The determination of the age of a sample of wood consists of determining the ratio of the amount of $^{14}_{6}C$ to that of $^{12}_{6}C$ in both the piece of wood, i.e., in fresh (living) piece and dead (cut) piece. As long as the plant is alive, the ratio of $^{14}_{6}C$ to $^{12}_{6}C$ atoms in the wood of the plant is the same as in atmosphere, but when the tree is cut, the ratio of $^{14}_{6}C$ to $^{12}_{6}C$ begins to decrease continuously due to continuous decrease in the amount of $^{14}_{6}C$ in the plant. This decrease in the amount of $^{14}_{6}C$ is due to continuous disintegration emitting β-radiation. From this the age of the wood can be determined.

8.16 Radioactive Dating

Because the half-life of any particular nuclide is constant, the half-life can serve as a molecular clock to determine the ages of different objects. Dating wood and similar carbon containing objects can be done with radioactive carbon, carbon –14, which has a half-life of 5730 years.

In the upper atmosphere neutrons from cosmic radiation bombard nitrogen 14 nuclei to form carbon:

$$^{14}_{7}N + ^{1}_{0}n \longrightarrow ^{14}_{6}C + ^{1}_{1}H$$

The carbon nucleus is unstable and decays to form $^{14}_{7}N$ through beta emission:

$$^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}e \qquad t_{1/2} = 5730 \text{ years}$$

It is generally assumed that the ratio of carbon 14 to carbon 12 has been constant for many thousands of years and that the $^{14}_{6}C$ gets oxidized to CO_2, absorbed by plants, which are then eaten by animals, which excrete the carbon 14 etc, so that the ratio of the two isotopes remains constant during the lifetime of the plant or animal. But after death, the carbon14 continues decaying in the organism and is not replaced, so that the $^{14}_{6}C/\,^{12}_{6}C$ ratio begins to drop. From the observed ratio in an ancient piece of wood, bone, etc., the age of the object can be determined.

Other isotopes can be similarly used to date other types of objects. For example, it takes 4.5×10^9 years for half of a sample of uranium –238 to decay to lead –206. The age of rocks containing uranium can therefore be determined by measuring the ratio of lead –206 to uranium –238. If the lead –206 had somehow become incorporated into the rock by normal chemical processes instead of by radioactive decay, the rock would also contain large amounts of the more abundant isotope lead –208. In the absence of large amounts of this "geonormal" isotope of lead, it is assumed that all of the lead –206 was at one time uranium –238.

Example 8.2: A rock contains 0.257 mg of lead –206 for every milligram of uranium –238. The half-life for the decay of uranium –238 to lead –206 is 4.5×10^9 years. How old is the rock?

Solutions: Let assume that the rock contains 1.000 mg of uranium –238 at present. The amount of uranium –238 in the rock when it was first formed therefore equals 1.000 mg plus the quantity that decay to lead –206. We obtain the latter quantity by multiplying the present mass of lead –206 by the ratio of the atomic mass of uranium to that of lead, into which it has decayed. The total original $^{238}_{92}U$ was thus:

$$\text{Original } ^{238}_{92}U = 1.000 \text{ mg} + \frac{238}{206}(0.257 \text{ mg}) = 1.297 \text{ mg}$$

$$k = \frac{0.693}{4.5\times10^{9}\ \text{year}} = 1.5\times10^{-10}\ \text{per year}$$

$$t = \frac{2.303}{k}\log\frac{N_t}{N_o} = \frac{2.303}{1.5\times10^{-10}\,y^{-1}}\log\frac{1.000}{1.297} = 1.7\times10^{9}\ \text{years}$$

Example 8.3: A bone taken from a garbage pile buried under a hill-side had $^{14}C/^{12}C$ ratio 0.477 time the ratio in a living plant or animal. The half-time of 14C, is 5730 years. What was the date when the animal was buried?

Solutions: From the half-life, we can calculate *k*.

$$k = \frac{0.693}{t_{1/2}} = \frac{0.693}{5730\ \text{years}} = 1.21\times10^{-4}\ \text{years}$$

$$t = \log\frac{^{14}C_o}{^{14}C_t}\times\frac{2.303}{k} = \log\frac{1.0}{0.477}\times\frac{2.303}{1.21\times10^{-4}\ \text{years}}$$

$$= \frac{0.3215\times2.303}{1.21\times10^{-4}\ \text{years}} = 6.1\times10^{4}\ \text{years} = 6100\ \text{years}$$

8.17 Important Applications of Radioactivity.

1. Atomic structure revealed. The experiment of scattering of *α* particles by Rutherford was reformed by radioactive material. The experiment led to the concept of *nucleus*. The artificial disintegration of atoms increased our knowledge about the nature of nucleus i.e., presence of protons and neutrons in it. Moreover, many fundamental particles like positron, mesons etc have been discovered as a result of radioactivity.

2. New source of energy. Nuclear fusion has opened a new source of atomic energy at our disposal. The controlled fission chain reactions can be used to run various industries. Research is going on to achieve controlled fusion reaction which will give even more amount of energy.

3. Discovery of new elements and new isotopes. The discovery of transuranic elements has been achieved by artificial radioactivity. Moreover, radioactive isotopes of other stable element have been discovered by the artificial transmutation of elements.

4. Sterilization. Antibiotics are sterilized by radiation from radioactive substances. Preservation sterilization of food is also done for its preservation.

5. Radiotherapy. Radiation from ^{60}Co sources have been used in the treatment of cancer. Sometimes Y-radiations from ^{198}Au are also used.

6. Preparation of luminiscents paints. If a radioactive substance like radio thorium, is mixed with fluorescent is treated with ZnS, it exhibits luminiscence, so that it becomes visible in the dark. Such mixtures constitute luminiscence paints. These are used to make the pointers and dials of watches visible during night.

7. Determination of Avogadro number. The γ-rays from radioactive material have been used to determine Avogadro number and the value has been found out to 6.022×10^{23} from this method.

8. Radioactive dating. The process of radioactivity is used in determining the age of material. The age of earth can be estimated by this method. The age of the earth calculated by this method comes out to be 2–3 billion years.

9. Measurements of the level of liquids. The level of liquids can be measured by radioactive source. A radioactive source is placed on the surface of a liquid in a closed container. The detector outside the vessel will detect the lever of the radioactive source, which will be the level of liquid inside the container. This technique is used to know the level of oil in refineries.

10. Preparation of nuclear batteries. Radioactive energy is converted into electrical energy in these batteries. Two electrodes are used in an evacuated chamber. One of the electrodes is cathode with β – emitter. The flow of β – particle inside the chamber, result in the passage of current in the external circuit connected with those electrodes.

11. Tracer applications. In these applications, the radioactive isotope is used as a label to study the behaviour of some material . These are the most important application of radioactive isotopes in various branches of applied sources.

12. Mutation induced by radiations. If the plants and seeds are irradiated by radioactive source, the rate of mutation is greatly increased and development of stains is achieved in a fraction of time taken otherwise.

13. Measurement of thickness of material. A source of β – or γ – rays is placed on one side of the material whose thickness is to be measured and the detector on the other side. The force experienced by the radiation is a function of the thickness through which it is passed. Hence from the measurement of force the thickness of the absorbing material can be obtained.

8.18 Biological Effects of Nuclear Radiation

We are continually bombarded by nuclear radiation from both natural and artificial sources. For example, we are exposed to infrared, ultraviolet and visible radiation from the sun, radio waves from radio and television stations, microwaves from microwave ovens and X-rays from various medical producers. In addition, we are also exposed to radioactivity from the soil and other natural materials. The different energies of these various kinds of radiation are important in understanding their different effect on matter.

When matter absorbs radiation, the energy of radiation can cause either excitation or ionization of the matter. Excitation occurs when the absorbed radiation excites electrons to higher energy states or increases the motion of molecules, causing them to move, vibrate or rotate, Ionization occurs when the radiation removes an electron from an atom or molecule. In general, radiation causes ionization, called **ionizing radiation,** is far more harmful to biological systems than radiation that does not cause ionization, called **nonionizing radiation.**

The effect of radiation on living systems is highly dependent on the frequency of radiation. Because the energy of photons increases with increasing frequency, most health-related issues concerning radiation have focused on the high-frequency (short wavelength) of the electromagnetic spectrum. Electromagnetic radiation with frequency greater than 10^{16} HZ (and therefore wavelength on the order of 10nm or smaller) is generally referred to as **ionizing radiation**. Ionizing radiation-which includes gamma rays, X-ray and high-energy ultraviolet light-can cause biological damage because it is energetic enough to eject electrons from atoms and to break chemical bonds, including those in genetic material such as DNA. Strong infrared and microwave radiation can also cause biological damage.

Most living tissue contains at least 70 percent water by mass. When living tissue is irradiated, most of the energy of the radiation is absorbed by water molecules. Thus, ionizing radiation is defined as radiation that can ionizing water, a process requiring a minimum energy of 1216 kJ/mol. Alpha, beta and gamma rays (as well as X rays an higher-energy ultraviolet radiation) possess energies in excess of 1216 kJ/mol and are therefore forms of ionizing radiation.

When ionizing radiation passes through living tissue, electrons are removed from water molecule, forming high reaction H_2O^+ ions. An H_2O^+ ion can react with another water molecule to form as H_3O^+ ion and a neutral OH molecule

$$H_2O^+ + H_2O \longrightarrow H_3O^+ + OH$$

The unstable and high reactive OH molecule is an example of **free radical,** a substance with one or more unpaired electron, $\cdot\underset{\cdot\cdot}{\ddot{O}}-H$. The presence of the unpaired electron is often written by writing the species, with a single dot, $\bullet OH$. In cells and tissues, such particles can attach a host of surrounding biomolecules to produce new free radical, which in turn, attack yet other compounds. Thus, the formation of a single free radical can initiate large number of chemical reactions that are ultimately able to disrupt the normal operations of cells.

The damage produced by radiation depends on the activity and energy of the radiation, the length of exposure, and whether the source is inside or outside the body. Outside the body, gamma rays are particularly harmful because they penetrate human tissue very effectively, just as X-rays do. Consequently, their damage is not limited to the skin. In contrast, most alpha rays are stopped by skin, and beta rays are able to penetrate only about 1cm beyond the surface of the skin. Hence, neither is as dangerous as gamma rays are, unless the radiation source somehow enters the body. Within the body, alpha rays are particularly dangerous because they transfer their energy quickly to the surrounding tissue, initiating considerable damage.

In general, the tissues that show the greatest damage from radiation are those that reproduce at a rapid rate, such as bone marrow, blood forming tissue, and lymph nodes. The principal effect of extended exposure to low doses of radiation is to induce cancer. Cancer is caused by damage to the growth-regulation mechanism of cells, including cells to reproduce in an uncontrolled manner. Leukemia, which is characterized by excessive growth of white blood cells, is probably the major cancer problem associated with radiation.

In light of the biological effects of radiation it is important to determine whether any levels of exposure are safe. Unfortunately, we are hampered in our attempts to set realistic standards by our lack of understanding of the effects of long-term exposure to radiation. Scientists concerned with setting health standards have used the hypothesis that the effects of radiation are proportional to exposure even down to low doses. Any amount of nuclear radiation is assumed to cause some finite risk of injury, and the effects of high dosage rates are extrapolated to those of lower ones. Other scientists however, believe that there is a threshold below which there are no radiation risk. Until scientific evidence enables us to settle the matter with some confidence , it is easier to assume that even low levels of radiation present some danger

8.19 Nuclear hazards and Safety measures

Nuclear weapons are harmful. In August 1945 the united states dropped atomic bombs on two Japanese cities; Hiroshima and Nagasaki, which ruined the cities.

The nuclear accident that occurred at the Chernobyl reactor, on April 26, 1986, renewed fears in some about the safety of nuclear reactors. It is important to understand the nature of the accident at Chernobyl. A nuclear reactor using normal fuel elements cannot become an atomic bomb. However, without proper design and safeguards, it is possible for a malfunction of a reactor to disperse dangerous radioactivity over a populated area. This is infact what occurred at Chernobyl. The cost of the Chernobyl accident was enormous. Many people died, and several hundred were hospitalized. Thousands of people had to be evacuated and resettled. The accident was the direct result of a faulty reactor coupled with a disregard of reactor safety procedures.

The radioactive noble gas radon is a potential risk to health. Radon -222 is a product of the nuclear disintegration series of uranium -238 and is continually generated as uranium in rocks and soil decays. Being a noble gas, radon is extremely unreactive and is therefore free to escape from the ground without chemically reacting along the way. It is readily inhaled and exhaled with no direct chemical effect. However, the half-life of radon -222 is short: 3.82 days. It decays through alpha-particle loss into a radioisotope of polonium.

$$^{222}_{80}\text{Rn} \longrightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\text{He}$$

Because radon has such a short half-life and alpha particles have a high RBE (relative biological effectiveness of the radiation, abbreviated RBE), inhaled radon is considered a probable cause of lung cancer. Even worse, however, is the fact that the decay product, polonium -218, is an alpha-emitting solid.

$$^{218}_{84}\text{Po} \longrightarrow {}^{214}_{82}\text{Pb} + {}^{4}_{2}\text{He}$$

The atoms of Po -218 can become trapped in the lungs, where they continually bathe the delicate tissue with harmful alpha radiation. The resulting damage is estimated to result as many as 10 percent of lung cancer deaths.

Radiation hazards arise from the exposure of the body by external and internal sources of radiations and its consequentional biological effects. The hazards are categorized a external and internal depending upon the source being external or internal to the body. Sources of penetrating radiations such as gamma ray emitters pose in general more external hazard that those emitting nonpentrating such as alpha emitter which exhibit more internal hazard.