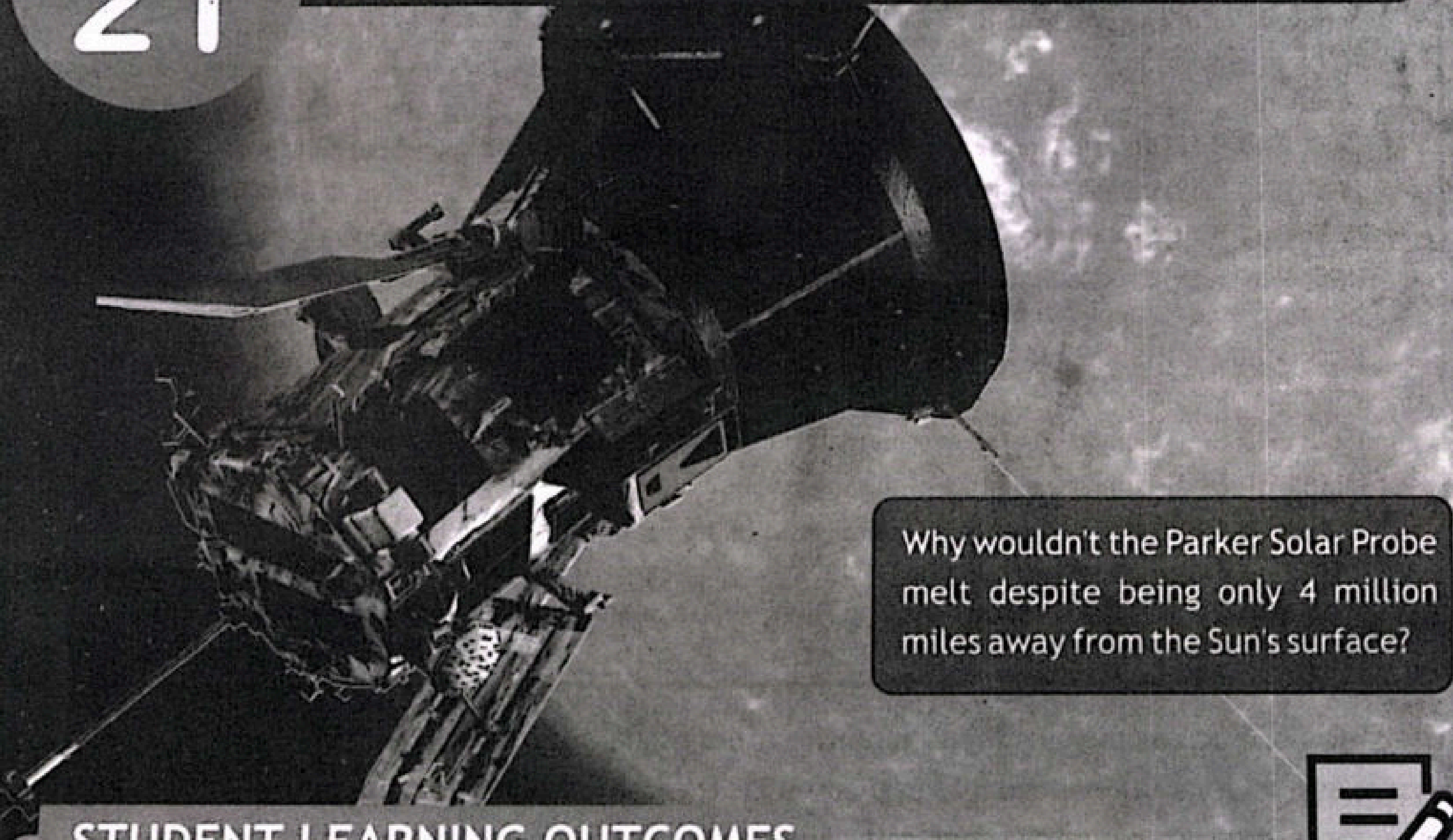
Unit 21

NUCLEAR PHYSICS



Why wouldn't the Parker Solar Probe melt despite being only 4 million miles away from the Sun's surface?

STUDENT LEARNING OUTCOMES

The students will:

- ✓ [SLO: P-10-F-01] Describe the structure of the atom.
- ✓ [SLO: P-10-F-02] Justify the findings of the alpha-particle scattering experiments.
- ✓ [SLO: P-10-F-03] Define the terms proton number (atomic number) Z and nucleon number (mass number) A and be able to calculate the number of neutrons in a nucleus.
- ✓ [SLO: P-10-F-04] Recall the term nuclide and use the nuclide notation $^{A}_{Z}X$.
- ✓ [SLO: P-10-F-05] Explain what is meant by an isotope and state that an element may have more than one isotope.
- ✓ [SLO: P-10-F-06] Explain what is meant by background radiation.
- ✓ [SLO: P-10-F-07] state the sources that make a significant contribution to background radiation.
- ✓ [SLO: P-10-F-08] Describe the emission of radiation from a nucleus as spontaneous and random.
- ✓ [SLO: P-10-F-09] Describe α-particles, β-particles and γ-radiation.
- ✓ [SLO: P-10-F-10] Justify qualitatively the order of strength for α-particles, β-particles and γ-radiation in terms of their (a) relative ionizing effects (b) relative penetrating powers
- ✓ [SLO: P-10-F-11] Describe the deflection of α-particles, β-particles and γ-radiation in electric fields and magnetic fields.
- ✓ [SLO: P-10-F-12] Explain that radioactive decay is a change in an unstable nucleus that can result, most commonly.
- ✓ [SLO: P-10-F-13] Use decay equations, using nuclide notation, to show the emission of α-particles, β-particles and γ-radiation.
- ✓ [SLO: P-10-F-14] Describe nuclear reactions (fission & fusion) with examples.

- ✓ [SLO: P-10-F-14] Recognise that matter can be converted to energy and vice versa (in this way the law of conservation of energy still holds).
- ✓ [SLO: P-10-F-15] Apply the equation $E = mc^2$ to calculate the energy released in the process of nuclear reactions.
- ✓ [SLO: P-10-F-16] Describe the activity of a radioactive material in terms of counts per unit time.
- ✓ [SLO: P-10-F-17] Define and infer the half-life of materials.
- ✓ [SLO: P-10-F-18] Explain and apply the concept of Carbon dating to solve problems.
- ✓ [SLO: P-10-F-19] Explain how the type of radiation emitted and the half-life of the isotope determine which isotope is used for applications.
- ✓ [SLO: P-10-F-20] State the effects of ionizing nuclear radiations on living things, including cell death, mutations and cancer.
- ✓ [SLO: P-10-F-21] Explain how radioactive materials are moved, used and stored in a safe way.
- ✓ [SLO: P-10-F-22] Explain the nature of the Sun.
- ✓ [SLO: P-10-F-23] Describe that it is hypothesized that most of the matter in the universe is made up of dark matter.
- ✓ [SLO: P-10-G-01] Explain, with examples in Physics, falsifiability as the idea that a theory is scientific only if it makes assertions that can be disproven.

The study of nuclear physics focuses on the atomic nucleus, composed of protons and neutrons known as nucleons. A key principle in this field is the conservation of mass-energy, which explains how mass-energy remains constant during conversions. Nuclear reactions involve the transformation of mass-energy into various forms of energy like kinetic energy, gamma rays, or thermal energy. Radioactivity, another important concept, involves the decay of unstable atomic nuclei and the emission of radiation such as alpha, beta, or gamma particles. The rate of decay is measured by half-life. Nuclear physics has applications in nuclear power generation, medicine, weapons, and astrophysics. It helps understand matter in extreme conditions and uncover the fundamental forces of the universe through the study of atomic nuclei and interactions.

21.1 DISCOVERY ATOMIC NUCLEUS

British physicist J.J. Thomson made a groundbreaking discovery on April 30, 1897, revealing that atoms are made up of smaller components. Following this, Thomson and other scientists worked to understand the complexities of atomic structure. In 1898, Thomson suggested that atoms are positively charged chunks of matter with negatively charged electrons scattered throughout, similar to raisins in a fruitcake. This idea, known as the "plum pudding model," gained attention because of Thomson's role in discovering electrons.

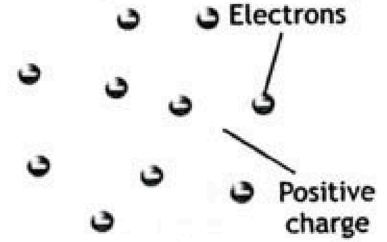


FIGURE 21.1

The Thomson plum pudding model of the atom. Electrons are imbedded in a uniform sphere of positive charge

By the end of the nineteenth century, scientists discovered that electrons make up only a tiny part of an atom's total mass. This led to the conclusion that the rest of the atom must consist of positive charge (since atoms are neutral) and most of the mass. The question remained: how is mass and positive charge spread out in the atom?

Thomson's plum pudding model was disproven in 1911 by Ernest Rutherford's alpha-particle scattering experiment. Rutherford studied uranium's radioactive decay and found that it emits two types of radiation. One type, called alpha (α) rays, is less penetrating than the other type, which he named beta (β) rays. Later in this chapter, we will delve into a detailed study of these rays.

Rutherford and his research assistant, Hans Geiger, created a special device (figure 21.2) to investigate how alpha particles interacted with thin gold foils. They directed alpha rays towards a piece of gold foil and used a screen coated with zinc sulfide to detect the scattered alpha rays. Whenever an alpha particle hit the zinc sulfide, it emitted light that could be seen through a detector. Rutherford moved the detector to different positions around the foil to see if the alpha rays would be deflected.

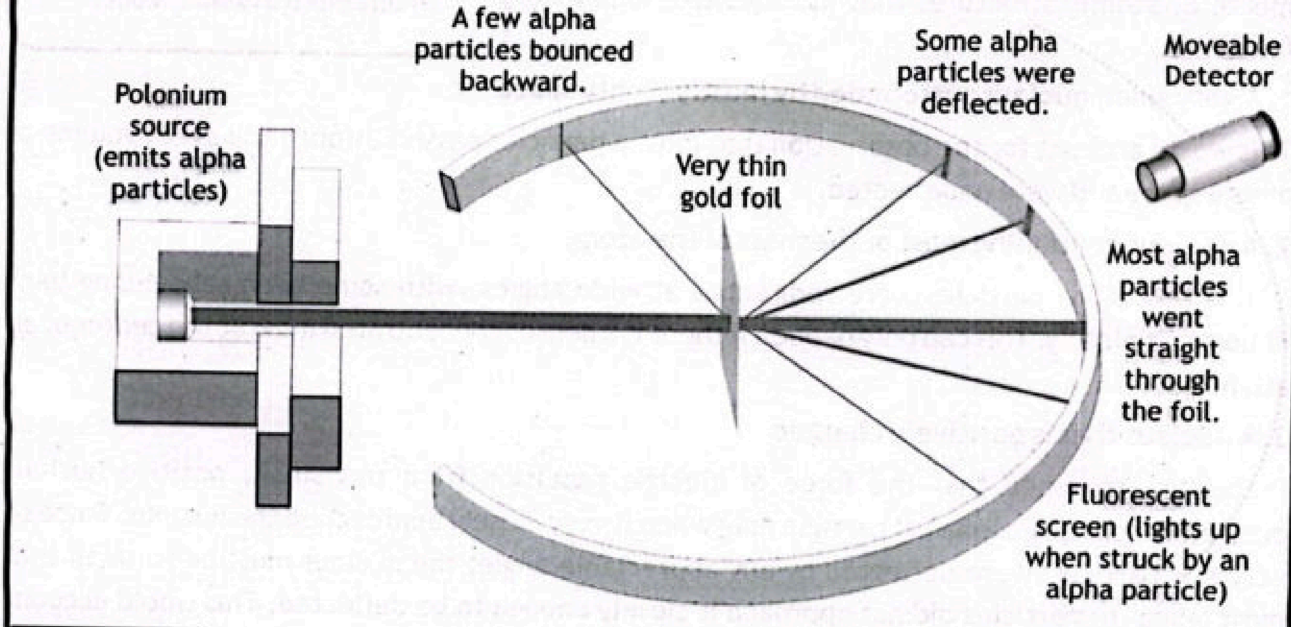


FIGURE 21.6 Rutherford's experiment aimed a beam of alpha rays at a sheet of gold foil.

According to Thomson's model of the atom, the alpha particles should have passed straight through the foil without much deflection. Initially, most of the alpha particles did pass through as expected. However, after a few days, Geiger excitedly informed Rutherford that they had observed some alpha particles scattering at angles greater than 90°.

Rutherford was amazed by this discovery and compared it to the unlikely event of a 15-inch shell bouncing back after hitting a piece of tissue paper. The observations consistently showed that about 1 in every 20,000 alpha particles was deflected more than 90°.

Rutherford determined that the alpha particles could only be repelled by an immensely powerful electrostatic field. For such a field to exist, all the positive charge had to be confined within a minuscule space at the atom's core. Hence, Rutherford put forth his atomic model known as nuclear model of atom, where the majority of an atom's positive charge and mass is concentrated in a tiny region at the center which he termed as 'nucleus', while the negatively charged electrons orbit around it, similar to planets revolving around the Sun, as shown in the Figure 21.3.

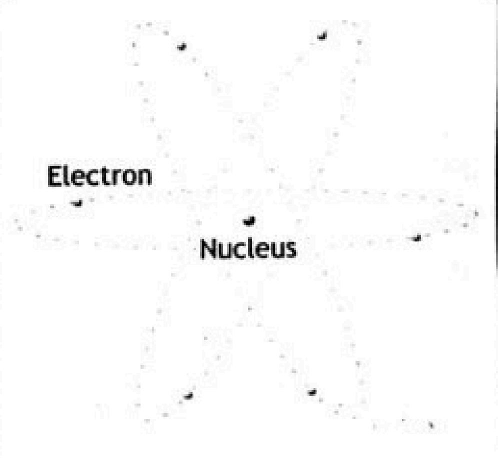


FIGURE 21.3
Rutherford's Atomic Model

In interpreting these results, Rutherford formulated a model of atomic structure, that includes the following features:

1. A very small nucleus surrounded by mostly empty space

This would account for the observation that most a particles passed through this great volume of empty space and were undeflected.

2. A nucleus containing most of the mass of the atom

Only a few alpha particles were redirected at wide angles, with some even rebounding back almost completely. This can only happen if there is a dense, concentrated mass at the center of an atom.

3. A nucleus that is positively charged

Rutherford reasoned that the force of electric repulsion from this small, positive nucleus deflected a positive alpha (α) particle only when it very closely approached the nucleus. Since so very few particles were deflected by any appreciable angle, the nucleus must be so small that most alpha (α) particles did not approach it closely enough to be deflected. This would account for the observation that most alpha (α) particles passed through this great volume of empty space and were un-deflected.

4. A number of very light, negatively charged electrons move in orbits around the nucleus.

As the alpha particles traveled straight through the empty space within the atom, every so often one of them would come across an electron, attract it due to electrostatic force, and continue on its path, hardly affected by the small mass of the electron it picked up.

The gold atom, now missing an electron, would become a positive ion. Rutherford proposed that these electrons orbited the positive nucleus, kept in place by electric attraction, similar to how planets orbit the Sun due to gravity. The currently accepted model is quite different from the Rutherford model of atom.

This simplistic picture is now replaced by more accurate and advanced quantum mechanical description of the atom. In this model the nucleus is made up of protons and neutrons, which are tightly packed together in very small volume. Protons have a positive charge, while neutrons have no charge. The number of protons in the nucleus determines the element of the atom. The size of an atom compared to the nucleus is quite significant. An atom is mostly empty space, with the nucleus located at the center.

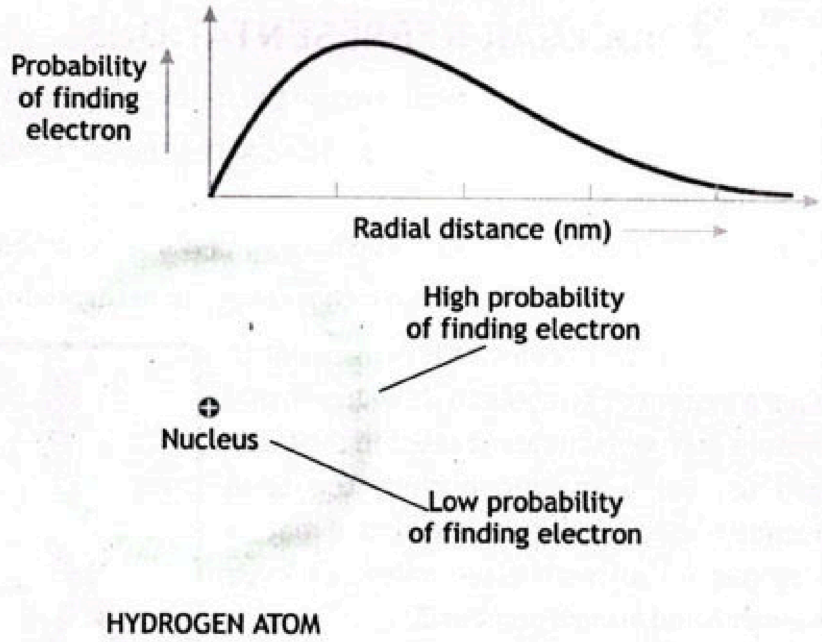


FIGURE 21.4 The electron cloud, or probability distribution, for the ground state of the hydrogen atom. The cloud is most dense—corresponding to the highest probability.

The size of the nucleus is typically about 10,000 times smaller than the size of the atom as a whole. The size difference is like a ping pong ball in the centre of a 2 km circle (akin to a football with flies around it in a boundary of several football fields). The electrons, on the other hand, are much smaller and lighter than the protons and neutrons. They are constantly in motion, buzzing around the nucleus at incredibly high speeds. However, their exact location and movement cannot be determined with certainty. Instead, we can only describe their probable location based on the probabilities dictated by quantum mechanics.

The electrons are organized into different energy levels or shells around the nucleus. These shells are not physical tracks or orbits like the planets in a solar system, but rather they represent the energy levels that the electrons can occupy. The closer a shell is to the nucleus, the lower the energy level of the electrons in that shell. Electrons can move between different energy levels by absorbing or releasing energy. When an electron absorbs energy, it jumps to a higher energy level. Conversely, when it releases energy, it drops to a lower energy level. This energy can come from various sources, such as heat, light, or electrical currents.

If we were able to see an atom, we would not see a distinct boundary between the nucleus and the electron cloud. Instead, we would see a fuzzy cloud of electrons surrounding the nucleus. This electron cloud represents the probable locations of the electrons at any given time (figure 21.4). The nucleus, on the other hand, would appear as a small, dense core within the cloud.

21.2 NUCLEAR REPRESENTATIONS

In describing the atomic nucleus, we use the following quantities

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

In representing a nucleus, it is convenient to have a system of symbols to show how many protons and neutrons are present in the given nucleus. For a specific nucleus the term nuclide is used to describe the kind of matter involving nuclei with given values of mass number A and atomic number Z.

The symbol used is ${}_{Z}^{A}X$, 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) as shown in figure 21.5.

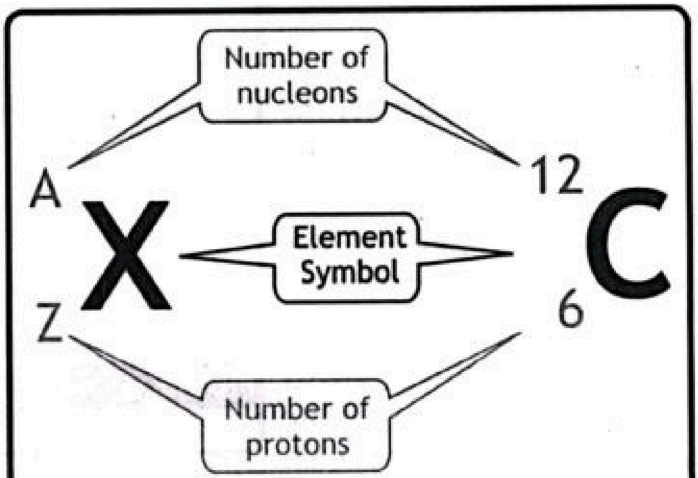


FIGURE 21.5 Nuclear representation for the nuclide of carbon-12

The number of neutrons can be calculated by subtracting number of protons 'Z', from number of nucleons 'A', such that the number of neutrons 'N' is 'A - Z'

21.3 ISOTOPES AND RADIOISOTOPES

Isotopes of an element have the same atomic number (i.e., the same number of protons) but a different mass number (i.e., different number of neutrons). The different numbers of neutrons in isotopes of an element result in different masses for each isotope. An element can exist in various isotopic forms because the number of neutrons in the nucleus of an atom of that element can vary while the number of protons remains the same.

For example consider three isotopes of hydrogen as shown in figure 21.6. The simple hydrogen atom ${}^{1}H$ (protium) has only one proton in its nucleus. ${}^{2}H$ (deuterium) has one proton and one neutron in its nucleus, whereas ^3H (tritium) has one proton and two neutrons in its nucleus. Figure 21.6 shows helium atom which is not an isotope of hydrogen as it has different number of protons (and therefore electrons).

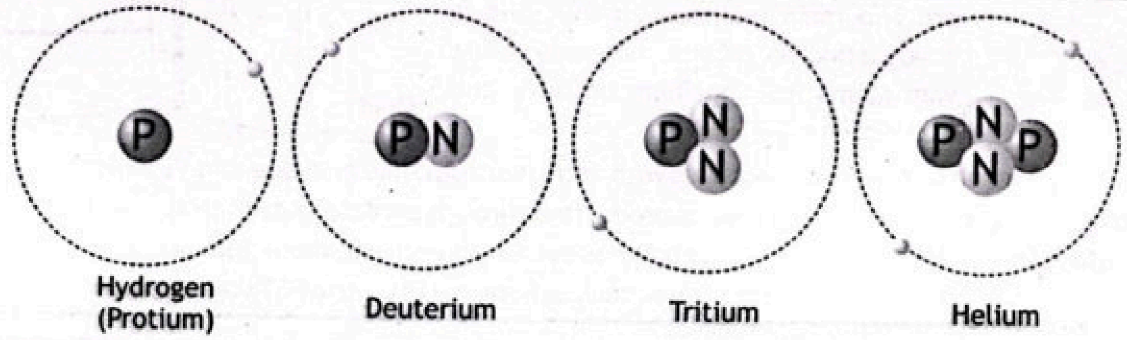


FIGURE 21.6 Three isotopes of hydrogen atom an helium atom.

Isotopes of the same element have same number of electrons therefore they have identical chemical properties. Isotopes cannot be separated by chemical methods, but only by methods that are based on their mass differences, such as mass spectrometry.

Isotopes can exist naturally and can be artificially produced. Some of these are unstable and thus are emit radiations to attain stability, these isotopes are called as radioisotopes.

Relative abundance is the percentage of atoms with a specific atomic mass found in a naturally occurring sample of an element. Relative abundance of ^{20}Ne is 90.48% and that of ^{21}Ne is 0.27%, and ^{22}Ne is 9.25% as shown in figure 21.7. Natural uranium contains two isotopes; ^{238}U (99%) and ^{235}U (little less than 1 %). ^{235}U is used as a fuel in nuclear reactors and in atomic bombs. Therefore, techniques have been developed to separate ^{235}U from natural uranium.

The first 80 elements on the periodic table have stable isotopes. Over 3,000 isotopes either exist

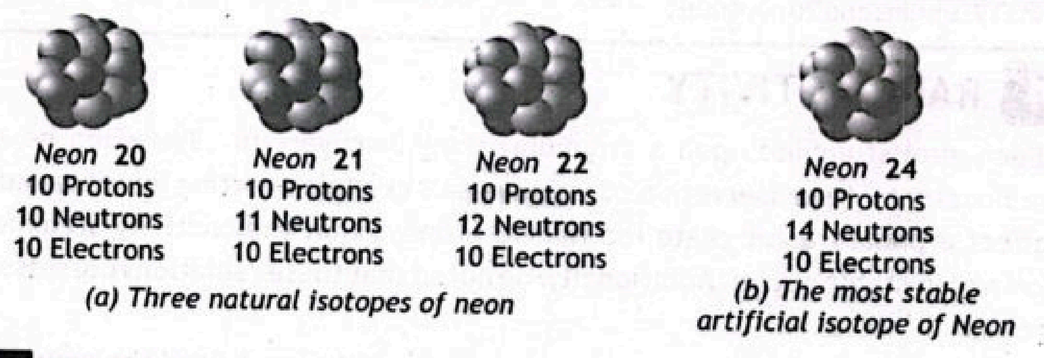
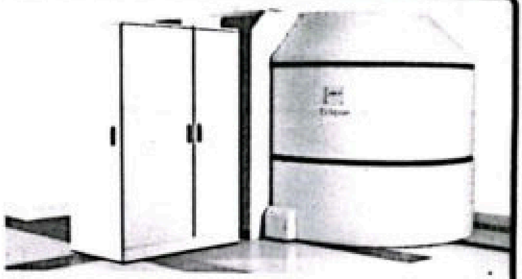


FIGURE 21.7 Isotopes of neon atom.

SCIENCE TIDBITS

Artificially produced radioisotopes are created in labs by bombarding stable atoms with high-energy particles. There are two main methods for this, one is inside a nuclear reactor, neutrons collide with atoms, making them unstable and radioactive.



This process is used to create radioisotopes with extra neutrons, like molybdenum-99 which is important for medical imaging. The other method is production through particle accelerators in which machines like cyclotrons accelerate particles (usually protons) and smash them into atoms. This creates radioisotopes with fewer neutrons than usual, such as fluorine-18 used in PET scans.

in nature or have been made artificially in particle accelerators, out of which only 257 are stable. The remaining isotopes are unstable and are termed as radioisotopes. Radioisotopes are artificially and safely produced in research reactors and accelerators. One of the many uses of radioisotopes is to manage cancer and chronic diseases using radioisotope therapy, which treats cancerous cells in a safe and effective manner.

POINT TO PONDER

Is it possible to have atoms with same nucleon number but different proton number?

Atomic species that have the same mass number (A), but a different atomic number (Z) are called isobars. Isobars should not be confused with isotopes, which share the same atomic number, and therefore belong to the same chemical element. Examples of isobars include ^{14}C; ^{14}N; ^{14}O.

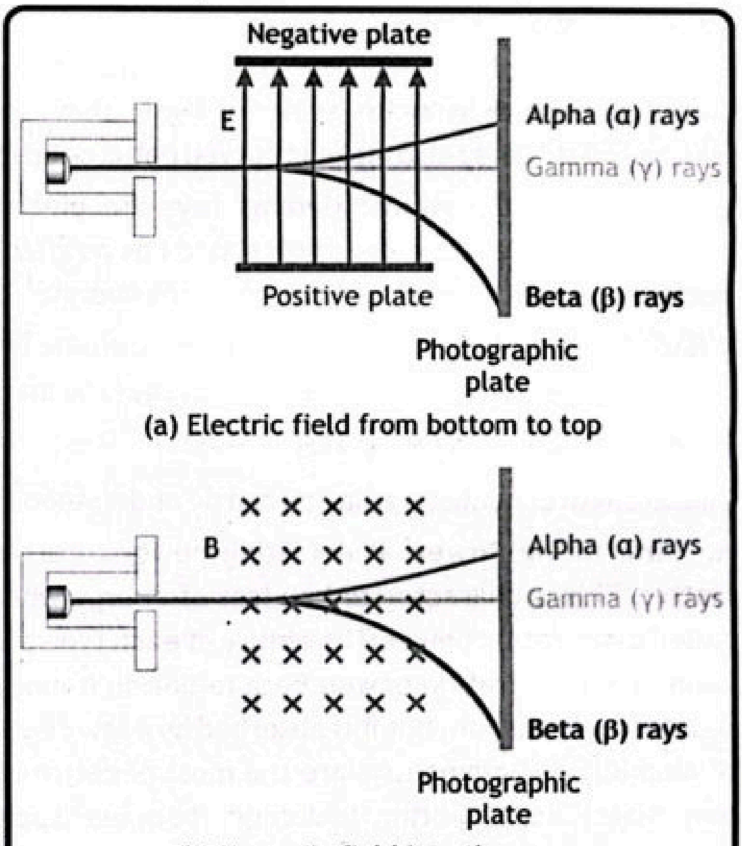
Apart from this two or more species of atoms or nuclei that have the same number of neutrons are called **isotones**. Chlorine-37 and potassium-39 are isotones, because the nucleus of this species of chlorine consists of 17 protons and 20 neutrons, whereas the nucleus of this species of potassium contains 19 protons and 20 neutrons.

21.4 RADIOACTIVITY

Henry Becquerel stumbled upon a groundbreaking discovery in 1896 when he accidentally found radioactivity. His observation of uranium salt crystals emitting invisible radiations that could affect a photographic plate led him to propose that radioactivity stemmed from the breakdown of unstable nuclei. Additionally, he noted that these radiations possessed the power to ionize gas.

Other researchers conducted further experiments that demonstrated the emission of similar radiations by different substances. Marie Curie and her spouse Pierre made the remarkable discovery of two new elements, polonium and radium, which emitted these radiations. Marie Curie coined the term "**radioactivity**" to describe this phenomenon of radiation emission by certain elements.

'The natural emission of radiations from unstable nuclei is called radioactivity'. The elements which emit such radiations are called radioactive elements. Radioactivity was found to be controlled or influenced by physical factors, such as heating and cooling, and it remained unchanged even after strong chemical reactions. Therefore, it was recognized as a fundamental property of atoms; as radioactive atoms decompose, their nuclei emit such radiations.



(a) Electric field from bottom to top

(b) Magnetic field into the page

FIGURE 21.8 Three types of nuclear radiations in electric and magnetic fields.

Rutherford and his colleagues, when passed the beam of radioactive emission in electric and magnetic field (Figure 21.8), it was found to split into three types, initially referred to as alpha particles, beta particles, and gamma rays. The amount and direction of deflection depend on their charge and mass. Neutral radiation, like γ-rays, does not get deflected at all.

21.4.1 NATURE OF NUCLEAR EMISSIONS

All thee three nuclear radiations were observed to have a distinct nature.

A. Alpha (α) Emissions: Alpha particles are equivalent to helium nuclei (i.e., two protons and two neutrons bounded 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).

In an electric field, they are attracted toward the negative plate. Their deflection is small because they are heavy. In a magnetic field, they move in a curved path determined by Fleming's Left-Hand Rule. Since α-particles are positive, the force acts in the same direction as shown by the thumb.

B. Beta (β) Emissions: Beta particles are mostly fast-moving electrons emitted from the nucleus, which carry a negative charge. 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.

In an electric field, negatively charged β-particles (electrons) are attracted to the positive plate, Because β-particles are very light, they are deflected more than α-particles. In a magnetic field, they also move in curved paths determined by Fleming's Left-Hand Rule.

C. Gamma (γ) Emissions: Gamma rays are electromagnetic radiations emitted from the nucleus, they are therefore neutral and has no charge. Gamma ray emission occurs when the nucleus of a radioactive atom has too much energy.

γ-Radiation is not affected by electric or magnetic fields. As a result, it passes straight through without any deflection. This makes γ-rays easy to distinguish from charged particles.

21.4.2 ORDER OF STRENGTH

The strength of nuclear radiation can be understood in two key ways:

A. Penetrating Power: Penetrating power refers to how far radiation can travel through matter. This is characterized by loss of energy when radiation interacts with a substance is called penetration power. The ability of each type of radiation to pass through matter depends upon thee penetration power. Beta radiation is more penetrating than alpha radiation. It can pass through the skin, but it is absorbed by a few centimetres of body tissue or a few millimetres of aluminium. Gamma rays are the most penetrating form of radiation and can pass through most materials, requiring thick concrete or lead to shield them effectively.

B. Ionizing Effects: The process in which an electron is given enough energy to break away from an atom is called ionization. In this process two charged particles or ions are formed. All types of nuclear radiation can ionize atoms and molecules, meaning they knock electrons off, which can damage living cells. Relative ionization ability compares the ionization caused by α,

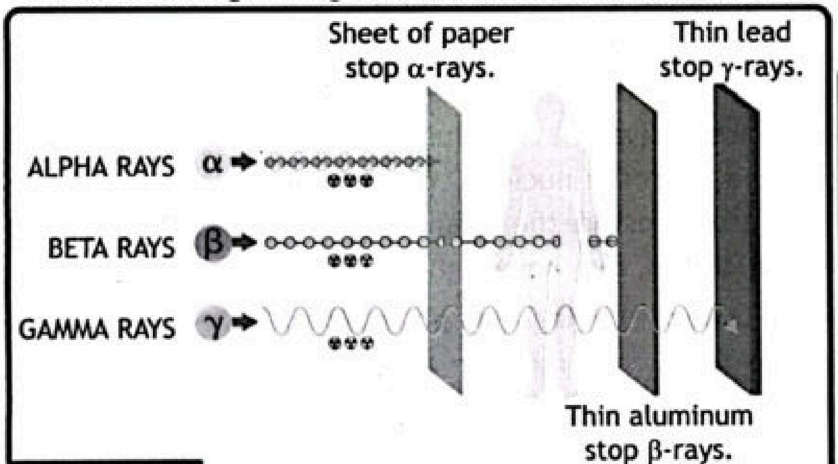
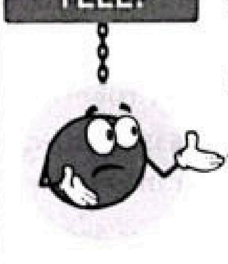


FIGURE 21.9 Three types of nuclear emissions

CAN YOU TELL?



Why beta particles tends to deflect more compared to alpha particles in the applied electric and magnetic fields?

Are beta particles similar to electrons that are in shells around the nucleus, or is there some difference?

TABLE 21.1: RADIOACTIVE EMISSIONS

Emission	Nature of radiations	Charge	Relative Penetrating Power	Relative Ionization ability
alpha (α)	Helium nuclei (two protons and two neutrons)	+2	Stopped by sheet of paper	Highest
beta (β)	Electrons	-1	Several millimetres of aluminum	Medium
gamma (γ)	Short wavelength electromagnetic radiations	0	Several centimetres of lead	Lowest

β, and γ radiations. Alpha particles cause the most ionization per unit path due to their large mass and charge. Beta and gamma rays cause less ionization but can still be harmful, especially because they can travel farther and penetrate deeper into living tissues.

The nature of nuclear emissions and their order of strength are depicted in figure 21.9, and summarized in table 21.1.

21.5 NUCLEAR DECAY

Nuclear disintegration follows several conservation principles, including mass-energy, momentum, and charge. To these laws we add another one for radioactive decay, called the conservation of nucleons. It states that the total number of nucleons (mass number A) must remain constant during nuclear reactions or decay.

21.5.1 ALPHA DECAY

In alpha decay, the original 'parent' nuclide changes into a 'daughter' nuclide by emitting an alpha particle, which is a helium nucleus. When the reaction is balanced, it shows that the daughter nuclide has a nucleon number reduced by four and a proton number decreased by two. This can be expressed mathematically as:

$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + \alpha \quad (21.1)$$

Example

$$^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^{4}_{2}He(\alpha)$$

In this example, radon-222 convert to polonium-218 by releasing an alpha (α) particle. Polonium - 218 is unstable and converts into lead-214, again by releasing another alpha particle as shown in the figure 21.10.

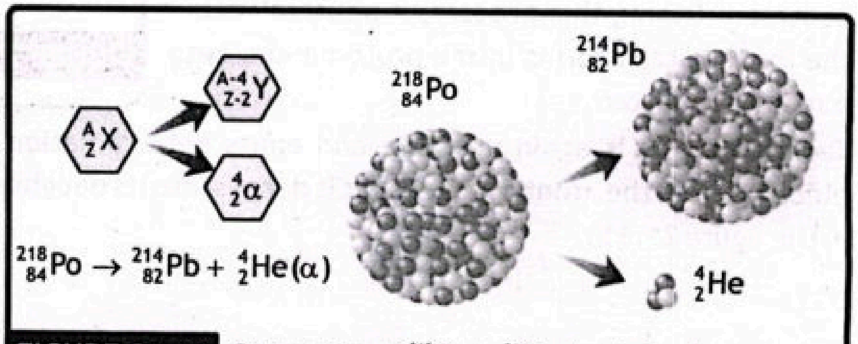


FIGURE 21.10 Conversion of ^{218}Po to ^{214}Pb by alpha decay.

Example 21.1

Find the atomic mass and atomic number of the nuclei that comes after alpha decay of Uranium (U-238)?

Solution:

Alpha decay nuclear reaction is given by: ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + \alpha$

For Uranium - 238, the nuclear reaction will become: ${}^{238}_{92}U \rightarrow {}^{238-4}_{92-2}Y + {}^{4}_{2}He(\alpha)$

$$\text{or,}\quad {}^{238}_{92}U \rightarrow {}^{234}_{90}Y + {}^{4}_{2}He(\alpha)$$

So, atomic number of the required nucleus is 90 and mass number is 234.

Every element has a unique atomic number. From periodic table, the new element to be Thorium (Th) with Z = 90.

The finalized nuclear reaction can now be written as:

$$\boxed{{}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He(\alpha)} \text{ — } \boxed{\text{ANSWER}}$$

21.5.2 BETA DECAY

In beta decay, the original 'parent' nuclide changes into a 'daughter' nuclide by emitting a beta particle (electron). This electron is expelled from the nucleus, converting a neutron into a proton, which remains in the nucleus. When the reaction is balanced, the nucleon number of the daughter nuclide remains unchanged, while the charge (proton) number increases by one. This can be expressed mathematically as:

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta \quad \boxed{21.2}$$

$$\text{Example}\quad {}^{99}_{42}Mo \rightarrow {}^{99}_{43}Tc + {}^{0}_{-1}\beta$$

Molybdenum-99 decays through beta decay due to its unstable nature caused by an excess of neutrons. During this process, a neutron within the nucleus transforms into a proton and a beta particle is emitted.

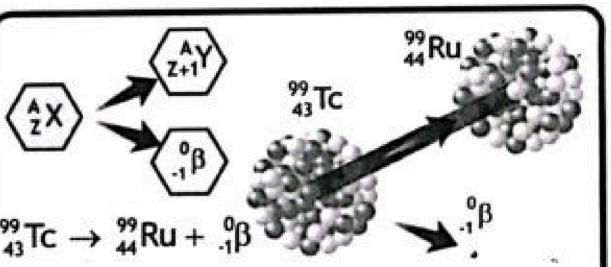


FIGURE 21.11 Conversion of ^{99}Tc to ^{99}Ru by Beta decay.

Technetium-99 is again unstable and emits beta radiation, or the release of an energized electron from the atomic nucleus, as it decays into its daughter isotope, ruthenium-99 as shown in the figure 21.11.

Example 21.2

Cobalt-60 undergoes beta decay. Write the reaction equation, and determine the identity of daughter nucleus.

Solution:

Beta decay is given by the reaction: ${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta$

For cobalt-60, the above nuclear reaction will become: ${}^{60}_{27}Co \rightarrow {}^{60}_{27+1}Y + {}^{0}_{-1}\beta$

or, ${}^{60}_{27}Co \rightarrow {}^{60}_{28}Y + {}^{0}_{-1}\beta$

Every element has a unique atomic number. The periodic table shows the new element to be Nickel (Ni) with Z = 28.

The finalized equation can now be written as:

$$\boxed{{}^{60}_{27}Co \rightarrow {}^{60}_{28}Ni + {}^{0}_{-1}\beta}$$ ANSWER

21.5.3 GAMMA DECAY

Gamma radiation is a form of high energy (high frequency/short wavelength) electromagnetic radiation. However, in most cases the α or β emission from the nucleus leave it in excited state such nuclei achieve further stability by radiating energy in the form of gamma rays. This can be expressed mathematically as:

$${}^{A}_{Z}X^{*} = {}^{A}_{Z}X + \gamma \quad \text{(21.3)}$$

Example ${}^{60}_{27}Co^{*} = {}^{60}_{27}Co + \gamma$

21.5.4 STABILITY THROUGH NUCLEAR TRANSMUTATION

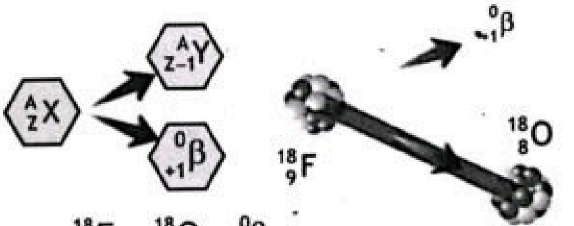
When a particle is emitted from a parent nucleus during radioactive decay, the ratio of neutrons to protons changes, and the resulting daughter nucleus tends to become more stable. This process of transforming one element into another is called nuclear transmutation. Typically, a series of successive decays takes place until a stable, non-radioactive configuration is reached.

Nuclear decay is a spontaneous and random process, governed by the inherent characteristics of atomic nuclei. The imbalance between protons and neutrons, along with the energy differences within the nucleus, drives this process without any external intervention—much like how a ball rolls down a hill due to gravity. However, just as we cannot predict exactly when the ball will start moving, it is impossible to determine the precise moment when a specific unstable nucleus will decay. This uncertainty is governed by the principles of quantum mechanics, which incorporate elements of probability.

SCIENCE TIDBITS

Beta radiation is also composed positrons that are emitted from the nucleus during beta decays. Positron (or antielectron) is the particle with same mass as an electron, however it has positive electric charge of same magnitude (just like proton, and is considered as an antiparticle of electron).

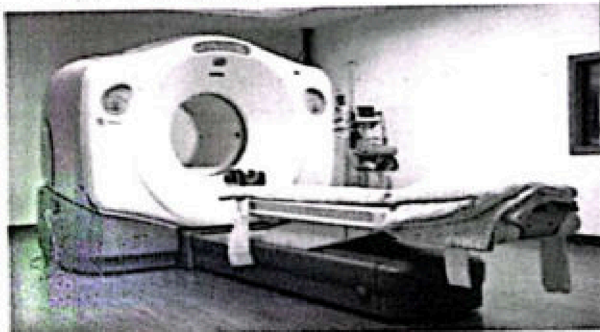
When a positron is emitted, the process is called beta plus decay to distiguish it from electron emmission. It is caused by the transformation of a proton into a neutron (which stays in the nucleus).



As a result, the proton number decreases by one, and the nucleon number does not change given by beta plus decay as:

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}\beta$$

Example $\quad {}^{46}_{24}Cr = {}^{46}_{23}V + {}^{0}_{+1}\beta \qquad {}^{18}_{9}F = {}^{18}_{8}O + {}^{0}_{+1}\beta$



The emission of a beta plus particle by Chromium-46 results in the formation of Vanadium-46. The emission of a beta plus particle transmute Fluorine - 18 into Oxygen - 18 is used for diagnostic purposes in conjunction with positron emission tomography (PET) imaging as shown. During a PET scan, a radioactive tracer that emits positrons is injected into the body. When these positrons collide with electrons in tissues, they release gamma rays.

By detecting these gamma rays, doctors can create a 3D image that shows which areas of the body are metabolically active, which can help diagnose various conditions like cancer and heart disease.

21.6 HALF LIFE

Radioactivity is an unpredictable and spontaneous process where we cannot foresee which nucleus will decay next. This is why we rely on the concept of half-life to measure the time taken for overall disintegrations.

The time duration in which half of the unstable radioactive nuclei disintegrates into daughter nuclei (by the emission of α, β or γ radiations) is called half life of the sample of radioactive element.

The value of the half life depends on the nature of the radioactive nucleus and not on any other variable like temperature, pressure, humidity etc. For example, iodine-131 has a half-life of 8 days, because it takes this duration for one half of a given quantity of this isotope to disintegrate. In 8 days, half of the sample will be left. In next 8 days only ¼ of the original present sample will be left and son on. In general, let there be N_0 - number of sample nuclei (may be in unit of mass) present at initial and N-number of nuclei present at any time.

21.6.1 USING AN EQUATION TO MODEL RADIOACTIVE DECAY

Quantities whose rate of decay depends upon the amount of substance present are said to undergo exponential decay.

The amount of radioactive isotope in the given sample decrease with time as shown in figure 21.12. The number of nuclei present at time t = 0 s is $N = N_o$, and the number present at $t = T_{½}$ is $N = N_o/2$. The number present at $t = 2T_{½}$ is $N = N_o/4$, and so on.

In this instance, the amount '*N*' of radioactive substance left after some time '*t*' has elapsed is given by:

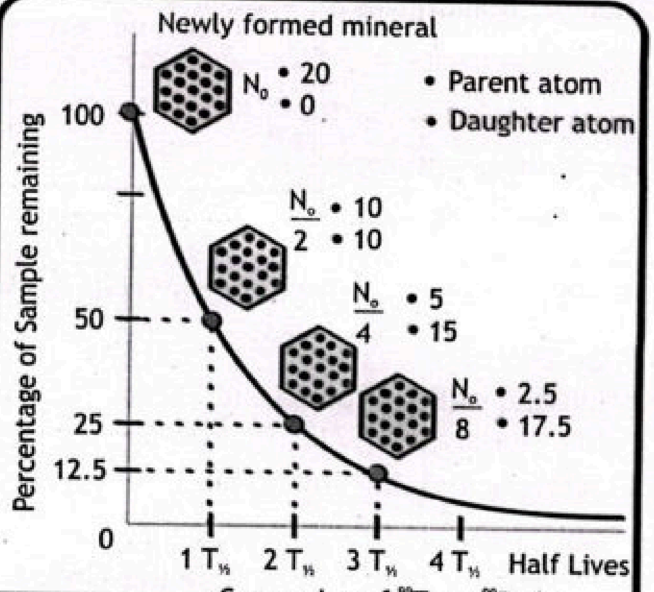


FIGURE 21.11 Conversion of ^{99}Tc to ^{99}Ru by Beta decay.

After 1 half-life: $N_1 = \frac{1}{2} N_o$

After 2 half-lives: $N_2 = \frac{1}{2} \times \frac{1}{2} N_o = \left(\frac{1}{2}\right)^2 N_o$

After 3 half-lives: $N_3 = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} N_o = \left(\frac{1}{2}\right)^3 N_o$

After 4 half-lives: $N_4 = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} N_o = \left(\frac{1}{2}\right)^3 N_o$

And so on ---------- $N = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} .....N_o$ or $N = \left(\frac{1}{2}\right)^n N_o = \frac{N_o}{2^n}$ — 21.4

TABLE 21.2: HALF LIVES OF SELECTED RADIOISOTOPES

Element	Half-life	Element	Half Life
Uranium-238	4.5 billion years	Iodine-131	8.02 days
Uranium-235	704 million years	Carbon-14	5,730 years
Plutonium-239	24,110 years	Tritium (Hydrogen-3)	12.3 years
Cesium-137	30 years	Radon-222	3.82 days
Strontium-90	28.8 years	Polonium-210	138 days

Number of half lives (n) can be found by the following relation:

$$\text{Number of half lives} = \frac{\text{Total time passed}}{\text{Half life}} \quad \text{Therefore,} \quad n = \frac{\Delta t}{T_{1/2}} \qquad \boxed{21.5}$$

Substituting the value for 'n' in equation 21.4, the final equation becomes: $N = \frac{N_o}{2^{\Delta t / T_{1/2}}}$ $\boxed{21.6}$

Example 21.3

You have a 50 mg sample of lead-212. It decays by beta and gamma emission with a half-life of 10.6 hours. How much of the pure sample is left after 53 hours?

GIVEN:
Initial quantity of pure Lead-212 'N_o' = 50 mg
Half-life of Lead - 212 '$T_{1/2}$' = 10.6h
Total elapsed time 'Δt' = 53h

REQUIRED:
Quantity left 'N' = ?

SOLUTION:
The number of half-lives 'n' is given by: $n = \frac{\Delta t}{T_{1/2}}$ putting values $n = \frac{53\,h}{10.6\,h}$

Therefore $n = 5$

Original sample remaining after "n" number of half-lives: $N = \left(\frac{1}{2}\right)^n N_0$

putting values $N = \left(\frac{1}{2}\right)^5 \times 50\,mg$

Therefore $\boxed{N = 1.56\,mg}$ ANSWER

So, 1.56 mg of Lead - 212 will be present after 53 hours or 5 half-lives.

Radioactivity in the natural environment was considered impossible to artificially create until 1934 when Frederic Joliot and Irène Curie successfully produced new radioactive materials using nuclear physics methods. Otto Hahn and Fritz Strassmann later achieved fission of uranium nuclei in 1938/39. The significance of fission was acknowledged by Lise Meitner and Otto Frisch, leading to the pursuit of creating super heavy elements beyond uranium. This quest has resulted in the synthesis of 26 elements that do not exist naturally.

21.6.2 ACTIVITY

The level of radioactivity in a substance can be thought of as the number of nuclear decays per unit time. A substance with high radioactivity experiences rapid decay, resulting in a shorter half-life. If a sample initially contains N unstable nuclei, the rate of decay can be expressed as $\Delta N/\Delta t$.

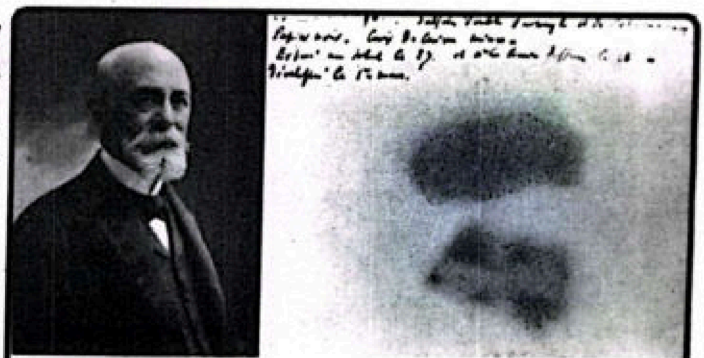
This measure is commonly referred to as activity, denoted as A, and is measured in decays per second.

The SI unit for Activity (decay rate) in disintegrations (counts) per second is the becquerel, symbolized as Bq in honour of Henri Becquerel. This is a very small unit. For example, 1.0 g of radium has an activity of 3.7×10^{10} Bq.

For example, 1.0 g of radium has an activity of 3.7×10^{10} Bq. Therefore, the kilobecquerel (kBq) and the megabecquerel (MBq) are commonly used, so we would say that the activity of 1.0 g of radium is 3.7×10^{4} Mbq.

Another common unit of activity is the curie (approximately equal to the activity of one gram of radium), abbreviated Ci, which is defined to be 3.70×10^{10} decays per second.

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



Henri Becquerel (1852-1908)

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

FIGURE 21.12 SI unit of radiation

15.6.3 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. The element carbon as we find it in nature consists of 98.89% ^{12}C atoms and only about 1.11% ^{13}C atoms. Carbon in living organisms also contains a trace but measurable amount of ^{14}C, about 1.3×10^{12}.

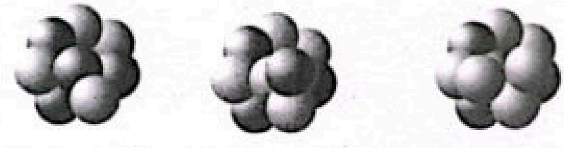


FIGURE 21.13 Isotopes of carbon atom.

Neutrons from deep space collide with nitrogen atoms in the atmosphere, causing a proton to be knocked off the nucleus of ^{14}N. The neutron is then absorbed, resulting in the formation of a ^{14}C atom. This carbon atom can react with oxygen in the atmosphere, forming a CO_2 molecule. Through the process of photosynthesis, plants can take in some of this radioactive carbon as they produce their own food. Similarly, animals that consume these plants can also acquire radioactive carbon. As long as the organism is alive, it will continue to absorb and accumulate carbon-14. However, once the organism dies, it will no longer take in carbon-14, and the proportion of carbon-14 will gradually decrease as shown in figure 21.14.

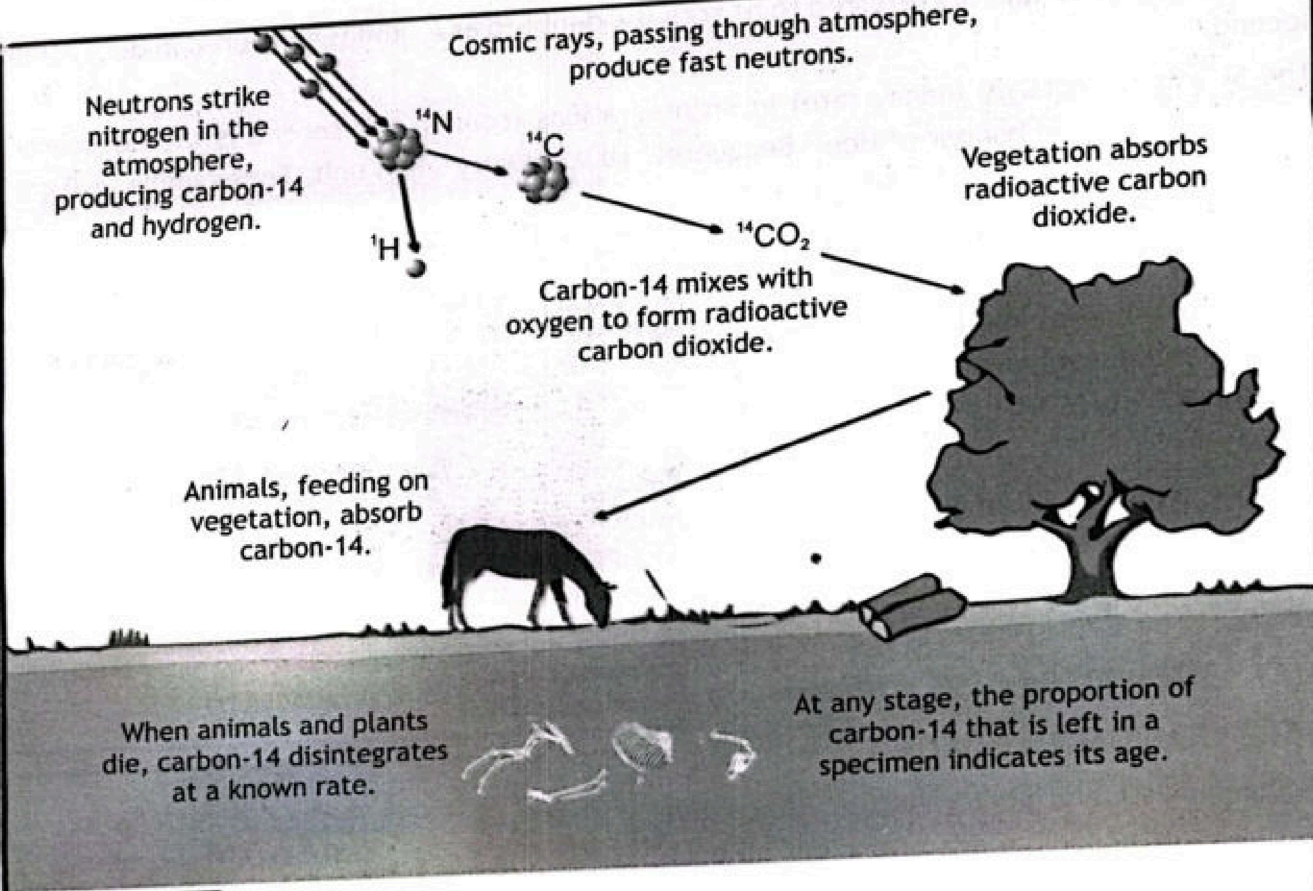


FIGURE 21.14 Radiocarbon dating

As discussed earlier the amount of carbon-14 in the total carbon is minimal, yet still measurable. By measuring the activity, one can estimate the age of a specimen. Carbon-14 dating is effective for biological tissues up to 50 or 60 thousand years old, but it is most accurate for younger samples due to higher ^{14}C nuclei abundance. Geologic formations' age can be determined using materials with longer half-lives. For instance, Uranium-238, with a half-life of 4.53×10^9 years, can date even the oldest Earth deposits.

Example 21.4

In an animal fossil ^{12}C to ^{14}C ratio is found to be one eighth of the ratio in the bone of living animal. The half life of ^{14}C is 5730 years, how old is the fossil?

GIVEN:
^{12}C to ^{14}C ratio 'N/N_o' = 1/8
Half-life of Carbon - 14 '$T_{½}$' = 5730 years

REQUIRED:
time 'Δt' = ?

SOLUTION:

The half-life equation is: $N = \dfrac{N_o}{2^{\Delta t/T_{1/2}}}$ or $\dfrac{N}{N_o} = \dfrac{1}{2^{\Delta t/T_{1/2}}}$

putting values $\dfrac{1}{8} = \dfrac{1}{2^{\Delta t/5730\,yrs}}$ or $\dfrac{1}{2^3} = \dfrac{1}{2^{\Delta t/5730\,years}}$

Equating powers on both sides $3 = \dfrac{\Delta t}{5730\,years}$ or $\Delta t = 3 \times 5730\,years$

Therefore $\boxed{\Delta t = 17{,}190\,years}$ — **ANSWER**

Therefore the fossil is 17,190 years old.

21.7 IONIZING NUCLEAR RADIATIONS

Radiation, or radiant energy, is energy in the form of waves or particles moving through space. Visible light, heat, radio waves, alpha particles and beta particles are examples of radiation. When we feel warmth from the sunlight, we are actually absorbing the radiant energy emitted by the sun.

Radiation can be categorized as ionizing or nonionizing based on its interaction with matter. Normally, an atom has an equal number of protons and electrons. However, through a process called ionization, atoms can lose or gain electrons. Certain types of radiation can ionize atoms by knocking off electrons, leaving the atom in an ionized state. Hydrogen, with the smallest atomic number, requires the least energy (13.6 eV) to eject its K-shell electron. Radiation with energy above 13.6 eV is referred to as ionizing radiation. Ionizing radiation has the ability to alter the chemical state of matter and cause biological damage, making it potentially harmful to human health. If electrons are raised to higher energy levels without being ejected from atoms, it is called excitation, and the atom is considered "excited."

Radiation of energy less than 13.6 eV is termed nonionizing radiation because it cannot eject this most easily removed electron. Nonionizing radiation bounces off or passes through matter without displacing electrons. Examples include visible light and radio waves. Currently, it is unclear whether nonionizing radiation is harmful to human health.

21.7.1 EFFECTS OF IONIZING NUCLEAR RADIATIONS ON LIVING THINGS

Ever since ionizing radiation was first discovered, its ability to cause harmful effects has been recognized. These effects occur when the human body absorbs the energy from the radiation. This energy absorption can lead to ionization (charged particles) and excitation within the body, as well as chemical changes through the creation of free radicals. Ultimately, this creates the potential for biological changes or damage to take place.

Radiation interacts with matter by transferring energy to the molecules of the material it is absorbed by. Since water is the most abundant molecule in a cell, the primary result of this process is an ionized water molecule ($H_2O^{\cdot+}$). These ionized water molecules then react with other water molecules to form hydroxyl radicals ($^{\cdot}OH$) (Figure 21.15). The ejected electrons may have enough energy to cause further ionizations until their energy is dissipated, resulting in the formation of an aqueous electron (e^-_{aq}) or combining with other species to produce reducing species like hydrogen atoms ($H^{\cdot}$) or superoxide ($O_2^{\cdot-}$).

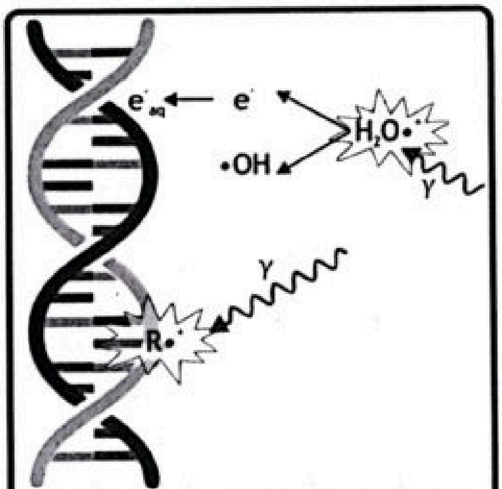


FIGURE 21.15 Effects of ionizing radiation on DNA

Ionizing radiation can harm all types of molecules in a cell, but DNA is a main target. Highly reactive $^{\cdot}OH$ radicals, along with less reactive species, can harm DNA.

Radiation can cause various types of damage to DNA, such as breaks in strands, damage to bases or sugars, and cross-links between molecules (like DNA-DNA or DNA-protein cross-links). Overall, the most harmful effect of radiation is believed to be the DNA double-strand break (DSB).

21.7.2 HARMFUL EFFECTS OF NUCLEAR RADIATIONS

Cell death by radiation occurs when ionizing radiation damages the vital components of a cell, especially its DNA. This damage can be so severe that the cell cannot repair itself and ultimately dies. There are two main types of radiation-induced cell death: mitotic cell death and apoptosis. Mitotic cell death happens when cells try to divide with damaged DNA, leading to their breakdown. Apoptosis, or programmed cell death, is a controlled process where cells self-destruct when they detect significant damage. Both types help protect the body by removing damaged cells that could otherwise cause harm.

Sometimes, the damage caused by ionizing radiation isn't fatal to the cell. However, the damage can alter the cell's DNA, leading to mutations. Mutations are changes in the DNA sequence of a cell's genetic material. These mutations can be passed on to daughter cells during cell division. Mutations can have a variety of effects, some harmless, but some can disrupt the normal functioning of the cell. Worryingly, some mutations can give a cell the ability to grow uncontrollably, which is a hallmark of cancer.

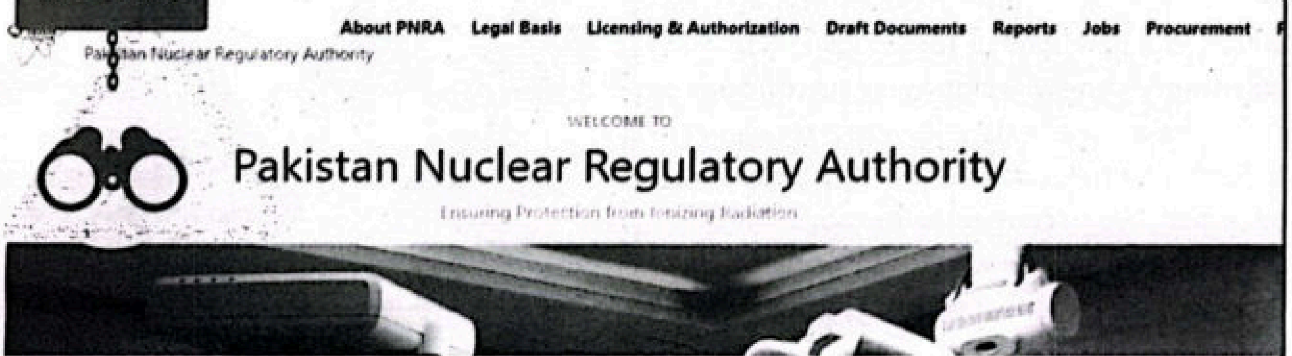
As mentioned above, mutations caused by ionizing radiation can increase the risk of cancer. Cancer is a disease where cells lose control of their growth and division, forming tumors that can invade healthy tissues. The risk of developing cancer from radiation exposure depends on factors like the amount of radiation received, the age of the person exposed, and other individual factors.

Nuclear radiation can harm humans by altering the structure of molecules in living cells through ionization. This can lead to cell death and potentially harm the entire organism. Additionally, if radioactive material is ingested or inhaled, it causes internal damage through contamination as the emitted radiation affects cells from within the body.

Radiation exposure can have serious health consequences, including radiation sickness, cancer, and genetic mutations. These effects can be immediate or develop over time, even from low-level exposure. Radiation sickness refers to the acute effects of radiation exposure. Symptoms can include nausea, vomiting, fever, diarrhea, hair loss, and can even lead to death depending on the dose's severity. Long-term effects of radiation exposure may include chronic health issues such as hair loss, eye cataracts, various types of cancer, and genetic defects that can be passed down to future generations.

Not everyone is equally susceptible to radiation exposure. Children, pregnant women, and people with weakened immune systems are more vulnerable. Radioactive materials can contaminate the environment, posing risks to wildlife and future generations. Therefore all over the world a comprehensive set of rules and guidelines are designed to ensure the safe and secure use of nuclear technology. These 'nuclear regulations' are typically enforced by independent regulatory bodies. These bodies may be national agencies, like the Office for Nuclear Regulation (ONR) in the UK or the Pakistan Nuclear Regulatory Authority (PNRA), or international organizations like the International Atomic Energy Agency (IAEA).

EXPLORE



PNRA in Pakistan has been given the important task of overseeing and managing all matters related to nuclear safety and radiation protection. It has the authority to create rules and regulations, provide guidance on safety measures, and implement policies and programs to safeguard life, health, and property from the risks associated with ionizing radiation. Additionally, PNRA is responsible for regulating the safety aspects of nuclear installations and radiation facilities, granting authorizations and licenses for the use of nuclear material and radioactive sources, and conducting inspections to ensure compliance with safety regulations. For further information, please visit the official website: https://www.pnra.org/.

21.7.3 SAFE HANDLING OF RADIOACTIVE MATERIALS

When working around ionizing radiation, remember the mantra: **time, distance, and shielding.** Minimize your exposure time near the source - the less time spent exposed, the lower the dose. Maximize the distance between yourself and the source - radiation intensity weakens rapidly, so even a few extra steps make a big difference. Whenever possible, use barriers like lead or concrete to block radiation.

In a radiation lab, additional precautions are crucial. Always wear personal protective equipment like lab coats, shoes, and safety glasses. Maintain a clean and organized workspace by avoiding unnecessary materials, and meticulously track all radioactive sources in the lab for proper handling and disposal.

Radiation symbols are important to have in places where there are radiation sources, containers, or products with radioactive parts. These symbols can be found on safety documents, warning signs in radiation zones, or permits for handling radioactive materials. They are crucial for alerting people to potential radiation dangers and ensuring clear communication in radiation safety measures. Figure 21.16 shows two common radiation symbols.

A. 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.

B. Supplementary Symbol: International Atomic Energy Agency (IAEA) in 2007 has launched a new symbol for 'Ionizing-Radiation Warning'. 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.

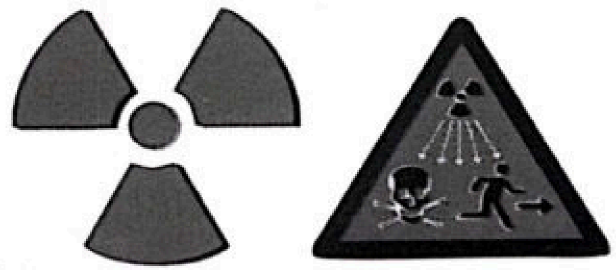
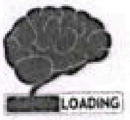


FIGURE 21.16 Symbols used for radiation

SCIENCE TIDBITS



The survey meter is a key tool in keeping nuclear facilities safe. It helps detect radiation levels, protecting workers from harm. Whether in power plants or research facilities, survey meters alert staff to dangers, keeping them safe from unnecessary risks. These devices are crucial for maintaining safety in the nuclear industry.

21.7.4 DOSE DESCRIPTORS

We measure radiation to understand its effects on living things, like humans. This helps us set safety limits to protect people from radiation exposure. There are several biological measures that are commonly used to evaluate the effects of radiation exposure:

A. **Absorbed dose:** Absorbed dose is a measure of the amount of energy absorbed by a tissue or organ exposed to radiation. It is usually measured in units of gray (Gy) or milligray (mGy).

B. **Equivalent dose:** Equivalent dose takes into account the type of radiation and the sensitivity of the tissue or organ exposed. It is measured in units of sievert (Sv) or millisievert (mSv).

C. **Effective dose:** Effective dose is a measure of the overall radiation dose to the entire body, taking into account the dose to different tissues and organs and their respective sensitivities to radiation. It is also measured in units of sievert (Sv) or millisievert (mSv).

TABLE 21.3: RADIATION DOSE LIMITS

Radiation dose limit	Description
1 millisievert (mSv) per year	Annual dose limit for members of the general public
20 mSv per year	Annual dose limit for radiation workers
1 mSv per year	Maximum dose limit for frequent exposure to the public, such as patients undergoing medical procedures
50 mSv in a single year	Maximum dose limit for radiation workers in emergency situations
100 mSv in a single year	Maximum dose limit for radiation workers in life-saving emergency situations

21.8 APPLICATIONS OF RADIATION

Radiation has a wide range of applications across various fields.

21.8.1 SMOKE ALARM

The radioactive material used in smoke detectors is typically americium-241, a man-made element that emits alpha particles. These particles collide with air molecules in the detector, creating ions that allow for the flow of electric current. When smoke particles enter the detector, they disrupt this ion flow, triggering the alarm and alerting occupants to the presence of a potential fire as shown in figure 21.17. This technology has been instrumental in saving countless lives by providing early warning of fires in homes and buildings.

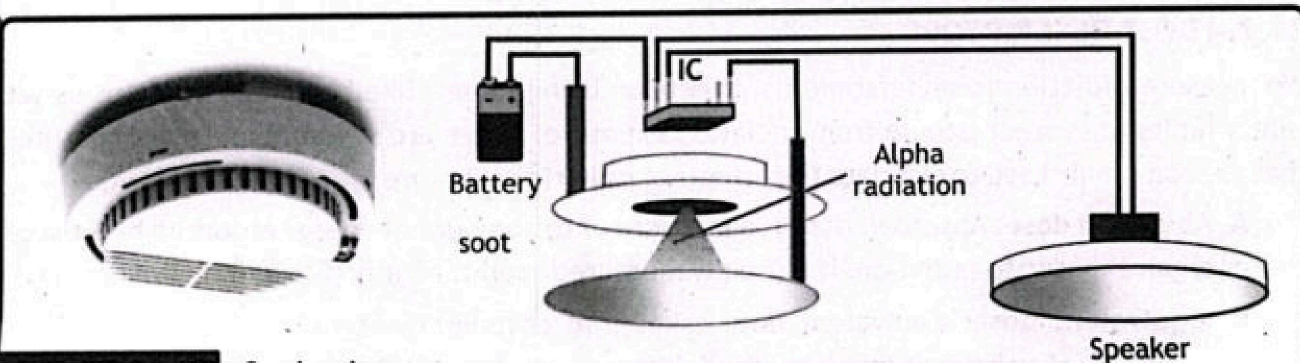


FIGURE 21.17 Smoke alarm

21.8.2 FOOD IRRADIATION

Food irradiation is a method that utilizes radiation to remove bacteria, mold, and insects, which helps to prolong the lifespan of food. It is often used to sterilize spices, meats, and other types of food. Even when food is packaged, gamma rays can still pass through the packaging and successfully eliminate harmful microorganisms, as demonstrated in Figure 21.18. Although this technique greatly extends the shelf life of food, it may sometimes affect the taste of the food.

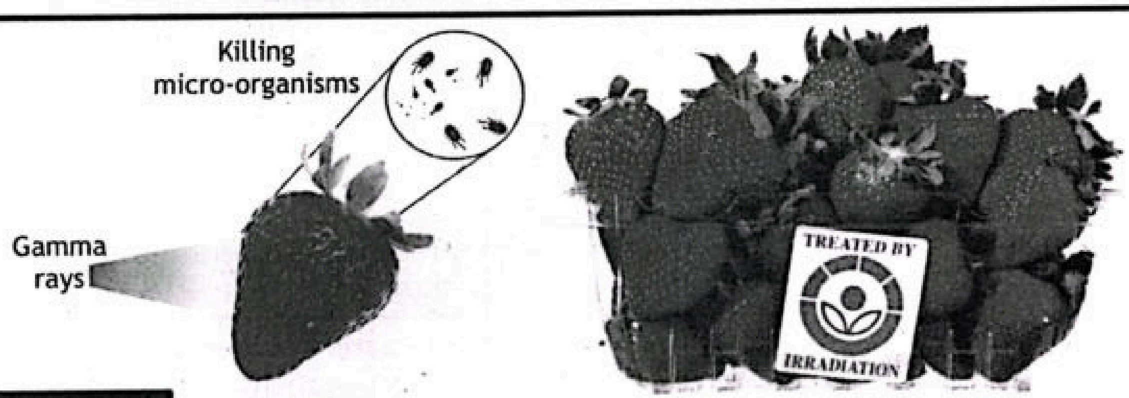


FIGURE 21.18 Food Irradiation

21.8.3 EQUIPMENT STERILIZATION

Radiation has the ability to eliminate bacteria and other tiny organisms, making it a valuable tool for sterilizing medical equipment, food, and various other items (figure 21.19). The use of radiation in healthcare settings is particularly beneficial as it ensures that equipment remains sterile, thus reducing the risk of infections. This is especially important for plastic equipment like syringes, which could be harmed if exposed to high temperatures.

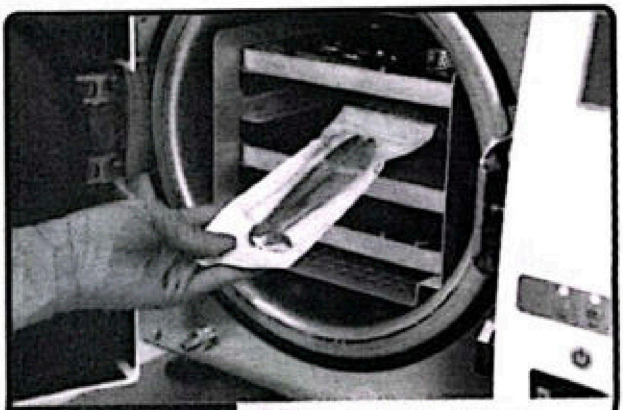


FIGURE 21.19 Equipment sterilization

21.8.4 CONTROLLING THICKNESSES

The choice of isotopes for measuring and controlling material thickness depends on the radiation they emit and their half-life. The main considerations in this selection are the radiation's ability to penetrate and the isotope's stability over time. Beta emitters with moderate penetration are used for thin materials, while gamma emitters with high penetration are used for thicker materials. The half-life ensures the source remains active for the required duration of the application.

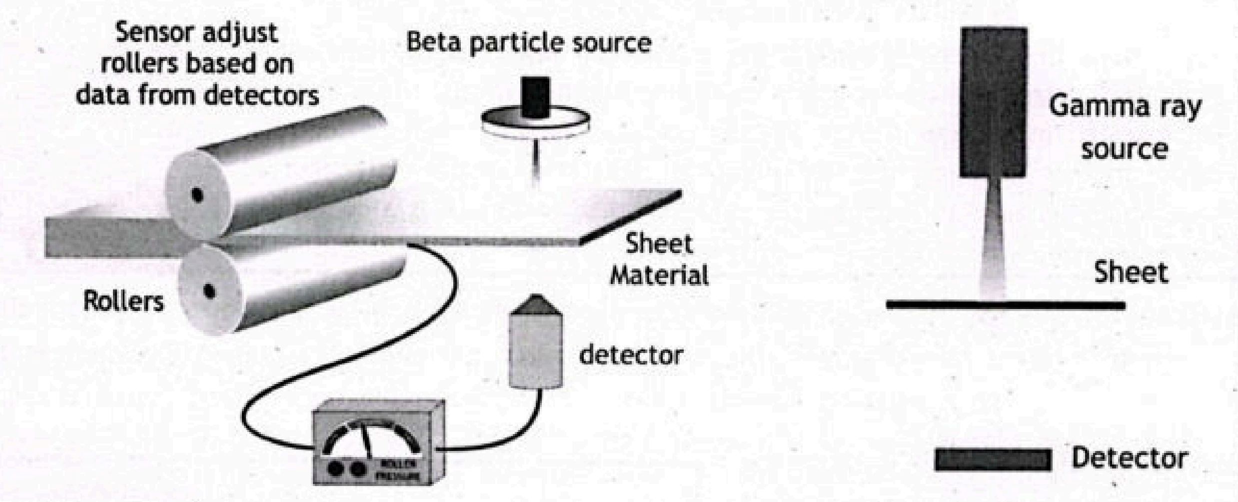


FIGURE 21.20 Food Irradiation

21.8.5 DIAGNOSIS AND TREATMENT OF CANCER

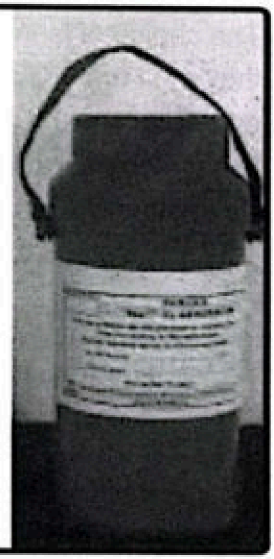
Radiopharmaceuticals play a crucial role in diagnosing and treating various diseases. These drugs, which contain radioactive material, can be administered through injection, inhalation, or oral consumption. They are used for both medical imaging of internal organs and bodily processes, as well as for therapeutic purposes. Ionizing radiation serves two distinct purposes in the field of medicine: diagnosis and therapy.

A. Medical diagnostics: Each organ in our bodies functions differently from a chemical perspective. Scientists and medical professionals have identified specific chemicals that are absorbed by certain organs. For instance, the thyroid absorbs iodine, while the brain consumes glucose, among others. Utilizing this knowledge, radiopharmacists can attach different radioisotopes to biologically active substances. These radioisotopes enable the accurate detection of disease progression and staging in vital organs through imaging techniques such as gamma camera or PET scans in nuclear diagnostics. When selecting a radioisotope for diagnosis, it is crucial that it emits gamma rays with enough energy to exit the body and has a short enough half-life to decay soon after imaging is completed.

POINT TO PONDER

What makes technetium-99m the top choice for nuclear diagnostics?

Technetium-99m, an isotope of technetium, is the most commonly used radioisotope in medicine due to its ideal characteristics for diagnostic scans. It has a six-hour half-life, allowing for thorough examination of metabolic processes while keeping radiation exposure to the patient at a minimum. Additionally, the low energy gamma rays it emits can easily exit the body and be accurately detected. The versatility of technetium's chemistry allows it to be incorporated into various biologically-active substances, ensuring it concentrates in the specific tissue or organ of interest. Lastly, the logistics of technetium generators, supplied to hospitals from nuclear reactors, make it a convenient choice for medical facilities.



B. Radiation therapy: Radiation treatment involves using high-energy radiation to target specific tissues, such as cancerous tumors. One common source of radiation is Cobalt-60, which emits beta particles and high-energy gamma rays that are effective in treating various types of cancer.

Similarly, high-energy gamma rays produced by linear accelerators can be used to achieve the same purpose. Radiation therapy using gamma rays involves targeting cancerous tissues with high-energy radiation to destroy or damage cancer cells, hindering their ability to grow and divide. The two common sources of gamma rays in radiation therapy are Cobalt-60 and linear accelerators (Linacs).

Cobalt-60 is an isotope that emits gamma rays and beta particles. It is contained in a machine known as a cobalt unit as shown in figure 21.21. The gamma rays are aimed at cancerous tissue, penetrating deep within the body due to their high penetration power.

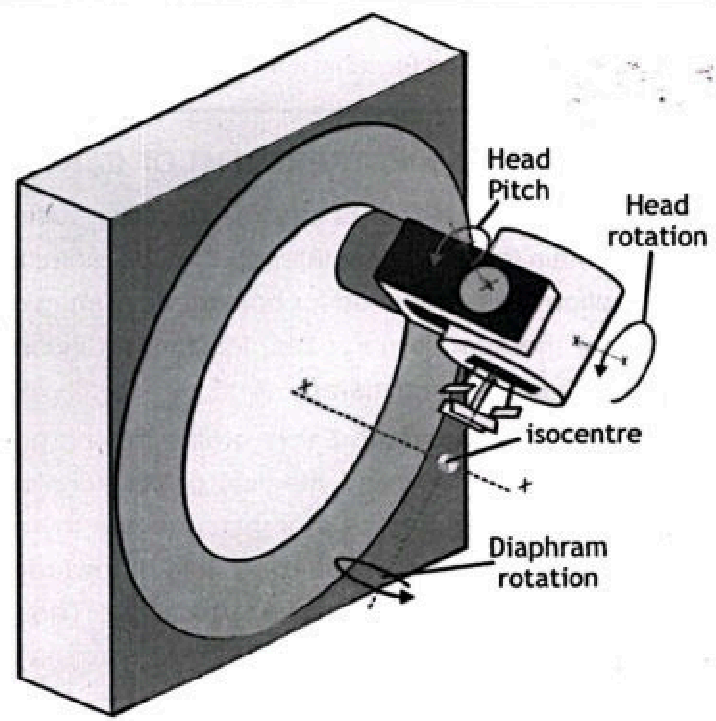


FIGURE 21.21 The cobalt unit

These rays ionize molecules in cells, creating free radicals that damage the DNA of cancer cells. This damage inhibits the cells' ability to replicate, eventually causing them to die off. The cobalt unit rotates around the patient to deliver radiation from various angles, focusing on the tumor while minimizing damage to healthy tissue.

Another approach in radiation therapy involves using radioisotopes, which are absorbed by specific organs. This allows radiation to be concentrated on the affected tissue. For example, iodine-131 is a radioisotope that is specifically absorbed by the thyroid gland, making it an effective treatment for thyroid cancer. By focusing the radiation on the cancerous tissue, these treatments minimize damage to surrounding healthy tissues and improve the effectiveness of cancer treatment.

21.9 BACKGROUND RADIATION

Background radiation refers to the ubiquitous ionizing radiation that everyone is exposed to, originating from natural and artificial sources.

21.9.1 NATURAL BACKGROUND RADIATION

Since the beginning of time, all living things on Earth have been bathed in a sea of radiation from natural sources. This radiation, called background radiation, comes from three main sources:

A. Cosmic rays: These high-energy particles bombard Earth from outer space. The amount of cosmic radiation we receive varies depending on where we live. Higher altitudes and areas with weaker magnetic fields experience slightly higher doses.

B. Terrestrial radiation: Radioactive materials like uranium and thorium exist naturally in soil, rocks, and even water. These materials decay over time, releasing radiation. The amount of terrestrial radiation also varies depending on the local geology.

- **Radon:** Radon, a radioactive gas, is produced from the decay of uranium and thorium in the Earth's crust. It can enter homes through cracks in the foundation, especially in basements. Radon is a major source of terrestrial radiation and a primary cause of lung cancer in non-smokers due to inhaling its decay products.
- **Rocks and Buildings:** Various rocks and minerals have radioactive elements like uranium, thorium, and potassium-40. The radiation from these substances adds to the terrestrial radiation dose people get, especially in regions with high concentrations of these elements.
- **Food and Drink:** Food and beverages naturally contain trace amounts of radioactive elements, namely potassium-40 and carbon-14. These elements are found in all living organisms, including plants and animals, and consequently, they are present in our food. Consuming these radioactive elements leads to internal exposure to radiation, which is a component of terrestrial radiation.

C. Internal radiation: Surprisingly, we even carry small amounts of radioactive materials inside our bodies! Elements like potassium-40 and carbon-14 occur naturally and emit low levels of radiation.

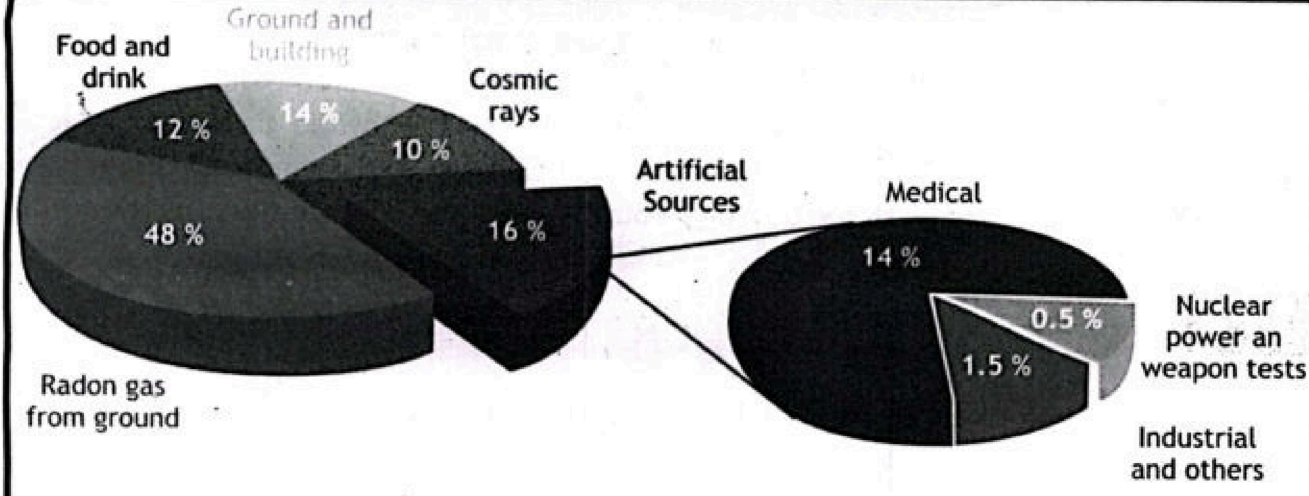


FIGURE 21.22 Percent contribution of various sources of exposure to the total dose per individual

21.9.1 ARTIFICIAL BACKGROUND RADIATION

Artificial sources of background radiation stem from medical procedures, industrial activities, and historical nuclear events.

A. Medical Radiation: Originates from medical procedures and treatments, encompassing diagnostic imaging (such as X-rays and CT scans) and therapeutic treatments (like radiation therapy). It plays a significant role in the overall radiation exposure experienced by individuals who undergo these procedures.

B. Industrial Radiation: Arises from industrial activities and products, including radiation emitted by nuclear power plants, radioactive materials utilized in industrial applications, and consumer products like smoke detectors and specific types of luminous watches. While its contribution to the overall background radiation is generally low, it can be noteworthy in proximity to specific industrial sites.

C. Fallout Radiation: Derives from nuclear weapons testing and nuclear accidents, involving the release of residual radioactive particles into the environment during nuclear explosions or accidents like Chernobyl and Fukushima. The extent of fallout radiation can vary greatly depending on location and historical events. In general, it constitutes a minor portion of the current background radiation.

21.10 NUCLEAR FISSION

Nuclear fission was discovered on December 17, 1938 by Otto Hahn and his assistant Fritz Strassman, 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/slow neutron), splits into two fragments of intermediate size.

The process of splitting up a heavy and unstable nucleus into comparatively smaller nuclei by absorbing a neutron with the emission of more neutrons and a large amount of energy is called nuclear fission.

It can be represented by the following nuclear reaction:

$$ {}_{0}^{1}n + {}_{Z}^{A}\Delta \rightarrow {}^{A+1}_{Z}\Delta^{*} \rightarrow X + Y + \text{neutrons} \qquad \boxed{21.7} $$

For practical considerations Δ may be Uranium-235 (U-235), Plutonium-239 (Pu-239) and Uranium-233 (U-233), Δ^* is an intermediate excited state that lasts for very short time before splitting into fission fragments X and Y. There are different possible fission fragments in different fission reactions. On the average, about 2.5 neutrons are released per fission along with a large amount of energy.

A typical fission reaction of this type is given below and shown in figure 21.23:

$$ {}_{0}^{1}n + {}_{92}^{235}U \rightarrow {}_{92}^{236}U^{*} \rightarrow {}_{56}^{141}Ba + {}_{36}^{92}Kr + 3\,{}_{0}^{1}n + Q $$

In this reaction, the total mass of the fission fragments is less than the original mass of the parent nucleus. This reduced mass (mass defect) is released as thermal energy, by Einstein famous mass energy relation:

$$ E = mc^2 $$

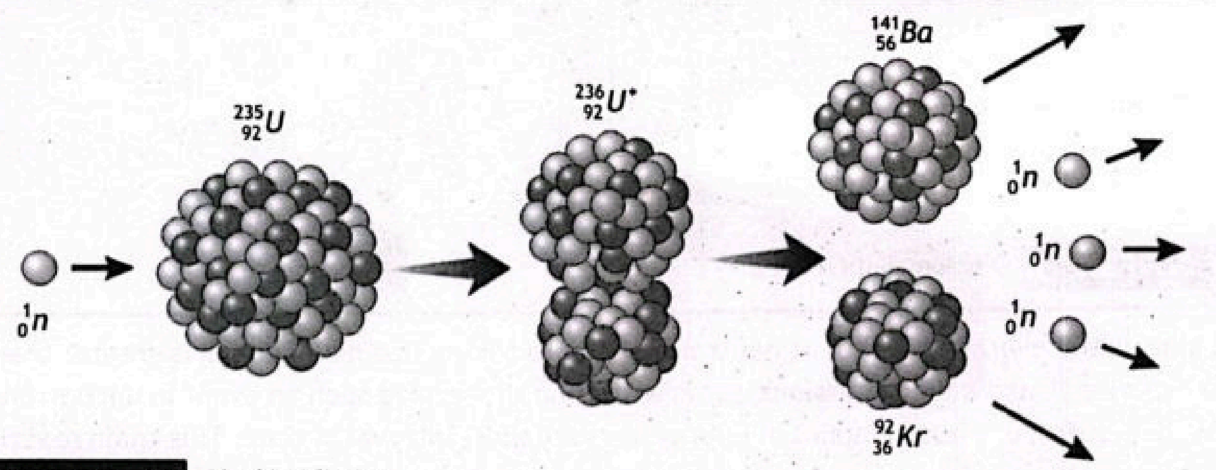


FIGURE 21.23 Nuclear fission

Measurements showed that about 200 MeV of energy is released in a single fission event. This is a large amount of energy as compared to the amount of energy released in chemical processes. For example, 1 kg of uranium delivers as much energy as about 3000 tons of coal.

The neutrons emitted in a fission reaction may cause additional fission reactions in other nuclei present in the sample. If each of the neutrons emitted in fission of uranium - 235 is absorbed by another nucleus of uranium-235 and thus induces another fission process, it will result in the emission of still more neutrons, followed by more fissions, and so forth. The process is called fission chain reaction, where different fission fragments may be produced as shown in figure 21.24.

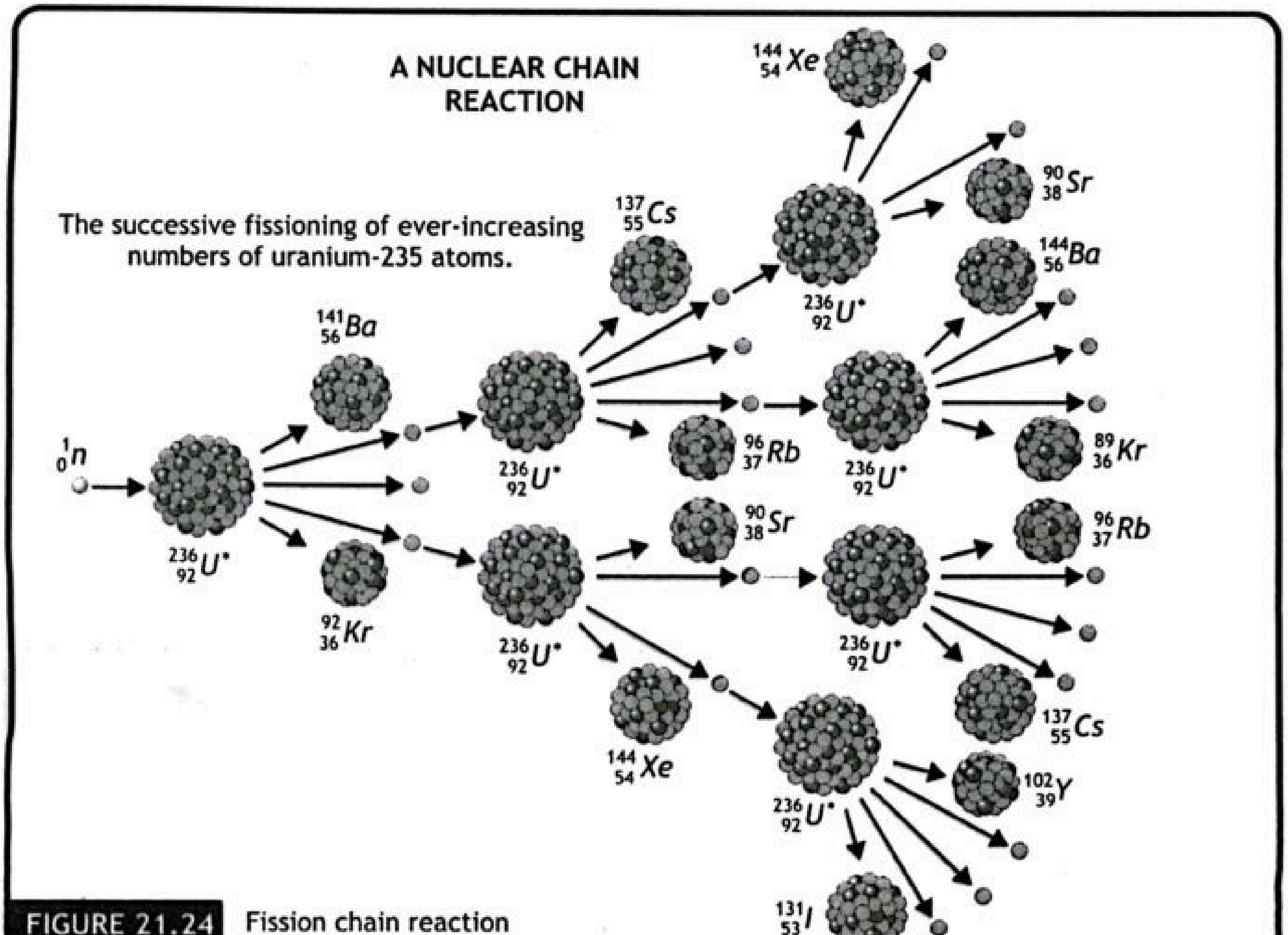


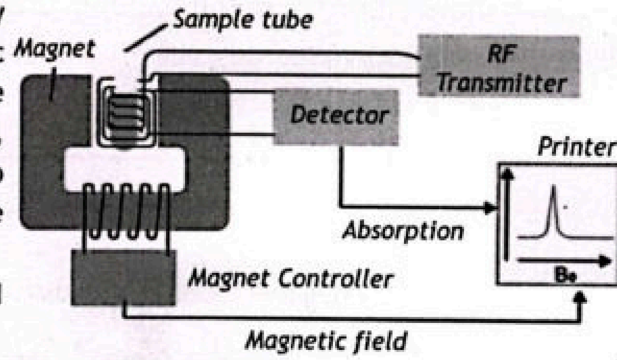
FIGURE 21.24 Fission chain reaction

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. If we have such an event in uncontrolled way, it may produce huge amount of energy in a very short interval of time. This chain reaction principle is used in atomic bomb, where a huge amount of energy is released in an uncontrolled fission chain reaction.

POINT TO PONDER

What is nuclear magnetic resonance spectroscopy?

NMRS is a method used to study magnetic fields around atomic nuclei. Initially, nuclear spins are aligned with a magnetic field, then disrupted by a radio frequency pulse to analyze the emitted electromagnetic waves.



Biophysicists utilize NMR to identify proteins and complex molecules, as well as in MRIs.

In contrast to fission chain reaction (uncontrolled fission), the nuclear reactors release the energy from nuclear fission in a controlled manner which is used for useful purposes as in case of nuclear reactor.

Example 21.5

During a reaction, 5×10^{18} J of energy is released. Calculate mass of the matter converted into energy

GIVEN:
Energy $E = 5 \times 10^{18}$ J
Speed of light $c = 3 \times 10^8$ m/s

REQUIRED:
mass 'm' = ?

SOLUTION:

By Einstein mass energy relation: $E = mc^2$ or $m = \frac{E}{c^2}$

putting values $m = \dfrac{5 \times 10^{18} J}{(3 \times 10^8 m/s)^2}$

Therefore $\boxed{m = 55.56\,kg}$ **ANSWER**

So, a mass of 55.56 kg is converted into energy during the reaction.

21.11 NUCLEAR FUSION

When two light nuclei combine to form comparatively 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 (mass defect) appears in the form of energy.

A self-sustaining fusion reaction is also possible but the energy required to start a fusion reaction is possible only in the environments of stars including sun.

One such cycle is proton proton cycle, in this process the direct collision of protons results in the formation of a heavier nucleus whose collision in turn produces helium nucleus as shown in figure 21.25.

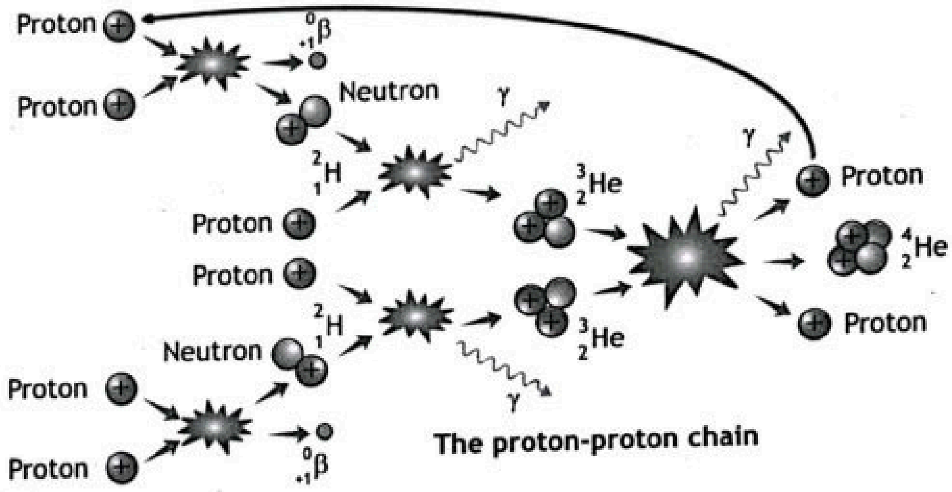


FIGURE 21.25 Fusion reaction

Step-1: In the first step, a proton reacts with another proton to form deuterium nucleus with emission of a beta particle and some energy.

$$^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{1}H + ^{0}_{+1}\beta$$

Step-2: In the second step, a proton reacts with the deuterium nucleus and forms a He-3 nucleus with the emission of some energy.

$$^{1}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + \gamma$$

Step-3: In the third step, two He-3 nuclei fuse together to form an alpha particle (He-4) with the emission of two protons and some energy.

$$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + ^{1}_{1}H + ^{1}_{1}H + \gamma \quad \text{--- } \boxed{21.8}$$

The "energy" factor on the right-hand side of the equation simply means that the particles on the right possess more kinetic and radiant energy than the particles on the left. In the reaction, mass has been converted into energy in conformity with Einstein's equation, $E = mc^2$ with the total energy released per fusion of about 26.3 MeV. Energy coming from the Sun and stars is supposed to be the result of fusion of hydrogen nuclei into helium nucleus with release of energy.

The Sun is a medium-sized star, just like other stars it is a self-luminous sphere of hot gas held together by gravity and energized by nuclear reactions in its core.

The bright, visible "surface" of the Sun is called the photosphere. The temperature of the photosphere is about 6000 K. Analysis of the Sun's spectrum shows that its photosphere is composed, by mass, of about 75% hydrogen, 25% helium, and less than 1% heavier elements, the most abundant being oxygen, carbon, neon, and iron.

A distinct feature of the Sun's surface is the periodic occurrence of sunspots. Sunspots are huge regions of cooler material on the surface of the Sun where the magnetic field is very intense. Other distinct features of the Sun's surface are solar flares and prominences. Flares are sudden, bright, explosive events originating on the Sun's surface. They are releases of energy associated with the Sun's magnetic field. Prominences are enormous filaments of excited gas arching over the surface and usually extending hundreds of thousands of kilometers outward. For us, one of the most important features of the Sun is that it radiates energy. It radiates most of its energy in the infrared, visible, and ultraviolet regions of the electromagnetic spectrum.

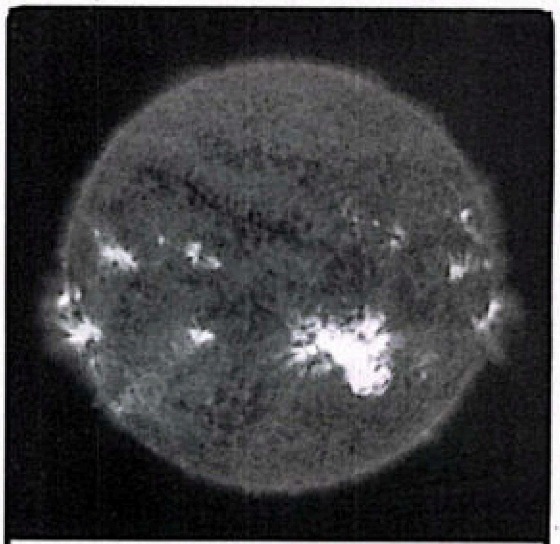


FIGURE 21.26 Our sun

However, not until 1938 did scientists understand that the Sun radiates energy because of nuclear fusion. The Sun's core is the site of several nuclear chain reactions that power its energy output. proton-proton chain is the dominant fusion reaction in the Sun, which converts hydrogen into helium. The fusion process in the sun is initiated by high temperatures and pressures in the sun's core, which cause the hydrogen nuclei to collide with enough energy to overcome their electrostatic repulsion and combine into a single helium nucleus. This fusion reaction is highly efficient, with only a small fraction of the hydrogen being converted into helium at any given time. The Sun contains about 10^{30} kg of hydrogen and has been fusing it into helium for about 5 billion years. Every second in the Sun's interior, about 6.0×10^{11} kg of hydrogen is converted into 5.96×10^{11} kg of helium and 4.0×10^{26} J of energy. Even at this rate, the Sun is expected to radiate energy from hydrogen fusion for another 5 billion years.

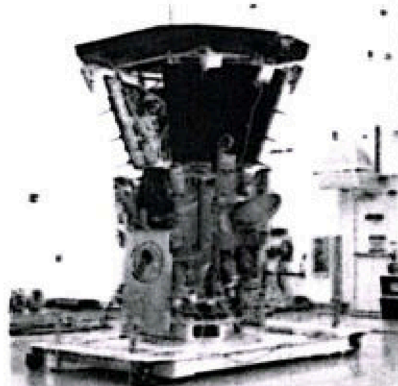
The amount of energy that reaches the Earth from the Sun is about 1400 joules per second per square meter ($J/s\ m^2$). This amount of energy is called the solar constant. Nearly all life on planet Earth is dependent on energy from the Sun because this energy controls our total environment: atmosphere, food supplies, water sources, and so on.

UNIT OPENER?

Why wouldn't the Parker Solar Probe melt despite being only 4 million miles away from the Sun's surface?

The Parker Solar Probe is a NASA spacecraft designed to study the outer atmosphere of the Sun, known as the corona, by traveling closer to the Sun than any previous mission. The Parker Solar Probe was launched on August 12, 2018, and mission is planned to last until 2025, during which the probe will complete 24 orbits around the Sun.

The Parker Solar Probe doesn't melt because it is protected by a heat shield made of a carbon-composite material that reflects and dissipates heat. Despite being only 4 million miles from the Sun, the temperature in space is not as extreme due to the lack of air to transfer heat efficiently. The heat shield keeps the probe's instruments cool, allowing it to withstand the Sun's intense radiation.



21.12 DARK MATTER

The universe is predominantly composed of dark matter and dark energy. Dark matter, an elusive and invisible substance, is five times more abundant than regular matter, making up about 27% of the universe. Although its exact composition remains unknown, we understand that it interacts through gravity but not with electromagnetic forces.

Unlike regular matter, dark matter does not emit, absorb, or reflect light, making it extremely challenging to detect. This enigmatic substance is termed "dark matter" because it is not visible. It occupies space and possesses mass, similar to regular matter, but its presence is inferred rather than directly observed.

One piece of evidence for the existence of dark matter comes from studying the rotation of galaxies. When we measure the orbital speed of matter at various distances from the galactic center, we observe that the speed does not decrease with distance as expected. Instead, the rotation speeds remain relatively constant. As illustrated in Figure 21.27, which shows distance in kiloparsecs (kpc)—equivalent to 3,261.56 light years—and rotation speed in kilometers per second, there is a clear graphical difference between the observed and expected outcomes.

Galaxies rotate at such high speeds that the gravitational force from their visible matter alone should be insufficient to keep them intact; they should have torn apart long ago. This discrepancy suggests the presence of a significant amount of unseen matter at the edges and beyond the visible parts of galaxies.

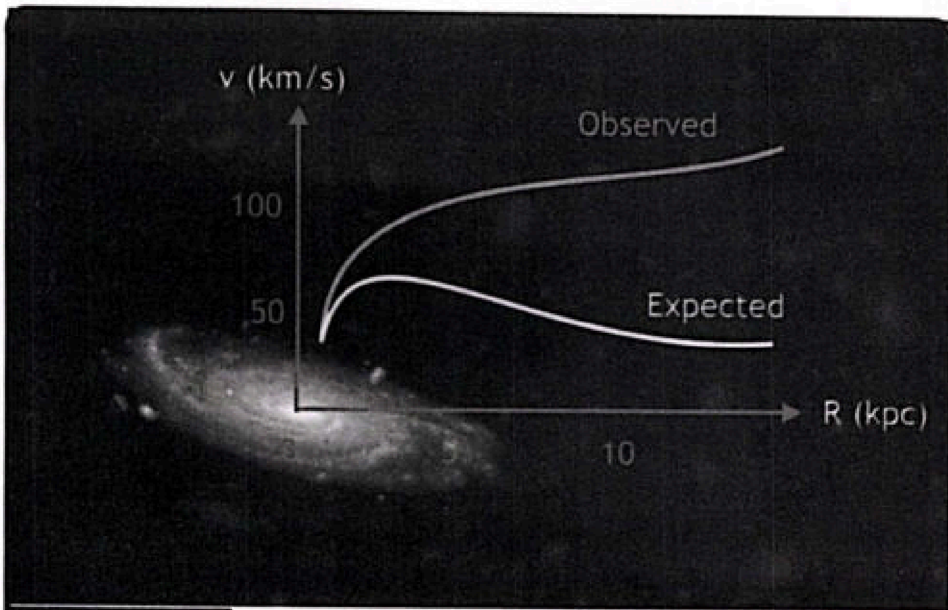


FIGURE 21.27 Dark matter

This phenomenon is also observed in galaxy clusters, suggesting it extends beyond galaxies as well. Scientists theorize that an undetected form of matter (dark matter) provides these galaxies with additional mass, creating the necessary gravitational pull to maintain their structure.

Current scientific understanding suggests that dark matter forms a vast, web-like structure permeating the universe, acting as a gravitational framework that attracts most of the cosmos' normal matter.

21.13 FALSIBILITY

What determines if an idea is legitimately scientific or not? Falsifiability is a key concept in the philosophy of science. It means that a scientific theory is considered valid only if it makes predictions or assertions that can be tested and potentially proven wrong.

Falsifiability means that for a theory to be scientific, there must be a possible observation or experiment that could show the theory to be false or incorrect. If no such test can be conceived, the theory is not scientific because it cannot be empirically tested. This principle helps distinguish scientific theories from pseudoscience, promotes rigorous testing, encourages objective evaluation, and enhances predictive power. This idea is crucial in every field of physics, including nuclear physics and the exploration of dark matter.

For example, observations of the sun's energy output and spectral analysis can test this theory. If the sun's energy output did not match the predictions made by nuclear fusion models, the theory would be questioned. Also by measuring the rotation curves of galaxies, scientists can test the existance of dark matter. If observations showed that galaxies could be explained solely by visible matter without any need for dark matter, the theory would be falsified.

Falsifiability is crucial in science because it allows scientific theories to be tested and potentially disproven. This process is essential for scientific progress. Scientists propose theories, conduct experiments to test these theories, and then refine or reject them based on the results. If a theory cannot be tested or disproven, it is not considered scientific because it lacks empirical validation.

Falsifiability ensures that theories are testable and open to refutation. However, it is not the only criterion for scientific theories. Scientists also consider other factors such as explanatory power, how well a theory fits with existing knowledge, its predictive accuracy, and its simplicity, often referred to as Occam's Razor. Combining these criteria helps ensure that scientific theories are robust and reliable.

SUMMARY

- **Nucleus** is the region consisting of protons and neutrons at the center of an atom.
- **Nucleons** are the particles found inside nucleus (i.e., protons and neutrons).
- **Nuclide** is a type of atom whose nucleus has specific numbers of protons and neutrons.
- **Radioactive Decay** is the process by which an atomic nucleus of an unstable atom loses mass and energy by emitting ionizing particles.
- **Alpha decay** is a type of radioactive decay in which an atomic nucleus emits an alpha particle (which is equal to helium nucleus).
- **Beta Decay** is a type of radioactive decay in which an atomic nucleus emits a beta particle (electron).
- **Gamma Decay** is a type of radioactive decay in which an atomic nucleus emits a gamma particle.
- **Radioactive substance** is a substance or object that emits nuclear radiation.
- **Half-life** is the time needed for half of the original nuclei of a sample of a radioactive substance to undergo radioactive decay.
- **Radioactive dating** is 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** is a radioactive dating technique based on the radioactivity of carbon-14.
- **Nuclear radiation** are the rays that originate in the nuclei of atoms
- **Nuclear Fission** is a nuclear reaction in which a heavy nucleus splits into small nuclei with the emission of large amount of energy.
- **Nuclear Fusion** is a nuclear reaction in which two nuclei are combined or fused together to form a larger nucleus and emit large amount of energy.
- **Shielding** is a technique to limit radiation exposure.
- **Background radiation** is a measure of the level of ionizing radiation present in the environment at a particular location which is not due to deliberate introduction of radiation sources.
- **Dark matter** is believed to comprise more than 80% of the universe's matter. Its existence is inferred because celestial objects and cosmic structures cannot be explained without it.
- **Falsibility** is the belief that for any hypothesis to have credence, it must be inherently disprovable before it can become accepted as a scientific hypothesis or theory.

EXERCISE

MULTIPLE CHOICE QUESTIONS

QI. Choose the best possible option in the following questions.

1. Charge on α-particle is how many times of the charge on proton?
   A. two times B. three times C. four times D. one time
2. Uranium with atomic number 92 has an isotope ^{239}U, the number of neutrons in it are:
   A. 92 B. 239 C. 147 D. 331
3. Which of the following is deflected at large angles by electric or magnetic field?
   A. α-particles B. β-particles C. γ-rays D. neutrons
4. Beta (β) particles are fast moving:
   A. electrons B. photons C. hydrogen nuclei D. helium nuclei
5. Cancer treatment involves targeting tumors with radiation. Which type of radiation is most commonly used for its ability to penetrate deep tissues?
   A. α-particles B. β-particles C. γ-rays D. protons
6. Which of the following decay modes is due to a transition between states of the same nucleus?
   A. alpha decay B. beta decay C. gamma decay D. all of these
7. During β-decay, the nucleon number:
   A. decreases by 4 B. does not change C. decreases by 1 D. increases by 1
8. A radioactive element with a half-life of two years, the sample remained after 6 years is
   A. 75 % B. 50 % C. 25 % D. 12.5 %
9. The half life of stable isotope is theoretically:
   A. zero B. 1 s C. 11 day D. infinite
10. The unit for absorbed radiation dose is:
    A. Bequerrel (Bq) B. Curie (Ci) C. Gray (Gy) D. Sievert (Sv)
11. Which of the following is the largest contributor to natural background radiation exposure for most people?
    A. Cosmic radiation B. Radon gas C. Food D. nuclear fallout
12. Radiocarbon dating is a technique used to estimate the age of organic materials. What is the approximate maximum age limit for reliable dating using this method?
    A. 10,000 years B. 50,000 years C. 1 million years D. 5 billion years

13. Food irradiation eliminates bacteria to extend shelf life. Which isotope would be ideal for this purpose?
    A. Strontium-90 (beta emitter, 28.8 years half-life)
    B. Cobalt-60 (gamma emitter, 5.27 years half-life)
    C. Iodine-131 (beta emitter, 8.02 days half-life)
    D. Plutonium-239 (alpha emitter, 24,100 years half-life)
14. A worker is preparing to use a radioactive source for an experiment. Which of the following is the PRIMARY reason to maintain a safe distance from the source during use?
    A. To conserve the radioactive material for future experiments.
    B. To minimize the risk of contamination from the source.
    C. To reduce the intensity of radiation reaching the worker.
    D. To prevent accidental activation of the source.
15. The energy of the sun is released due to:
    A. nuclear fission B. nuclear fusion C. reduction D. oxidation
16. The existence of dark matter is primarily inferred from its:
    A. Light emitted from distant galaxies B. Gravitational influence on visible matter
    C. Chemical reactions with normal matter D. Abundance in meteorites

CONSTRUCTED RESPONSE QUESTIONS

QII. Follow the directions to respond to the following questions.

1. Complete the following nuclear decay equations:

(a) Lead-210 converts in to Bismuth (Bi):

$$^{210}_{82}Pb = ^{210}_{83}Bi + \boxed{}$$

(b) Radon-222 emits an alpha particle and transforms into polonium (Po):

$$^{222}_{86}Rn \rightarrow \boxed{} + ^{4}_{2}He$$

(c) Radium - 224 transforms into Radon (Rn):

$$^{220}_{86}Rn \rightarrow ^{216}_{84}Po + \boxed{}$$

(d) Neptunium - 239 releases beta particle converts in to Plutonium (Pu):

$$^{239}_{93}Np \rightarrow \boxed{} + ^{0}_{-1}\beta$$

(e) Iodine - 131 emits a gamma particle:

$${}^{131}_{53}I \rightarrow \boxed{} + \gamma$$

2. Which isotope X is needed to complete:

(a) the fission reaction ${}^{1}_{0}n + {}^{235}_{92}U \rightarrow X + {}^{134}_{54}Xe + 2\,{}^{1}_{0}n$

⊙. ${}^{102}_{38}Sr$ ⊙. ${}^{101}_{37}Rb$ ⊙. ${}^{102}_{36}Kr$ ⊙. ${}^{100}_{38}Sr$

$$X = \boxed{}$$

(b) the fusion reaction ${}^{2}_{1}H + X \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$

⊙. ${}^{1}_{1}H$ ⊙. ${}^{2}_{1}H$ ⊙. ${}^{3}_{1}H$ ⊙. ${}^{3}_{2}He$

$$X = \boxed{}$$

SHORT RESPONSE QUESTIONS

QIII. Give a short response to the following questions.

1. Imagine you're explaining the difference between a nucleon and a nuclide to a younger sibling. How would you describe each term in a way they could understand?
2. Think about the everyday materials we encounter. How does the presence or absence of radioactivity fundamentally change the properties of a material?
3. Our bodies are made up of countless atoms. Is there a perfect balance between the number of neutrons and protons in every atom within our bodies? Explain your reasoning.
4. Why can a beta particle travel farther through air than an alpha particle, even if they have the same energy level?
5. Alpha particles are known to cause more ionization in solids than beta particles. What explains this difference in their ability to interact with matter?
6. Radium-226 undergoes alpha decay. Explain the process of alpha decay using a balanced nuclear equation and describe the resulting daughter nuclide.
7. Why is carbon dating technique primarily limited to dating materials that were once living organisms?
8. What makes Cobalt-60 a suitable choice in radiotherapy for treating cancer compared to other isotopes?
9. Some food is irradiated with gamma rays to kill bacteria. While gamma rays are powerful, why is there no concern about people consuming food containing residual gamma radiation?
10. Standing too close to a bonfire can burn your skin. How is this similar to the potential dangers of radiation exposure? Explain the fundamental mechanisms behind both phenomena.

11. We are constantly exposed to low levels of ionizing radiation from various sources. What practical steps could you take to reduce your exposure to this radiation?
12. How does the presence of dark matter significantly contribute to our understanding of the universe's structure and evolution?

LONG RESPONSE QUESTIONS

QIV. Give a detailed response to the following questions.

1. How did the discovery of the atomic nucleus transform our understanding of atomic structure and what implications did it have for modern physics?
2. In what ways do stable and unstable isotopes of an element differ in terms of their nuclear properties and applications in science and industry?
3. How do the characteristics of alpha, beta, and gamma radiation influence their use in medical treatments, industrial applications, and scientific research?
4. What are the potential consequences of alpha decay on the stability of an atomic nucleus, and how does this process compare to other types of radioactive decay?
5. When a nucleus ejects an electron during beta decay, what fundamental changes occur in the atomic structure, and how does this process affect the element's identity?
6. How does the concept of half-life facilitate our understanding of radioactive decay, and what practical implications does it have for fields such as archaeology and geology?
7. In what ways do ionizing nuclear radiations impact biological systems, and what are some of the long-term health effects observed in humans exposed to such radiation?
8. What are the most effective safety protocols for handling radioactive materials, and what strategies can be implemented to ensure safe disposal of radioactive waste?
9. How do the applications of radiation in everyday technologies, like smoke alarms and food irradiation, reflect the balance between safety and utility in modern society?
10. What are the primary sources of background radiation in our environment, and how do they contribute to the overall exposure experienced by living organisms?
11. Can you explain the significance of neutron-induced fission in sustaining a nuclear chain reaction, and what factors can influence the rate of this reaction?
12. What are the essential conditions required for nuclear fusion to occur, and how do these conditions relate to the processes occurring in stars like the sun?
13. How does the sun's emission of various wavelengths within the electromagnetic spectrum contribute to life on Earth, and what implications does this have for our understanding of solar energy?
14. What evidence supports the existence of dark matter in the universe, and how does this hypothesis challenge or reinforce our current understanding of cosmology?

15. Why is falsifiability considered a cornerstone of the scientific method, and how does it influence the development and acceptance of scientific theories?

NUMERICAL RESPONSE QUESTIONS

QV. Solve the questions given below.

1. Polonium $^{209}_{84}Po$ is a radioactive nuclei. Determine number of protons, number of neutrons and number of nucleons in it. (Ans. 84, 125, 209)
2. Americium $^{241}_{95}Am$ undergoes alpha decay and produces an alpha particle. Write down the chemical equation for it and name the nucleus formed. (Ans. $^{237}_{93}Np$)
3. A radioactive substance has a half-life of 16 months. In how much time, one-eighth of the substance will be left? (Ans. 48 months)
4. In a nuclear reaction, 2 μg of mass is converted into energy. Find the energy. (Ans. 180 MJ)
5. In 420 days, one-eighth of polonium (Po) remains un-decayed. Calculate the half-life of polonium? (Ans. 140 days)
6. The half-life of radium is about 1600 years. In how much time, 250 g will remain un-decayed when 1 kg of radium was there initially? (Ans.3200 y)
7. Three-fourth of the initial mass of a certain radioactive isotope decays after one hour. Find half-life of isotope in minutes? (Ans. 30 min)
8. The half-life of $^{210}_{83}Bi$ is 5 days. If we start with 64,000 nuclei of this isotope then how many number of atoms will left after one month? (Ans. 1,000 nuclei)
9. An archeologist digs up a human skull at a dig site. It was found that concentration of carbon-14 with a half-life of 5730 years is 25% of its initial concentration. What is the age of the skull? (Ans. 11,460 y)
10. The C-14 content with a half-life of 5730 years of an ancient piece of wood was found to have three tenths of that in living trees (indicating 70% of the C-14 had decayed). How old is that piece of wood? (Ans.9953 y)

GLOSSARY

A.C Generator is a device that converts mechanical energy into electrical energy.

AC is the type of electric current which changes its direction continuously.

Acoustic Lensing is the technique in which some materials are used to focus or diverge sound waves.

Acoustic Protection is the application of soft and porous material to protect individuals against undesirable sounds and noises.

Alpha Decay is a type of radioactive decay in which an atomic nucleus emits an alpha particle (which is equal to helium nucleus).

Ammeter is a device used to measure electric current through any device.

Ampere is the unit of electric current and is defined as one coulomb charge per second.

Analogue-to-Digital Converter is an electronic circuit which converts the continuously changing analogue signals to discrete digital signals.

Apparent volume expansion is thermal expansion of volume of liquid in a container without considering the expansion of its container

Audible Frequency Range is the range of frequency from 20 Hz to 20,000 Hz that humans can hear.

Background Radiation is a measure of the level of ionizing radiation present in the environment at a particular location which is not due to deliberate introduction of radiation sources.

Beta Decay is a type of radioactive decay in which an atomic nucleus emits a beta particle (electron).

Bimetallic Strips consists of two thin strips of different metals joined together which bend on heating.

Bit is a digit in binary (0 or 1), which is an abbreviation of binary digit.

Carbon - 14 Dating is a radioactive dating technique based on the radioactivity of carbon-14.

Charging by contact is the process when a charged object comes into contact with a neutral object, some electrons transfer between them, causing the neutral object to acquire the same charge type (positive or negative) as the charged object, but to a lesser degree.

Charging by friction involves rubbing two dissimilar materials together which transfers electrons from one material to the other.

Charging by induction is a method where a charged object influences the distribution of charge in a nearby neutral object without physically touching it which creates a temporary separation of charges in the neutral object.

Coefficient of linear thermal expansion is the fractional change in length per kelvin change in temperature.

Coefficient of volume thermal expansion is the fractional change in volume per kelvin change in temperature.

Concave Lens is a type of lens which is thin from the center and thick from the outer edges it diverges the parallel light rays.

Condensation is a phenomenon in which gases (vapours) change into liquids.

Conduction is the mode of transfer of heat due to direct contact of medium particles, which do not change their positions. It occurs in solids because of difference in temperatures.

Conductors are materials that allow electric charge to flow freely through them because they have loosely bound electrons that can easily move under the influence of an electric field e.g. metals like copper and aluminum.

Conservation of charge is a fundamental law stating that the total electric charge in an isolated system remains constant or charge can't be created or destroyed, only transferred between objects.

Convection is the mode of transfer of heat due to the motion of particles. It occurs in liquids and gases because of the density difference between different regions.

Conventional current is the direction of flow of positive charges per unit time.

Convex lens is a type of lens which is thick from the center and thin from the outer edges it converges the parallel light rays to a single point.

Corona discharge is a faint glow or ionization of air caused by a strong electric field around a conductor which can be seen around high-voltage power lines.

Critical angle is the angle of incident light ray for which in spite of transmission into other medium the light ray moves along the boundary between the two media.

Critical temperature is the temperature at which and below which the resistance and resistivity of substance become zero is called the critical temperature.

Cyclones are large revolving tropical storms caused by winds blowing around a central area of low atmospheric pressure.

Dark matter is believed to comprise more than 80% of the universe's matter, existence of dark matter is inferred because celestial objects and cosmic structures cannot be explained without it.

DC is the type of electric current that is unidirectional and does not change its direction.

Deposition is a phenomenon in which gas changes directly to solid.

Diffraction is the bending of waves around the edges of an obstacle.

Digital-to-Analogue Converter is an electronic circuit which converts discrete digital signal to analogue signals.

Discharging is the process by which an object loses its electric charge which can happen through conduction (touching a grounded object), convection (charged particles carried by air), or a spark (sudden movement of charge).

Dispersion from a prism is the phenomenon in which white light splits into its seven constituent colors due to different extent of refraction.

Drought is a prolonged dry period (deficiency of precipitation) in the natural climate cycle that can occur anywhere in the world.

Earth's magnetic field is generated by the rotation of the Earth and its molten iron core that contains charged particles in motion.

Echo is the reflected sound that can be distinguished from original sound (is heard after 0.1 s or more of the original sound).

Electric Circuit is a closed pathway through which electricity flows, typically consisting of a power source, wires, and components like resistors.

Electric Current is the rate of flow of charges.

Electric field is a region of space where a charged object experiences a force whose strength and direction depends on the amount and type of charge present.

Electric field lines are imaginary lines that depict the direction and strength of an electric field, which point away from positive charges and towards negative charges, with the density of lines indicating the field's strength.

Electric Motor is device that converts electric energy into mechanical energy.

Electric Power is the rate at which electrical energy is transferred or consumed in a circuit, measured in watts (W).

Electrical Energy is the ability of electricity to do work or produce heat, measured in joules (J) or kilowatt-hours (kWh).

Electrical Safety involves the practices and measures to prevent accidents and injuries related to electricity, including proper installation, maintenance, and following safety guidelines.

Electrification is the process by which an object acquires an electric charge which can happen through various methods like friction, contact, or induction.

Electromagnetic induction is the production of an electromotive force across a conductor when it is exposed to a varying magnetic field.

Electromagnetic spectrum is the range of different wavelengths of electromagnetic waves is called the spectrum of the electromagnetic waves.

Electromagnetic waves are the waves that do not require any media for their production and propagation.

Electronics is the branch of physics that helps to study the emission and behaviour of electrons with electronic devices is known as electronics.

Electroscope is a simple instrument used to detect the presence and sign (positive or negative) of electric charge, which typically consists of two thin metal leaves that diverge when charged.

Electrostatic precipitator is a device that uses an electric field to remove dust particles and other pollutants from air.

Emf source is any device that converts non-electrical energy into electrical energy.

Evaporation is phenomenon of conversion liquid into vapours at any temperature.

Extrinsic semiconductors are those semiconductors that are doped with some specific impurities, which are of two types; p-type and n-type.

Falsibility is the belief that for any hypothesis to have credence, it must be inherently disprovable before it can become accepted as a scientific hypothesis or theory.

First law of reflection states that the incident ray, the reflected ray and the normal all lie in same plane.

Flooding is an overflow of water onto normally dry land.

Focal length is the distance from the lens to its focal point for a converging lens the focal length is positive while for a diverging lens the focal length is negative.

Forward biased is when the positive terminal of a DC source is connected to p-type and negative terminal is connected to n-type semiconductor of a pn junction, the junction is said to be in forward biased and the diode allows current to flow.

Freezing is the phenomenon in which liquid changes into solid.

Fundamental logic gates are three logic gates AND, OR and NOT.

Gamma decay is a type of radioactive decay in which an atomic nucleus emits a gamma particle.

Gamma rays are the most penetrating nuclear radiations and are used in medical treatment in detecting and killing cancerous cells, sterilizing food and medical equipment, engineering applications such as detecting cracks in metal etc.

Geothermal activity is a group of natural heat transfer processes, caused by the presence of excess heat in the subsurface of the affected area, occurring on Earth's surface.

Global warming is the long-term heating of Earth's surface observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning.

Good thermal conductors are those materials, through which, heat can easily pass.

Good thermal emitters are those materials, from which, heat can easily emit.

Gravitational Lensing is the phenomenon in which light bends while passing by a heavy galactic object due to its strong gravity.

Greenhouse Effect is the process through which heat is trapped near Earth's surface by substances known as greenhouse gases.

Half-life is the time needed for half of the original nuclei of a sample of a radioactive substance to undergo radioactive decay.

Heat Capacity is the amount of heat required to raise the temperature of any amount of substance by 1 °C or 1 K.

Heat Wave is a period of abnormally hot weather generally lasting more than two days and can occur with or without high humidity.

Humidity is content of water in air.

Hurricane is a tropical system with winds that have reached a constant speed of 74 miles per hour or more.

Induced polarization occurs when a charged object is brought near an insulator, the electric field from the charged object redistributes the charges within the insulator, creating a slight separation of positive and negative charges.

Infrared Radiations are in general produced by thermal motion, the vibration and rotation of atoms and molecules and have applications in household electrical appliances, remote controllers, intruder alarms, thermal imaging and optical fibers.

Infrared Thermometer is a thermometer that measures temperature from infrared radiations emitted by a body due to its temperature.

Infrasound waves are the sound waves having frequency less than 20 Hz, which human cannot hear.

Insulators are materials that resist the flow of electric charge because they have tightly bound electrons that are difficult to move e.g. rubber, plastic, and wood.

Intensity is the power per unit area (or energy per unit area per unit time) carried by a wave.

Intrinsic Semiconductors are pure semiconductors (such as Si or Ge) are called intrinsic semiconductors.

Kilowatt Hour (kWh) is the unit of electrical energy commonly used to measure consumption or production over time, equal to one kilowatt of power used for one hour.

Latent Heat is the amount of heat energy absorbed or lost by a substance during its phase change without change in its temperature.

Latent Heat of Fusion is the amount of heat energy required to convert a given mass of a substance from the solid state to the liquid state without change in its temperature is called its latent heat of fusion

Latent Heat of Vaporization is the amount of heat energy required to convert a given mass of a substance from the liquid state to the gaseous state without any change in its temperature is called its latent heat of vaporization.

Lenses are transparent objects that refract light in a specific way to form images.

Lenz's Law states that the direction of induced current in a circuit is always such that it opposes the cause which produces it.

Lichtenberg figures are branching, fern-like patterns left on an insulator's surface when a high-voltage discharge passes through it.

Light-Emitting Diode is a types of diode that emits energy in the form light when the electric current passes through it.

Lightning control rod are a well-established and effective method for protecting structures from lightning strikes.

Lightning Generation is the rapid discharge of electricity that occurs within a cloud or between a cloud and the ground, which is caused by the build-up of electric charge within the cloud due to various atmospheric processes.

Linear thermal expansion of solids is increase in length of substance on heating.

Logic Gates are the digital electronic circuits used to implement binary operations.

Longitudinal waves are the waves in which particles of the medium vibrate/oscillate parallel to the direction of motion of waves.

Long-sightedness or hyperopia is the condition in which a person can see distant objects clearly but near objects appear blurry to him.

Loudness is the perception of sound intensity; greater the intensity, louder the sound will be.

Magnetic Field is produced around a wire when a current is passing through it.

Magnifying glass is a single lens device which is used to see bigger images of the objects.

Majority Charge Carriers are electrons in n-type semiconductors and holes in p-type semiconductors.

Mechanical Waves are the waves that require medium for their propagation.

Melting is the phenomenon in which solid changes into liquid.

Microwaves have a higher frequency and lower wavelength than radio waves, but they are still generally thought of as low energy radiations and are used by some radars, Bluetooth, headphones, speakers and even Wi-Fi.

Minority Charge Carriers are electrons in p-type semiconductors and holes in n-type semiconductors.

Modulation is the process in which low frequency signal (modulator) is added with the high frequency carrier wave, the sum of these two is called the modulated wave for radio transmission.

Musical Sound is a sound that is pleasant and harmonious.

Nature of Light have two aspects a wave like and a particle like.

Near Point is the minimum distance at which if the object is placed we have clear image on our retina.

Noise is any loud, discordant or dis-agreeable sound.

N-Type Semiconductors are semiconductors with pentavalent impurity.

Nuclear Fission is a nuclear reaction in which a heavy nucleus splits into small nuclei with the emission of large amount of energy.

Nuclear Fusion is a nuclear reaction in which two nuclei are combined or fused together to form a larger nucleus and emit large amount of energy.

Nuclear Radiations are the rays that originate in the nuclei of atoms

Nucleons are the particles found inside nucleus (i.e., protons and neutrons).

Nucleus is the region consisting of protons and neutrons at the center of an atom.

Nuclide is a type of atom whose nucleus has specific numbers of protons and neutrons.

Ohm's Law states that the amount of electric current in a circuit depends upon the potential difference while keeping temperature constant.

Optical Fibers are the doubly refractive indices concentric tubes of glass or plastic which are used for transmission of light using the phenomenon of total internal reflection.

Optics is the science of light and its interaction with matter.

Parallel Combination of Resistors include connecting resistors side by side across the same voltage source, allowing multiple current paths.

Pentavalent impurities such as phosphorus, arsenic, antimony, and bismuth have five valance electrons and belong to group V-A of periodic table.

Perspex Block is a tough transparent plastic block which is used instead of glass blocks.

Photon is a tiny massless particle from which the light is composed of.

Pitch is the perception of frequency of sound; greater the frequency, greater will be the pitch and shriller will be the sound.

Potential barrier is the value of potential barrier for Ge crystal is 0.3 V and for Si crystal is 0.7 V.

Potential difference is the amount of work done in moving a unit positive charge from one point to another inside an electric field.

Potential divider is a circuit arrangement used to divide a voltage into smaller fractions using resistors connected in series.

Pressure is Force on unit area on an object perpendicularly.

Pressure of gas is the measure of force exerted by the gas particles on unit area of the walls of the container perpendicularly.

Projector is an optical device which use single lens to enlarge the image of an object.

P-Type semiconductors are semiconductors with trivalent impurity.

Quality is number and relative intensity of multiple sound frequencies.

Quantization of charge is the principle that electric charge exists in discrete units called electrons and protons.

Quantum computing uses phenomena in quantum physics to create new ways of computing.

Radiation is the mode of transfer of heat due to electromagnetic waves. It *does* not require material medium for its motion.

Radiation Pressure is the phenomenon in which due to transfer of momentum light can exert pressure on objects.

Radio Waves are the range of longest wavelengths in the family of electromagnetic waves is the radio waves and can travel at the speed of light and can be used in radio transmission, television transmission and in astronomy.

Radioactive Dating is 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.

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

Radioactive Substance is a substance or object that emits nuclear radiation.

Real volume expansion is thermal expansion in volume of liquid when it is heated directly.

Reflection is the throwing back by a body or surface of light, heat, or sound without absorbing it.

Reflection of light is when a ray of light approaches a smooth polished surface and bounces back is called reflection.

Refraction is the change in direction of a wave passing from one medium to another caused by its change in speed.

Refraction of light is the phenomenon in which the light ray's direction changes when it enters from one medium to another.

Refractive index is the measure of bending of a light ray when passing from one medium to another.

Refrigerant is a material used to produce cooling in refrigerator.

Relay is an electrically operated switch that open and close the circuits by receiving electrical signals from outside sources.

Resistance is the opposition to the flow of charges or opposition to electric current.

Resistivity is the resistance of unit length and unit area.

Resistor is an electrical component that limits the flow of electric current in a circuit, measured in ohms (Ω).

Reverberation is the reflected sound that cannot be distinguished from original sound (is heard before 0.1 s of the original sound).

Reverse biased is when potential at anode (p-type) is smaller than the potential at cathode (n-type), the diode is said to be reverse biased and the current is blocked.

Scattering of Light is the reflection of light waves in different directions from the particles of the medium.

Second law of reflection states that the angle of incident ray is equal to the angle of the reflected ray.

Seismic waves are caused by the sudden movement of materials within the Earth, such as slip along a fault during an earthquake.

Series Combination of Resistors include connecting resistors end-to-end in a single path so that the same current flows through each.

Shielding is a technique to limit radiation exposure.

Short-sightedness or Myopia is the condition in which a person can see near objects clearly but distant objects appear blurry to him.

Solar Sail is a spacecraft propulsion method that utilizes a curious quirk of photons.

Sound intensity level is a unit less quantity that tells about the level of sound relative to a fixed standard.

Sound is a disturbance of matter that is transmitted from its source to outwards and which produces sensation of hearing in ear.

Specific Heat Capacity is the amount of heat required to raise the temperature of one gram of a substance by 1 °C or 1 K.

Spectroscopy is the branch of physics which is used to study the ways different electromagnetic waves interact with matter.

Step-down Transformer is used to decrease the incoming voltage.

Step-up Transformer is used to increase the incoming voltage.

Sublimation is a phenomenon in which solids change directly into gases.

Superconductor are those material through which current flows without resistance.

Temperature Coefficient of Resistance (α) is a measure of how a material's resistance changes with temperature.

Thermal expansion means increase in size of matter on heating.

Total internal reflection is the phenomenon in which a light ray travelling in denser medium bounces back to the same medium after striking the boundary of a rarer medium.

Transformer is an electrical device which is used to increase or decrease the value of an alternating voltage.

Transistor is a device that acts as both a transmitter and resistor and is made in two types: PNP and NPN.

Transverse waves are the waves in which particles of the medium vibrate/oscillate perpendicular to the direction of motion of waves.

Trivalent impurities such as boron, aluminum, indium, and gallium have three valance electrons and belongs to group III-A of periodic table.

Tsunamis are a series of enormous ocean waves caused by earthquakes, underwater landslides, volcanic eruptions or asteroids.

Two Long Parallel Wires carrying a current in same direction attract each other.

Ultrasound waves are the sound waves having frequency greater than 20 kHz, which human cannot hear.

Universal Logic Gates are the logic gates NAND and NOR because they can be used to make all the other gates.

Vaporization is the phenomenon in which a liquid is converted into gas (vapours) upon boiling.

Visible Light is the narrow segment of the electromagnetic spectrum to which the normal human eye responds.

Voltmeter is a device used to measure potential difference across any device.

Volume thermal expansion of solids is increase in volume of substance on heating.

Wave is the energy transfer mechanism without the transport of material media.

Wildfires is an unplanned, unwanted fire burning in a natural area, such as a forest or grassland.

Winter Storms is an event in which the main types of precipitation are snow, sleet or freezing rain.

X-rays of low range overlaps with the ultraviolet and high energy x-rays overlaps gamma rays (in low energy region) and its applications are in medical, technological and social applications some of them are use in medical imaging, security scanners, killing cancerous cells and engineering applications such as detecting cracks in metal etc.

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