Chapter. 20

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NUCLEAR RADIATIONS

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20.1. Interaction of Nuclear Radiations with matter.

In the previous chapter we have discussed natural radioactivity in which α and β particles and γ-rays are emitted from the disintegrating nucleus of an atom. In nuclear fission and fusion reactions neutrons and other particles together with certain radiations are emitted from the nucleus. Moreover, interaction of high energy particles (natural or artificial) with matter produce certain nuclear or atomic reactions with the emission of particles like protons, deuterons, neutrons and ionising radiations like γ-rays from the nucleus and x-rays and ultraviolet rays from the atom. These particles and radiations have been studied carefully for their properties and effects which are as follows:

(i) **Alpha Particle**

It shoots out from the nucleus with a high velocity (0.1×10^8 m/s). Thus it possesses very high energy (7.7 Mev for the most energetic from R_{ac} (i.e: Bismuth-214). Due to its large size, more charge and high energy it can make very large number of collisions with the atoms and ionise them as it passes through them, before it stops. Head-on collisions are rare, however, if an α-particle passes close to an atom, the strong electrostatic attraction between it and an electron tears the electron off from the atom and ionises it. An α-particle loses about 35 eV energy in each collision. Thus a 7.7 MeV α-particle from RaC (Bi 214) produces about 0.2×10^6 ions before it stops. The range of α-particle is small (about 7×10^{-2}m in air and only 4×10^{-5}m in aluminium for the 7.7 MeV α-particle). Thus metal sheets form good shields for α-particle: The number of ions produced by an α-particle or its range in air is a measure of its energy. Alpha particles produce fluorescence on striking certain substances such as zinc sulphide and bariumplatinocynide.

(ii) Protons

A proton is also a positively charged particle with properties similar to the α-particle. Its mass is one-fourth and charge is one half of that of an α-particle. It is smaller in size and carries less energy at the same velocity. Obviously, it suffers fewer collisions with the atoms of the medium as compared with the α-particle and penetrates the medium to a greater distance (about 5 to 10 times) before stopping. Its ionising power is also much less, about one-fifth that of the α-particle. The mechanism of ionisation is however identical.

(iii) Beta Particles.

A β-particle also ionises the atoms of the medium along its path but this ionisation is much less than that produced by an α-particle or a proton. The reason is that due to ts very small size the collisions are fewer and farther apart. Even in a single collisions most of its energy is lost. Head-on collisions being rare, it can ionise an atom by strong electrostatic repulsion when it passes close to its electron. The range of β-particle in a medium is very large, nearly 100 times that of an α-particle of the same energy. The ionisation produced by it is less than one-hundredth of that by the α-particle. Alpha particles are stopped by an ordinary paper, but the β-particles may pass through a thick book. However, a small thickness of a heavy metal rich in electrons is enough to stop the β-particles e.g. 5×10^{-3} m of aluminium. Fluorescence is also produced when β-particles strike calciumtungstate and barium platinocynide.

(iv) Gamma Rays

Gamma rays are very high energy electromagnetic radiations of extremely short wavelength emitted from the nuclei of radioactive atoms originating from the high energy transitions of the nucleons in the nuclei. They are accompanied with the emission of α- or β-particles. They carry no charge and have no rest mass but possess very high energy of the order of several MeV. They penetrate far greater distance in material media as compared to α-or β-particles. Very energetic γ-rays are capable of penetrating several centimeters of concrete.

Like ultraviolet rays and x-rays,γ-rays are also capable of ionising even far more strongly the atoms of the medium they pass through. Being a photon, a γ-ray can produce ionisation in three ways:

(i) It may lose all its energy in a single encounter with the electron of an atom (Photoelectric effect).

(ii) It may lose only a part of its energy in an encounter (Compton effect).

(iii) Very few of very high energy, γ-ray photons may impinge directly on heavy nuclei, be stopped and annihilated giving rise to electron-positron pairs (the materialization of energy).

Through a gas many of its photons may pass several meters without any encounter. A good many, however, do have encounters with the electrons of the atoms which are knocked off with the production of ions. This ionisation is much less strong than that produced by α- or β-particles. Since most of the photons are absorbed by electrons and substance rich in electrons, e.g. lead will stop most of the γ-ray photons and serve as a good shield against γ-rays.

(v) Neutrons

A neutron is essentially emitted from the nucleus of an atom. It is so called because it is electrically neutral and carries no charge. Its mass is very nearly equal to that of a proton. Consequently, unlike charged particles it can neither experience or exert any electrostatic force of attraction or repulsion. Therefore, it can interact with an electron or the nucleus of an atom only by direct impact. When it hits an electron, it knocks it out from the atom (ionisation) with practically no change in its own energy or direction of motion. However, when it hits a nucleus, appreciable changes in its energy and direction of motion are likely. Nevertheless, such direct collisions are very rare. Hence a neutron is a highly penetrating but very slightly ionising particle.

It is evident from the above discussion that nearly all the particles and radiations ionise the atoms in their path. This effect, therefore, is used as the basis for most of the detection devices, a few of which will now be discussed here.

20.2 Wilson Cloud Chamber

Wilson cloud chamber is a device for making visible the paths of ionising particles. It helps to examine the mechanism of ionisation of various ionising radiations and the products of their interaction with the material inside the chamber. This device was devised in 1895 by the British physicist, C.T.R. Wilson.

It consists of a closed cylindrical chamber with transparent glass top,T, and a movable piston,P, at the bottom (Fig.20.1). On the sides near the top, the cylinder is provided with a glass window, L, for admitting illuminating light and an inlet, I, for the ionising particles or

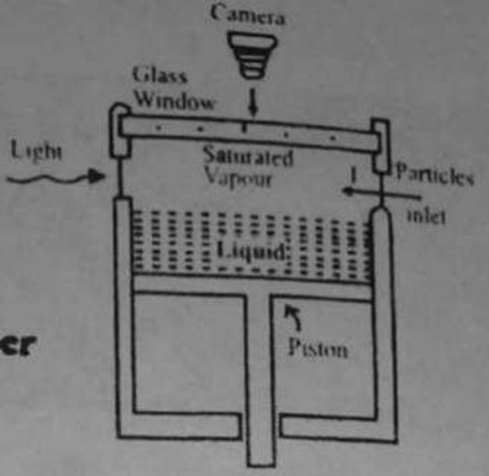


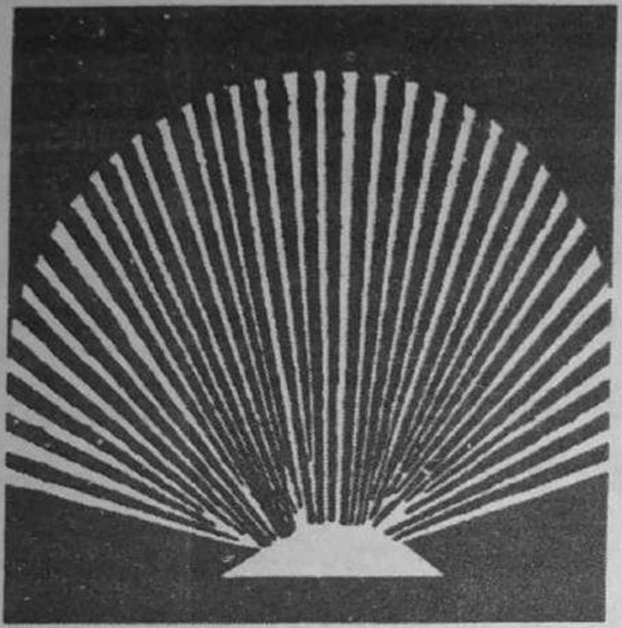
Fig.20.1. **Wilson Cloud Chamber**

radiations. The piston can be moved up or down by a lever attached to it (not shown in the figure).

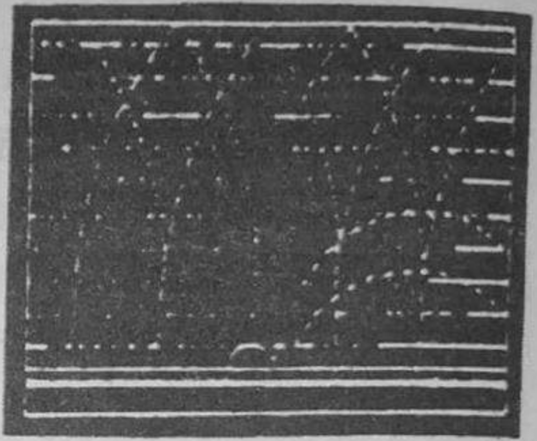
Before making the enclosed space above the piston airtight, enough quantity of a low boiling point liquid such as water or alcohol is introduced in the space to produce its saturated vapours. A small quantity of the liquid stay on the piston. The vapour of a liquid usually condense at its dew point but the condensation never takes place in the absence of some particles— dust particles or ions— which are essential to form the nuclei (centers) of condensation. In particle-free space the saturated vapour may cool much below the dew point. Then they are called super saturated vapour. Under this condition if some ions are incidentally produced amidst these vapours,condensation immediately takes place a round them forming tiny droplets of fog which shows itself when illuminated. This explains the underlying principle of the cloud chamber.

To investigate any ionising particle or radiation, the particle source is mounted in the chamber at the inlet. or the radiation may be admitted through the inlet window. An intense beam of light is projected into the chamber through the window,L. to illuminate the fog track, and a photographic camera is mounted above the glass top of the chamber.

(a) (b) (c)



(d)



(e)

With the above pre-setting of the apparatus, the piston is pulled down suddenly with the help of the lever. The saturated vapours cool down below the dew point into supersaturated vapours. If an ionising particle or radiation passes into the chamber at the same time, the gas molecules all along its path ionise into a trail behind it. The super saturated vapours immediately condense round these ions forming tiny droplets of fog which becomes visible by the reflection of light from them. The track of the particle shows as a bright line which can be photographed at the proper instant.

An α-particle is highly ionising. The ions produced are so numerous that its track is a thick and continuous line, Fig. 20.2 (a). The β-particle is much less ionising. Its track is, therefore, a thin and broken line. Fig. 20.2(b). Gamma rays are photons emitted in a widening cone of some angle. They produce ionisation by photoelectric effect distributed over a wide space. Some of the high energy photoelectrons ejected by them give tiny line-tracks in random directions like the β-particles. The overall effect of γ-rays (as also of x-rays and ultraviolet rays) is that the whole region exposed to radiations shows scattered dots and small lines rather like a fog and no well-defined line track, Fig.20.2(c)

Often a magnetic field is applied vertically across the cloud chamber to cause the particles to deflect. From the deflection, its direction and magnitude, and the length and curvature of the paths, additional information about the charged and uncharged nature, the magnitude of the charge, the charge to mass ratio (e/m), etc of the incident particle or the particle produced by their interaction with the atoms, can be obtained By this very method a number of particles have been discovered.

20.3 Geiger Counter

Geiger counter is a portable device which is widely used for the detection of ionising particles or radiations.Fig.20.3 shows its basic construction. It consists of a hollow metal cylinder one end of which is closed by an insulating cap. At the centre of the cap is fixed a stiff straight wire along the axis of the cylinder. A thin mica or glass disc closes the other end which also serves as the entrance window for the ionising particles or radiations. The sealed tube usually contains a special mixture (air, argon, alcohol, etc.) at a low pressure of 50 to 100 millimetres of mercury. A potential difference of the order of one thousand volts is applied between the metal cylinder and the axial wire through a suitable series resistor, R (about 10^9 – ohms). The potential difference is only slightly less than that necessary to start a discharge between the wire and the cylinder.

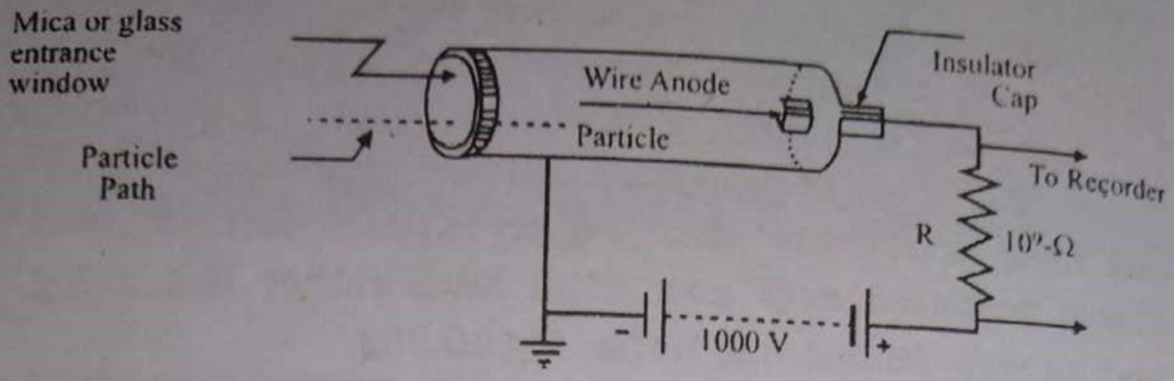


Fig.20.3 Geiger Counter

When an ionising particle enters the tube through the window, it ionises some gas molecules in it. These ions are accelerated by the strong radial electric field producing more ions by collision with the atoms and causing the ionisation current to build up rapidly. So a momentary surging current flows between the wire and the cylinder and through the resistor,R, producing a momentary potential difference across R. The ends of R are connected to a loudspeaker or an electronic counter. Thus each time a particle enters the counter an ionisation current pulse occurs which gives a click in the loudspeaker or a count in the electronic counter. The ionisation current, however, decays rapidly in a small fraction of a second since the circuit has a small time constant and the counter is ready to register another particle almost immediately.

In the case of ionising radiations, the number of counts registered by the counter measures the intensity or ionising power of the incident radiation.

20.4. Solid-State Detectors.

These devices basically make use of the solid-state semiconductor diodes i.e. the p-n junction. It may be recalled that no current passes through a semiconductor diode when it is reverse biased. However, if an energetic ionising particle (or radiation) passes through the p-n junction region, a reverse current pulse passes through the diode due to the ionisation of the atoms of the region.

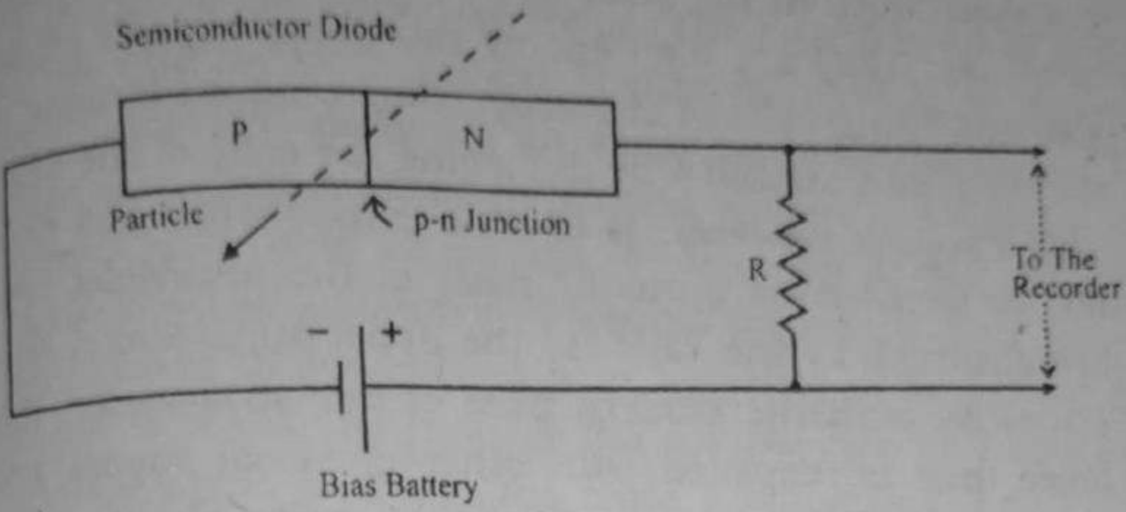


Fig.20.4 Solid State Detector

This can be made to produce a small potential difference across a suitable resistor,R, connected in series with the diode and the battery. The current pulse so produced is then fed into an amplifier and the amplified pulse is applied to a loudspeaker or an electronic counter which can register the number of clicks or counts respectively as the Geiger counter. Fig.20.4 shows the schematic arrangement of the device.

The advantage of this device over the Geiger counter is that it eliminates the use of Geiger tube, the special gaseous mixture in it and the low pressure that it demands. Moreover, the dangerously high potential difference (~ 1000 volts) between the axial wire and the metal cylinder and the precaution of earthing the cylinder for safety are done away with, since this device works at low potential differences up to 9 volts. The size and cost of the apparatus also are very much reduced. It can detect particles having energy only a few electron volts.

20.5 Radiation Exposure

The most common type of damage is due to the ultraviolet rays in sunlight. Ultraviolet rays are electromagnetic radiations of frequencies higher than that of the violet rays in the solar spectrum but lower than that of x-rays. They are high energy radiations capable of destroying living cells of the body. They produce tanning of the skin and sunburn by damaging the cells of the skin. This damage, however, is of little consequence and need not be avoided as normally most of the ultraviolet rays are absorbed by the layer in the upper atmosphere. Nevertheless, with the modern pace of industrialization this layer may be depleted with other chemical vapors and gases resulting in the increased intensity of ultraviolet rays reaching us. There might, then, be an increased danger of the incidence of skin cancer in the human beings and animals which the rays can cause.

In addition to the ultraviolet rays in the sunlight we are constantly exposed to other ionising radiations. All the substances in the earth contain atoms of the radioactive species. Consequently, our bodies are all the time exposed to a low level of background radiations. The other sources of such radiations are the cosmic ray showers from space and the x-ray exposures for diagnostic purposes. Moreover, our food and drinking water also contain some radioactive atoms from which we receive these radiations. Lastly, the nuclear centres and power stations, and the nuclear explosions may create a lot of these radiations. These are all unavoidable. However, normally the overall intensity of the background radiation is within a safe limit, not causing us very serious harm. Besides affecting the living organisms, constant exposure to these radiation also likely to affect the non-living materials. It is found that materials used in construction and manufacture suffer loss in strength by constant exposure to intense radiations.

20.6. Radiation Damage

As explained in the preceding discussion, ionising radiations are dangerously harmful, though within a certain intensity limit their effects may be repairable. The radiations and their different sources, both natural and artificial, are in wide use today. The interactions of radiation with living tissue are highly complex. It is known that excessive exposure to radiations like sunlight, x-rays and other nuclear radiations, causes destruction of tissues . In mild cases the destruction shows as the burn like the sunburn. A greater exposure can cause very severe illness or death in a variety of ways one of which is the destruction of the components of the bone marrow which produces the blood corpuscles in the body. The apparently safe limit of exposure has been established under a subject called 'dosimeter'. When exposure to radiation is unavoidable, it must never be allowed to exceed the safe limit. The safe level of radiation exposure is also open to question. Available evidence shows that exposure to the extent of 10 to 100 times that from natural sources is rarely harmful.

20.7. Effect of Radiation Damage

A general reference has already been made to the fact that considerable damage can be caused by an ionising radiation when it passes through matter. The damage produced in the biological organisms is of great importance and concern for us. It is mainly due to the ionisation produced in the living cells. Several processes may occur. Highly reactive ions and radicals may be produced in the organism and may take part in chemical reactions that may interfere with the normal functioning of the cells. For example, free radicals H^+ and OH^- may be produced from the water present in the cells which may react and break the chemical bonds and disrupt the vital molecules such as proteins.

All radiations ionise atoms and molecules by knocking out electrons. The molecule may split up or its structure may alter such that it either fails to perform its normal function or starts performing a harmful function. If too many molecules of the cell are damaged it may die altogether. The damage to the vital DNA molecules may be of very serious consequence. The disruption of the cells of an organism may continue producing more defective cells to the detriment of the whole organism. Thus, radiation can cause cancer, (the rapid production of defective cell) even at low levels or doses. Another effect of radiation damage is the 'radiation sickness' characterised by nausea, fatigue, loss of body hair and so on. Radiation can also destroy the components of the bone-marrow that produce red blood cells, thus causing leukemia, the so called 'blood cancer'. Radiation damage from large doses may also bring quick death.

Even more disastrous is the effect of the radiation damages the cells of the reproductive organ's of either sex. Damage to the genes results in mutations which are very harmful. This damage can be transmitted to generation after generation in the form of birth defects and abnormalities. The effect of radiation including that of the x-ray exposure, is a cause of great concern. For this reason no one of the child-bearing age should be exposed to unnecessary radiation treatment of the reproductive organs. Children who are growing rapidly are more vulnerable to radiation. For this reason most good doctors are reluctant to prescribe x-ray exposure to children unless absolutely necessary.

20.8. Biological and Medical Uses of Radiation.

The application of radioactivity and radiation to human beings and other biological organisms is a vastly growing field.

These fall into two categories:

(i) Their use as tracers.

(ii) Their use as therapeutic agents in medicine and as sterilizing agents

(i) Radioactive Tracers.

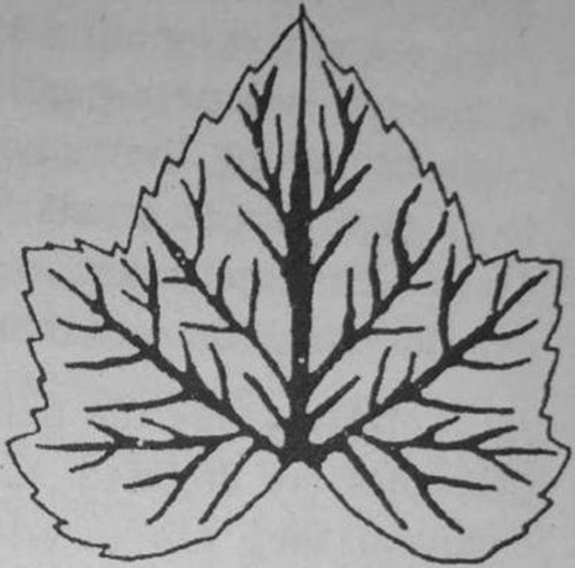
In biological and medical research radioactive isotopes of different elements are widely used as tracers. First a given compound is artificially prepared using a radioactive isotope e.g ${}_6C^{14}$ or ${}_1H^3$. Such 'tagged' molecules containing the radioisotope are then administered to an organism in small doses and as they move or undergo a chemical reaction they are traced by a radiation detector which detects them by the radiation they emit.

In this way the details can be traced of how food molecules are digested; to what parts of the body of an organism they are diverted and how certain essential compounds are synthesized by the organism. Isotopes which are γ-rays emitters are the best for this application.

Tracer studies reveal that if a small quantity of radioactive iodine, ${}_{53}I^{131}$, is taken in the food, most of it deposits in the thyroid glands of man and animals. If radioactive calcium, ${}_{20}Ca^{45}$, is taken by man or animals orally or by injection, nearly 90% of it deposits in the bones of the young ones while only 40% in the old individuals. Sodium being an important constituent of the body fluids, the rate of flow of the blood, etc. in the body can be traced by giving radioisotope of sodium, ${}_{11}Na^{24}$.

In plants also the distribution of different minerals taken through the roots can be traced by using their suitable radioisotopes. The absorption of carbon dioxide, the seat of photosynthesis and the distribution of plant food prepared by photosynthesis can be traced by placing the plant in the atmosphere of carbon dioxide prepared from radioisotope of carbon ${}_6C^{14}$. By a technique called auto-radiography the position of the radioisotope is detected on the photographic film. In this technique the leaf is firmly placed on a photographic plate or film.

The film is darkened most strongly by the emitted radiations where the isotope is concentrated most densely.



Autoradiograph of a leaf of squash plant exposed to CO_2 containing radio active $_6C^{14}$ atoms, showing abundance of $_6C^{14}$ atoms in the blackened Photosynthetic green tissue region and their absence in the non-blackened region of the Veins

Fig.20.5.

The trace shows the distribution of carbohydrates produced in the leaf from the absorbed carbon dioxide (Fig.20.5)

(ii) Radiation Therapy and Diagnostics

The usefulness of x-rays in medical diagnosis is very well known. The rays can easily pass through less dense tissues of the flesh and the cracks or fractures of bones. However, they are stopped by denser parts like bones and to a less degree by tumors, etc. They can, therefore, give a shadow graph of any internal part of the body on a photographic film from which diagnosis of a crack or fracture in a bone or a tumor in the fleshy part can be made. The diagnostic usefulness of x-rays outweighs the small radiation hazard involved with the exposure. However, unnecessary frequent exposures must always be avoided.

(iii) Treatment of Cancer.

No doubt that radiation can cause cancer, it can also be used to treat it as it can destroy rapidly growing cancer cells. Some of the normal cells surrounding a cancerous tumor are inevitably killed causing side effects characteristic of radiation sickness.

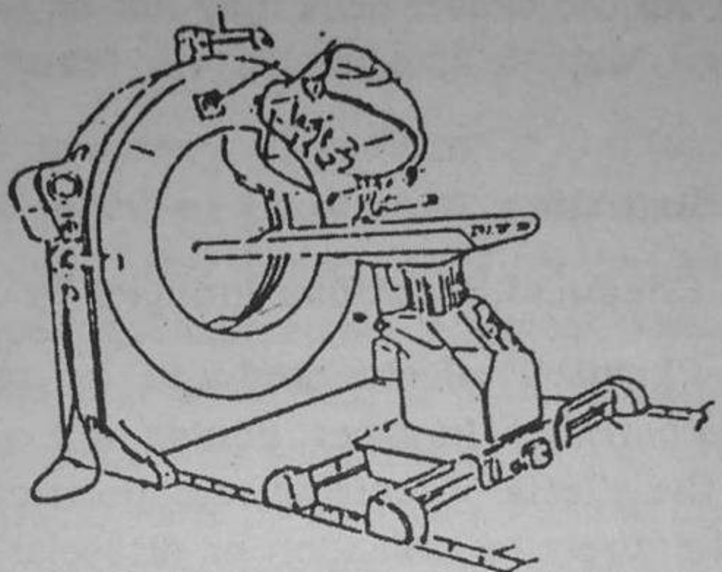


Fig.20.6 Cobalt Therapy Machine.

In treating a localized cancerous tumor a narrow beam of γ-rays from cobalt-60 or energetic x-rays is often used. The beam is directed at the tumor and the source is continuously rotated such that while the beam impinges on the tumor all the time, its surrounding region receives as low a dose as possible. The cancerous cells on the tumor can thus be destroyed to the relief of the patient without causing appreciable damage to the surrounding tissues. This is the so-called external therapy.

The other mode of treatment is called internal therapy. In some cases of internal therapy a tiny γ-ray source of very short half life may be inserted directly inside a tumor by surgical operation. It will kill majority of the cancer cells. This technique is sometimes used to treat cancer or of the thyroid glands with radioisotope of iodine, $_{53}I^{131}$. Alternatively the radioisotope $_{53}I^{131}$, is injected into the blood. As iodine has special affinity to the thyroid glands, it concentrates there, particularly in the cancerous region. The intense radiation from the radioisotope kills most of the defective cells. Similarly, cancerous affections in other parts of the organism may be treated by using the radioisotope of an element having special affinity to them.

The radiation treatment may increase the life-span of a cancer patient but it may not be completely effective. All the cancer cells may not be destroyed. Hence, there is always a likelihood of the recurrence of the disease.

20.9. Radiation Techniques in Other Fields

(I) Chemical Reactions induced by Radiations

Chemical effects produced by radiations are of great importance. In gases, liquids and covalently bonded solids the effects of ionising radiations can be attributed almost entirely to ionisation or dissociation of the molecules. Consequently a great variety of products may be obtained from organic compounds by radiolysis i.e. decomposition or dissociation by exposure to radiations.

Gases like hydrogen, carbon monoxide and carbon dioxide may be obtained by decomposition using radiation. Carbon dioxide and water molecules may synthesize in presence of chlorophyll into carbohydrates as in photo synthesis.By induced chain reactions many molecules of the same type may link together to give bigger molecules or polymers e.g. styrene and ethylene may polymerize into polystyrene and polyethylene respectively. The exchange of identical (or non-identical) radicals or groups may occur between two types of molecules mixed together. This can be tested by introducing radioactive $_6C^{14}$ atoms in one type, mixing the two types together and then separating them after sometime. If both types show radioactivity, exchange of radicals is confirmed.

Radiation-induced change of practical importance can be produced in the mechanical or physical properties of some polymers such as polyethylene which are due to cross linkages between the polymer chains. Irradiation of solids with fast neutrons or ions may alter many physical properties such as thermal and electrical conductivity, hardness and other mechanical properties.

(II) Radio Processes in Space, the Cosmic Rays.

After the discovery of radioactivity, a source of ionising radiations, it was found that radiation-detection instruments showed the presence of radiations even when not exposed to radioactive sources. This background effect was first attributed to natural radioactive substance in the earth. The shielding of the detection device oven with thick walls of lead could never eliminate the effect. Moreover, by removing the detection device several thousand metres from the ground, the effect increased manifold instead of decreasing. The conclusion was that a radiation of very high penetrating power is falling on the earth from outer space. This radiation was, therefore, named 'cosmic rays.

Early investigations were confined to the earth's surface or to low altitudes within earth's atmosphere where the radiations observed are, in fact, not the primary particles but the secondary radiations produced by the interaction of the primary particles with the atoms or molecules of the gases at the top of earth's atmosphere. These secondary radiations were found to consist of very high energy radiations comprising nearly all known elementary particles and the γ-rays.They are capable of penetrating lead more than a metre thick and are observed up to appreciable depths below water and ground.

mostly of protons, having very high energies extending up to 10^{18} eV A small percentage of heavier nuclei is also present such as those of He (15%) and C, N, O (less than1%).

Most of the primary cosmic rays are believed to originate from the galaxies, shooting out constantly as showers in all directions and filling the space. They are accelerated to high energies by interstellar magnetic fields. During the solar flares the sun contributes significantly to the low energy (mostly< 1 GeV) cosmic rays arriving the earth. During intense sun-spot activity the galactic cosmic-ray flux reaching the earth decreases a bit, which probably, is a magnetic effect.

(iii) Uses of radiation

(i) Polymerisation

Many plastics, synthetic rubbers, synthetic textile fibres,etc. much as polyethylene, polystyrene, polyester, so commonly used today, are composed of the polymers of certain simpler molecules. The important characteristic of a polymer is its long chain of carbon atoms to which various chemical groups are attached. As hinted to earlier, radiations can split long chains of molecules or establish cross-linkages between smaller chains. Breaking of chains shortens the average molecular length whereas cross-linkage increases it and enhances the physical properties like hardness, mechanical strength, temperature resistancy, surface texture and finish, transparency, etc. By proper treatment the radiation polymers with improved characteristics can be synthesized from the parent molecules or their polymers of lower order. Polymerisation by radiation has thus become an important process in industry for the manufacture of many useful materials.

(ii) Sterilization and Food Preservation

Another useful application of radiation is for the sterilization of food and medical supplies. Since radiation kills or deactivates bacteria, medical supplies such as bandages, syringes, needles, surgeon's gloves, catheters, surgical instruments and other hospital equipments can be irradiated with a strong dose to sterilize them, instead of using old-fashioned high temperature treatment or antiseptic medicines. For the preservation of foods, fresh or seasoned,they can be irradiated with appropriate high dose before or after vacuum packing to kill the bacteria responsible for spoilage. Similarly, milk can be pasteurised and drinking water of town supplies freed from harmful germs by irradiation with suitable doses of x-rays or γ-rays.

(iii) Gauging and Control

In industry when a material such as paper, cloth or metal is manufactured in sheet form by a continuous process its thickness can be measure and controlled by a beta-ray thickness gauge without interrupting the production. A beta-ray source is fixed under the moving sheet and a detection device above it which is connected to an amplifying recording device. The reading of the detection device is related to the thickness of the sheet, which may be read all the time on a calibrated dial and hence it can be measured and controlled during the entire production. Alternatively, an automatic system can be installed to maintain the constancy of any desired thickness of the sheet.

(iv) Radiography

For the detection of porosity, cavity or other infirmities in a metal casting and cracks or imperfections of welded joints in engineering and ship-building industries, radiographic examination can be made. X-rays are widely used for this purpose. This is simply an extension of the use of x-rays for diagnostic purposes of the human body discussed in the preceding section.

(v) Radiation Methods in Archaeology

Small amounts of the radioisotope of carbon, ${}_6C^{14}$, are produced in the carbon dioxide molecules in the upper atmosphere by cosmic-ray neutrons. The half-life of C^{14} is about 5730 years. Assuming that the cosmic ray intensity has not changed during the past 20,000 to 50,000 years, the rate of formation an decay of C^{14} now must nearly be equal and the abundance of C^{14} and C^{12} atoms should be constant throughout the atmosphere. Carbon dioxide circulating through the atmosphere is absorbed by plants. From the plant kingdom it goes to the bodies of men and animals as food. Hence all living things constantly absorb some radioactive C^{14} and are slightly radioactive, the abundance of C^{14} in their bodies being the same as in the atmosphere as long as they are alive. The ratio of C^{14} to C^{12} atoms in plants was found to be 1.5×10^{-12} before the use of nuclear weapons. When plants and animals die the absorption of C^{14} stops while the disintegration of C^{14} in them continuous and their activity goes on decreasing. If the activity of C^{14} in a dead body, such as wood, bone or a fossil, can be measured it can provide a clue to the age of the specimen i.e. the time elapsed after its death. This method of finding the age of a specimen by the C^{14} method is called 'radiocarbon dating which has now become the most powerful tool for the archaeologists and geologists. However, the nuclear explosions and accidents have definitely disturbed the constant activity of C^{14} in the atmosphere and the living things and may do so in future too, rendering this method of dating rather unreliable. Many other systems of dating also exist which make use of other radioactive isotopes of elements viz. U^{238}, Cl^{36}, etc.

(vi) Activation Analysis

The detection and estimation of an element in a mixture is sometimes nearly impossible if it is present in very minute traces or if its chemical properties are very similar to those of the other elements in the mixture.A technique developed in recent years, called activation analysis' is found to be very effective for this purpose.

It is seen that if a mixture containing different elements is subjected to the thermal neutrons inside a nuclear reactor for appropriately chosen lengths of time, some atoms of each element present in the mixture become radioactive beta-emitters. The β-emission from them is usually followed by γ-radiation. The activated atoms of different elements emit γ-rays of different energies from which they can be identified even in concentrations as low as 1 part in 10^5. The energies of the emitted γ-rays can be measured by a γ-ray spectrometer. This method is called neutron-activation analysis'. It has proved to be of great use in the analysis of archaeological and geological objects. Occasionally, charged particles such as protons, and deuterons are also used for activation and investigation carried out by the emitted β-rays with a Geiger Counter.

QUESTIONS

20.1 Describe as many points of difference between α-,β-, and γ- rays as possible.

20.2 Explain how you would test whether the radiations from a radicactive source α-,β-or γ- radiations with the simplest equipment.

20.3 It said that an α - or β- particle carries an atom without colliding with its electrons. How can each do so ? Explain.

20.4 In how many ways can γ-rays produce ionisation of the atoms? Explain.

20.5 In what way does a neutron produces ionisation of an atom?

20.6 Name the different electromagnetic radiations which are capable of producing ionisation of atoms. By what process do they usually ionise?

20.7 Why is lead a better shield against α-, β- and γ-radiations than an equal thickness of water column?

20.8. Lead is heavier and denser than water, yet what is a more effective shield against neutrons? Explian why?

20.9. In an x-ray photograph bones show up very clearly while the fleshly part shows very faintly. Why?

20.10. In a cloud chamber photograph the path of an α-praticles is a thick and continuous line whereas that of a β-particle is a thin and broken line. Explain why?

20.11. Why do γ-rays not give a line-track in the cloud chamber photograph?

20.12. A neutron can produce little ionisation. Is there any sure chance of getting a cloud-chamber track for it or a count in the Geiger-counter?

20.13. A cloud chamber photograph of an α-particle is usually straight. Sometime as abrupt bend accompanied by a small branched track, the so-called forked track is obtained near the end. What could possibly be the cause of this forked track?

20.14. Why is the recommended maximum dose for radiation a bit higher for women beyond the child bearing age that for younger women?

20.15. It is possible for a man to burn his hand with x-or γ-rays so seriously that he must have it amputated and yet may suffer no other consequence. However, a whole-body x- or γ-ray overexposure so slight as to cause no detectable damage might cause birth deformity in one of his subsequent children. Explain why?

20.16. Which of the rays ----- α,β,or γ would you advise for the treatment of:

(i) Skin cancer?

(ii) The cancer flesh just under the skin?

(iii) A cancerous tumor deep inside the body ? Give reasons.

20.17 Two radioisotopes of an element are available one of long half-life and the other of short half-life. Which isotope is advisable for the treatment of patients and why?

20.18 Why are many artificially prepared radioisotopes of elements rare in nature.

20.19. Can radiocarbon dating be used to measure the age of stone-walls of the ancient civilizations?

Some Common Conversions

Length

1 m = 3.281 ft = 39.37 in; 1 cm = 0.3937 in
1 km = 1000 m = 0.6214 mi
1 ft = 30.48cm; 1 in = 2.540 cm
1 yd = 0.9144m
1 mi = 5280 ft = 1.609 km

Area

1cm^2 = 0.155m^2
1m^2 = 10^{1}cm^2 = 10.76 ft^2
1 in^2 = 6.452 cm^2
1 ft^2 = 929.0 cm^2 = 0.09290 m^2

Volume

1m^3 = 1000 liters = 10^8 cm^3 = 1.308 yd^3 = 35.31 ft^3
1 liters = 1000 cm^3 = 0.001 m^3 = 61.03 1n^3 = 0.0353 ft^3
1 ft^3 = 0.02832 m^3 = 7.481 gallons = 28.32 liters

Time

1 day = 86,400 s; 1yr = 3.156 x 10^{2}s

Velocity

1 m/s = 3.281 ft/s = 3.6 km/h
1 km/h = 0.2778 m/s = 0.6214 mi/h = 0.9113 ft/s
1 mi/h = 1.609 km/h = 0.447 m/s = 1.467 ft/s

Acceleration

1m/s^2 = 100 cm/s^2 = 3.281 ft/s^2
1ft/s^2 = 30.48 cm/s^2 = 0.3048 m/s^2

Mass

1 kg = 1000 g = 0.0685 slug
1 slug = 14.59 kg = 32.17 lb mass
1 metric ton = 1000 kg

Density

1 g/cm^3 = 1,000 kg/m^3 = 1.940 slug/ft^3
= 62.43 lb-mass/ft^3
1 lb-mass/ft^3 = 0.0311 slug/ft^3 = 16.02 kg/m^2
= 0.01602 g/cm^3

Force

1 N = 10^5 dyn = 0.2248 lb
1 lb = 4.45 N = 4.45 x 10^6 dys
1 ton = 2000 lb

Pressure

1 N /m^2 = 1.451 x 10^{-4} 1h/in^2 = 0.200 1b/ft^2
1 lb/in^2 = 6.89 x 10^3 N/m^2 = 6.89 x 10^4 dyn/cm^2
1 atm = 76 cm Hg = 760 torr = 14.70lb/in^2
= 1.013 x 10^5 N/m^2
= 1.013 bar = 1.013 x 10^5 dyn/cm^2

Work and Energy

1 J = 10^7 ergs = 0.239 cal = 0.7376 ft-lb
1 ft-lb = 1.356 J
1 cal = 4.184 J = 3.068 ft-lb
1 Btu = 252 cal = 778 ft-lb = 1054 J
1 kilowatt-h [kWh] = 3.60 x 10^5 J
1 eV = 1.60 x 10-^{19} J

Power

1 W = 1 J/s = 0.738 ft-lb/s
1 hp = 0.746 kW = 550 ft-lb/s
1 Btu/h = 0.293 W

Specific Heat and Latent Heat

1 cal/g-C^0 = 4.184 J/g = 4184 J/kg-C^0
1 cal/g = 4.184 J/g = 4184 J/kg = 1.80 Btu/kg-C^0
R = 8.314 J/mol-K = 1.99 cal/mol-K
= 0.0621 (atm-l/mol-K)

Multiples, Submultiples, and Prefixes

(Applicable to All SI Units)

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 $= 10^{12}$	tera	T
1 000 000 000 $= 10^{9}$	giga	G
1 000 000 $= 10^{6}$	mega	M
1 000 $= 10^{3}$	kilo	k
100 $= 10^{2}$	hecto	h
10 $= 10^{1}$	deka	da
base unit: 1 $= 10^{0}$		
0.1 $= 10^{-1}$	deci	d
0.01 $= 10^{-2}$	centi	c
0.001 $= 10^{-3}$	milli	m
0.000 001 $= 10^{-6}$	micro	μ
0.000 000 001 $= 10^{-9}$	nano	n
0.000 000 000 001 $= 10^{-12}$	pico	p