

How is the age of the dead remains determined?

# unit 18

## RADIOACTIVITY

After studying this chapter you should be able to

- ✓ describe the structure of an atom in terms of a nucleus and electrons.
- ✓ describe the composition of the nucleus in terms of protons and neutrons.
- ✓ explain that number of protons in a nucleus distinguishes one element from the other.
- ✓ represent various nuclides by using the symbol of proton number  $Z$ , nucleon number  $A$  and the nuclide notation  $X$ .
- ✓ explain that some nuclei are unstable, give out radiation to get rid of excess energy and are said to be radioactive.
- ✓ describe that the three types of radiation are  $\alpha$ ,  $\beta$  &  $\gamma$ .
- ✓ state, for radioactive emissions:
  - o their nature
  - o their relative ionizing effects.
  - o their relative penetrating abilities.
- ✓ explain that an element may change into another element when radioactivity occurs.
- ✓ represent changes in the composition of the nucleus by symbolic equations when alpha or beta particles are emitted.
- ✓ describe that radioactive emissions occur randomly over space and time.
- ✓ explain the meaning of half life of a radioactive material.
- ✓ describe what are radio isotopes. What makes them useful for various applications?
- ✓ describe briefly the processes of fission and fusion.
- ✓ show an awareness of the existence of background radiation and its sources.
- ✓ describe the process of carbon dating to estimate the age of ancient objects.
- ✓ describe hazards of radioactive materials.

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- 18.2 Natural radioactivity
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- 18.5 Radio isotopes
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- 18.7 Nuclear fusion
- 18.8 Background radiation
- 18.9 Hazards and safety measures
- Key Points and Projects

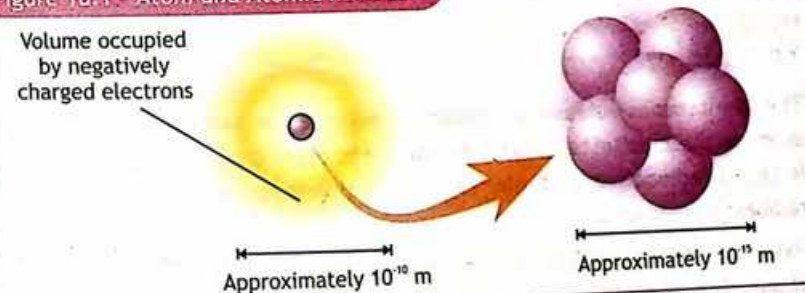
Exercise

In this chapter, we discuss the properties and structure of the atomic nucleus. We start by describing the phenomenon of radioactivity, nuclear transmutations and half life. We also discuss the various processes by which nuclei decay and the ways that nuclei can react with each other. In nuclear reactions, however, we will study how a nucleus breaks apart or is particles combine.

## 18.1 ATOM AND ATOMIC NUCLEUS

All matter is composed of atoms that are in turn composed of a heavier, central, positively charged core called 'nucleus' surrounded by a less massive negatively charged cloud of 'electrons'. The nucleus lies at the center of the atom, occupying only  $10^{-15}$  of its volume since the electrical force comes from both the electron and the nucleus as shown in figure 18.1. The nucleus is about 10,000 times smaller than atom. The size difference is like a ping pong ball in the center of a 2 km circle.

Figure 18.1 - Atom and Atomic nucleus

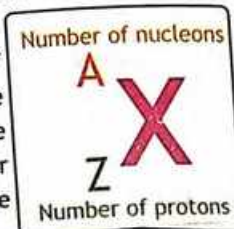


All nuclei are composed of two types of particles: protons and neutrons (called nucleons). The only exception is the ordinary hydrogen nucleus, which is a single proton. In describing the atomic nucleus, we must use the following quantities:

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- The atomic number,  $Z$  (sometimes called the charge number), which equals the number of protons in the nucleus.
- The nucleon (or mass) number,  $A$ , which equals the number of nucleons (neutrons plus protons) in the nucleus.
- The neutron number,  $N$ , which equals the number of neutrons in the nucleus ( $N = A - Z$ ).

In representing nuclei, it is convenient to have a system of symbols to show how many protons and neutrons are present. The symbol used is  ${}^A_ZX$ , where  $X$  represents the chemical symbol for the element,  $Z$  represents the number of protons and  $A$  represents the number of nucleons (i.e. number of protons and neutrons).



For example,  ${}^{56}_{26}\text{Fe}$  (iron) has a nucleon number of 56 and an atomic number of 26; it therefore contains 26 protons and  $(56 - 26)$  30 neutrons. The subscript  $Z$  is thus sometimes dropped. For example for nitrogen  ${}^{15}_7\text{N}$ , we already know that  $Z = 7$  for nitrogen and we simply write  ${}^{15}\text{N}$ , call it as 'nitrogen fifteen' (or may write as nitrogen - 15).

The nuclei of all atoms of a particular element contain the same number of protons (and consequently electrons in a neutral atom) but often contain different numbers of neutrons. The nuclei of atoms which have the same number of neutrons and protons are termed as nuclides.

Within the nucleus there are  $Z$  positive charges. To keep these charges from flying apart, the nuclear force must supply an attraction that overcomes their electrical repulsion.

## 18.2 RADIOACTIVITY

The spontaneous release of subatomic particles or gamma rays by unstable atoms as their nuclei tend to break apart into other particles to attain stability is called radioactivity. An element which possesses such property is called radioactive element.

Some nuclides are unstable, in order to attain stability, elements emit three types of radiation: alpha ( $\alpha$ ), in which the emitted particles are  ${}^4_2\text{He}$  nuclei; beta ( $\beta$ ), in which the emitted particles are either electrons or positrons (positive electrons); and gamma ( $\gamma$ ), in which the emitted "rays" are high-energy electromagnetic radiations. Nuclei which do not emit radiations are termed as 'stable nuclei'.

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It is possible to distinguish these three forms of radiation using the scheme shown in Figure 18.2 (a). The radiation from a radioactive sample (e.g. Radium) is directed into an evacuated chamber (region from which air is pumped out) in which there is a magnetic field.

The image on photographic plate shows that the beam splits into three components, two bending in opposite directions and the third experiencing no change in direction. By using the force on charged particles in magnetic field, we can conclude that the radiation of the un-deflected beam carries no charge (the gamma ' $\gamma$ ' ray), the component deflected upward consists of positively charged particles (alpha ' $\alpha$ ' particles), and the component deflected downward consists of negatively charged particles (beta ' $\beta$ ' particles).

Similar observations can be made by passing a beam emitted from radium through an electric field placed perpendicular to the beam as shown in the figure 18.2 (b).

Radioactivity occurs without apparent external cause and cannot be speeded up or slowed down by physical or chemical means. Radioactivity is a process without defined pattern, rule or method and occur randomly. Radioactivity cannot be predicted because the precise moment of disintegration is not known for a particular nuclei. Individual disintegrations occur randomly.

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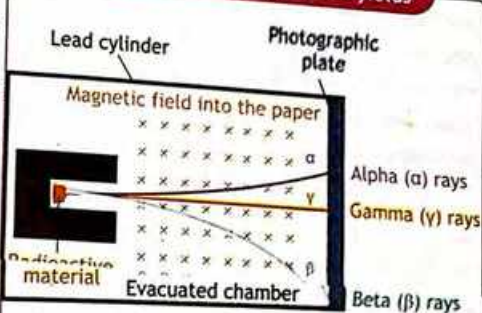
Individual disintegrations occur randomly.

Individual disintegrations occur randomly.

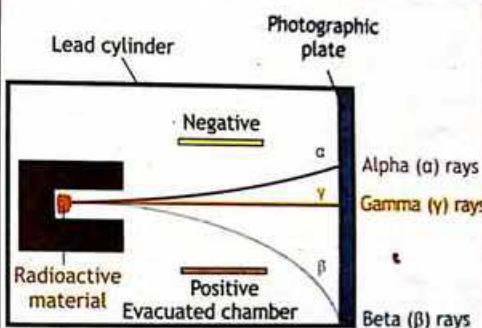
Individual disintegrations occur randomly.

Individual disintegrations occur randomly.

Figure 18.2 - Radioactivity in force fields



(a) Alpha, Beta and Gamma rays in magnetic field



(b) Alpha, Beta and Gamma rays in electric field

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**18.2.1 Nature of emissions:** It is found that all the three kinds of radiation have different nature.

**i. Alpha ( $\alpha$ ) emissions:** Alpha particles are infact helium nuclei (i.e two protons and two neutrons bound together) emitted from the nucleus. When the ratio of neutrons to protons in the nucleus is too low, certain atoms restore the balance by emitting alpha particles.

Alpha emissions occur in very large atoms (that is, they have high atomic numbers).

**ii. Beta ( $\beta$ ) emissions:** Beta particles consist of electrons emitted from the nucleus. Beta particle emission occurs when the ratio of neutrons to protons in the nucleus is too high. In this case, an excess neutron transforms into a proton and an electron. The electron is ejected energetically. A neutron by itself is unstable; the lone neutron on average of about 12 minutes will decay into a proton and an electron.

The spontaneous decay of free protons has never been observed and the proton is therefore, considered a stable particle. A neutron with a proton is stable.

**iii. Gamma emissions:** Gamma rays are electromagnetic radiation emitted from the nucleus. Gamma ray emission occurs when the nucleus of a radioactive atom has too much energy.

Figure 18.3 - Beta Emission

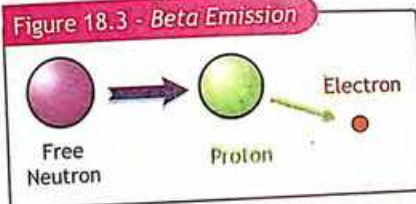


TABLE 18.1 ALPHA, BETA, AND GAMMA RADIATION

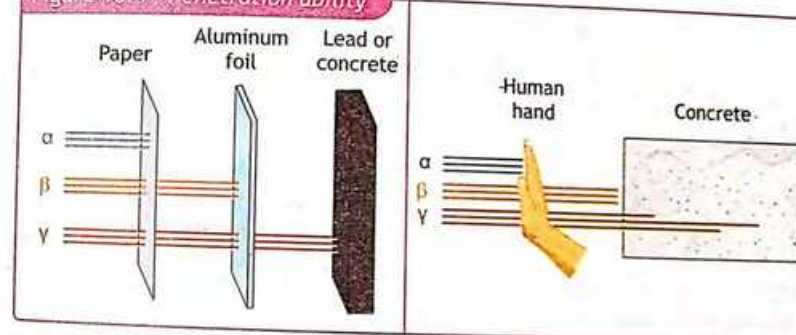
| Particle | Symbols  | Composition                            | Charge | Effect on parent nucleus                |
|----------|----------|----------------------------------------|--------|-----------------------------------------|
| alpha    | $\alpha$ | 2 protons and 2 neutrons               | +2     | Mass loss: new element produced         |
| beta     | $\beta$  | electron                               | -1     | No change in mass: new element produced |
| gamma    | $\gamma$ | high energy electromagnetic radiations | 0      | energy loss                             |

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**18.2.2 Relative Ionizing abilities:** The phenomena by which radiation can split matter into positive and negative ions is called ionization. All the three types of radiation (alpha ' $\alpha$ ', beta ' $\beta$ ' and gamma ' $\gamma$ ') have quite different ionizing abilities in air. Alpha ( $\alpha$ ) particles ionizes air much strongly due to its large mass and charge than beta ( $\beta$ ) and gamma ( $\gamma$ ) radiations. Gamma radiation has the least ionizing ability as compared to alpha ' $\alpha$ ' and beta ' $\beta$ ' radiations.

**18.2.3 Relative Penetration abilities:** Penetrating ability is how deeply a radiation can go into a material. All the three types of radiation (alpha ' $\alpha$ ', beta ' $\beta$ ' and gamma ' $\gamma$ ') have quite different penetrating abilities as well. Alpha particles barely penetrate a sheet of paper and has range of no more than a few centimeters in air; beta particles can penetrate a few millimeters of aluminum has range in air of about 1 m; and gamma rays can penetrate several centimeters of lead and has an infinite range in air as shown in figure 18.4 (a).

Figure 18.4 - Penetration ability



In figure 18.4 (b), it is shown that  $\alpha$ -particles can be easily absorbed by our hand, whereas beta and gamma will pass through. Beta radiations on the other hand will be easily stopped by concrete block. Whereas gamma will travel few centimeters before being absorbed in concrete.

### 18.3 NUCLEAR TRANSMUTATIONS

In radioactivity, an unstable nucleus emits radiations to become more stable. Among 3000 known nuclides, only 257 are stable. The process through which an unstable nucleus (parent nucleus) transforms (or changes) into a more stable nuclide (daughter nucleus) is called nuclear transmutation (or nuclear decay).

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## Unit 18 Radioactivity

In these nuclear transmutations, the original element is called parent and newly formed element is termed as daughter.

**18.3.1 Alpha decay:** In alpha decay, the original 'parent' nuclide is converted to a 'daughter' by the emission of an  $\alpha$  particle. Balancing the reaction shows that the daughter nuclide has a nucleon number reduced by four and a charge reduced by two. Mathematically

$${}^A_ZX = {}^{A-4}_{Z-2}Y + {}^4_2\alpha + Q \quad \text{18.1}$$

Where 'Q' is the energy released in the process. Nuclide 'X' changes into nuclide 'Y' with the emission of alpha ' $\alpha$ ' particle and the release of energy 'Q'.

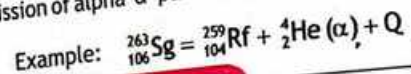
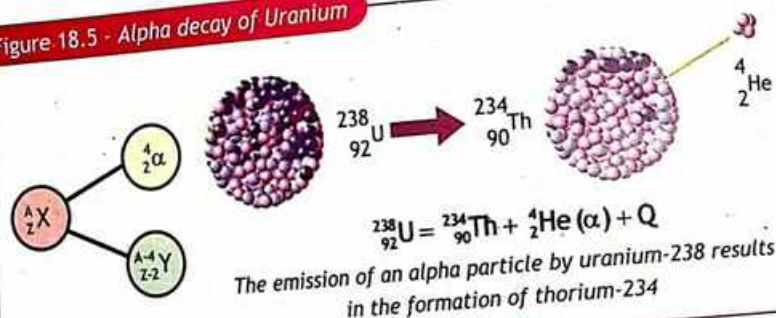


Figure 18.5 - Alpha decay of Uranium

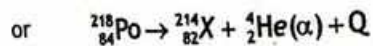
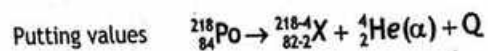


### EXAMPLE 18.1: ALPHA DECAY OF POLONIUM

An unstable polonium - 218 ( ${}^{218}_{84}\text{Po}$ ) atom spontaneously emits an alpha ( $\alpha$ ) particle and transmutes into an atom of some other element. Show the process, including the new element, in standard nuclear-reaction notation.

**SOLUTION:** Alpha decay is given by the relation  ${}^A_ZX = {}^{A-4}_{Z-2}Y + \alpha + Q$

From the periodic table, we find that polonium chemical symbol is Po and atomic number is 84. Therefore:

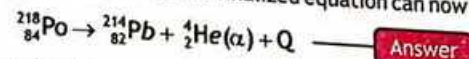


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Every element has a unique atomic number. The periodic table shows the new element to be lead (Pb) with  $Z = 82$ . The finalized equation can now be written as



When polonium - 218 undergoes  $\alpha$ -decay it converts into lead - 214.

### ASSIGNMENT 18.1: ALPHA DECAY OF RADIUM

Find the daughter nucleus when radium - 224 undergoes alpha decay.

**18.3.2 Beta decay:** Unlike  $\alpha$ -decay,  $\beta$  (or electron) decay of a nuclei does not change the number of nucleons. In essence,  $\beta$ -decay changes a neutron into a proton.

$${}^A_ZX = {}^A_{Z+1}Y + \beta^- + Q \quad \text{18.2}$$

Where 'Q' is the energy released in the process. Nuclide 'X' changes into nuclide 'Y' with the emission of alpha ' $\alpha$ ' particle and the release of energy 'Q'.

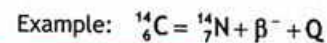
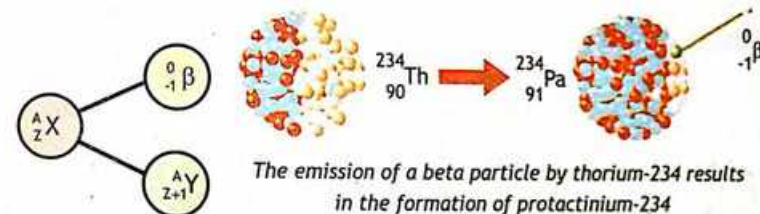


Figure 18.6 - Beta decay of Thorium



### EXAMPLE 18.2: BETA DECAY OF IODINE

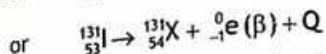
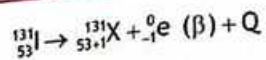
The isotope iodine-131 undergoes beta decay. Write the reaction equation, and determine the identity of the daughter nucleus.

**SOLUTION:** Beta decay is given by the relation  ${}^A_ZX = {}^A_{Z+1}Y + \beta^- + Q$

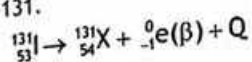
From the periodic table, we find that iodine's chemical symbol and atomic number are I and 53. Therefore:

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Putting values



The mass number stays the same, and the atomic number is increased by 1 to 54. From the periodic table we find that this is the element xenon (Xe). The daughter nucleus is xenon-131.



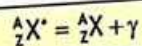
Answer

When iodine - 131 undergoes  $\beta$  - decay it converts into xenon - 131.

### ASSIGNMENT 18.2: BETA DECAY OF SODIUM

An atom of Sodium-24 can transmute into an atom of some other element by emitting a beta particle. Represent this reaction in symbols, and identify the daughter element.

**C. Gamma decay:** In most cases the  $\alpha$  or  $\beta$  emission from the nucleus leave it in excited state such nuclei achieve further stability by emitting gamma rays.



18.3

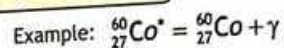
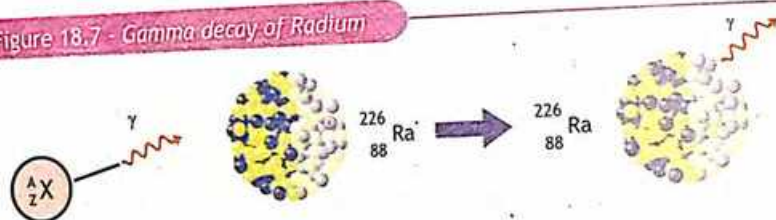


Figure 18.7 - Gamma decay of Radium



The emission of a gamma ray by radium-226 results radium-226 with gamma

**Units of Activity:** A common unit of activity is the curie, abbreviated Ci, which is defined to be  $3.70 \times 10^{10}$  decays per second. This is approximately equal to the activity of one gram of radium. The SI unit of activity is the becquerel, abbreviated Bq. One becquerel is one decay per second.

$$1 \text{ Ci} = 3.70 \times 10^{10} \text{ Bq} = 3.70 \times 10^{10} \text{ decays/s}$$

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### A SHORT HISTORY OF RADIOACTIVITY

In 1896 Henri Becquerel (French physicist) accidentally discovered Radioactivity. Becquerel discovered that uranyl potassium sulfate crystals emitted an invisible radiation that could darken a photographic plate even when the plate was covered to exclude light.



Becquerel's photographic plate. The bottom of the image shows shadow cast due to absorbed radiation.



Henri Becquerel (1852-1908)

Marie (1867-1934) and Pierre Curie (1859-1906) conducted the most significant investigations of this type. Curies reported the discovery of two unknown elements, both radioactive, which they named polonium and radium.



### 18.4 HALF LIFE

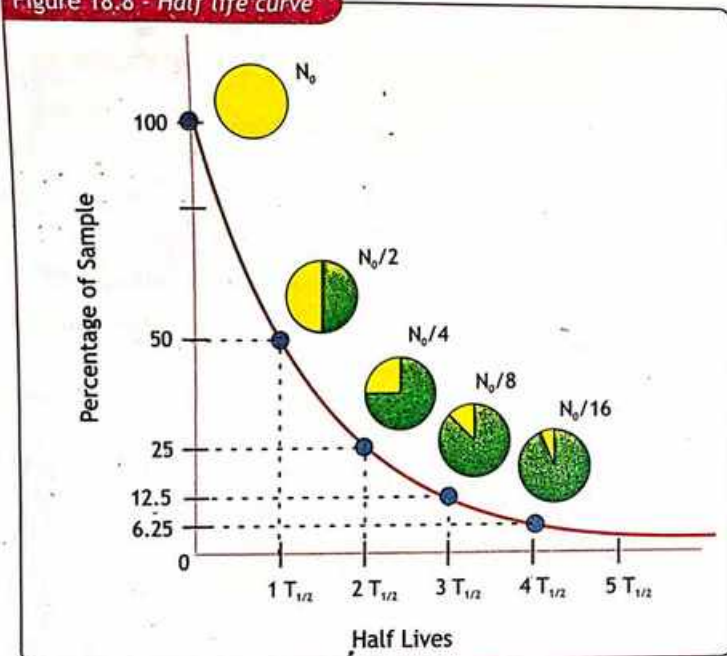
'The time it takes for half of the radioactive nuclei in a sample to decay is called half life'.

Individual disintegrations of nuclei are random, but the probability that any given nucleus will decay in a given interval of time is constant and is a characteristic of that particular nuclide.

The amount of radioactive isotope in the sample decreases with time as shown in the Half life curve shown in Figure 18.8. The number of nuclei present at time  $t = 0$  is  $N = N_0$ , and the number present at  $t = T_{1/2}$  is  $N = N_0/2$ . The number present at  $t = 2 T_{1/2}$  is  $N = N_0/4$ , and so on. The value of the half-life depends on the nature of the radioactive nucleus. For example, radium has a half-life of 1600 years, because it takes this amount of time for one-half of a given quantity of this isotope to disintegrate.

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Figure 18.8 - Half life curve



In another 1600 years, one-half of the remaining radium atoms will have disintegrated, leaving only one-fourth of the original number intact. Let  $N$  represent the amount of the original sample remaining after any given time interval ' $\Delta t$ ' and ' $N_0$ ' represent the original amount in the sample; given in the same units as ' $N$ '. Then

After 1 half-life 
$$N = \frac{1}{2} N_0$$

After 2 half-lives 
$$N = \frac{1}{2} \times \frac{1}{2} N_0 = \left(\frac{1}{2}\right)^2 N_0$$

After 3 half-lives 
$$N = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} N_0 = \left(\frac{1}{2}\right)^3 N_0$$

Generally 
$$N = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \dots N_0 = \left(\frac{1}{2}\right)^n N_0$$
 18.4

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Where, the number,  $n$ , of half-lives is equal to the time interval ( $\Delta t$ ) divided by the time for one half-life ( $T_{1/2}$ ).

$$n = \frac{\Delta t}{T_{1/2}} \quad 18.5$$

Different materials have different half lives which ranges from  $10^{10}$  years to a fraction of second. Half lives of some common radioisotopes are shown in table 18.2.

TABLE 18.2 HALF LIVES OF SOME COMMON RADIOISOTOPES

| Radioisotope | Decay     | Half Life               |
|--------------|-----------|-------------------------|
| beryllium-8  | $\alpha$  | $2.0 \times 10^{-10}$ s |
| polonium     | $\alpha$  | $1.64 \times 10^{-4}$ s |
| iodine-131   | $\beta^-$ | 8.04 d                  |
| cobalt-60    | $\beta^-$ | 5.3 y                   |
| radium-226   | $\alpha$  | $1.62 \times 10^3$ y    |
| carbon-14    | $\beta^-$ | $5.73 \times 10^3$ y    |
| uranium-235  | $\alpha$  | $7.04 \times 10^8$ y    |
| uranium-238  | $\alpha$  | $4.45 \times 10^9$ y    |

## EXAMPLE 18.3: HALF LIFE OF POLONIUM -218

You have a 160.0  $\mu\text{g}$  sample of polonium-218. It decays by alpha emission with a half-life of 3.0 min. How much of the pure sample is left after 9.0 min?

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Total quantity of pure polonium-218 ' $N_0$ ' = 160  $\mu\text{g}$

Half life of polonium-218 ' $T_{1/2}$ ' = 3.0 min

Total elapsed ' $\Delta t$ ' = 9 min

## REQUIRED

Quantity left ' $N$ ' = ?

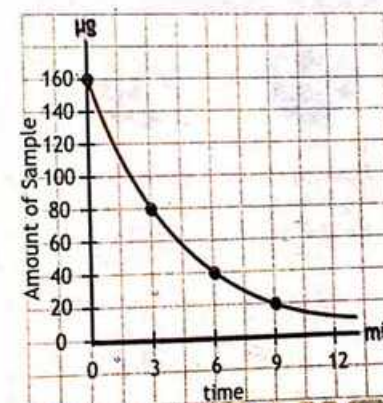
**SOLUTION:** The number of half lives ' $n$ ' past are

$$n = \frac{\Delta t}{T_{1/2}}$$

Putting values 
$$n = \frac{9.0 \text{ min}}{3.0 \text{ min}} = 3$$

Original sample remaining after any given time interval is

$$N = \left(\frac{1}{2}\right)^n N_0$$



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Putting values  $N = \left(\frac{1}{2}\right)^3 \times 160 \mu\text{g}$

or  $N = \frac{1}{8} \times 160 \mu\text{g}$  Hence  $N = 20 \mu\text{g}$  — **Answer**

The graphical representation confirms that 20  $\mu\text{g}$  of polonium-218 with half life of 3.0 min will be present after 9.0 min.

### ASSIGNMENT 18.3: HALF LIFE OF LEAD - 210

Lead - 210 has a half life of 22.3 years. How much of the 80 mg of lead will be left after 66.9 years?

### 18.5 RADIOISOTOPES

One of two or more forms of a chemical element having the same number of protons, or the same atomic number, but having different numbers of neutrons, or different atomic weights is called an isotope. The isotope that are unstable and emit radiations are called radioactive isotopes or simply radioisotopes.

Isotopes of elements that occur naturally are somewhat stable. But the isotopes, manufactured in nuclear laboratories by bombarding of subatomic particles, usually have a short life span, mostly due to their unstable nature and radioactivity. Among about 3000 known nuclides, only 257 are stable. The time scale of these decay processes ranges from a small fraction of a microsecond to billions of years.

Figure 18.9: Isotopes of Carbon



Carbon 12  
6 Protons  
6 Neutrons  
6 Electrons



Carbon 13  
6 Protons  
7 Neutrons  
6 Electrons



Carbon 14  
6 Protons  
8 Neutrons  
6 Electrons

(a) Three natural isotopes of carbon



Carbon 11  
6 Protons  
5 Neutrons  
6 Electrons

(b) The most stable artificial isotope of carbon

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The element carbon (figure 18.9) as we find it in nature consists 98.89% of  $^{12}\text{C}$  atoms and only about 1.11%  $^{13}\text{C}$  atoms. Whereas  $^{12}\text{C}$  isotopes of carbon is in trace amounts, with a half life of 5,700 years. Carbon as a whole has 15 known isotopes, from  $^6\text{C}$  to  $^{22}\text{C}$ , of which the most stable artificial radioisotope is  $^{11}\text{C}$ , which has a half-life of 20.334 minutes. All other radioisotopes have half-lives under 20 seconds, most less than 200 milliseconds.

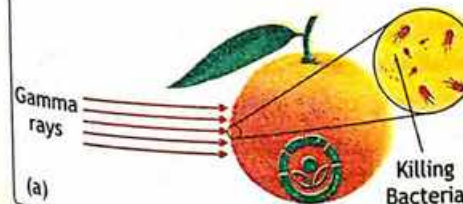
Most elements have between two and six stable isotopes (as opposed to unstable, or radioactive ones). Twenty elements, including fluorine, sodium, aluminum, phosphorus, and gold consist of only one stable isotope each. Tin, however, has ten—more than any other element.

**18.5.1 Uses of radioisotopes:** A radioactive isotope behaves in just the same way as the normal isotope chemically, which make it useful in wide variety of applications. Over 2,000 radioisotopes — radioactive isotopes — either exist in nature or have been made artificially by bombarding stable isotopes in particle accelerators. They are useful in so many applications that the word isotope is commonly used to mean radioisotope, as if stable isotopes did not exist. Few of the uses of radioisotopes are discussed below.

i. **Food Preservation:** Food irradiation is a method of treating food in order to make it safer to eat and have a longer shelf life. Even after it has been packaged, gamma rays can penetrate the packing and be used to kill bacteria, mould and insects in food as shown in figure 18.10 (a): This process prolongs the shelf-life of the food, but sometimes changes the taste.

ii. **Sterilising:** Gamma rays are also used to sterilise hospital equipment by irradiation, especially plastic syringes that would be damaged if heated as shown in figure 18.10 (b).

Figure 18.10: Gamma Irradiation



(a)



(b)

Sterilizing Medical equipment

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iii. **Agriculture:** If a plant is given fertilizer tagged with radioactive carbon-14 then the plant releases "beta radiation" and thus by measuring radioactivity in different parts of the plant, the uptake of fertilizer by plant can be determined. This technique has helped in elaborating the complex process of photosynthesis as well. Higher yield varieties of seeds have also been developed after mutation through radiation.

Figure 18.11 - Radioisotopes in agriculture



iv. **Medical Uses:** Radiopharmaceuticals — drugs that contain radioactive material — are important in the diagnosis and treatment of many diseases. They can be injected into the body, inhaled, or taken orally as medicines or to enable imaging of internal organs and bodily processes. Ionizing radiation has two very different uses in medicine — for diagnosis and therapy.

a. **Medical diagnostics:** Every organ in our bodies acts differently from a chemical point of view. Doctors and chemists have identified a number of chemicals which are absorbed by specific organs. The thyroid, for example, takes up iodine, the brain consumes quantities of glucose, and so on. With this knowledge, radiopharmacists are able to attach various radioisotopes to biologically active substances. Images are then obtained via gamma camera or a PET scan in nuclear diagnostics which enables to accurately detect disease progression and staging in vital organs.

A radioisotope used for diagnosis must emit gamma rays of sufficient energy to escape from the body and it must have a half-life short enough for it to decay away soon after imaging is completed.

b. **Radiation therapy:** High energy radiations can be used to destroy selected tissues, such as cancerous tumor.

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## Tip Bits

Why  $^{99m}\text{Tc}$  is the most preferred radioisotope for nuclear diagnostics?

The radioisotope most widely used in medicine is technetium-99m. It is an isotope of the artificially-produced element technetium and it has almost ideal characteristics for a diagnostic scan. These are:

- It has a half-life of six hours, which is long enough to examine metabolic processes yet short enough to minimise the radiation dose to the patient.
- The low energy gamma rays it emits, easily escapes the human body and are accurately detected.
- The chemistry of technetium is so versatile it can form tracers by being incorporated into a range of biologically-active substances to ensure that it concentrates in the tissue or organ of interest.
- Its logistics also favor its use. Technetium generators, a lead pot enclosing a glass tube containing the radioisotope, are supplied to hospitals from the nuclear reactor where the isotopes are made. They contain molybdenum-99, with a half-life of 66 hours, which progressively decays to technetium-99.



A technetium-99m generator

Cobalt 60 which emit beta particle and high energy gamma ray can be used to treat various cancers. Some radioisotopes are made to absorb by selected organ and radiation is concentrated on the infected tissue. For example cancerous thyroid can be treated with iodine-131.

v. **Radioactive Dating:** Archaeologists and geologists use radioactive dating to estimate the age of ancient objects. One common procedure uses carbon-14 which has a half-life of 5730 years. As long as the creature is alive, it will continue to absorb and collect carbon-14. Once the creature dies, no further carbon-14 will be ingested, and the proportion of carbon-14 will start to decline.

The proportion of the total amount of carbon that is carbon-14 is very small. Nevertheless the amount is measurable. A measurement of the activity present can therefore be used to estimate the age of the specimen. Carbon-14 dating can be used for biological tissues as old as 50 or 60 thousand years, but is most accurate for younger samples, since the abundance of  $^{14}\text{C}$  nuclei in them is greater. Very old biological materials contain no  $^{14}\text{C}$  at all.

NOT FOR SALE

Materials with relatively longer half-lives can be used to determine the age of geologic formations. Uranium-238, for example, with a half-life of  $4.53 \times 10^9$  years, can be used to date even the oldest deposits on Earth.

**EXAMPLE 18.4: CARBON-14 DATING**

Suppose you found a frozen dead animal remains in the Himalays. You took a sample from it and found that carbon-14 (half life ' $T_{1/2}$ ' = 5730 years) activity is reduced 1/8 per gram from original value. How old are the dead animal remains?

**GIVEN**

Quantity left of carbon-14 ' $N$ ' =  $1/8 N_0$   
half life of carbon-14 ' $T_{1/2}$ ' = 5730 years

**REQUIRED**

Total elapsed ' $\Delta t$ ' = ?

**SOLUTION:** Original sample remaining after any given time interval is

$$N = \left(\frac{1}{2}\right)^n N_0 \quad \text{--- ①}$$

Putting values  $N = \frac{1}{8} N_0$  or  $N = \frac{1}{(2)^3} N_0$  or  $N = \left(\frac{1}{2}\right)^3 N_0$  --- ②

Comparing equation 1 and equation 2  $n = 3$

Thus in three half lives the quantity left of carbon 14, will be  $1/8 N_0$ .

The number of half lives ' $n$ ' past is given by relation  $n = \frac{\Delta t}{T_{1/2}}$

or  $\Delta t = n T_{1/2}$  Putting values  $\Delta t = 3 \times 5730 \text{ years}$

Therefore  $\Delta t = 17,190 \text{ years}$  --- **Answer**

The remains of the dead animal are 17,000 years old.

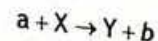
**ASSIGNMENT 18.4: CARBON-14 DATING**

Suppose the fossil of bone you are examining has 1/4 of the carbon -14 deposits as compared to bone of the living animal per gram. The half life of  $^{14}\text{C}$  is 5730 years, what is the approximate age of the fossil?

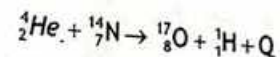
**NOT FOR SALE**

**NUCLEAR REACTIONS:** A nuclear reaction is said to occur whenever an incident nucleus, particle, or photon causes a change to occur in a target nucleus.

Such a structural change can be brought about in the nucleus by bombarding the target with sufficiently energetic particle such as neutrons, alpha particles etc. As a result the nucleons are added, removed or rearranged within a target nucleus. When Nucleus X is bombarded with some light particle  $a$ , the product nucleus Y and light particle  $b$  will be obtained by nuclear reaction. Mathematically



In 1919, Ernest Rutherford observed that when an  $\alpha$  particle strikes a nitrogen nucleus, an oxygen nucleus and a proton are produced. This nuclear reaction is written as



In such nuclear processes the conservation laws must be followed. And in nuclear reaction the sum of number of protons and neutrons should remain constant.

**Number of nucleons on LHS = Number of nucleons on RHS**

For example in the reaction  ${}^4_2\text{He} + {}^{14}_7\text{N} \rightarrow {}^{17}_8\text{O} + {}^1_1\text{H} + Q$

We can see that on both sides, there are 18 nucleons each.

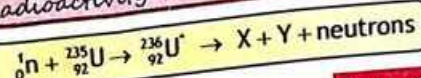
**18.6 NUCLEAR FISSION**

The process of splitting of nuclei into intermediate size nuclei is called nuclear fission. The fission process often produces free neutrons and gamma rays, and releases a large amount of energy.

**18.6.1 Discovery:** Nuclear fission was discovered in December 17, 1938 by Otto Hahn and his assistant Fritz Strassmann, and explained theoretically in January 1939 by Lise Meitner and her nephew Otto Robert Frisch.

They found that a uranium nucleus, after absorbing a low energy neutron (thermal neutron), splits into two fragments of intermediate size. The splitting of a massive nucleus into two less massive fragments was termed as nuclear fission. It can be represented by the following nuclear reaction

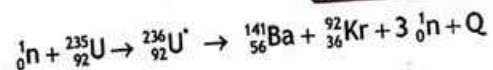
**NOT FOR SALE**



18.6

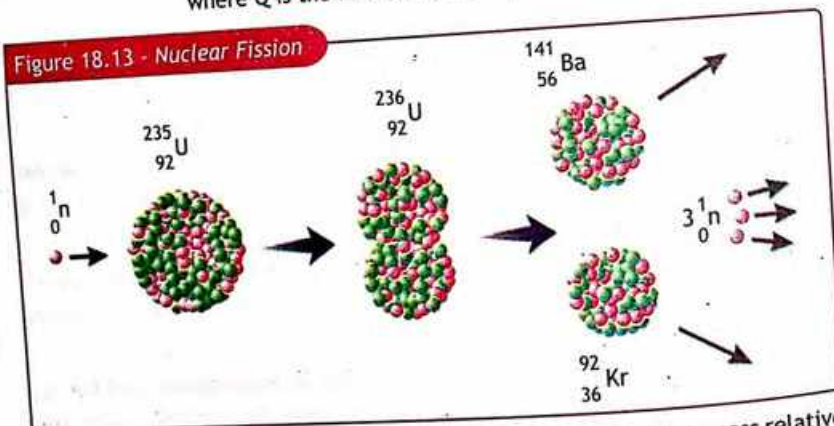
Where  ${}_{92}^{236}\text{U}^*$  is an intermediate excited state that lasts for only about  $10^{-12}$  s before splitting into X and Y. The resulting nuclei X and Y are called fission fragments. Many combinations of X and Y are possible as fission fragments in the above nuclear reaction.

Figure 18.13 shows the actual mass distribution of fragments in the fission of  ${}_{92}^{235}\text{U}$ . The process results in the production of several neutrons, typically two or three. On the average, about 2.5 neutrons are released per event. A typical reaction of this type is



where Q is the nuclear reaction energy.

Figure 18.13 - Nuclear Fission



Measurements show that a large amount of energy is released in this process relative to the amount of energy released in chemical processes. Thus, energy released is very high. It is found that 1 kg of uranium delivers as much energy as 3000 tons of coal.

**NOT FOR SALE**

Figure 18.12 - Lise Meitner

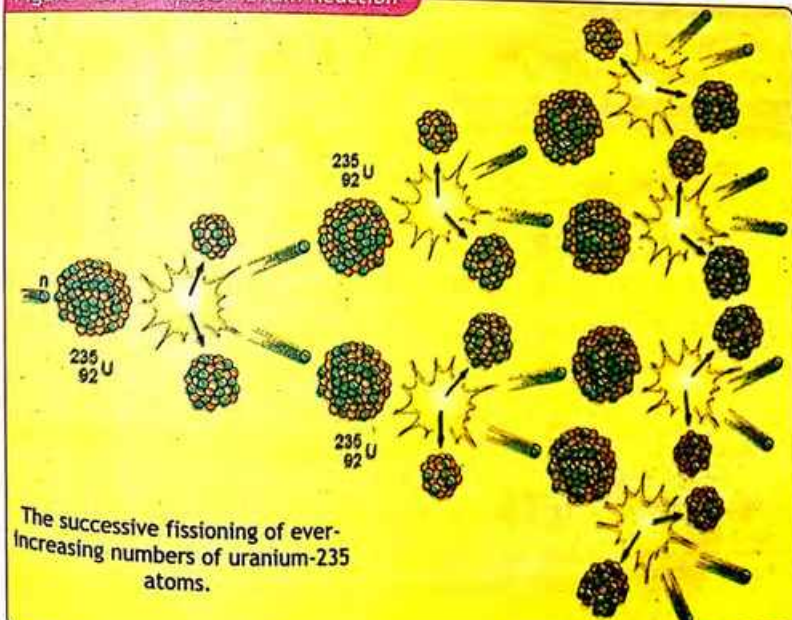


**18.6.2 Fission Chain Reaction:** When one nuclear reaction causes an average of one or more nuclear reactions, thus a self-propagating series of these reactions is achieved and is called *Fission Chain Reaction*.

The fact that fission reactions of uranium-235 give off more than one neutron on average has significant implications. As the fission of uranium-235 is initiated by the absorption of a neutron, so the neutrons given off by one fission reaction may cause additional fission reactions in other nuclei. If each of the neutrons emitted in fission of uranium-235 is absorbed by another nucleus of  ${}_{92}^{235}\text{U}$  and thus induce another fission process, it will result in the emission of still more neutrons, followed by more fissions, and so forth. As long as the average number of neutrons available to produce new fissions is greater than 1 per reaction, the number of fissions grows with time as shown in figure 18.14. If we have such an event in uncontrolled way, it may produce huge amount of energy in very short time. In explosion of atomic bomb we produce such an uncontrolled fission chain reaction.

The nuclear reactors on the other hand release the energy from nuclear fission in a controlled manner.

Figure 18.14 - Fission Chain Reaction



The successive fissioning of ever-increasing numbers of uranium-235 atoms.

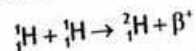
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## 18.7 NUCLEAR FUSION

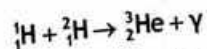
When two light nuclei combine to form a heavy nucleus, the process is called nuclear fusion.

When two nuclei form a large nucleus, the mass of larger nucleus is less than the mass of nuclei that formed it. This loss in mass appears in the form of energy. A self-sustaining fusion reaction is also possible but the energy required is possible only in the environments of stars including sun. One such cycle is:

A. Proton-proton cycle: In this process the direct collision of protons result in the formation of heavier nuclei whose collision in turn produces helium nuclei as shown in figure 18.15. The initial reaction in proton-proton cycle is



A deuteron produced in the above reaction may combine with other proton as



Finally, two such reactions can combine to form helium-4 with the release of two protons as

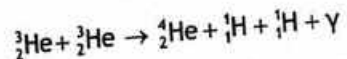
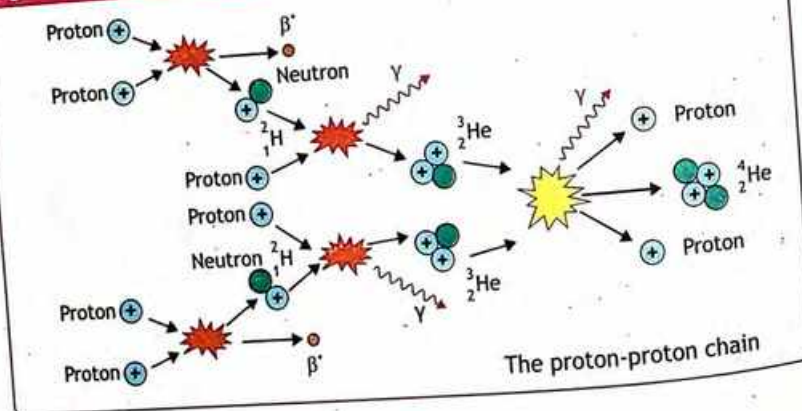


Figure 18.15: Nuclear Fusion (Chain)



NOT FOR SALE

## 18.8 BACKGROUND RADIATION

All living creatures, from the beginning of time, have been and are still being exposed to radiation. When a radiation detector is used it will record these radiations called **natural background radiation**, it comes from three sources:

**Cosmic Radiation:** The earth, and all living things on it, are constantly bombarded by radiations from space. The dose from cosmic radiation varies in different parts of the world due to differences in elevation and to the effects of the earth's magnetic field.

**Terrestrial Radiation:** Radioactive material is also found throughout nature. It is in the soil, water and vegetation. Low levels of uranium, thorium, and their decay products are found everywhere. The dose from terrestrial sources also varies in different parts of the world.

**Internal Radiation:** All people also have radioactive potassium-40, carbon-14, lead-210, and other isotopes inside their bodies from birth.

## 18.9 HAZARDS AND SAFETY FROM RADIOACTIVE MATERIALS

Nuclear radiation is potentially harmful to humans because the ionization it produces can significantly alter the structure of molecules within a living cell. The alterations can lead to the death of the cell and even of the organism itself. The amount of biological damage produced by ionizing radiation is different for different kinds of radiation.

Everyone is continually exposed to background radiation from natural sources, such as cosmic rays (high-energy particles that come from outside the solar system), radioactive materials in the environment, radioactive nuclei (primarily carbon and potassium  ${}^{40}_{19}\text{K}$ ) within our own bodies, and radon.

The effects of radiation on humans can be grouped into two categories, according to the time span between initial exposure and the appearance of physiological symptoms: (1) short-term or acute effects that appear within a matter of minutes, days, or weeks, and (2) long-term or latent effects that appear years, decades, or even generations later.

The radiation from the material can damage the cells of the person directly. This is damage by irradiation. Some of the radioactive material can be swallowed or breathed in. While inside the body, the radiation it emits can produce damage. This is damage by contamination.

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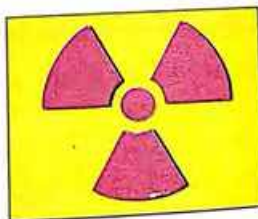
**18.9.1 Radiation sickness** is the general term applied to the acute effects of radiation. Depending on the severity of the dose, a person with radiation sickness can exhibit nausea, vomiting, fever, diarrhea and loss of hair. Ultimately, death can occur. The severity of radiation sickness is related to the dose received, and in the following discussion, the biologically equivalent doses quoted are whole-body, single doses.

Long-term or latent effects of radiation may appear as a result of high-level, brief exposure or low-level exposure over a long period of time. Some long-term effects are hair loss, eye cataracts, and various kinds of cancer. In addition, genetic defects caused by mutated genes may be passed on from one generation to the next.

**18.9.2 Safety Measures:** There are three general guidelines for controlling exposure to ionizing radiation: minimizing exposure time, maximizing distance from the radiation source and shielding yourself from the radiation source.

While working with radiation. Lab coats, shoes and safety glasses must be worn in the laboratory. Materials/equipment which are not required must not be brought into the laboratory or stored inside. An inventory of radioactive sources used in the laboratory must be maintained and updated.

**POINT TO CONSIDER** International (trefoil) symbol of radiation. This sign must be posted where radioactive materials are handled or where radiation-producing equipment is used. Sign is used as a warning to protect people from being exposed to radioactivity.



International Atomic Energy Agency (IAEA) in 2007 has launched a new symbol for 'Ionizing Radiation Warning – Supplementary Symbol'. New symbol is intended to supplement the existing, well recognized, radiation trefoil symbol. The new symbol has been designed to convey the message "Danger – Stay Away" to anyone who sees it, regardless of their age, education or cultural background.



**NOT FOR SALE**

Food items must not be stored or consumed inside the laboratory. Radiation symbols must be displayed wherever active sources are being manipulated or stored.

**Nucleus:** a region consisting of protons and neutrons at the center of an atom

**Nucleons:** the particles found inside nuclei

**Nuclide:** a type of atom whose nucleus has specific numbers of protons and neutrons

**Decay:** the process by which an atomic nucleus of an unstable atom loses mass and energy by emitting ionizing particles

**Alpha Decay:** type of radioactive decay in which an atomic nucleus emits an alpha particle (Helium nuclei)

**Beta Decay:** type of radioactive decay in which an atomic nucleus emits a beta particle (electrons)

**Gamma Decay:** type of radioactive decay in which an atomic nucleus emits gamma rays (electromagnetic rays of high frequency and short wavelength)

**Half life:** the time needed for half of the original nuclei of a sample of a radioactive substance to undergo radioactive decay

**Radioactive:** a substance or object that emits nuclear radiation

**Radioactive Dating:** an application of radioactive decay in which the age of a material is determined by the amount of radioactivity of a particular type that occurs

**Carbon - 14 Dating:** a radioactive dating technique based on the radioactivity of carbon-14

**Nuclear Radiation:** rays that originate in the nuclei of atoms

**Nuclear Fission:** reaction in which a nucleus splits

**Nuclear Fusion:** a reaction in which two nuclei are combined, or fused to form a larger nucleus

**Shielding:** a technique to limit radiation exposure

**PROJECTS**

**GROUP A 'MARIE CURIE':** It is said that Marie Curie died of aplastic anemia from exposure to radiation in the course of her scientific research and radiological work at field hospitals during World War I. What is meant by the damaging effects of ionizing radiation? How much was known about damaging effects of radiation at curies time? Research her life and give a presentation about her achievements.

**GROUP B 'ATOMIC BOMBS':** During the final stage of World War II, the United States detonated two nuclear weapons over the Japanese cities of Hiroshima and Nagasaki on August 6 and 9, 1945, respectively. Explain the destruction from these bombs in a classroom presentation.

**NOT FOR SALE**

**GROUP C 'PNRA':** Pakistan Nuclear Regulatory Authority (PNRA) control, regulates and supervises all matters related to nuclear safety in Pakistan. Search the internet and other materials to find out the activities, targets and performance of this organization. Prepare a report to be published in school magazine.

**GROUP D 'NUCLEAR MEDICINE':** Investigate careers in nuclear medicine. Interview people who work with radiation or with isotopic tracers in a hospital. Find out what kind of patients they treat or test and the technology they use. What training is necessary for this type of career? Make a presentation and discuss it with your classmates.

**GROUP E 'HARMFUL EFFECTS OF RADIATION':** Design a questionnaire to investigate what people in your community know about harmful effects of radiation. Give the questionnaire to your classmates for their comments and if your teacher approves, conduct a study with people in your community. Present your results in the form of a class presentation and discussion.

## EXERCISE

- What is the number of neutrons in the plutonium  $^{242}_{92}\text{Pu}$ ?  
A. 92      B. 142      C. 150      D. 242
- Which one or more of the three decay processes ( $\alpha$ ,  $\beta$ , or  $\gamma$ ) results in a new element?  
A. Only  $\alpha$       B. Only  $\beta$       C. Only  $\gamma$       D.  $\alpha$  and  $\beta$
- What type of nuclear decay leaves the number of protons and neutrons unchanged?  
A. alpha decay      B. beta decay      C. gamma decay      D. both A & B
- What type of nuclear decay most often produces the greatest mass and charge loss?  
A. alpha decay      B. beta decay      C. gamma decay      D. both B & C
- $^{214}_{84}\text{Po}$  undergoes  $\alpha$ -decay to produce a daughter nucleus that itself undergoes  $\beta$ -decay. Which one of the following nuclei is the one that ultimately results?  
A.  $^{211}_{82}\text{Pb}$       B.  $^{215}_{80}\text{Hg}$       C.  $^{211}_{81}\text{Tl}$       D.  $^{212}_{83}\text{Bi}$
- Radium-226 decays by emitting an alpha particle. What is the daughter nucleus?  
A. Rd      B. Rn      C. Bi      D. Pb

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- $^{39}\text{Ar}$  is an isotope with a half-life of 269 yr. It will reduce to half in  
A. 134.5 min      B. 134.5 Years      C. 269 min      D. 269 Years
- A sample starts with 1000 radioactive atoms. How many half-lives have elapsed when 750 atoms have decayed?  
A. 0.25      B. 1.5      C. 2.0      D. 2.5
- Origin of energy from the sun and stars is  
A. fission      B. fusion      C. Carbon dating      D. radioactivity

## CONCEPTUAL QUESTIONS

Give a brief response to the following questions

- The atomic number of one particular isotope is equal to its mass number. Which isotope is it?
- Which is more likely to expose, a film kept in a cardboard box,  $\alpha$ -particles or  $\beta$ -particles? Explain
- Is it possible for a form of heavy hydrogen to decay by emitting an alpha particle? Explain.
- Different isotopes of a given element have different masses but they have the same chemical properties. Explain why chemical properties are unaffected by a change of isotope.
- What fraction of a radioactive sample has decayed after two half-lives have elapsed?
- Can carbon-14 dating give the age of fossil dinosaur skeletons? Explain.
- Some food is treated with gamma radiation to kill bacteria. Why is there not a concern that people who eat such food might be consuming food containing gamma radiation?
- Radioactive  $\alpha$ -emitters are relatively harmless outside the body, but can be dangerous if ingested or inhaled. Explain.
- If nuclear radiation is harmful. How it can be used for treatment of diseases?

## COMPREHENSIVE QUESTIONS

Give an extended response to the following questions

- What is nucleus? How a nuclide is represented symbolically?
- What is radioactivity? Give the nature, ionizing and penetration abilities of the three types of radioactive emissions.

NOT FOR SALE

- 3 What are nuclear transmutations? What changes in the composition of the nucleus is observed when alpha or beta particles are emitted? Explain by symbolic equations.
- 4 Radioactive sources are said to have half life. What is the meaning of half life?
- 5 What are radioisotopes? Explain their uses for various applications?
- 6 How is carbon-14 used to determine the ages of wood, bones and other artifacts?
- 7 What are fission and fusion?
- 9 What are background radiations? What are its major sources?
- 10 What are radiation hazards? How can we safeguard ourselves from radiation?

## NUMERICAL QUESTIONS

- 1 How many neutrons are contained in a gold nucleus  $^{197}_{79}\text{Au}$ ?
- 2  $^{220}_{86}\text{Rn}$  decays via alpha decay. Identify the daughter nuclide.
- 3 Write the nuclear equations for the beta decay of  $^{210}_{82}\text{Pb}$  and  $^{234}_{90}\text{Th}$
- 4 Iodine - 131 is an important radioisotope for medical diagnostic and treatment procedures. The half life of  $^{131}\text{I}$  is 8.02 days. Out of 100 g of the sample how much will be left after 24 days?
- 5 Phosphorus-32 is used in plant sciences for tracking a plant's uptake of fertiliser from the roots to the leaves. The half life of  $^{32}\text{P}$  is 15 days. Out of 800  $\mu\text{g}$  of the activity given as fertilizer how much will be left after one month?
- 6  $^{14}\text{C}$  to  $^{12}\text{C}$  ratio in an animal fossil is found to be one fourth of the ratio in the bone of living animal. The half life of  $^{14}\text{C}$  is 5730 years, how old is the fossil?

NOT FOR SALE

## Glossary

**Alternating current:** The current which changes its direction a number of times in one second is called alternating current.

**Ammeter:** A current measuring instrument is called ammeter.

**Analogue electronics:** The branch of electronics which deals with variable quantities is called analogue electronics.

**Antinode:** The points of maximum amplitude of stationary waves are called antinodes.

**Atomic mass number:** Total numbers of protons and neutrons present in the nucleus.

**Atomic number:** Number of protons present in the nucleus.

**Audio cassette:** Device for collecting sound.

**Capacitance:** Capacitance is the ability of a capacitor to store an electrical charge.

**Centre of curvature:** The centre of that spherical surface whose part is the mirror.

**Chromatic aberration:** Defect of any lens produced due to dispersion of light.

**Compressional waves:** Waves in which particles of the medium vibrate parallel to the direction of the wave.

**Computer:** A machine which can communicate and analyse information efficiently and has a vast and long last memory.

**Concave mirror:** A spherical mirror whose inner polished surface reflects.

**Conventional current:** The current due to positive charge equivalent to negative charge flowing in the opposite direction.

**Convex mirror:** A spherical mirror whose external surface reflects.

**Crest:** In case of transverse waves, the portion of the displacement above the equilibrium position.

**Critical angle:** The angle in the denser medium whose respective angle of refraction in the rare medium is  $90^\circ$ .

**Compact disc or CD:** A device used to store data with the help of digital technology.

NOT FOR SALE

**Diffraction:** Bending of waves round an obstacle.

**Digital electronics:** Name of processing data provided in the form of digits.

**Direct current:** Current which always flows in one direction.

**Electric current:** The rate of flow of electric charge through any cross sectional area.

**Electric field:** The space around a charged body in which another charge experiences its effect in the form of a force.

**Electric intensity:** The influence of a force acting on a unit positive charge at any place.

**Electric lines of force:** Lines drawn in the direction of electric intensity in an electric field.

**Electric potential:** Potential energy of a unit charge in any electric field.

**Electric power:** Amount of energy obtained from electric current in unit time.

**Electromagnetic field:** Production of magnetic field due to passage of electric current through a conductor.

**Electromagnetic induction:** The phenomenon in which e.m.f. is produced due to relative motion of coil and magnet.

**Electromagnetic waves:** Such waves, which do not require any material medium for their propagation.

**Electromotive force:** The energy needed to move a charge through the whole circuit including the battery.

**Electronics:** The branch of physics in which the flow of electrons is controlled and used according to the need in semiconductor devices.

**Electroscope:** An instrument used for measuring the nature and presence of charge on a body.

**Far sightedness:** A defect of eyes due to which near objects are not clearly visible.

**Fixed capacitor:** The capacitor whose parts are fixed by design.

**Floppy:** A device used for storing computer data.

**Focal length:** The distance between the pole and principal focus of any mirror or the distance between optical centre and principal focus of any lens.

**NOT FOR SALE**

**Fusion reaction:** The phenomenon in which small nuclei diffuse each other to form a larger nucleus.

**Galvanometer:** An instrument which indicates the current in a circuit.

**Half life:** The time in which the number of atoms of a radioactive element becomes half.

**Information technology:** Scientific method of collecting, arranging processing and arranging information.

**Infrasound:** Sound of frequency less than 20 hertz, which are inaudible to human ears.

**Intensity of sound:** Energy transmitting per second through a unit area placed perpendicular to the direction of sound waves.

**Interference:** Resultant displacement of two or more waves in a medium by combining the two coherent waves.

**Internet:** Important source of global contact.

**Isotopes:** Atoms of an element whose atomic number is same but mass number is different.

**Kilowatt hour:** Quantity of that energy which is obtained from one kilowatt power in one hour.

**Magnetic flux:** The number of magnetic lines of forces passing through any surface.

**Magnification:** The ratio of the height of the image to the height of the object.

**Mechanical waves:** Such waves which require a material medium for their propagation.

**Music:** Pleasant and musical sound.

**Mutual induction:** The current induced in the coil by the change of flux in the nearby coil.

**Natural radioactivity:** The natural, spontaneous emission of radiation from radioactive element.

**Noise:** Unpleasant sound.

**N-type Semi-conductor:** A semi-conductor in which pentavalent impurity is doped.

**NOT FOR SALE**

**Nuclear fission reaction:** The splitting of heavy nucleus into two parts in which huge amount of energy is released.

**Pitch:** Characteristic of sound due to which shrill and grave sound is distinguished.

**P-N junction:** A semi-conductor diode.

**Pole:** Centre of the mirror.

**Power of lens:** Inverse value of focal length (in metre).

**Principal focus:** Point from where rays parallel to the principal axis pass after reflection from a concave mirror.

**P-type semi-conductor:** A semi-conductor in which trivalent impurity is doped.

**Quality of sound:** Characteristic of sound due to which different sounds are distinguished.

**Radio isotopes:** Isotopes which emits different radiation.

**Radio:** An instrument which imparts sounds to us.

**Rectification:** Conversion of alternating current into direct current.

**Reflection:** Bouncing of waves after striking from the other medium.

**Refractive index:** Ratio of speed of light in air to the speed of light into any other medium.

**Remote control:** An instrument which controls television or electronic equipments by sitting at a place in line with a device.

**Self induction:** The e.m.f. induced in a coil due to change in the current of that coil.

**Semi-conductor:** Elements of the 4<sup>th</sup> group silicon and germanium.

**Short sightedness:** A defect of eyes due to which distant objects are not seen clearly.

**Simple harmonic motion:** Vibratory motion in which the acceleration of the body is directly proportional to its displacement.

**NOT FOR SALE**

**Solenoid:** Cylindrical coil of the wire having more than one turn.

**Sound:** A form of energy which is transferred from one place another due to compressional waves.

**Specific resistance:** Resistance of unit length and unit cross sectional area of a conductor.

**Spherical aberration:** Defect of thick and large aperture of a lens.

**Stationary waves:** Waves in which the amplitude of all particles of the medium remains constant.

**Tele communication:** To impart information quickly to far off areas.

**Total internal reflection:** The reflection of light in the same denser medium from the surface of a rare medium.

**Transformer:** An electric instrument which increases or decreases the value of alternating voltage.

**Transverse waves:** Waves in which particles of the medium vibrate perpendicular to the direction of motion of the wave.

**Trough:** In case of transverse waves, portion of the displacement below the equilibrium position.

**Ultrasonics:** Sound of frequency more than 20000 hertz, which are inaudible to human ears.

**Variable capacitor:** A capacitor whose area of plates can be changed and desired capacitance can be achieved.

**Video cassette:** A device used to store sound and pictures.

**Voltmeter:** An instrument used for the measurement of potential difference between the ends of a circuit.

Handwritten calculation:

$$\begin{array}{r}
 3050 \\
 150 \\
 \hline
 0600 \\
 152500 \\
 305000 \\
 \hline
 457508
 \end{array}$$

**NOT FOR SALE**

# Answers

## Answer Chapter 10

|                         |                                 |
|-------------------------|---------------------------------|
| Assignment 10.1 :       | 2 s                             |
| Assignment 10.2 :       | - 45 N                          |
| Assignment 10.3 :       | 1.4 s                           |
| Assignment 10.4 :       | 54.6°                           |
| Assignment 10.5 :       | 9.77 N/kg                       |
| Assignment 10.6 :       | 2.02 × 10 <sup>4</sup> Hz       |
| Numerical problem 10.1: | 1.25 Hz, 0.8 s                  |
| Numerical problem 10.2: | 2.5 × 10 <sup>3</sup> N/m       |
| Numerical problem 10.3: | 0.99 m, 0.16 m, 0.5 s and 0.5 s |
| Numerical problem 10.4: | 50 Hz, 0.02 s                   |
| Numerical problem 10.5: | 1.4 Hz                          |
| Numerical problem 10.6: | 0.5 Hz                          |
| Numerical problem 10.7: | 244 m, 3.26 m                   |

## Answer Chapter 11

|                         |                                       |
|-------------------------|---------------------------------------|
| Assignment 11.1 :       | 2.39 dB                               |
| Assignment 11.2 :       | 1.7 km or 1 mile                      |
| Assignment 11.3 :       | Speed = 350 m/s and Frequency 1400 Hz |
| Assignment 11.4 :       | 1320 m                                |
| Numerical problem 11.1: | 109.14 dB                             |
| Numerical problem 11.2: | 1.5 × 10 <sup>3</sup> m/s or 1500 m/s |
| Numerical problem 11.3: | 134 decibels                          |
| Numerical problem 11.4: | 106.02                                |
| Numerical problem 11.5: | 319.2 m/s.                            |
| Numerical problem 11.6: | 1.7 km or mile                        |
| Numerical problem 11.7: | 17 m and 1.7 cm                       |
| Numerical problem 11.8: | 330 m/s, 32 m                         |

## Answer Chapter 12

|                   |                                            |
|-------------------|--------------------------------------------|
| Assignment 12.1 : | - 1.64                                     |
| Assignment 12.2 : | -0.45 m (virtual image, behind the mirror) |
|                   | 0.18 m (upright, smaller image)            |
| Assignment 12.3 : | 1.44                                       |
| Assignment 12.4 : | 1.33, water                                |
| Assignment 12.5 : | 42.2°                                      |
| Assignment 12.6 : | 15.0 cm, - 0.500                           |
|                   | - 5.56 cm, 0.445                           |
|                   | 3 times, 4 times                           |
| Assignment 12.7 : | The magnification is reduced in magnitude. |
| Assignment 12.8 : | Its new value is -79                       |
| Assignment 12.9 : | -197, 990 mm                               |

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|                         |                            |
|-------------------------|----------------------------|
| Numerical problem 12.1: | 60 cm, - 4.5 cm            |
| Numerical problem 12.2: | - 3.33 cm, - 0.8 cm        |
| Numerical problem 12.3: | 1.56 × 10 <sup>4</sup> m/s |
| Numerical problem 12.4: | 33°, 74°                   |
| Numerical problem 12.5: | 66.3°                      |
| Numerical problem 12.6: | 0.571, +4                  |
| Numerical problem 12.7: | 9.3                        |
| Numerical problem 12.8: | 30 mm, 1200 mm             |

## Answer Chapter 13

|                         |                                                                       |
|-------------------------|-----------------------------------------------------------------------|
| Assignment 13.1 :       | 26.0 N                                                                |
| Assignment 13.2 :       | 8 μN                                                                  |
| Assignment 13.3 :       | 60 J                                                                  |
| Assignment 13.4 :       | 4 μF                                                                  |
| Assignment 13.5 :       | 2 × 10 <sup>4</sup> F or 2 μF, 33.3 V and 66.6 V                      |
| Assignment 13.6 :       | 9 × 10 <sup>4</sup> F or 9 μF, 2400 μC and 4800 μC                    |
| Numerical problem 13.1: | 8.22 × 10 <sup>4</sup> N and                                          |
| Numerical problem 13.2: | (a) 11.25 N (b) force on 10 μC charge is same as force on 5 μC charge |

## Numerical problem 13.3:

|                         |                                               |
|-------------------------|-----------------------------------------------|
| Numerical problem 13.4: | (c) 2.25 × 10 <sup>6</sup> N/C or ) 2.25 MN/C |
| Numerical problem 13.5: | (a) 0.129 N positive x-direction              |
| Numerical problem 13.6: | (b) 0.428 N negative x-direction              |
| Numerical problem 13.7: | 5 C                                           |

## Answer Chapter 14

|                         |                                      |
|-------------------------|--------------------------------------|
| Assignment 14.1 :       | 0.704 μC or 7.04 × 10 <sup>7</sup> C |
| Assignment 14.2 :       | 0.54 μF, 60 V, 30 V and 20 V         |
| Assignment 14.3 :       | 5 pF, 18 pC, 27 pC                   |
| Assignment 14.4 :       | 180 A                                |
| Assignment 14.5 :       | 8.0 A                                |
| Assignment 14.6 :       | 1.5 Ω                                |
| Assignment 14.7 :       | 0.5 A                                |
| Assignment 14.8 :       | 9.09 s                               |
| Numerical problem 14.1: | 4.54 s                               |
| Numerical problem 14.2: | 3.6 Ω                                |
| Numerical problem 14.3: | Rs. 1784.2                           |
| Numerical problem 14.4: | 30 V                                 |
| Numerical problem 14.5: | 3.2 A                                |
| Numerical problem 14.6: | 600 Ω                                |
| Numerical problem 14.7: | 0.3 A                                |
|                         | 15.6 A, 34000 J (34 kJ)              |
|                         | 17 J                                 |
|                         | Rs. 5.84                             |

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|-------------------------|-----------------------------------------------------------------------------------|
| Answer Chapter 15       | 2.8 N                                                                             |
| Assignment 15.1 :       | 8.6 mH                                                                            |
| Assignment 15.2 :       | 1350 V                                                                            |
| Assignment 15.3 :       | 0.3 N                                                                             |
| Numerical problem 15.1: | $2.5 \times 10^{-3}$ N                                                            |
| Numerical problem 15.2: | 8 A                                                                               |
| Numerical problem 15.3: | 14 mH                                                                             |
| Numerical problem 15.4: | 80, 22000                                                                         |
| Numerical problem 15.5: | 5.45                                                                              |
| Numerical problem 15.6: | 0.06                                                                              |
| Numerical problem 15.7: |                                                                                   |
| Answer Chapter 18       | Radon - $^{220}_{86}\text{Rn}$                                                    |
| Assignment 18.1 :       | Magnesium - $^{24}_{12}\text{Mg}$                                                 |
| Assignment 18.2 :       | 10 mg                                                                             |
| Assignment 18.3 :       | 11,460 years                                                                      |
| Assignment 18.4 :       | 118                                                                               |
| Numerical problem 18.1: | $^{220}_{86}\text{Rn} \rightarrow ^{216}_{82}\text{Pb} + ^4_2\text{He}$ (Bismuth) |
| Numerical problem 18.2: | $^{210}_{82}\text{Pb} \rightarrow ^{210}_{83}\text{Bi} + \beta^-$ (Bismuth)       |
| Numerical problem 18.3: | $^{234}_{90}\text{Th} \rightarrow ^{234}_{91}\text{Pa} + \beta^-$ (Protactinium)  |
| Numerical problem 18.4: | 12.5 g                                                                            |
| Numerical problem 18.5: | 200 $\mu\text{g}$                                                                 |
| Numerical problem 18.6: | 22,920 years                                                                      |

## Author's Profile

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مومن تو آپس میں بھائی بھائی ہیں  
پس اپنے دو بھائیوں میں صلح کرادیا کرو  
اور اللہ سے ڈرتے رہو  
تاکہ تم پر رحمت کی جائے۔  
(سورۃ الحجرات: ۱۰)