way of determining the quantity of substance or volume of solution. Suppose we want to determine the amount of $NaNO_3$ present in a solution. First a known quantity of additional $NaNO_3$ containing radioactive sodium 24 is dissolved in the solution. Then water is evaporated until some $NaNO_3$ has crystallized out of solution. The radioactivity of this solid is then measured, and if, for example, it is 3 percent of that of the added $NaNO_3$, then the ratio of original to added $NaNO_3$ in the crystals must be 97:3. But this must also be the ratio in the original solution, and so from the quantity of radioactivity tagged $NaNO_3$ added, the quantity of $NaNO_3$ originally present can be determined.

(b) Neutron activation analysis *is an analysis of elements in a sample based on the conversion of stable isotopes to radioactive isotopes by bombarding a sample with neutrons.* Human hair contains trace amounts of elements. By determining the exact amounts and the position of the elements in the hair shaft, we can identify whom the hair comes from. Consider the analysis of human hair for arsenic, for example, when the natural isotope $^{75}_{33}As$ is bombarded with neutrons, a metastable nucleus $^{76}_{33}As$ is obtained.

$$^{75}_{33}As + ^{1}_{0}n \longrightarrow ^{76}_{33}As \quad \text{(metastable)}$$

A metastable nucleus is an excited state. It decays or undergoes a transition, to a lower state by emitting gamma rays. The frequencies or energies, of the gamma rays emitted are characteristic of the element and serve to identify it. Also, the intensities of gamma rays emitted are proportional to the amount of the element present. This method is very sensitive; it can identify as little as 10^{-9}g of As.

6. Radiotherapy (uses of radioisotopes in the treatment of diseases).

The treatment of diseases by the use of radioisotopes is called **radiotherapy.** Some examples of radiotherapy are mentioned below:

(a) Treatment of thyroid complaints. Radioactive iodine I^{131} has been used for the treatment of certain thyroid complaints. Stable iodine and radioactive iodine are preferentially absorbed by the thyroid gland. Radioactive iodine destroys abnormal tissues in the thyroid gland more rapidly and in this way checks the abnormal growth.

(b) Treatment of cancer growth. Radiocobalt (^{60}Co) is now used in the treatment of cancer. $^{60}_{27}Co$ is a β- and γ emitter and the radiation is focused on malignant tissue to destroy it.

(c) Radioactive phosphorus in the form of phosphate is widely used in the *treatment of certain blood disorder.*

(d) Radiophosphorus (^{30}P) is used for skin diseases.

7. Determination of the age of the earth by rock dating method.

The age of a rock gives an approximate idea of the age of the earth provided that it is assumed that the rock or the mineral is as old as the earth.

8. Determination of the age of recent objects by radiocarbon dating method.

The age of recent objects such as those of animal or vegetable origin like a piece of wood or animal fossil can be determined by radio-carbon dating method, since rock dating method is useful only for the minerals or rocks of considerable age.