Nuclear Reactions & its application

1) **Nuclear fission**: The splitting of a heavier atom like that of uranium – 235 into a number of fragments of much smaller mass, by suitable bombardment with sub-atomic particles with liberation of huge amount of energy is called **Nuclear fission**. Hahn and Startsman discovered that when uranium-235 is bombarded with neutrons, it splits up into two relatively lighter elements.

\[ _{92}^{235}U + 0\ n^1 \rightarrow _{56}^{140}Ba + _{36}^{93}Kr + 2-3\ 0\ n^1 + \text{Huge amount of energy} \]

Spallation reactions are similar to nuclear fission. However, they differ by the fact that they are brought by high energy bombarding particles or photons.

Elements capable of undergoing nuclear fission and their fission products. Among elements capable of undergoing nuclear fission, uranium is the most common. The natural uranium consists of three isotopes, namely \( ^{234}U (0.006\%) \), \( ^{235}U (0.7\%) \) and \( ^{238}U (99.3\%) \). Of the three isomers of uranium, nuclear fission of \( ^{235}U \) and \( ^{238}U \) are more important. Uranium-238 undergoes fission by fast moving neutrons while \( ^{235}U \) undergoes fission by slow moving neutrons; of these two, \( ^{235}U \) fission is of much significance. Other examples are \( ^{239}Pu \) and \( ^{233}U \).

Uranium-238, the more abundant (99.3%) isotope of uranium, although itself does not undergo nuclear fission, is converted into plutonium-239.

\[ _{92}^{238}U + 0\ n^1 \rightarrow _{92}^{239}U \; ; \; _{92}^{238}U + 0\ n^1 \rightarrow _{92}^{239}U \; ; \; _{92}^{238}U + 0\ n^1 \rightarrow _{92}^{239}U \]
Which when bombarded with neutrons undergo fission to emit three neutrons per plutonium nucleus. Such material like $U\text{-}238$ which themselves are non-fissible but can be converted into fissible material ($Pu\text{-}239$) are known as **fertile materials**.

**Release of tremendous amount of energy** : The importance of nuclear fission lies in the release of tremendous amount of energy during this process. During the $U\text{ }^{235}$ fission nearly 0.215 mass unit per uranium nucleus is found to be converted into energy.

$$U_{235.124}^{\text{235}} + _{1.009}^0n\rightarrow Xe_{138.955}^{139} + Sr_{94.945}^{95} + 2_{2.009}^0n + E$$

The released energy is due to difference in the total sum of masses of the reactants and products, in according to the Einstein's mass energy relation *i.e.* $E = mc^2$.

Alternatively, $\Delta m = 236.133 - 235.918 = 0.215$ amu

$\therefore 1$ amu $= 931$ MeV

$0.215$ amu $= 931 \times 0.215$ MeV $= 198$ MeV $= 198 \times 2.3 \times 10^7$ kcal

$\therefore$ Energy released by the fission of 1 g of

$$U_{235}^{235} = \frac{198 \times 2.3 \times 10^7}{235} = 1.9 \times 10^7$$ kcal

Recall that the combustion of 1 g of carbon releases only $94.0/12 = 7.83$ kcal of energy while the fission of 1 g of $U\text{ }^{235}$ releases $1.9 \times 10^7$ kcal. Hence nuclear fission releases several million times higher energy than the ordinary chemical combustion.
**Release of neutrons**: During $^{235}\text{U}$ fission it is obvious that 2-3 neutrons per uranium molecule are emitted. Some neutrons are ejected within an extremely short interval and are called *prompt neutrons*; fission products for an appreciable time fraction of a second to several seconds emit the rest after the fission. These are called *delayed neutrons*.

Note: $\Box$ Each fission yields 3 neutrons each of which can cause further fission to give 3 neutrons goes on increasing in geometric progression 1, 3, 9, 27, 81, 243,.... and many geometric progression take place in a very small fraction of a second.

**Chain reaction**: With a small lump of $^{235}\text{U}$, most of the neutrons emitted during fission escape but if the amount of $^{235}\text{U}$ exceeds a few kilograms (*critical mass*), neutrons emitted during fission are absorbed by adjacent nuclei causing further fission and so producing more neutrons. Now since each fission releases a considerable amount of energy, vast quantities of energy will be released during the chain reaction caused by $^{235}\text{U}$ fission.

**Atomic bomb**: An atomic bomb is based upon the process of that nuclear fission in which no secondary neutron escapes the lump of a fissile material for which the size of the fissile material should not be less than a minimum size called the critical size. There is accordingly a sudden release of a tremendous amount of energy, which represents an explosive
force much greater than that of the most powerful TNT bomb. In the world war II in 1945 two atom bombs were used against the Japanese cities of Hiroshima and Nagasaki, the former contained $U$-235 and the latter contained $Pu$-239.

**Atomic pile or Nuclear reactor :** *It is a device to obtain the nuclear energy in a controlled way to be used for peaceful purposes.* The most common reactor consists of a large assembly of graphite (an allotropic form of carbon) blocks having rods of uranium metal (fuel). Many of the neutrons formed by the fission of nuclei of $^{235}U$ escape into the graphite, where they are very much slow down (from a speed of about 6000 or more miles/sec to a mile/sec) and now when these low speed neutrons come back into the uranium metal they are more likely to cause additional fissions. Such a substance likes graphite, which slow down the neutrons without absorbing them is known as a **moderator**. Heavy water, $D_2O$ is another important moderator where the nuclear reactor consists of rods of uranium metal suspended in a big tank of heavy water (swimming pool type reactor). Cadmium or boron are used as control rods for absorbing excess neutrons.

**Plutonium from a nuclear reactor :** For such purposes the fissile material used in nuclear reactors is the natural uranium which consists mainly (99.3%) of $U$-238. In a nuclear reactor some of the neutrons produced in $U$-235 (present in natural uranium) fission converts $U$-238 to a long-lived plutonium isotope, $Pu$-239 (another fissionable material). Plutonium is an important nuclear fuel. Such reactors in which neutrons produced from fission are partly used to carry out further fission and
partly used to produce some other fissionable material are called **Breeder reactors**.

**Production of radioactive isotopes by bombarding with neutrons from a nuclear reactor** : These radioactive isotopes are used in medicine, industry and hospitals.

**Nuclear reactors in India** : India is equipped with the five nuclear reactors, namely Apsara (1952), Cirus (1960), Zerlina (1961), Purnima (1972) and *R*-5. Purnima uses plutonium fuel while the others utilize uranium as fuel.

Apsara the first nuclear reactor was completed on 14th August 1952 at Trombay under the guidance of the late Dr. H.J. Bhabha. It is the swimming pool reactor, which consists of a lattice of enriched uranium (fuel) immersed in a large pool of water. Water acts as a moderator, coolant and shield. This reactor is simple, safe, flexible, easily accessible and cheap.

(2) **Nuclear fusion** : "Oposite to nuclear fission, nuclear fusion is defined as a process in which lighter nuclei fuse together to form a heavier nuclei. However, such processes can take place at reasonable rates only at very high temperatures of the order of several million degrees, which exist only in the interior of stars. Such processes are, therefore, called **Thermonuclear reactions** (temperature dependent reactions). Once a fusion reaction initiates, the energy released in the process is sufficient to maintain the temperature and to keep the process going on.

\[
\begin{array}{c}
\text{Hydrogen} & \text{Helium} & \text{Positron} \\
\text{4}_1^1\text{H}^1 & \text{2}_2^4\text{He}^4 & 2\text{1}_1^1\text{e}^0 \\
\end{array}
\]
This is not a simple reaction but involves a set of the thermonuclear reactions, which take place in stars including sun. In other words, *energy of sun is derived due to nuclear fission.*

**Calculation of energy released in nuclear fusion**: Let us write the reaction involving the fusion of four hydrogen nuclei to form helium nucleus.

\[
\begin{array}{c}
4_1 H^1 \\
\text{Mass: } 4 \times 1.008144 \\
\text{or } = 4.003576
\end{array}
\quad \rightarrow \quad
\begin{array}{c}
2_{4} He^4 \\
\text{Mass: } 4 \times 0.003873 \\
4.004989
\end{array}
\quad + 
\begin{array}{c}
2_{+1} e^0 \\
\text{Mass: } 2 \times 0.000558 = 0.001116
\end{array}
\]

\[\implies \text{Loss is mass, } \Delta m = 4.032576 - 4.004989 = 0.027587 \text{ amu}\]

\[\therefore \text{Energy released } = 0.027587 \times 931 \text{ MeV} = 26.7 \text{ MeV}\]

\[\therefore \text{Energy released/gm of hydrogen consumed}\]

\[\frac{26.7}{4} = 6.7 \text{ MeV} = 6.7 \times 2.3 \times 10^7 \text{ kcal} = 1.54 \times 10^8 \text{ kcal}\]

**Controlled nuclear fusion**: Unlike the fission process, the fusion process could not be controlled. Since there are estimated to be some \(10^{17}\) pounds of deuterium (\(_1^2 H\)) in the water of the earth, and since each pound is equivalent in energy to 2500 tonnes of coal, a controlled fusion reactor would provide a virtually inexhaustible supply of energy.

**Comparison of nuclear fission and nuclear fusion**: Now let us compare the efficiency of the energy conversion of the two processes, *i.e.* nuclear fission and nuclear fusion.

Nuclear fission reaction,

\[^{\text{92}}_\text{U}^{235} + ^{\text{0}}_\text{n} \rightarrow ^{\text{56}}_\text{Ba}^{141} + ^{\text{36}}_\text{Kr}^{92} + 2 - 3 \times ^{\text{0}}_\text{n} + 200 \text{ MeV}\]
If one atom of uranium is fissioned by one neutron, the percent efficiency in terms of mass converted into energy (where 1 mass unit = 931 MeV) will be:

$$\frac{200 \text{ MeV}}{(235+1) \text{ mass units} \times 931} \times 100 = 0.09\%$$

Nuclear fusion reaction, $$^1\text{H}_2 + ^1\text{H}_3 \rightarrow ^2\text{He}_4 + ^0\text{n}_1 + 17.8 \text{ MeV}$$

The percent efficiency of the reaction = $$\frac{17.8 \text{ MeV}}{(2+3 \text{ mass units}) \times 931} \times 100 = 0.35\%$$

Thus it indicates that for these two fission and fusion reactions the percent efficiency is approximately four times greater for the fusion reaction.

**Hydrogen bomb**: Hydrogen bomb is based on the fusion of hydrogen nuclei into heavier ones by the thermonuclear reactions with release of enormous energy.

As mentioned earlier the above nuclear reactions can take place only at very high temperatures. Therefore, it is necessary to have an external source of energy to provide the required high temperature. For this purpose, the atom bomb, (i.e., fission bomb) is used as a primer, which by exploding provides the high temperature necessary for successful working of hydrogen bomb (i.e., fusion bomb). In the preparation of a hydrogen bomb, a suitable quantity of deuterium or tritium or a mixture of both is enclosed in a space surrounding an ordinary atomic bomb. The first hydrogen bomb was exploded in November 1952 in Marshall Islands; in 1953 Russia exploded a powerful hydrogen bomb having power of 1 million tonnes of TNT

*A hydrogen bomb is far more powerful than an atom bomb*. Thus if it were possible to have sufficiently high temperatures required for nuclear
fusion, the deuterium present in sea (as D₂O) sufficient to provide all energy requirements of the world for millions of years.

Note: The first nuclear reactor was assembled by Fermi in 1942.

**Difference between Nuclear fission and fusion**

<table>
<thead>
<tr>
<th>Nuclear fission</th>
<th>Nuclear fusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>The process occurs only in the nuclei of heavy elements.</td>
<td>The process occurs only in the nuclei of light elements.</td>
</tr>
<tr>
<td>The process involves the fission of the heavy nucleus to the lighter nuclei of comparable masses.</td>
<td>The process involves the fission of the lighter nuclei to heavy nucleus.</td>
</tr>
<tr>
<td>The process can take place at ordinary temperature.</td>
<td>The process takes place at higher temperature 10⁸ °C.</td>
</tr>
<tr>
<td>The energy liberated during this process is high (200 MeV per fission)</td>
<td>The energy liberated during the process is comparatively low (3 to 24 MeV per fusion)</td>
</tr>
<tr>
<td>Percentage efficiency of the energy conversion is comparatively less.</td>
<td>Percentage efficiency of the energy conversion is high (four times to that of the fission process).</td>
</tr>
<tr>
<td>The process can be controlled for useful purposes.</td>
<td>The process cannot be controlled.</td>
</tr>
</tbody>
</table>
Isotopes, Isobars, Isotones, Isodiaphers, Isoelectronic species, Isosters and Nuclear isomers.

(1) **Isotopes**: Atoms of a given element which have same atomic number (*nuclear charge*) but different mass number are called isotopes. In other words, isotopes are the atoms of the same element differing in mass number. Thus isotopes have same number of protons and electrons but different number of neutrons. They have same position in the periodic table, same chemical properties and same atomic charge. The term was first coined by Soddy. However, Aston using mass spectrometer first separated isotopes (Ne^{20} and Ne^{22}).

**Examples:**

(i) \( _1^1 \text{H}^1 \), \( _1^2 \text{H}^2 \), \( _1^3 \text{H}^3 \)  
Hydrogen (Protium), Deuterium, Tritium

(ii) \( _6^{12} \text{C} \), \( _6^{13} \text{C} \) and \( _6^{14} \text{C} \)  

(iii) \( _8^{16} \text{O} \), \( _8^{17} \text{O} \), \( _8^{18} \text{O} \)  

(iv) \( _{17}^{35} \text{Cl} \) and \( _{17}^{37} \text{Cl} \)

Of all the elements, tin has maximum number of stable isotopes (ten).

The fractional atomic weight (35.5) of chlorine is due to the fact that in the ordinary chlorine atom, Cl^{35} and Cl^{37} are present in the ratio of 3 : 1.

\[
\text{Average atomic weight of Cl} = \frac{3 \times 35 + 1 \times 37}{4} = 35.5 \text{ amu}
\]
The percentage of a given isotope in the naturally occurring sample of an element is called **Isotopic abundance**. As the isotopic abundance of an element is constant irrespective of its source, atomic weight of an element is constant.

(2) **Isobars**: *Isobars are the atoms of different elements with the same mass number but different atomic numbers*. In other words, isobars have different number of protons, neutrons and electrons but the sum of protons and neutrons (i.e., number of nucleons) is same.

**Examples**: (i) \( ^{18}\text{Ar}^{40}, ^{19}\text{K}^{40} \text{ and } ^{20}\text{Ca}^{40} \) (ii) \( ^{52}\text{Te}^{130}, ^{54}\text{Xe}^{130} \text{ and } ^{56}\text{Ba}^{130} \).

Since isobars are the atoms of different elements, they will have different physical and chemical properties.

(3) **Isotones**: *Isotones are the atoms of different elements with the same number of neutrons but different mass numbers*, e.g. \( ^{14}\text{Si}^{30}, ^{15}\text{P}^{31} \text{ and } ^{16}\text{S}^{32} \). Since the variable factor in isotones is the number of protons (atomic number), they must have different physical and chemical properties.

**Examples**: (i) \( ^{14}\text{Si}^{30}, ^{14}\text{P}^{31} \text{ and } ^{16}\text{S}^{32} \) (ii) \( ^{19}\text{K}^{39} \text{ and } ^{20}\text{Ca}^{40} \)

(iii) \( ^{1}\text{H}^{3} \text{ and } ^{2}\text{He}^{4} \) (iv) \( ^{6}\text{C}^{13} \text{ and } ^{7}\text{N}^{14} \)

(4) **Isodiaphers**: *Atoms having same isotopic number* are called isodiaphers.

Mathematically, isotopic number (isotopic excess) = \((N − Z)\) or \((A − 2Z)\)

Where, \(N = \) Number of neutrons; \(Z = \) Number of protons
Examples: (i) $^{235}_{92}U$ and $^{231}_{90}Th$  
(ii) $^{39}_{19}K$ and $^{19}_{9}F$  
(iii) $^{65}_{29}Cu$ and $^{55}_{24}Cr$

(5) **Isoelectronic species**: Species (atoms, molecules or ions) having same number of electrons are called *isoelectronic*.

Examples: 
(i) $N^3-, O^2-, F-, Ne, Na^+, Mg^{2+}, Al^{3+}, CH_4, NH_3, H_2O$ and $HF$ have 10 electrons each.
(ii) $P^3-, S^{2-}, Cl-, Ar, K^+$ and $Ca^{2+}$ have 18 electrons each.
(iii) $H-, He, Li^+ and Be^{2+}$ have 2 electrons each.
(iv) $CO, CN^-$ and $N_2$ have 14 electrons each.
(v) $N_2O, CO_2$ and $CNO^-$ have 22 electrons each.

(6) **Isosters**: *Molecules having same number of atoms and also same number of electrons are called isosters.*

Examples: 
(i) $N_2$ and $CO$
(ii) $CO_2$ and $N_2O$
(iii) $HCl$ and $F$
(iv) $CaO$ nad $MgS$
(v) $C_6H_6$ (benzene) and inorganic benzene $B_6N_6$.

(7) **Nuclear isomers**: *Nuclear isomers (isomeric nuclei) are the atoms with the same atomic number and same mass number but with different radioactive properties*. They have same number of electrons, protons and neutrons. An example of nuclear isomers is uranium-$X$ (half-life 1.4 min)
and uranium-Z (half-life 6.7 hours). **Otto Hahn** discovered nuclear isomers.

The reason for nuclear isomerism is the different energy states of the two isomeric nuclei. One may be in the ground state whereas the other should be in an excited state. The nucleus in the excited state will evidently have a different half-life.

Now-a-days as much as more than 70 pairs of nuclear isomers have been found. Few examples areas follows

(i) \( ^{69} \text{Zn} \) \((T_{1/2}=13.8 \text{ hour})\) and \( ^{69} \text{Zn} \) \((T_{1/2}=57 \text{ min})\)

(ii) \( ^{80} \text{Br} \) \((T_{1/2}=4.4 \text{ hour})\) and \( ^{80} \text{Br} \) \((T_{1/2}=18 \text{ min})\)

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**Examples based on Isotopes**

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**Example 1:** Naturally occurring boron consists of two isotopes whose atomic weights are 10.01 and 11.01. The atomic weight of natural boron is 10.81. Calculate the percentage of each isotope in natural boron

(a) 80  
(b) 90  
(c) 70  
(d) 20

**Solution:** (a) Let the % of isotope with at. wt. 10.01 = \( x \)

\[ \therefore \% \text{ of isotope with at. wt. 11.01} = (100 - x) \]

Now since, At. wt. = \( \frac{x \times 10.01 + (100 - x) \times 11.01}{100} \)
\[
10.81 = \frac{x \times 10.01 + (100 - x) \times 11.01}{100} \quad x = 20
\]

Hence, % of isotope with at. wt. 10.01 = 20

\[\therefore \% \text{ of isotope with at. wt. 11.01} = 100 - 20 = 80\]

**Application of radioactivity and Hazards of radiations**

Radioisotopes find numerous applications in a variety of areas such as medicine, agriculture, biology, chemistry, archeology, engineering and industry. Some of the are given below:

1. **Age determination (carbon dating)**: Radioactive decay follows a very exact law, and is virtually unaffected by heat, pressure, or the state of chemical combination of the decaying nuclei, it can be used as a very precise clock for dating past events. For instance, the age of earth has been determined by uranium dating technique as follows. Samples of uranium ores are found to contain \( \text{Pb}^{206} \) as a result of long series of \( \alpha \)- and \( \beta \)-decays. Now if it is assumed that the ore sample contained no lead at the moment of its formation, and if none of the lead formed from \( U^{238} \) decay has been lost then the measurement of the \( \text{Pb}^{206} / U^{238} \) ratio will give the value of time \( t \) of the mineral.

\[
\frac{\text{No. of atoms of Pb}^{206}}{\text{No. of atoms of U}^{238} \text{ left}} = e^{-\lambda t - 1},
\]

where \( \lambda \) is the decay constant of uranium-238

Alternatively,

\[
t = \frac{2.303}{\lambda} \log \left( \frac{\text{Initial amount of U}^{238}}{\text{Amount of U}^{238} \text{ in the mineral present till date}} \right)
\]
Similarly, the less abundant isotope of uranium, $^{235}\text{U}$, eventually decays to $^{207}\text{Pb}$; $^{232}\text{Th}$ decays to $^{208}\text{Pb}$ and thus the ratios of $^{207}/^{235}\text{U}$ and $^{208}/^{232}\text{Th}$ can be used to determine the age of rocks and minerals. Many ages have been determined this way to give results from hundreds to thousands of million of years.

Besides the above long-lived radioactive substances viz. $^{238}\text{U}$, $^{235}\text{U}$ and $^{232}\text{Th}$ (which have been present on earth since the elements were formed), several short-lived radioactive species have been used to determine the age of wood or animal fossils. One of the most interesting substances is $^{14}\text{C}$ (half-life 5760 years) which was used by Willard Libby (Nobel lauret) in determining the age of carbon-bearing materials (e.g. wood, animal fossils, etc.) Carbon-14 is produced by the bombardment of nitrogen atoms present in the upper atmosphere with neutrons (from cosmic rays).

$$^{14}\text{N} + n \rightarrow ^{14}\text{C} + ^1\text{H}$$

Thus carbon-14 is oxidised to $\text{CO}_2$ and eventually ingested by plants and animals. The death of plants or animals puts an end to the intake of $^{14}\text{C}$ from the atmosphere. After this the amount of $^{14}\text{C}$ in the dead tissues starts decreasing due to its disintegration.

$$^{14}\text{C} \rightarrow ^{14}\text{N} + e^0$$

It has been observed that on an average, one gram of radioactive carbon emits about 12 $\beta$-particles per minute. Thus by knowing either the amount of $^{14}\text{C}$ or the number of $\beta$-particles emitted per minute per gram of carbon at the initial and final (present) stages, the age of carbon material can be determined by using the following formulae.
where \( t \) = Age of the fossil, \( \lambda \) = Decay constant, \( N_0 \) = Initial radioactivity (in the fresh wood), \( N_t \) = Radioactivity in the fossil

The above formula can be modified as

\[
t = \frac{2.303}{\lambda} \log \frac{\text{Initial ratio of } {^{14}}C/^{12}C \text{ (in fresh wood)}}{\text{C}^{13}/C^{12} \text{ ratio in the old wood}}
\]

\[
= \frac{2.303}{\lambda} \log \frac{\text{Initial amount of } {^{14}}C/^{12}C \text{ (in fresh wood)}}{\text{Amount of } {^{14}}C \text{ in the old wood}}
\]

\[
= \frac{2.303}{\lambda} \log \frac{\text{Radioactivity in fresh wood due to } {^{14}}C}{\text{Radioactivity in old wood due to } {^{14}}C}
\]

\[
= \frac{2.303 \times T_{1/2} \text{ of } {^{14}}C}{0.693} \log \frac{\text{counts min}^{-1} \text{ g}^{-1} \text{ of } {^{14}}C \text{ in fresh wood}}{\text{counts min}^{-1} \text{ g}^{-1} \text{ of } {^{14}}C \text{ in old wood}}
\]

Similarly, tritium \(^1H^3\) has been used for dating purposes.

(2) **Radioactive tracers (use of radio–isotopes)**: A radioactive isotope can be easily identified by its radioactivity. Because of similar physical and chemical properties of radioisotopes and non-radioisotopes of an element, if a small quantity of the former is mixed with normal isotope, then chemical reactions can be studied by determining the radioactivity of the radioisotope. The radioactivity can, therefore act as a tag or label that allows studying the behaviour of the element or compounding which contains this isotope. An isotope added for this purpose is known as isotopic tracer. The radioactive tracer is also known as an isotopic tracer. The radioactive tracer is also known as an indicator because it indicates the reaction. Radioisotopes of moderate half-life periods are used for tracer work. The activity of radioisotopes can be
detected by means of electroscope, the electrometer or the Geiger-Muller counter. Tracers have been used in the following fields:

(i) **In medicine**: Radioisotopes are used to diagnose many diseases. For example, Arsenic – 74 tracer is used to detect the presence of tumours, Sodium –24 tracer is used to detect the presence of blood clots and Iodine –131 tracer is used to study the activity of the thyroid gland. It should be noted that the radioactive isotopes used in medicine have very short half-life periods.

(ii) **In agriculture**: The use of radioactive phosphorus $^{32}\text{P}$ in fertilizers has revealed how phosphorus is absorbed by plants. This study has led to an improvement in the preparation of fertilizers. $^{14}\text{C}$ is used to study the kinetics of photo synthesis.

(iii) **In industry**: Radioisotopes are used in industry to detect the leakage in underground oil pipelines, gas pipelines and water pipes. Radioactive isotopes are used to measure the thickness of materials, to test the wear and tear inside a car engine and the effectiveness of various lubricants. Radioactive carbon has been used as a tracer in studying mechanisms involved in many reactions of industrial importance such as alkylation, polymerization, catalytic synthesis etc.

(iv) **Analytical Studies**: Several analytical procedures can be used employing radioisotopes as tracers.

(a) **Adsorption and occlusion studies**: A small amount of radioactive isotope is mixed with the inactive substance and the activity is studied before and after adsorption. Fall in activity gives the amount of substance adsorbed.
(b) **Solubility of sparingly soluble salt** : The solubility of lead sulphate in water may be estimated by mixing a known amount of radioactive lead with ordinary lead. This is dissolved in nitric acid and precipitate as lead sulphate by adding sulphuric acid. Insoluble lead sulphate is filtered and the activity of the water is measured. From this, the amount of $\text{PbSO}_4$ still present in water can be estimated.

(c) **Ion-exchange technique** : Ion exchange process of separation is readily followed by measuring activity of successive fractions eluted from the column.

(d) **Reaction mechanism** : By labelling oxygen of the water, mechanism of ester hydrolysis has been studied.

\[
\begin{align*}
\text{R} \ - \ 
\begin{array}{c}
\text{C} \\
\text{OR}
\end{array}
\rightleftharpoons \text{O} \\
\text{O}
\end{align*}
\]

\[
\text{R} \ + \text{HOH} \rightarrow \text{R} \ - \ 
\begin{array}{c}
\text{C} \\
\text{OH}
\end{array}
\rightleftharpoons \text{O} \\
\text{R'}\text{OH}
\]

(e) **Study of efficiency of analytical separations** : The efficiency of analytical procedures may be measured by adding a known amount of radio-isotopes to the sample before analysis begins. After the completion, the activity is again determined. The comparison of activity tells about the efficiency of separation.

(3) **Use of $\gamma$-rays** : $\gamma$-rays are used for disinfecting food grains and for preserving food stuffs. Onions, potatoes, fruits and fish etc., when irradiated with $\gamma$-rays, can be preserved for long periods. High yielding disease resistant varieties of wheat, rice, groundnut, jute etc., can be developed by the application of nuclear radiations. The $\gamma$-rays radiations are used in the treatment of cancer. The $\gamma$- radiations emitted by cobalt –
60 can burn cancerous cells. The $\gamma$-radiations are used to sterilize medical instruments like syringes, blood transfusion sets, etc. These radiations make the rubber and plastics objects heat resistant.

**Hazards of radiations** : The increased pace of synthesis and use of radioisotopes has led to increased concern about the effect of radiations on matter, particularly in biological systems. Although the radioisotopes have found widespread uses to mankind such as atomic power generation, dating, tracer technique, medicinal treatment, the use of nuclear energy is an extremely controversial social and political issue. You should ask yourself, how you would feel about having a nuclear power plant in your town. The accident of Chernobyl occurred in 1986 in USSR is no older when radioisotopes caused a hazard there. The nuclear radiations (alpha, beta, gamma as well as X-rays) possess energies far in excess of ordinary bond energies and ionisation energies. Consequently, these radiations are able to break up and ionise the molecules present in living organisms if they are exposed to such radiations. This disrupts the normal functions of living organisms. The damage caused by the radiations, however, depends upon the radiations received. We, therefore, conclude this chapter by examining the health hazards associated with radioisotopes.

The resultant radiation damage to living system can be classified as :

(i) **Somatic or pathological damage** : This affects the organism during its own life time. It is a permanent damage to living civilization produced in body. Larger dose of radiations cause immediate death whereas smaller doses can cause the development of many diseases such
as paralysis, cancer, leukaemia, burns, fatigue, nausea, diarrhoea, gastrointestinal problems etc. Some of these diseases are fatal.

Many scientists presently believe that the effect of radiations is proportional to exposure, even down to low exposures. This means that any amount of radiation causes some finite risk to living civilization.

(ii) **Genetic damage**: As the term implies, radiations may develop genetic effect. This type of damage is developed when radiations affect genes and chromosomes, the body's reproductive material. Genetic effects are more difficult to study than somatic ones because they may not become apparent for several generations.