CHAPTER 12

Nuclear and Particle Physics

STUDENT LEARNING OBJECTIVES

Core Concepts of Nuclear Processes

- State that nucleon number and charge are conserved in nuclear processes.
- Describe the composition, mass, and charge of alpha (α), beta (β), and gamma (γ) radiations, including both beta-minus (electrons) and beta-plus (positrons).
- Explain that alpha-particles have discrete energies, but beta-particles have a continuous range of energies because (anti) neutrinos are emitted in beta-decay.

Matter and Antimatter

- Explain that an anti-particle has the same mass but the opposite charge to its corresponding particle, giving the example that a positron is the anti-particle of an electron.
- State that electron anti-neutrinos are produced during beta-minus decay and electron neutrinos are produced during beta-plus decay.
- Illustrate that anti-particles usually have the same weight but opposite charge compared to their matter counterparts.
- Describe annihilation reactions where a particle meets its anti-particle, leading to mass conversion into heat and light energy, or the formation of new sub-atomic particles.
- State that most of the matter in the observable universe is matter.
- Describe the asymmetry of matter and anti-matter in the universe as an unsolved mystery.

Fundamental Particles and Forces

- Describe quarks and anti-quarks as fundamental particles, noting that there are six flavors: up, down, strange, charm, top, and bottom.
- Describe protons and neutrons in terms of their quark composition.
- State that a hadron may be either a baryon (consisting of three quarks) or a meson (consisting of one quark and an anti-quark).
- Describe the changes to quark composition that take place during beta-minus and beta-plus decay.
- State that electrons and neutrinos are fundamental particles called leptons.
- State W, Z, gluon, and photons as fundamental particles called exchange particles or force carriers.
- State the Higgs Boson as a fundamental particle responsible for a particle's mass.
- Explain that every subatomic particle has a corresponding anti-particle that has the same mass but opposite electric or magnetic properties, according to the Standard Model of Particle Physics.
- Explain that there are various theories about how 'mass' and 'force' are generated, such as from quantum fields when energized, or from multi-dimensional 'strings' that vibrate in higher dimensions to give rise to particles.

INTRODUCTION

What are the primary reasons physicists sought more fundamental particles beyond protons, neutrons, and electrons by the late 1960s?

All atoms are believed to be composed of neutrons, protons, and electrons. The antiparticles of these particles are also known, such as the positron (a positive electron), the neutrino, and the photon. By the late 1960s, many new particles similar to neutrons and protons, called mesons, were discovered. Some mesons had masses less than nucleons but more than electrons, while others had masses greater than nucleons. This led physicists to search for even more fundamental constituents, which were later confirmed as quarks. This chapter will discuss the basic building blocks of matter.

12.1 STRUCTURE AND PROPERTIES OF THE NUCLEUS

Q **What is atomic Nucleus? Define its mass number and charge numbers?**

Ans

ATOMIC NUCLEUS:

In 1911, from his experiments, Ernest Rutherford developed a nuclear model of the atom. According to this model, an atom consists of a small dense, positively charged nucleus with negative electrons orbiting about it. About 99.9% of mass of atom is concentrated in the nucleus. The radius of the atom is 10[illegible] times the radius of the nucleus.

A nucleus consists of protons and neutrons called nucleon. A proton has a positive charge equal to 1.6×10^{-19}C while neutron has no charge. The mass of proton is 1.673×10^{-27} kg while mass of neutron is 1.675×10^{-27} kg i.e the mass of a neutron is almost equal to mass of proton.

Unified Mass Scale:

The mass of atomic particles cannot be expressed in terms of very large standard units of mass such as kilogram. It is expressed in terms of unified mass scale (u), which may be stated as:

1 u is exactly equal to the one twelfth the mass carbon-12 atom.

i.e. $1\ u = 1.6606\times10^{-27}$ kg

In unified mass scale:

Mass of proton = 1.007276 u
Mass of neutron = 1.008665 u
Mass of electron = 0.00055 u

For Your Information

Some atomic masses

[illegible]	[illegible]
e	0.00055
n	1.008665
^{1}H	1.007276
^{2}H	2.014102
^{3}H	3.01605
^{3}He	3.01603
^{4}He	4.002603
^{7}Li	7.016004
^{10}Be	10.013534
^{14}N	14.0031
^{17}O	16.9991

Atomic Number:

The number of protons inside a nucleus is called the atomic number or the charge number of an atom.

It is donated by Z.

Thus;

The total charge of nucleus = Ze
Where e indicates charge on one proton.

Mass Number:

The combined number of protons and neutrons in a nucleus is known as its mass number.

It is usually denoted by A.

Neutron Number:

The number of neutrons in a nucleus is called neutron number.

It is denoted by N and is given by,

$$N = A - Z$$

Symbolic Representation of Nuclei:

A nucleus of an element X with mass number A and charge number Z is represented by the symbol;

$$^{\text{mass number}}_{\text{charge number}}X \quad \text{or} \quad ^{A}_{Z}X$$

For Example:

(i) For hydrogen A = 1 and Z = 1 and is represented by the symbol $^{1}_{1}H$.

(ii) For helium, A = 4 and Z = 2 so it is represented by the symbol $^{4}_{2}He$.

(iii) For uranium, A = 235 and Z = 92 so it is represented by the symbol $^{235}_{92}U$.

Nucleons:

A nucleus consists of protons and neutrons; these particles are called the nucleons.

Proton:

A proton has a positive charge equal to 1.6×10^{-19}C and its mass is 1.673×10^{-27} kg.

Neutron:

A neutron has no charge, but its mass is 1.675×10^{-27} kg. The mass of neutron is nearly equal to the mass of proton.

UNIFIED MASS SCALE (u):

The unified mass scale based on the mass of the carbon atom $^{12}C_6$ which is taken exactly equal to 12u. Thus 1 u is equal to 1/12 of the mass of the carbon atom

$$1\ u = \frac{1}{12} \times \text{mass of carbon atom}$$

Or $$1\ u = 1.6606 \times 10^{-27}\ kg$$

➢ In this unit the mass of proton is 1.007276 u and that of neutron is 1.008665 u while that of electron is 0.00055 u.

Charge on an atom:

➢ An atom on the whole is electrically neutral. Number of proton inside the nucleus is equal to the number of electrons outside the nucleus

The atomic nucleus consists of two types of particles: protons and neutrons. A proton is the nucleus of the simplest atom, hydrogen (protium). It carries a positive charge equal in magnitude to that of an electron (1.6×10^{-19} C) and has a mass of 1.67×10^{-27} kg. The neutron, discovered by James Chadwick in 1932, is electrically neutral and has a mass nearly identical to that of a proton. Both neutrons and protons are collectively called nucleons.

Isotopes

Nuclei with the same number of protons but different numbers of neutrons are called isotopes. For a particular element, like carbon, nuclei can have varying numbers of neutrons while maintaining the same number of protons. For example, carbon nuclei always have 6 protons but may have different neutron counts. Examples of carbon isotopes are $^{12}_{6}C$, $^{13}_{6}C$, and $^{14}_{6}C$. Among these, $^{12}_{6}C$ and $^{13}_{6}C$, are stable, but $^{14}_{6}C$ is unstable and decays into nitrogen with the emission of a beta particle and a neutrino.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Define a nucleon.**

Ans: A nucleon is a collective term for the particles that make up the atomic nucleus: protons and neutrons.

- **What is the significance of the atomic number (Z) for an element?**

Ans: The atomic number (Z) determines the number of protons in an atom's nucleus, which uniquely defines the chemical identity of an element.

- **Briefly explain what isotopes are.**

Ans: Isotopes are atoms of the same element (meaning they have the same number of protons or atomic number Z) but differ in the number of neutrons in their nucleus, leading to different mass numbers (A).

- **How is the mass number (A) related to the number of protons (Z) and neutrons (N) in a nucleus?**

Ans: The mass number (A) is the sum of the number of protons (Z) and the number of neutrons (N) in a nucleus, i.e., $A = Z + N$

- **What is the approximate mass of a proton in unified mass units (u)?**

Ans: The approximate mass of a proton is 1.007276 u

- **What is unified mass scale?**

Ans: **Unified Mass Scale (U):**

The unified mass scale based on the mass of the carbon atom $^{12}C_6$ which is taken exactly equal to 12u. Thus 1 u is equal to 1/12 of the mass of the carbon atom

$$1\ u = \frac{1}{12} \times \text{mass of carbon atom}$$

Or $$1\ u = 1.6606 \times 10^{-27}\ kg$$

In this unit the mass of proton is 1.007276 u and that of neutron is 1.008665 u while that of electron is 0.00055 u.

- **What is the charge on an atom?**

Ans: An atom on the whole is electrically neutral. Number of protons inside the nucleus is equal to the number of electrons outside the nucleus with equal and opposite charge.

MULTIPLE CHOICE QUESTIONS

- **Which of the following defines the chemical identity of an element?**

(a) Number of neutrons (b) Mass number (c) Atomic number (d) Total number of nucleons

Answer: (c) Atomic number **Explanation:** The atomic number (Z), which represents the number of protons, uniquely determines an element's chemical identity and its position in the periodic table.

- **An isotope of an element shares the same:**

(a) Mass number but different proton number (b) Neutron number but different proton number
(c) Atomic number but different neutron number (d) Total nucleons but different proton number

Answer: (c) Atomic number but different neutron number **Explanation:** Isotopes of an element have the same number of protons (same atomic number) but a different number of neutrons, leading to different mass numbers.

- **The unified mass scale (u) is defined as:**

(a) The mass of a proton (b) Exactly one-twelfth the mass of a carbon-12 atom
(c) The sum of masses of a proton and a neutron (d) The mass of an electron

Answer: (b) Exactly one-twelfth the mass of a carbon-12 atom **Explanation:** The unified atomic mass unit (u) is defined precisely as 1/12th the mass of a neutral carbon-12 atom.

- **A nuclide is denoted as $^{A}_{Z}X$. What does 'A' represent?**

(a) Atomic number (b) Number of protons
(c) Number of neutrons **(d) Total number of nucleons**

Answer: (d) Total number of nucleons

Explanation: 'A' is the mass number, which is the sum of protons (Z) and neutrons (N) in the nucleus, hence the total number of nucleons.

- **If a carbon nucleus has 6 protons and 8 neutrons, its notation would be:**

(a) $^{14}_{6}C$ (b) $^{14}_{8}C$ (c) $^{8}_{6}C$ (d) $^{6}_{14}C$

Answer: (a) $^{14}_{6}C$ **Explanation:** The atomic number (Z) is 6 (for carbon), and the mass number (A) is the sum of protons and neutrons, 6+8=14. So it's $^{14}_{6}C$.

- **The nuclei $_6C^{14}$ and $_7N^{14}$ can be described as:**

(a) Isotones (b) Isobars (c) Isotopes of carbon (d) Isotopes of nitrogen

Explanation: Isobars have same mass number

- **Particles which can be added to the nucleus of an atom without changing its chemical properties are called:**

(a) Neutrons (b) Electrons (c) Protons (d) Alpha-particles

Explanation: Chemical properties depend on number of protons

- **Atoms having equal number of neutrons as well as equal number of protons but with nucleons in different energy states are called:**

(a) Isotopes **(b) Isobars** (c) Isotones (d) Isomers

Explanation: It is definition of Isobars

- **In stable nuclei, the number of neutrons (N) is related to the number of protons(Z) as:**

(a) $N < Z$ (b) $N = Z$ (c) $N > Z$ (d) $N \geq Z$

Explanation: For stable nuclei: **For light nuclei,** the number of neutrons (N) is **often equal** to the number of protons (Z) ($N = Z$).

For heavier nuclei, the number of neutrons (N) must be greater than the number of protons (Z) ($N > Z$) to overcome increasing electrostatic repulsion between protons. Therefore, the most general and correct statement is (d) $N \geq Z$.

12.2 FUNDAMENTAL FORCES OF NATURE

Q. **12.7 What are fundamental forces of nature? Describe four fundamental forces in nature.**

Ans

FUNDAMENTAL FORCES OF NATURE

All interactions in the universe are governed by **four basic forces**, known as fundamental forces. These forces control how objects move, interact, and behave at different scales.

1. **Gravitational Force (Gravity):**
   - **Nature:** Weakest of the four forces, but long-range and always attractive.
   - **Source:** Arises from gravitational interaction between bodies due to their mass.
   - **Significance:** Significant for massive objects (like planets and stars). Negligibly weak at the atomic level.
   - **Dependence:** Proportional to the product of masses and inversely proportional to the square of the distance.
2. **Electromagnetic Force:**
   - **Nature:** Much stronger than gravity, also long-range. Can be attractive or repulsive.
   - **Source:** Responsible for electric and magnetic field interactions.
   - **Significance:** Governs atomic structure, chemical bonding, electricity, magnetism, and light propagation.
   - **Formulation:** James Clerk Maxwell unified electricity and magnetism with "Maxwell's equations."
3. **Strong Nuclear Force:**
   - **Nature:** Strongest of the four fundamental forces. It is a very short-range force.
   - **Source:** Responsible for holding the nuclei of atoms together, overcoming the electrostatic repulsion between protons.
   - **Range:** Only exists inside the nucleus (range $<10^{-15}$ m).
   - **Interaction:** Acts as an attractive force between all nucleons (protons and neutrons).
4. **Weak Nuclear Force:**
   - **Nature:** Short-range force.
   - **Source:** Responsible for radioactive decay, particularly beta decay, and interactions involving neutrinos.
   - **Significance:** Can change the identity of particles, essential for nuclear fusion in stars and the decay of unstable atomic nuclei.

- 1967 Steven Weinberg and Abdus Salam used their ideas to build a model of electron mass and weak boson mass.
- Also earlier ideas by Sheldon Glashow

Nobel prize in 1979

FORCE	APPROXIMATE RELATIVE STRENGTH (COMPARED TO STRONG FORCE)	RANGE
Gravity	10^{-38}	∞ (Infinite)
Weak nuclear force	10^{-13}	$<10^{-18}$ m
Electromagnetic	10^{-2}	∞ (Infinite)
Strong nuclear force	1	$<10^{-15}$ m

MULTIPLE CHOICE QUESTIONS

- **Which fundamental force is responsible for holding the nucleus together?**
  (a) Gravitational force (b) Electromagnetic force (c) Weak nuclear force (d) Strong nuclear force

Answer: **(d) Strong nuclear force**

Explanation: The strong nuclear force overcomes the electrostatic repulsion between protons to bind nucleons within the nucleus.

- **Among the four fundamental forces, which one has an infinite range but is weakest at the subatomic level?**
  (a) Strong nuclear force (b) Electromagnetic force (c) Weak nuclear force (d) Gravitational force

Answer: (d) Gravitational force

Explanation: Gravity is the weakest of the four forces by far, and while it has an infinite range, its effects are negligible at the atomic and subatomic scales.

- **The electromagnetic force is mediated by which particle?**
  (a) Gluon (b) Photon (c) W boson (d) Graviton

Answer: (b) Photon

Explanation: Photons are the exchange particles (gauge bosons) for the electromagnetic force.

- **Which force is responsible for radioactive beta decay?**
  (a) Strong nuclear force (b) Electromagnetic force (c) Weak nuclear force (d) Gravitational force

Answer: (c) Weak nuclear force

Explanation: The weak nuclear force is responsible for processes like beta decay, where particles change their identity.

- **If you consider two protons, what two fundamental forces are acting between them simultaneously?**
  (a) Gravitational and weak nuclear (b) Strong nuclear and electromagnetic
  (c) Electromagnetic and weak nuclear (d) Gravitational and strong nuclear

Answer: (b) Strong nuclear and electromagnetic

Explanation: Protons have mass (gravitational force), charge (electromagnetic repulsion), and are nucleons (strong nuclear force attraction at short range). However, at nuclear distances, gravity is negligible, and weak force is about identity change, not primarily binding. The two dominant forces between protons in a nucleus are the repulsive electromagnetic force and the attractive strong nuclear force.

SLO BASED SHORT QUESTIONS & ANSWERS

- **List the four fundamental forces of nature.**

Ans: The four fundamental forces are gravitational, electromagnetic, weak nuclear, and strong nuclear.

- **Why is the strong nuclear force essential for the stability of atomic nuclei?**

Ans: It provides a powerful attractive force between nucleons (protons and neutrons) over very short distances, overcoming the electrostatic repulsion between positively charged protons that would otherwise cause the nucleus to break apart.

- **What phenomena are governed by the electromagnetic force?**

Ans: The electromagnetic force governs phenomena such as atomic structure, chemical bonding, electricity, magnetism, and light propagation.

- **Briefly describe the range of the strong nuclear force.**

Ans: The strong nuclear force has an extremely short range, acting only within the atomic nucleus (less than 10^{-15} m), and its strength rapidly drops to zero beyond this distance.

- **Which force can change the identity of particles, and why is it important in stars?**

Ans: The weak nuclear force can change the identity of particles (e.g., transforming a proton into a neutron or vice-versa). It is crucial for nuclear fusion processes in stars, where it facilitates the necessary particle transformations.

- **What are Maxwell Equations? What is their significance?**

James Clerk Maxwell (1861) formulated a set of four fundamental equations named as "Maxwell's equations" that unified electricity and magnetism into electromagnetism. These equations describe how electric and magnetic fields interact and how electromagnetic waves propagate. These equations showed that electric and magnetic fields are not separate forces but are two aspects of a single electromagnetic force.

- **Why nuclear forces were considered necessary for the stability of nucleus in the presence of electromagnetic and gravitational forces.**

  Out of the four fundamental forces, nuclear forces are the strongest attractive forces. Electromagnetism holds the matter together, but there was no explanation on how the nucleus is held together in the atom. If we only consider the forces of electromagnetism and gravity, the nucleus should fly off in different directions. The stability of the nucleus implies that another force should exist within the nucleus which is stronger than the gravitational force and electromagnetic force. This is where nuclear forces come into play.

4.3 MATTER AND ANTI-MATTER

Q. What do you mean by matter and anti matter?

Ans

For your information

1. A particle accelerator is a huge machine that accelerates charged particles, such as electrons, protons, or ions, to extremely high energies and speeds, approaching the speed of light.
2. Linear Accelerators, Cyclotrons and Betatrons are important particle accelerators.

An anti-particle is defined as a particle that has the same mass as its corresponding particle but possesses opposite charges and magnetic moments. For instance, a positron is the anti-particle of an electron, it has the same rest mass as an electron but carries an equivalent positive charge. Anti-particles are commonly represented by a letter with a bar over it, such as an anti-proton ($\bar{p}$) or an anti-neutrino ($\bar{\upsilon}$).

When a particle meets its corresponding anti-particle, they undergo an annihilation reaction. In this process, either all their mass is converted into heat and light energy, or some mass is left over in the form of new sub-atomic particles.

CONCEPT OF ANTI-PARTICLES

Interesting information

For their work on this discovery, Dirac and Anderson received the Nobel Prize in Physics Dirac in 1933 and Anderson in 1936. In 1955, Segre and Chamberlain discovered anti-proton using a particle accelerator and were awarded the Nobel Prize in physics in 1959 for their discovery of anti-proton.

Define an anti-particle and provide an example, highlighting how its properties compare to its corresponding particle.

Paul Dirac predicted in 1928 that fundamental particles have corresponding anti-particles. Anti-particles have the same rest mass as their corresponding particles but possess opposite charges and magnetic moments. For example, a positron (e^+) is the anti-particle of an electron (e^-). It has the same rest mass as an electron but carries a positive charge of the same magnitude.

DISCOVERY OF ANTI-PARTICLES

Which was the first anti-particle discovered, and what were the key subsequent discoveries in this field?

The positron was the first anti-particle discovered by Anderson in 1932 during a cloud chamber experiment, marking the first experimental discovery of an anti-particle. Dirac and Anderson received Nobel Prizes in Physics for their work (Dirac in 1933, Anderson in 1936). In 1955, Segre and Chamberlain discovered the anti-proton using a particle accelerator, earning them the Nobel Prize in Physics in 1959.

Typically, anti-particles are represented by a letter with a bar over it, e.g., anti-proton ($\bar{p}$), anti-neutrino ($\bar{\upsilon}$), and so on.

Q. What is the difference between matter and anti-matter? Discuss reasons why our universe is almost entirely composed of matter. (comprehensive question)

Ans

DIFFERENCE BETWEEN MATTER AND ANTIMATTER

An anti-particle is defined as a particle that has the same mass as its corresponding particle but possesses opposite charges and magnetic moments. For instance, a positron is the anti-particle of an electron, it has the same rest mass as an electron but carries an equivalent positive charge. Anti-particles are commonly represented by a letter with a bar over it, such as an anti-proton ($\bar{p}$) or an anti-neutrino ($\bar{\upsilon}$).

When a particle meets its corresponding anti-particle, they undergo an **annihilation reaction**. In this process, either all their mass is converted into heat and light energy, or some mass is left over in the form of new sub-atomic particles. A notable example is the annihilation of an electron and a positron, which results in the production of two gamma-ray photons. This process conserves both energy and momentum. Annihilation reactions are not limited to electrons and positrons; they can occur between any particle and its anti-particle, including protons and anti-protons, leptons and anti-leptons, or quarks and anti-quarks.

Reasons Why Our Universe is Almost Entirely Composed of Matter

TALENT INFORMATION

The **Standard Model of particle physics** is the most successful theory in physics describing the fundamental particles that make up all matter and three of the four known fundamental forces through which they interact.

It has been observed that most of the matter in the observable universe is composed of matter rather than antimatter. This asymmetry of matter and antimatter in the universe is a "most remarkable feature" and an **unsolved mystery**. This is one of the greatest unsolved puzzles in cosmology, known as the **baryon asymmetry problem** or the **matter-antimatter asymmetry problem**. According to the Big Bang theory, the early universe should have produced nearly equal amounts of matter and antimatter. If this were strictly true, then as the universe cooled, matter and antimatter would have annihilated each other completely, leaving behind a universe filled only with radiation and no stable matter (no stars, planets, or us!).

Since we clearly exist and the universe is full of matter, there must have been a slight imbalance - an extremely tiny excess of matter over antimatter - that survived the annihilation. For every billion antimatter particles, there was roughly one billion and one matter particles. This tiny excess of matter is what makes up everything we see today.

The conditions necessary for this matter-antimatter asymmetry to arise were first outlined by Soviet physicist **Andrei Sakharov** in 1967, known as the **Sakharov conditions**.

Conclusion: In summary, the universe is almost entirely composed of matter because, in the very early universe, a slight, tiny excess of matter particles over antimatter particles was created. This "one extra particle for every billion pairs" survived the subsequent annihilation, forming the basis for all the matter we see today. The precise physical processes responsible for this fundamental asymmetry remain one of the most significant unsolved problems in physics.

Q What is pair production and under what conditions it could happen? Explain. Or Explain the phenomenon of pair annihilation with an example. Explain the utility of its principle in the medical field.

Ans

PAIR PRODUCTION?

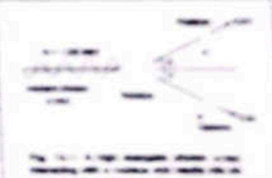
[illegible]

The pair production cannot take place in vacuum of space. The pair production can happen only in the presence of an external object like an atomic nucleus which can experience some recoil during the collision process to conserve the energy and the momentum at the same time.

Pair production occurs when a high-energy photon (gamma-ray, denoted by γ) passes near an atomic nucleus and converts its energy into a particle-antiparticle pair.

- **Example:** An electron-positron pair (e^- and e^+) is commonly produced.
- **Conservation Laws:** The process conserves charge, momentum, and energy. The presence of a third particle (the nucleus) is necessary to conserve linear momentum.
- **Minimum Energy Requirement:** According to Einstein's mass-energy equivalence ($E=mc^2$), the minimum energy of the photon for pair production must be equal to the sum of the rest mass energies of the created particles.

  For an electron-positron pair, the minimum energy is $2m_0c^2$ which is approximately 1.02 MeV (since an electron's rest mass energy is 0.51 MeV).
- **Excess Energy:** If the photon's energy is greater than 1.02 MeV, the excess energy is converted into the kinetic energies of the emitted electron and positron.



[illegible]

- Energy equation of photon = [energy required for pair production] + [Kinetic energy of the particles]

$$hf = 2m_oc^2 + K.E(e^-) + K.E(e^+)$$

Here $$2m_oc^2 = \frac{2\times9\times10^{-31}(3\times10^8)^2}{1.6\times10^{-19}\times10^6}\ MeV$$

$$2m_oc^2 = 1.02\ MeV$$

Condition for pair production

- The pair production can only take palace if the energy of photon must be greater than or equal to the sum of rest mass energy of electron and positron according the law of mass energy equivalence.
- The presence of heavy nucleus must be there so that the linear momentum remains conserved.
- This phenomenon is also known as materialization of energy.
- According to Einstein relation ($E = mc^2$), the mass and energy are inter-convertible.

Utility of its principle in the medical field.

Pair annihilation is used in **Positron Emission Tomography (PET) scans**, a medical imaging technique.

In a PET scan:

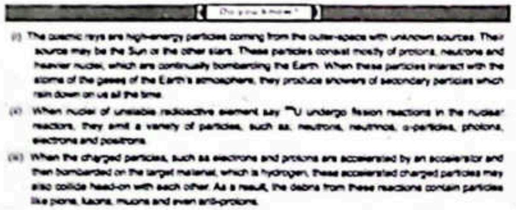
1. A patient is injected with a **radiotracer** containing a positron-emitting isotope.
2. When a **positron** from the tracer meets an **electron** in the body, they **annihilate**, producing two gamma rays.
3. These gamma rays are detected by the PET scanner, allowing doctors to create 3D images of **metabolic activity** in the body.

This helps in:

- **Cancer detection** and monitoring (e.g., finding tumors and checking treatment effectiveness).
- **Diagnosing brain disorders** like Alzheimer's and Parkinson's.
- **Assessing heart disease** by showing blood flow and tissue damage.

Do you know?

Pair production cannot take place in a vacuum or empty space; it requires the presence of an external object like an atomic nucleus to ensure the conservation of energy and momentum during the collision



Do you know?

(i) The cosmic rays are high-energy particles coming from the outer-space with unknown sources. Their source may be the Sun or the other stars. These particles consist mostly of protons, neutrons and heavier nuclei, which are continually bombarding the Earth. When these particles interact with the atoms of the gases of the Earth's atmosphere, they produce showers of secondary particles which rain down on us all the time.

(ii) When nuclei of unstable radioactive element say ^{235}U undergo fission reactions in the nuclear reactors, they emit a variety of particles, such as, neutrons, neutrinos, α-particles, photons, electrons and positrons.

(iii) When the charged particles, such as electrons and protons are accelerated by an accelerator and then bombarded on the target material, which is hydrogen, these accelerated charged particles may also collide head-on with each other. As a result, the debris from these reactions contain particles like pions, kaons, muons and even anti-protons.

'Do you know?

- **Particle Accelerators:** Huge machines that accelerate charged particles (electrons, protons, ions) to extremely high energies and speeds, approaching the speed of light. Examples include Linear Accelerators, Cyclotrons, and Betatrons.
- **Cosmic Rays:** High-energy particles from outer space (Sun or other stars), mostly protons, neutrons, and heavier nuclei, that continually bombard Earth. They produce showers of secondary particles upon interacting with atmospheric atoms.
- **Nuclear Reactions:** Unstable radioactive elements (like Uranium-235) in nuclear reactors undergo fission, emitting various particles (neutrons, neutrinos, alpha-particles, photons, electrons, positrons).
- **High-Energy Collisions:** When accelerated charged particles (protons, electrons) collide with target materials or each other in accelerators, the debris can contain new particles like pions, kaons, muons, and anti-protons.

INTERESTING INFORMATION:

Quarks and leptons are fundamental particles that also have anti-particles.

Q **What do you mean by annihilation of matter? Explain. or Explain the law of conservation of energy and momentum in electron-positron pair-annihilation.**

ANNIHILATION OF MATTER:

Annihilation is the opposite process of pair production. It occurs when a particle meets its corresponding anti-particle, and they mutually destroy each other, converting their entire mass into energy (typically photons).

Example: When an electron and a positron interact, they annihilate into two gamma-ray photons:

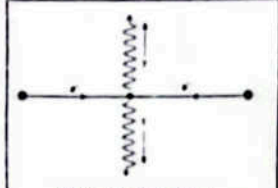


Fig. 12.2 Annihilation of matter

$$e^- + e^+ \longrightarrow \gamma + \gamma$$

- **Energy Release:** Each gamma-ray photon typically has an energy equal to the rest mass energy of one of the particles (e.g., 0.51 MeV for an electron/positron).
- **Conservation Laws:** Energy and momentum are conserved in annihilation reactions.
- **The two photons are emitted in opposite directions in order to conserve momentum.**
- **Other Examples:** Annihilation can occur for other particle-antiparticle pairs, such as proton-anti-proton, lepton-anti-lepton, and quark-anti-quark.
- **LHC and Annihilation:** Experiments at particle accelerators like the Large Hadron Collider (LHC) at CERN have shown that during high-energy collisions, some mass of colliding particles is changed into electromagnetic radiation, and any leftover mass appears in the form of new sub-atomic particles figure 12.3.

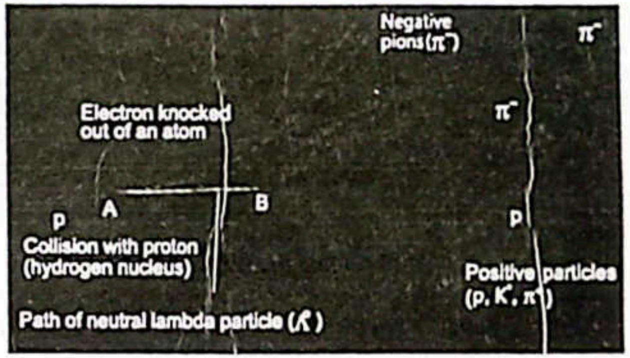


Fig. 12.3: A high energetic $p\bar{p}$ collision producing 18 new particles.

MULTIPLE CHOICE QUESTIONS

- **An anti-particle has the same:**

(a) Charge but opposite mass (b) Mass but opposite charge
(c) Spin but opposite mass (d) Mass and same charge

Answer: (b) Mass but opposite charge

Explanation: An antiparticle has the identical mass as its corresponding particle, but its electric charge (and other quantum numbers like magnetic moment) is opposite.

- **The first anti-particle to be discovered was the:**

(a) Anti-proton (b) Anti-neutrino (c) Positron (d) Anti-muon

Answer: (c) Positron

Explanation: The positron (e+), the antiparticle of the electron, was discovered by Carl D. Anderson in 1932

- **Pair production occurs when a high-energy photon transforms into:**
  (a) Two photons (b) A single particle
  (c) A particle and its anti-particle (d) A proton and an electron

Answer: (c) A particle and its anti-particle

Explanation: Pair production is the process where a high-energy photon converts its energy into a particle-antiparticle pair (e.g., an electron-positron pair).

- **What is the minimum energy required for a photon to create an electron-positron pair?**
  (a) 0.51 MeV (b) 1.02 MeV (c) 1.60 MeV (d) 2.04 MeV

Answer: (b) 1.02 MeV

Explanation: The rest mass energy of an electron is 0.51 MeV. For pair production, the photon must have at least enough energy to create both an electron and a positron, so 2×0.51 MeV=1.02 MeV.

- **The annihilation of an electron and a positron typically results in the emission of:**
  (a) One gamma ray photon (b) Two gamma ray photons
  (c) Three gamma ray photons (d) Alpha particles

Answer: (b) Two gamma ray photons

Explanation: To conserve both energy and momentum, an electron-positron annihilation usually produces two gamma ray photons traveling in opposite directions.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Define an anti-particle.**

Ans: An anti-particle is a subatomic particle that has the same mass as a corresponding particle but opposite electric charge and other quantum numbers.

- **Briefly explain the process of pair production.**

Ans: Pair production is the phenomenon where a high-energy photon (gamma ray) passing near an atomic nucleus converts its energy into a particle-antiparticle pair (e.g., an electron and a positron).

- **Why is an external object (like a nucleus) necessary for pair production to occur?**

Ans: An external object (like a nucleus) is necessary for pair production to conserve both energy and momentum during the transformation of a photon into a particle-antiparticle pair, as the nucleus can absorb some recoil momentum.

- **Describe the process of matter-antimatter annihilation with an example.**

Ans: Matter-antimatter annihilation is when a particle and its corresponding anti-particle collide and convert their entire mass into energy, typically in the form of photons. For example, an electron (e^-) and a positron (e^+) annihilate to produce two gamma-ray photons ($\gamma+\gamma$).

- **What conservation laws are satisfied during pair production and annihilation?**

Ans: Both pair production and annihilation reactions satisfy the fundamental laws of conservation of energy, momentum, and charge.

12.4 RADIOACTIVITY

Q. What is meant by the term radioactivity? Give an account of the radiations emitted by radioactive substance. Or What is meant by radioactivity? Compare the properties and behaviour of three types of radiations.

Ans

RADIOACTIVITY:

The elements having atomic number Z greater than 82 are unstable and emit three types of radiations. Such elements are called radioactive elements and the phenomenon is called radioactivity.

- **Natural Radioactivity:** Occurs for nuclei with atomic numbers greater than 82 (e.g., Uranium, Radium), which are naturally unstable.
- **Artificial Radioactivity:** Unstable isotopes (radioisotopes or radionuclides) can be produced artificially in laboratories by bombarding stable elements with high-energy particles (neutrons, protons, alpha particles, gamma rays).

Discovery of Radioactive Elements:

- In 1896, Henry Becquerel found that uranium (Z = 92) emits an invisible radiation and affects the photographic plate after penetrating through it.
- After Becquerel's discovery, Marie Curie and Pierre Curie discovered two new radioactive elements named as polonium and radium.

The radiations coming out of the radioactive elements are called alpha (α), beta (β) and gamma (γ) radiation.

Analysis of The Radiations:

To study the nature of the radiations, radioactive material such as radium is placed at the center of a lead block. The emitted radiations pass through a hole in the lead block and enter a vacuum chamber passing between the two parallel plates. Then these radiations strike a photographic plate at three different points.

Conclusions:

From this experiment, we conclude that all radiations emitted from radioactive material are not alike.

Types of Radiations (from naturally radioactive substances) These radiations behave differently in an electric field:

1. **Alpha (α) particles:**
   - **Nature:** Helium nuclei ($^4_2$**He**), consisting of two protons and two neutrons.
   - **Charge:** Positive charge (2e). Deflect towards the negative terminal in an electric field.
   - **Mass:** Relatively large mass.
   - **Speed:** ~10^7 m s^{-1}.
   - **Ionization Power:** Highest (about 10^4 ion pairs per mm in air). This means they cause significant ionization when passing through matter.
   - **Penetrating Power:** Lowest. Can be absorbed by a sheet of paper.
   - **Range in air:** Several centimeters.
2. **Beta (β) particles:**
   - **Nature:** Fast-moving electrons (e^-) or positrons (e^+) created within the nucleus during decay. They are indistinguishable from orbital electrons.
   - **Charge:** Negative charge (e^-) or positive charge (e^+). β^- particles deflect towards the positive terminal in an electric field.
   - **Mass:** Much lighter than alpha particles.
   - **Speed:** Up to 0.9995 c (close to the speed of light).
   - **Ionization Power:** Medium (about 10^2 ion pairs per mm in air).
   - **Penetrating Power:** Medium. Can be absorbed by 1-5 mm of aluminum sheet.
   - **Range in air:** Several meters.
3. **Gamma (γ) radiations:**
   - **Nature:** Electromagnetic radiations (photons) emitted from excited nuclei.
   - **Charge:** No charge. Pass through an electric field without deflection.
   - **Mass:** Massless (photons).
   - **Speed:** Travel at the speed of light (3×10^8 m s^{-1}).
   - **Ionization Power:** Lowest (about 1 ion pair per mm in air).
   - **Penetrating Power:** Highest. Can be absorbed by 1-10 cm of lead sheet.
   - **Range in air:** Obeys the inverse square law (can travel very far).

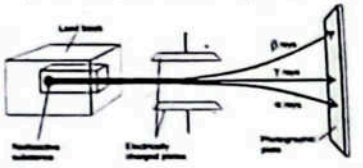


Fig. 12.4: The three radioactive radiations, namely alpha, beta and gamma rays

Q. **What is nuclear transmutation and how parent nuclei changes after emission of alpha, beta and gamma radiation? Explain. or Elaborate the phenomenon of beta-positive decay and beta-negative decay with examples.**

Ans

NUCLEAR TRANSMUTATION:

Radioactivity is a nuclear phenomenon and is not affected by any physical or chemical reaction.

When any particle/radiation is emitted from some radioactive element, then this element changes into a new element called daughter element. The original element is called the parent element. The phenomenon of change of nucleus is called nuclear transmutation of radioactive decay.

During the nuclear changes, the laws of conservation of mass, energy, momentum and charge remain applicable.

Emission Of Alpha Particles: (Alpha Decay)

If the nucleus has more protons than the number of neutrons, the electrostatic force of repulsion becomes greater than the strong nuclear force of attraction. In this case, the nucleus becomes unstable and emits alpha particles in radioactive decay.

When a nucleus of radioactive element emits an α-particle, then due to law of conservation of charge its charge number decreases by 2 and due to law of conservation of mass, the mass number decreases by 4. The emission of α-particle is represented by the following equation;

$$ {}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He $$

Where ${}^{A}_{Z}X$ represents the parent nucleus and ${}^{A-4}_{Z-2}Y$ the daughter nucleus and ${}^{4}_{2}He$ is alpha particle.

For Example:

A radium-226(${}^{226}_{88}Ra$) isotope after emitting an alpha particle decay into radon-222(${}^{222}_{86}Rn$) gas and is represents as

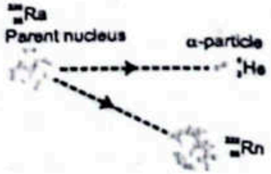
$$ {}^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He $$

In the above nuclear reaction, the daughter nucleus (${}^{226}_{86}Rn$) is different from the parent nucleus (${}^{226}_{88}Ra$). This transition of one element into another is called the transmutation of the elements.

It is experimentally found that the mass of the parent nucleus is greater than the total mass of the daughter nucleus and the mass of the α-particle. Thus, the total mass-energy ($E=mc^2$) of the decay products is less than the mass-energy of the original nuclide. This difference in mass-energy is called the disintegration energy Q, or the Q-value of the decay.

For your information

The neutrino was first proposed by Wolfgang Pauli in 1930 to obey the energy conservation in the beta-minus and beta-plus decays. Later in 1953, neutrino was detected by F. Reines and C. L. Cowan in a high-power nuclear reactor. On this discovery, F. Reines received the Nobel prize in 1995.



For your information

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TALENT INFORMATION

A neutrino is a **tiny, neutral subatomic particle** with **very little mass**. It's often called a "ghost particle" because it **barely interacts with anything**, passing through most matter due to having **no electric charge** and only interacting via the **weak nuclear force** and gravity. There are **three types (flavors)**, and they can **change between these types (oscillate)**, a phenomenon that proved they have mass. Neutrinos are **extremely abundant** in the universe, produced by stars and other cosmic events.

Emission of Beta Particles: (Beta Decay)

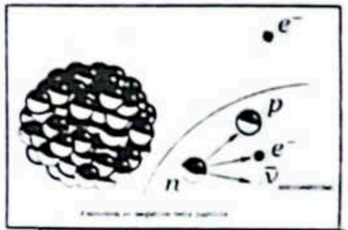
There are two types of β-decay; β^--decay and β^+-decay.

(i) β-minus decay

Some nuclides have neutron-to-proton ratio (N/P) too large and are the source of β-decay. The β-particles are not the orbital electrons but they are created within the nucleus at the moment of emission. In this process, a neutron in the nucleus decays into a proton and an electron, plus another particle called anti-neutrino which is the antiparticle of neutrino. The neutrino is denoted by a Greek symbol ν (nu) and anti-neutrino is denoted by a bar over the $\bar{\nu}$. The decay process is given by the following relation

$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{\nu} $$

One of the neutrons changes to a proton and in order to conserve charge it emits an electron. These electrons are called beta particles. However, they are indistinguishable from orbital electrons. Both the neutrino and the anti-neutrino have zero charge and very small mass, that is why they are very difficult to observe when passing through the matter. No nucleons are lost when a β-particle is emitted, and the total number of nucleons A remains the same but the mass number Z changes. Beta decay process can be written as



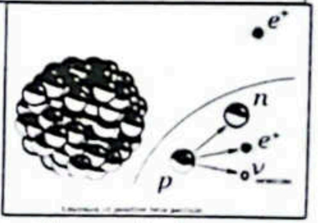
$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \bar{\nu} $$

From the above equation, it is clear that the parent element of atomic number Z is transmuted to another element of atomic number (Z+1). An example is the isotope of thorium, which is unstable and decays into protactinium by beta

$$ {}^{232}_{90}Th \rightarrow {}^{232}_{91}Pa + {}^{0}_{-1}e + \bar{\nu} $$

(ii) β-plus decay

There are also nuclides that have neutron-to-proton ratio (N/P) too small for stability and decay by emitting a positron instead of an electron. The positron (e^+) has the same mass as the electron but it has a positive charge. The positron is the anti-particle of the electron. In this process, a proton in the nucleus decays into a neutron and a positron, plus a neutrino. The generalized decay is given below:



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

An example of a decay of Neon into Flourine by emitting positron and neutrino is:

$$ {}^{19}_{10}Ne \rightarrow {}^{19}_{9}F + {}^{0}_{+1}e + \nu $$

Emission Of Gamma Particles: (Gamma Decay)

After the emission of α and β-particles, the daughter nucleus becomes in an excited state. So, the nucleus comes back to the ground state (un-excited state) after the emission of γ-rays. Both mass number and charge number of the parent nucleus remain unchanged, as the γ-rays photon is mass less and charge less. The emission of γ-radiation from a nucleus is represented by the following equation;

$$ {}^{A}_{Z}X^{*} \longrightarrow {}^{A}_{Z}X + \gamma - \text{radiation} $$

Here ${}^{A}_{Z}X^{*}$ represents an excited nucleus while ${}^{A}_{Z}X$ shows ground state of the nucleus.

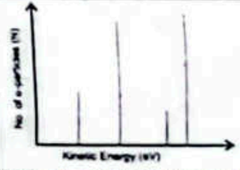
Q. **How energy associated with alpha and beta particles in case of alpha and beta emission in radioactive decay?**

Ans

Energy of Alpha and Beta Particles in Radioactive Decay

In both alpha-decay and beta-decay, the same amount of energy is released for a particular radionuclide.

- **Alpha-decay:** For a given radionuclide, every emitted alpha particle has the same sharply defined kinetic energy. When the number of alpha particles is plotted against kinetic energy, distinct spikes appear on the graph (Figure 12.5), demonstrating that alpha particles have discrete energies.
- **Beta-decay:** In beta-particle emission, energy is shared among the beta particle and the anti-neutrino (or neutrino) in varying proportions. However, the sum of the electron's (or positron's) energy and the anti-neutrino's (or neutrino's) energy remains constant in every case. Therefore,



12.5: Discrete energy values of α-particles in beta-decay, the energy of an electron or a positron can range from zero to a maximum value. When the number of beta particles is plotted against kinetic energy, the graph shows a continuous curve (Figure 12.6), demonstrating that beta particles have a continuous range of energies. The principle of conservation of momentum and energy applies to both alpha and beta emission.


Fig. 12.6: Continuous spectrum of β-particles

Here is a summary of the nature of alpha, beta, and gamma radiations:

Characteristics	α-particles	β-particles	γ-rays
1. Nature	Helium nuclei of charge 2e	Electrons or positrons from the nucleus of charge ±e	E.M waves from excited nuclei with no charge
2. Typical sources	Radon-222	Strontium-94	Cobalt-60
3. Ionization (Ion pairs mm^{-1} in air)	About 10^4	About 10^2	About 1
4. Range in air	Several centimeters	Several meters	Obeys inverse square law
5. Absorbed by	A paper	1-5 mm of Al sheet	1-10 cm of lead sheet
6. Energy spectrum	Emitted with the same energy	Variable energy	Variable energy
7. Speed	$\sim 10^7\ m/s$	$\sim 1\times10^8\ m/s$	$\sim 3\times10^8\ m/s$

Table 12.2: The summary of nature of alpha, beta and gamma radiations

Q. How β-particle comes from nucleus?

Ans

The emission of β-particle from any element X is represented by the following equation

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$$

The emission of electron from the nucleus is considered as a neutron converts into a proton emitting an electron and is represented by the following equation:

$$^{1}_{0}n \longrightarrow {}^{1}_{1}H + {}^{0}_{-1}e$$

MULTIPLE CHOICE QUESTIONS

- **Which type of radiation is equivalent to a helium nucleus?**

  (a) Alpha (b) Beta-minus (c) Beta-plus (d) Gamma

Answer: (a) Alpha

Explanation: An alpha particle is a helium nucleus, consisting of two protons and two neutrons

- **A radioactive decay process in which the atomic number increases by one while the mass number remains constant is:**

  (a) Alpha decay (b) Beta-minus decay (c) Beta-plus decay (d) Gamma decay

Answer: (b) Beta-minus decay

Explanation: In β− decay, a neutron converts to a proton, increasing Z by 1 and keeping a constant

- **Which radiation has the highest penetrating power?**

  (a) Alpha (b) Beta-minus (c) Beta-plus (d) Gamma

Answer: (d) Gamma

Explanation: Gamma rays are high-energy photons with no charge or mass, allowing them to penetrate matter much more easily than charged alpha or beta particles

- **The continuous energy spectrum of beta particles indicates that:**

  (a) Beta particles lose energy to the medium (b) The decay energy is shared among three particles
  (c) The parent nucleus has variable energy levels (d) Beta decay does not conserve energy

Answer: (b) The decay energy is shared among three particles

Explanation: The continuous spectrum is evidence for the emission of a third, unseen particle (the neutrino/antineutrino) that carries away variable amounts of energy

- **If a nucleus undergoes alpha decay, its mass number will decrease by:**

  (a) 1 (b) 2 (c) 3 (d) 4

Answer: (d) 4 **Explanation:** An alpha particle consists of 4 nucleons (2 protons and 2 neutrons), so its emission reduces the mass number by 4

SLO BASED SHORT QUESTIONS & ANSWERS

- **Define natural radioactivity.**

Ans: Natural radioactivity is the spontaneous emission of radiation (alpha, beta, or gamma) from naturally unstable atomic nuclei, typically those with atomic numbers greater than 82.

- **How do alpha, beta, and gamma radiations differ in their response to an electric field?**

Ans: Alpha particles (positive) deflect towards the negative plate, beta particles (negative β^- or positive β^+) deflect towards the positive/negative plate, and gamma radiations (neutral) pass through without deflection.

- **Briefly describe the process of gamma radiation.**

Ans: Gamma radiation occurs when an excited atomic nucleus (often after an alpha or beta decay) transitions to a lower energy state by emitting a high-energy photon called a gamma ray, without changing its atomic or mass number.

- **What is "transmutation" in the context of radioactive decay?**

Ans: Transmutation is the process in which an unstable parent nucleus transforms into a different element (a daughter nucleus) through radioactive decay by changing its number of protons.

- **Why does alpha decay result in discrete energy levels for the emitted particles?**

Ans: Alpha decay results in discrete energy levels because the available decay energy is uniquely shared between only two final particles: the emitted alpha particle and the recoiling daughter nucleus, as required by energy and momentum conservation.

12.5 FUNDAMENTAL PARTICLES

Q. What do you means by fundamental particle and how new particles discovered and discuss the classification of different particles on the basis of different properties.

Ans

FUNDAMENTAL PARTICLES

A fundamental particle is a particle that has no internal structure, meaning it is indivisible.

Current Understanding of Fundamental Particles:

Presently, the fundamental constituents of matter are considered to be:

1. **Quarks:** Make up composite particles like protons, neutrons, and mesons.
2. **Leptons:** Include particles like electrons, positrons, and neutrinos.

These are considered the basic building blocks of matter. When nuclei are smashed in particle accelerators, new types of particles are created, which are outcomes of violent collisions.

Strange Particles:

More than a hundred new particles have been identified to be classified into families with similar properties. Many of these were accounted well with the scheme of theoretical physicist while the rest were named "strange particle". They are always created in pairs, e.g., when a pion (π^-) collides with a proton, two strange particles k^0 (kaon), and Λ^0(lamda) are created. The nuclear reaction is:

$$\pi^- + p \rightarrow k^0 + \Lambda^0$$

Spin of Particles:

All particles have an intrinsic property called spin.

- **Fermions:** Particles with half-integer spin (e.g., 1/2, 3/2). They obey the Pauli Exclusion Principle (only one fermion can occupy a given quantum state). Examples: electrons, protons, neutrons, quarks, leptons. They obey Fermi-Dirac statistics.
- **Bosons:** Particles with zero or whole-number spin (e.g., 0, 1, 2). They do not obey the Pauli Exclusion Principle. They are often force carriers. Examples: photons (spin 1), pions (spin 0), Higgs boson (spin 0), gluons (spin 1), W and Z bosons (spin 1). They obey Bose-Einstein statistics.

Classification by Interaction(Forces) (Hadrons and Leptons):

- **Hadrons:**
  - Particles that experience the **strong nuclear force**.
  - They are **composite** particles (not fundamental).
  - **Categories:**
    - **Baryons:** Made of an **odd number of quarks** (usually three quarks). They are fermions. Examples: protons, neutrons.
    - **Mesons:** Made up of an **even number of quarks** (usually two quarks: one quark and one anti-quark). They are bosons. Examples: pions, kaons.
  - **Historical Note:** The discovery of many such particles led to the idea that they must be made of smaller constituents (quarks).
- **Leptons:**
  - Particles that **do not interact via the strong force**. They interact only through weak or electromagnetic forces.
  - They appear to be **truly fundamental** particles with no internal structure.
  - All known leptons have spin 1/2 (so they are fermions).
  - **The Lepton Family (six known leptons, grouped in three pairs):**
    1. **Electron** (e^-) and Electron neutrino (ν_e)
    2. **Muon** (μ^-) and Muon neutrino (ν_μ)
    3. **Tau** (τ^-) and Tau neutrino (ν_τ)
  - Each pair includes a charged particle (electron, muon, tau) and its associated neutral neutrino. All have corresponding anti-particles.
  - Charged leptons can form composite particles (like atoms). Neutrinos rarely interact with anything. The best-known lepton is the electron.

Q. **How can you say that nucleons are not fundamental particles?**

Ans

Nucleons (protons and neutrons) are not considered fundamental particles because they are composed of smaller, more fundamental particles called quarks. Both beta-decay processes (β^- and β^+) provide evidence that protons and neutrons are not fundamental particles.

This was shown by experiments in 1960 where high-energy electrons scattered off "point-like" structures inside protons. According to the standard model of particle physics, protons are made of two "up" quarks and one "down" quark, while neutrons are made of one "up" quark and two "down" quarks. These quarks are held together by gluons, and quarks themselves are currently considered fundamental. The ability to "break down" protons and neutrons into quarks, as observed in high-energy scattering experiments and described by the standard model, is the definitive reason why nucleons are not considered fundamental particles.

Q. **What are the classifications of particles on the basis of fundamental forces? Explain.**

Ans

Particles can also be classified based on how they interact via the four fundamental forces. Although gravitational force affects all particles, its impact at the subatomic level is so minimal that it is generally disregarded. The electromagnetic force, which acts on all electrically charged particles, is well understood and considered when necessary, but its effects are largely ignored.

Particles are broadly classified based on whether they experience the strong force:

- **Hadrons:** These particles experience the strong force. Examples include protons, neutrons, and pions. Hadrons are composite subatomic particles.
  - **Mesons:** These are bosons and consist of an even number of quarks, specifically a quark-antiquark pair. Examples include pions.
  - **Baryons:** These are fermions and consist of an odd number of quarks, usually three quarks. Protons and neutrons are key examples.
- **Leptons:** These particles do not experience the strong force and interact only through weak or electromagnetic interactions. No experiments have yet revealed any internal structure for leptons; they appear to be truly fundamental particles. All known leptons have a spin of 1/2, making them fermions.

Q. **How are new types of particles created and identified in particle accelerators, and what are "strange particles"?**

Ans

New Particle Discoveries

When a nucleus is smashed in an ultra-high energy particle accelerator, or when two high-energy particles collide, entirely new types of particles are created that do not ordinarily exist within the atoms of everyday matter. These particles are the result of the violent collisions required to probe the basic structure of matter. More than a hundred new particles have been identified and classified into families with similar properties. Many of these were well-accounted for by theoretical physicists' schemes, while others were named "strange particles." Strange particles are always created in pairs; for example, when a pion (π^-) collides with a proton (p), two strange particles, K^0 (Kaon) and Λ^0 (Lambda), are created. The nuclear reaction is:

$$\pi^- + p \rightarrow k^0 + \Lambda^0$$

Q. **Differentiate between fermions and bosons based on their spin characteristics and adherence to the Pauli Exclusion Principle. Provide examples.**

Ans

Particle Spin: Fermions and Bosons

All particles possess spin on their axes, and the spin of charged particles makes them act as tiny magnets. The characteristic spin of electrons, protons, and neutrons is 1/2, while the spin of a photon is 1, and pions have a spin of zero.

- **Fermions:** Half-spin particles obey Pauli's exclusion principle, which states that no two identical fermions can occupy the same quantum state simultaneously. These particles are called "fermions."
- **Bosons:** Particles with zero or whole number spin do not obey Pauli's exclusion principle. They are called "bosons" as they obey Bose-Einstein statistics.

Q. **Beyond spin, what are the two major classifications of particles based on their mass and decay products, and what led to the idea that some of these particles are not fundamental?**

Ans

Major Classifications of Particles

Further major classifications include:

1. **Baryons (heavy):** This category includes nucleons (protons and neutrons) and heavier particles such as Λ^0

and K^0 that decay into nucleons.

2. **Leptons (small):** These particles do not interact strongly with nucleons and include electrons, muons, tau particles, and neutrinos.

Both beta-decay processes (β^- and β^+) provide evidence that protons and neutrons are not fundamental particles. By the 1960s, many new particles similar to neutrons and protons were discovered, as well as "midsized" particles called mesons. Mesons typically had masses less than nucleons but more than electrons (though later-discovered mesons had masses greater than nucleons). Strongly interacting particles were called mesons or pions, while weakly interacting particles were named μ (mu) mesons or muons.

Thus led to the conclusion that these particles could not be fundamental and must be composed of even smaller constituents, which were named quarks.

Table 12.3: The lepton family

Table 12.3 : The lepton family					
Family	**Particle**	**Symbol**	**Mass (MeV/c²)**	**Charge q**	**Antiparticle**
Electron	**Electron**	e^{-1}	0.511	-1	e^{+1}
	neutrino	ν_e	$>> 1 \times 10^{-7}$	0	$\bar{\nu}_e$
Muon	**Muon**	μ^{-1}	105.7	-1	μ^{+1}
	Muon neutrino	ν_m	$>> 1 \times 10^{-7}$	0	$\bar{\nu}_m$
Tau	**Tau**	τ^{-1}	1777	-1	τ^{+1}
	Tau neutrino	ν_τ	$>> 1 \times 10^{-7}$	0	$\bar{\nu}_\tau$

TALENT INFORMATION

Bose-Einstein and Fermi-Dirac statistics are two fundamental ways to describe the distribution of identical, indistinguishable particles among available energy states in quantum mechanics. The key difference lies in the type of particles they apply to and whether these particles obey the Pauli Exclusion Principle.

Bose-Einstein Statistics

- **Particles:** Applies to **bosons**, which are particles with **integer spin** (0, 1, 2, etc.). Examples include photons, phonons, and helium-4 atoms.
- **Pauli Exclusion Principle:** Bosons **do not obey** the Pauli Exclusion Principle. This means that an **unlimited number of bosons can occupy the same quantum state** at the same time.
- **Behavior at Low Temperatures:** At very low temperatures, a significant fraction of bosons can "condense" into the lowest available energy state, forming a state of matter known as a **Bose-Einstein Condensate (BEC)**. This phenomenon accounts for properties like the cohesive streaming of laser light and the frictionless flow of superfluid helium.
- **Developed by:** Satyendra Nath Bose (for photons) and Albert Einstein (generalized to atoms).

Fermi-Dirac Statistics

- **Particles:** Applies to **fermions**, which are particles with **half-integer spin** (1/2, 3/2, etc.). Examples include electrons, protons, neutrons, and neutrinos.
- **Pauli Exclusion Principle:** Fermions **obey** the Pauli Exclusion Principle. This principle states that **no two identical fermions can occupy the same quantum state** simultaneously. Each available discrete energy state can be occupied by only one fermion.
- **Behavior at Low Temperatures:** Due to the Pauli Exclusion Principle, fermions at low temperatures **fill up** available energy states from the lowest energy level upwards, much like stacking items in distinct slots, rather than all collapsing into the lowest state. This principle is crucial for understanding the electron structure of atoms, why electrons remain in separate states rather than collapsing, and aspects of electrical conductivity in materials.
- **Developed by:** Enrico Fermi and Paul Dirac.

KEY DIFFERENCES SUMMARIZED

FEATURE	BOSE-EINSTEIN STATISTICS	FERMI-DIRAC STATISTICS
Type of Particles	Bosons	Fermions
Spin Value	Integer spin (0, 1, 2, ...)	Half-integer spin (1/2, 3/2, ...)
Pauli Exclusion	**Not obeyed** (multiple particles per state)	**Obeyed** (only one particle per state)
Low Temp. Behavior	Bose-Einstein Condensation (particles gather in lowest state)	Particles fill states from lowest energy upwards, each occupying a distinct state

These statistical frameworks are essential for describing the behavior of particles in quantum systems, from the fundamental building blocks of matter to phenomena like superconductivity and super fluidity.

MULTIPLE CHOICE QUESTIONS

- **Which of the following particles is classified as a lepton?**

(a) Proton (b) Neutron (c) Pion (d) Muon

Answer: (d) Muon

Explanation: Protons, neutrons, and pions are hadrons (made of quarks). Muons are fundamental particles that do not experience the strong force, classifying them as leptons.

- **Particles with half-integer spin that obey the Pauli Exclusion Principle are called:**

(a) Bosons (b) Hadrons (c) Fermions (d) Mesons

Answer: (c) Fermions

Explanation: Fermions are matter particles with half-integer spin that cannot occupy the same quantum state.

- **Hadrons are composed of:**

(a) Leptons (b) Photons (c) Quarks (d) Neutrinos

Answer: (c) Quarks

Explanation: Hadrons (like protons, neutrons, mesons) are composite particles made up of quarks.

- **A meson is an example of a:**

(a) Baryon (b) Lepton (c) Boson (d) Fundamental particle

Answer: (c) Boson

Explanation: Mesons are hadrons (composite particles made of a quark-anti quark pair) and have integer spin, classifying them as bosons.

- **Which fundamental force do leptons NOT experience?**

(a) Gravitational (b) Electromagnetic (c) Weak nuclear (d) Strong nuclear

Answer: (d) Strong nuclear

Explanation: Leptons are defined as fundamental particles that do not interact via the strong nuclear force.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Define a fundamental particle.**

Ans: A fundamental particle is a particle that is believed to have no internal structure and cannot be broken down into smaller components.

- **Distinguish between hadrons and leptons, giving one example for each.**

Ans: Hadrons are composite particles (made of quarks) that experience the strong nuclear force (e.g., proton). Leptons are fundamental particles that do not experience the strong nuclear force (e.g., electron).

- **What are the two sub-categories of hadrons?**

Ans: The two sub-categories of hadrons are baryons (made of three quarks, like protons) and mesons (made of a quark-antiquark pair, like pions)

- **Why electrons are considered fundamental particles?**

Ans: Electrons are considered fundamental particles because, to the best of our current knowledge and experimental abilities, they have no internal structure and cannot be divided into smaller constituents.

- **How do fermions and bosons differ in terms of spin and the Pauli Exclusion Principle?**

Ans: Fermions have half-integer spin and obey the Pauli Exclusion Principle (no two identical fermions can occupy the same quantum state). Bosons have integer spin and do not obey the Pauli Exclusion Principle (multiple bosons can occupy the same quantum state).

12.6 QUARKS

Q What are quarks and how are they classified and give the composition of porton and neutron in terms of quarks? or Describe protons and neutrons in terms of their quark composition.

Ans

QUARKS

In 1964, Murray Gell-Mann and George Zweig proposed that hadrons (protons, neutrons, mesons) are not fundamental but are instead made up of combinations of more fundamental entities called quarks. Quarks are considered truly fundamental particles, like leptons.

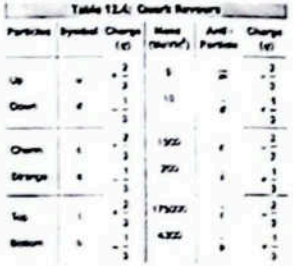


Table 12.4: Quark flavours

Particles	Symbol	Charge (q)	Mass (MeV/c²)	Anti-Particle	Charge (q̄)
Up	u	$+\frac{2}{3}$	5	$\bar{u}$	$-\frac{2}{3}$
Down	d	$-\frac{1}{3}$	10	$\bar{d}$	$+\frac{1}{3}$
Charm	c	$+\frac{2}{3}$	1500	$\bar{c}$	$-\frac{2}{3}$
Strange	s	$-\frac{1}{3}$	200	$\bar{s}$	$+\frac{1}{3}$
Top	t	$+\frac{2}{3}$	175000	$\bar{t}$	$-\frac{2}{3}$
Bottom	b	$-\frac{1}{3}$	4300	$\bar{b}$	$+\frac{1}{3}$

QUARK FLAVORS (TYPES):

There are six known "flavors" of quarks, based on a presumed symmetry in nature.

1. Up (u)
2. Down (d)
3. Strange (s)
4. Charm (c)
5. Bottom (b)
6. Top (t)

Particles	Symbol	Charge (q)	Mass (MeV/c²)	Anti-particle	Charge (q̄)
Up	u	2/3	2	ū	-2/3
Down	d	-1/3	5	d̄	1/3
Charm	c	+2/3	1500	c̄	-2/3
Strange	s	-1/3	200	s̄	1/3
Top	t	2/3	175000	t̄	[illegible]
Bottom	b	-1/3	4700	[illegible]	[illegible]

PROPERTIES OF QUARKS:

- All quarks have a spin of $\frac{1}{2}$

- They have fractional electric charges (e.g., $+\frac{2}{3}e$ or $-\frac{1}{3}e$), a fraction of the electron's charge.
- Quarks are "invisible" and never appear on their own; they are always confined within hadrons.

Quark Composition of Hadrons:

- **Mesons:** Consist of a **quark-antiquark pair**. For example, a π⁺ meson is an (up, anti-down) combination. $q_u = +\frac{2}{3}$, $q_{\bar{d}} = +\frac{1}{3} \Rightarrow +\frac{2}{3} + \frac{1}{3} = +1$ (a π⁺ meson is a $u\bar{d}$ combination. A π⁻ can be made of $u\bar{u}$)
- **Baryons:** Consist of **three quarks**.
  - **Proton:** Quark composition is **uud**. Its charge is $q_{proton} = \frac{2}{3} + \frac{2}{3} + (-\frac{1}{3}) = +1$
  - **Neutron:** Quark composition is **udd**. Its charge is $q_{neutron} = \frac{2}{3} + (-\frac{1}{3}) + (-\frac{1}{3}) = 0$

Fig. 12.7 (a): Colourless baryons
blue + red + green = white

Fig. 12.7 (b): A colourless anti-baryon
anti-blue + anti-red + anti-green = white

Q What is colour charge theory of quarks and also briefly explain QCD?

Ans

Colour or Colour Charge theory

- Quarks possess another property called **color** or "color charge" (analogous to electric charge).
- Each quark flavor can have one of three colors: red, green, and blue. Anti-quarks have anti-colors (anti-red, anti-green, anti-blue).
- **Colorless Hadrons:** Baryons are made of three quarks, one of each color (red + green + blue = "white" or colorless). Mesons consist of a quark-anti-quark pair of a particular color and its anti-color (e.g., red + anti-red = "white" or colorless). This ensures that all observable hadrons are colorless.
- **Color Force:** The strong force between quarks is called the **color force**. The theory describing this strong force is called **Quantum Chromodynamics (QCD)**.

TALENT INFORMATION

Quantum Chromodynamics (QCD) is the theory of the **strong force**, which binds quarks together to form protons and neutrons.

Key ideas:

- **Quarks** (fundamental particles) carry "color charge" (red, green, blue).
- **Gluons** are the force-carrying particles for the strong force and also carry color charge.
- **Color Confinement:** Quarks are always "confined" within composite particles (like protons), never observed in isolation, because the strong force gets stronger with distance.
- **Asymptotic Freedom:** At very short distances (high energies), the strong force between quarks becomes very weak.

Q Explain beta decay in terms of Quarks.

Ans

Beta Decay in Terms of Quarks

We can understand beta decay at a more fundamental level.

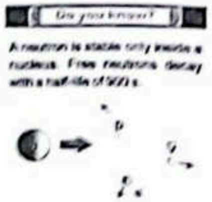
- **Beta-Minus Decay** $(n \rightarrow p + e^- + \bar{\nu})$: A neutron (udd) converts into a **proton (uud)** by changing a down quark into an up quark.

$${}_{0}^{1}n \rightarrow {}_{1}^{1}p + {}_{-1}^{0}e + \bar{\nu}$$

- Fundamental decay process: $d \rightarrow u + e^- + \bar{\nu}$

- **Beta-Plus Decay ($p \rightarrow n + e^+ + \nu$):** A proton (uud) converts into a neutron (udd) by changing **an up quark into a down quark.**
  - Fundamental decay process: $u \rightarrow d + e^+ + \nu$

This illustrates how our understanding of the fundamental nature of matter deepens, allowing us to analyze familiar processes at increasingly intricate levels. The quark model not only enhances our comprehension of particle structures but also provides insight into their interactions.



Do you know?

A neutron is stable only inside a nucleus. Free neutrons decay with a half-life of about 900 seconds (approximately 15 minutes).

MULTIPLE CHOICE QUESTIONS

- **The fractional electric charge of an up quark (u) is:**

(a) +1/3 e (b) -1/3 e (c) +2/3 e (d) -2/3 e

Answer: (c) +2/3 e

Explanation: Up, charm, and top quarks have a charge of +2/3 e.

- **A proton is composed of which combination of quarks?**

(a) udd (b) uud (c) uuu (d) ddd

Answer: (b) uud

Explanation: A proton's charge (+1e) is derived from two up quarks (+2/3e each) and one down quark (-1/3e) (2/3+2/3-1/3)e=1e.

- **What property, analogous to electric charge, do quarks possess that is crucial for the strong force?**

(a) Spin (b) Flavor (c) Color (d) Parity

Answer: (c) Color

Explanation: Quarks possess "color charge" (red, green, blue), and the strong force is mediated by gluons acting between these color charges, in a theory called Quantum Chromodynamics.

- **Beta-minus decay (neutron to proton) involves a change in a quark from:**

(a) up to down (b) down to up (c) strange to charm (d) top to bottom

Answer: (b) down to up

Explanation: In beta-minus decay, a neutron (udd) transforms into a proton (uud), which means one of its down quarks changes into an up quark.

- **Mesons are composed of:**

(a) Three quarks (b) A quark and an antiquark (c) Two antiquarks (d) Four quarks

Answer: (b) A quark and an antiquark

Explanation: Mesons are composite particles made of a quark-antiquark pair.

SLO BASED SHORT QUESTIONS & ANSWERS

- **List the six flavors of quarks.**

Ans: The six flavors of quarks are up (u), down (d), strange (s), charm (c), bottom (b), and top (t).

- **Briefly explain why quarks are never observed in isolation.**

Ans: Quarks are never observed in isolation due to a phenomenon called "color confinement," which is a property of the strong nuclear force. The force between quarks increases with distance, making it energetically impossible to separate them.

- **What is the quark composition of a neutron?**

Ans: A neutron is composed of one up quark (u) and two down quarks (d), or (udd).

- **What is "color charge" in the context of quarks?**

Ans: "Color charge" is a fundamental property of quarks (and gluons), analogous to electric charge, that is responsible for the strong nuclear force. Quarks come in three "colors" (red, green, blue).

- **How does the quark model explain beta-plus decay?**

Ans: In the quark model, beta-plus decay (proton to neutron) is explained by an up quark transforming into a down quark, emitting a positron and a neutrino in the process ($u \rightarrow d + e^+ + \nu$).

12.7 HIGGS BOSON

Q **What are boson and how they exchange fundamental forces?**

Ans

Fundamental particles are considered to be the six quarks, the six leptons and the gauge bosons (Higgs bosons), which are the carriers of the fundamental forces. Leptons and quarks interact with each other by sending and receiving bosons.

For example, **electromagnetic interactions** occur when two positively charged particles send and receive (exchange) photons. The photons are said to "carry" the force between charged particles.

Likewise, attraction between two quarks in an atomic nucleus occurs when two quarks send and receive gluons. Similarly, the W⁺, W⁻ and Z are the bosons that are the carriers of weak nuclear force and gravitons are the carriers of gravitational force.

Q **What are Higgs boson and Higgs fields and give key features of Higgs boson?**

Ans

Fundamental particles are considered to be the six quarks, the six leptons, and the gauge bosons (force carriers), plus the Higgs boson.

Gauge Bosons (Force Carriers):

Leptons and quarks interact by exchanging gauge bosons, which "carry" the fundamental forces:

- **Photons (γ):** Mediate the **electromagnetic force.**
- **Gluons (g):** Mediate the **strong nuclear force** between quarks.
- **W and Z bosons** ($W^+, W^-, Z0$): Mediate the **weak nuclear force.**
- **Gravitons (hypothetical):** Expected to mediate the **gravitational force.**

What is the Higgs Boson?

- A special particle discovered in 2012 at CERN's Large Hadron Collider (LHC).
- It is associated with the **Higgs field,** which permeates all of space.
- **Crucial Role:** The Higgs boson provides the explanation for how other fundamental particles acquire mass by interacting with the Higgs field.
- **Mass Acquisition:** Particles that interact strongly with the Higgs field get more mass (e.g., W and Z bosons). Particles that do not interact with the Higgs field have zero rest mass (e.g., photons).
- **Properties:** The Higgs boson has a mass of around 125 GeV/c^2 and decays rapidly into other particles.
- **Significance (Key Facts about Higgs Boson):**
  - It serves as a unique portal to understand the conditions of the universe shortly after the Big Bang and to search for signs of dark matter.
  - The Higgs boson obtains its mass from its interactions with its associated Higgs field.

Peter Higgs (born May 29, 1929, Newcastle upon Tyne, Northumberland, England—died April 8, 2024, Edinburgh, Scotland) was a British physicist who was awarded the 2013 Nobel Prize for Physics for proposing the existence of the Higgs boson, a subatomic particle that is the carrier particle of a field that endows all elementary particles with mass through its interactions with them. He shared the prize with Belgian physicist François Englert.

Higgs Field

The Higg's field is a theoretical field that exist throughout the universe. The particles that interact strongly with Higg's field get more mass such as carriers of electroweak interaction i.e., W⁺, W and Z bosons whereas the particles like photons do not interact with Higg's field and hence, their rest mass is considered zero. Higgs boson has a mass of around 125 giga-electron-volts (GeV/c^2) and decays rapidly into other particles.

SLO BASED SHORT QUESTIONS & ANSWERS

- **What is the primary role of the Higgs field?**

Ans: The primary role of the Higgs field is to give mass to fundamental particles that interact with it.

- **List three fundamental forces and their respective mediating particles (gauge bosons).**

Ans: Electromagnetic (photon), Strong nuclear (gluon), Weak nuclear (W and Z bosons). (Gravitational is hypothetical graviton)

- **Briefly describe how a particle acquires mass through interaction with the Higgs field.**

Ans: Particles acquire mass by interacting with the pervasive Higgs field. Those that interact more strongly with the field experience greater "resistance" or "drag," manifesting as a larger intrinsic mass, while those that don't interact (like photons) remain massless.

MULTIPLE CHOICE QUESTIONS

- **The Higgs boson is primarily responsible for:**

(a) mediating the strong nuclear force
(b) giving mass to other fundamental particles
(c) detecting gravitational waves
(d) preventing radioactive decay

Answer: (b) giving mass to other fundamental particles

Explanation: The Higgs boson is associated with the Higgs field, which interacts with other particles to give them mass.

- **Which fundamental force is NOT directly mediated by a gauge boson within the Standard Model (as of its original formulation)?**

(a) Electromagnetic (b) Strong nuclear (c) Weak nuclear (d) Gravitational

Answer: (d) Gravitational

Explanation: The Standard Model includes gauge bosons for the electromagnetic (photon), strong (gluon), and weak (W/Z bosons) forces, but not for gravity (graviton is hypothetical and not part of the Standard Model).

- **A particle that interacts strongly with the Higgs field will typically have:**

(a) zero rest mass (b) a very small rest mass (c) a larger rest mass (d) a negative charge

Answer: (c) a larger rest mass

Explanation: According to the Higgs mechanism, the more strongly a particle interacts with the Higgs field, the more massive it becomes.

12.8 CONSERVATION LAWS

Q. 10 What are the laws of conservation which are obeyed by nuclear processes or reactions?

Ans

All nuclear processes (nuclear reactions and decays) obey various conservation laws.

1. **Conservation of energy, momentum, and charge:** These fundamental laws are always obeyed. This also includes the conservation of nucleon number (A) and atomic number (Z).
2. **Baryon number conservation:** The total number of baryons (protons, neutrons, etc.) minus the total number of antibaryons remains constant in any interaction.
3. **Lepton number conservation:** The total number of leptons (electrons, muons, neutrinos, etc.) minus the total number of antileptons remains constant for each lepton family.

For your information:

- **Hadrons:** Mesons (pions, kaons), Baryons (protons, neutrons, omega, sigma, lambda particles)
- **Non-hadrons:** Leptons (electrons, muons, neutrinos), Photons, Gravitons

SLO BASED SHORT QUESTIONS & ANSWERS

- **In nuclear processes, what does the conservation of nucleon number imply?**

Ans: The conservation of nucleon number implies that the total number of protons and neutrons (nucleons) remains the same before and after a nuclear reaction or decay.

- **What is lepton number conservation?**

Ans: Lepton number conservation states that the total number of leptons (counting antileptons as negative) remains constant in any particle interaction or decay.

MULTIPLE CHOICE QUESTIONS

- **Which of the following is NOT a conserved quantity in all nuclear processes?**

(a) Energy (b) Momentum (c) Temperature (d) Charge

Answer: (c) Temperature

Explanation: Energy, momentum, and charge (along with nucleon number, baryon number, and lepton number) are conserved in nuclear processes, but temperature is a macroscopic property related to average kinetic energy, not a fundamental conserved quantity in individual particle interactions.

- **Baryon number is conserved in nuclear processes. What does this imply about the total number of baryons and antibaryons?**

(a) It must be zero (b) It must increase (c) It remains constant (d) It must decrease

Answer: (c) It remains constant

Explanation: Conservation of baryon number means the net number of baryons (number of baryons minus number of antibaryons) remains the same before and after a nuclear process.

12.9 THE ASYMMETRY OF MATTER AND ANTI-MATTER IN THE UNIVERSE

Q. 11 What is the concept of asymmetry of matter and antimatter in the universe? Explain.

Ans

ASYMMETRY

Asymmetry mean imbalance in matter and antimatter of the universe.

Explanation:

Observations show a significant asymmetry between matter and anti-matter in the observable universe. The universe consists almost entirely of matter rather than anti-matter.

Evidence:

- The universe is assumed to be composed of about 5% ordinary matter (electrons, protons, and neutrons).
- About 71% is hydrogen atoms and 24% is helium atoms, with virtually no contribution from anti-hydrogen or anti-helium atoms.
- There's no significant amount of antimatter galaxies or stars, for example.

The Unsolved Mystery:

The experimental results suggest that this matter-antimatter asymmetry is due to a violation of the conservation of baryon number (an imbalance between baryons and anti-baryons). If particle-antiparticle symmetry is also violated, it would provide a mechanism for creating more quarks than anti-quarks, more leptons than anti-leptons, and eventually more matter than anti-matter. However, the exact reason for this asymmetry remains an unsolved mystery in physics.

12.10 MOST OF THE MATTER IN THE OBSERVABLE UNIVERSE IS PLASMA

Q. **Which form of observable matter the universe has in greater amount?**

Ans

THE UNKNOWN UNIVERSE:

We currently understand only about 5% of the universe. The remaining 95% is composed of:

- **Dark Matter (approx. 27%):** An unknown form of matter that interacts gravitationally but does not emit or absorb light, making it undetectable by conventional means.
- **Dark Energy (approx. 68%):** A mysterious antigravity material believed to be responsible for the accelerating expansion of the universe.

The "Known" 5%:

Of the 5% of the universe that we know about (ordinary matter), most of it is in the plasma state.

- Hydrogen and helium, which make up the vast majority of ordinary matter, are almost entirely in the plasma state in stars and interstellar medium.
- Therefore, it is concluded that most of the matter in the observable universe is plasma.

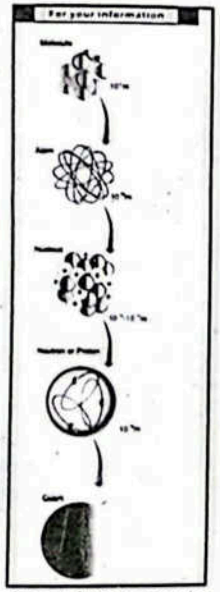
12.11 THETHEORIES ABOUT THE FORCES BETWEEN THE MASSES OF PARTICLES

Q. **Explain the theories that explain the interaction between the particles through different mediators.**

Ans

Two main theories attempt to explain the interactions between particles through different mediators:

1. **The Quantum Field Theory (QFT):**
    - **Core Idea:** Each particle is represented by a "quantum field." Interactions between particles are described in terms of the exchange of **field particles** (or quanta) which are all bosons.
    - **Mechanism:** A charged particle, for example, produces an electric field. This field mediates the force on other charged particles. The field carries energy and momentum. The energy and momentum of all fields are quantized (exist in discrete packets).
    - **Examples of Field Particles (Force Carriers):**
        - Electromagnetic force: mediated by **photons**.
        - Strong nuclear force: mediated by **gluons**.
        - Electroweak force: mediated by **W and Z bosons**.
        - Gravitational force: mediated by **gravitons** (hypothetical).
2. **String Theory:**
    - **Core Idea:** An advanced concept proposing that the fundamental particles of the universe are not point-like but are actually tiny, vibrating one-dimensional strings.
    - **Vibrations Define Properties:** The different ways these strings vibrate (like notes on a musical instrument) determine the properties of the particles, including their mass and the forces they exert.
    - **Status:** String theory is a framework that offers a potential "theory of everything," but it remains unproven experimentally.



For your information (Particle Sizes):

Molecule (10^{-9} m) → Atom (10^{-10} m) → Nucleus (10^{-14} to 10^{-15} m) → Neutron or Proton (10^{-15} m) → Quark (undetectable size, less than 10^{-18} m).

MULTIPLE CHOICE QUESTIONS

- **The observed "matter-antimatter asymmetry" in the universe suggests a slight excess of:**

  (a) antimatter over matter (b) matter over antimatter
  (c) photons over matter (d) neutrinos over antineutrinos

Answer: (b) matter over antimatter

Explanation: The universe is predominantly made of matter, implying a tiny initial excess of matter particles that survived annihilation with antimatter.

- **What percentage of the observable universe is currently understood as "ordinary matter"?**

  (a) 5% (b) 27% (c) 68% (d) 95%

Answer: (a) 5%

Explanation: Only about 5% of the universe is ordinary matter, while the rest is dark matter (approx. 27%) and dark energy (approx. 68%).

- **According to Quantum Field Theory, interactions between particles are described by the exchange of:**

  (a) Strings (b) Quanta of fields (c) Dark matter (d) Virtual particles only

Answer: (b) Quanta of fields

Explanation: Quantum Field Theory describes forces as mediated by the exchange of discrete energy packets, or quanta, of fundamental fields.

- **Which concept proposes that fundamental particles are tiny, vibrating, one-dimensional entities rather than point-like?**

  (a) Quantum Chromodynamics (b) String Theory
  (c) Standard Model (d) Electroweak Theory

Answer: (b) String Theory

Explanation: String Theory postulates that elementary particles are not points but rather vibrating strings, with different vibration modes corresponding to different particles.

- **Most of the ordinary matter in the observable universe exists in which state?**

  (a) Solid (b) Liquid (c) Gas (d) Plasma

Answer: (d) Plasma

Explanation: Hydrogen and helium, which make up most ordinary matter, exist primarily in the plasma state within stars and interstellar medium.

SLO BASED SHORT QUESTIONS & ANSWERS

- **Briefly state the "matter-antimatter asymmetry" problem.**

Ans: The "matter-antimatter asymmetry" problem is the cosmological mystery of why the observable universe is almost entirely composed of matter, despite theories suggesting equal amounts of matter and antimatter should have been created in the Big Bang.

- **What are dark matter and dark energy, and what percentage of the universe do they roughly constitute?**

Ans: Dark matter (approx. 27%) is an invisible form of matter that interacts gravitationally but not electromagnetically. Dark energy (approx. 68%) is a mysterious force driving the accelerated expansion of the universe.

- **According to the Quantum Field Theory, what mediates forces between particles?**

Ans: According to Quantum Field Theory, forces between particles are mediated by the exchange of "field particles" or "quanta" of the fundamental fields associated with those forces.

- **What is the core idea of String Theory?**

Ans: The core idea of String Theory is that the fundamental particles of the universe are not dimensionless points but rather tiny, vibrating one-dimensional strings, whose different vibration modes correspond to different particle properties.

- **Why is it believed that most of the ordinary matter in the universe is in the plasma state?**

Ans: It is believed that most ordinary matter is in the plasma state because the vast majority of ordinary matter in the universe exists within stars (like the Sun) and interstellar gas, where extreme temperatures cause atoms to be ionized into a plasma state.

12.12 THE STANDARD MODEL

Q. What is standard model, which particles it contains and what are its drawbacks

Ans

The Standard Model?

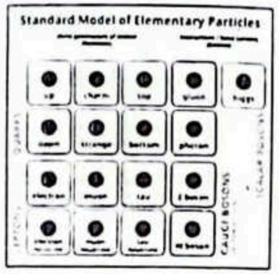
The Standard Model is a comprehensive theory that describes the smallest experimentally observed particles of matter and their fundamental interactions (forces). It is currently our most successful theory of particle physics.

Categories of Particles in the Standard Model: There are three categories of particles that form the standard model.

1. **Fermions ("Matter Particles"):** These are the building blocks of matter (it makes up only 5% of universe).
   - **Quarks:** (up, down, charm, strange, top, bottom)
   - **Leptons:** (electron, muon, tau, and their associated neutrinos: electron neutrino, muon neutrino, tau neutrino)
2. **Bosons ("Force-Carriers"):** These mediate the fundamental forces.
   - **Photon (γ):** Electromagnetic force
   - **Gluon (g):** Strong nuclear force
   - **W and Z bosons (W^+, W^-, Z^0):** Weak nuclear force
3. **Higgs Boson (h):** Provides an explanation for how other particles acquire mass.

Limitations of The Standard Model:

Despite its success, the Standard Model is considered incomplete because it cannot explain several important features of the known universe:


Standard Model of Elementary Particles

1. **Gravity:** It does not fully incorporate gravity (it doesn't include the graviton).
2. **Dark Matter:** It does not explain the existence of dark matter (which makes up about 27% of the universe).
3. **Dark Energy:** It does not explain the existence of dark energy (which makes up about 68% of the universe).
4. **Neutrino Mass:** Initially assumed mass less, neutrinos are now known to have tiny masses, which the original Standard Model didn't account for.
5. **Matter-Antimatter Asymmetry:** It doesn't fully explain why there is so much more matter than antimatter in the universe.

TALENT INFORMATION CLASSIFICATION OF PARTICLES ON THE BASIS OF STANDRED MODEL

The classification of elementary particles is primarily based on the **Standard Model of Particle Physics**, which is our most comprehensive theory describing the fundamental building blocks of the universe and how they interact.

I. **By Spin and Statistics:** The most fundamental classification divides all particles into two broad categories based on their intrinsic angular momentum, called **spin**, and the quantum statistics they obey:

- **Fermions:**
  - Have **half-integer spin** (e.g., $1/2h$, $3/2h$, etc.)
  - Obey **Fermi-Dirac statistics**, meaning they adhere to the **Pauli Exclusion Principle**. This principle states that no two identical fermions can occupy the same quantum state imultaneously, which is why matter has structure
  - (e.g., electrons in an atom occupy different energy levels)

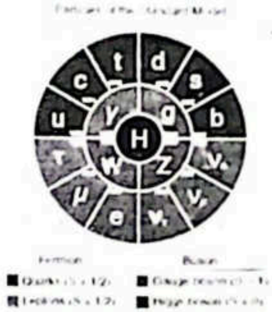
  Fermions are generally considered **matter particles**
- **Bosons:**
  - Have **integer spin** (e.g., $0h$, $1h$, $2h$, etc.)

  - Obey **Bose-Einstein statistics**, meaning multiple identical bosons can occupy the same quantum state. This property is crucial for phenomena like lasers and superconductivity.

  Bosons are generally considered **force-carrying particles** or **mediators of interactions**

II. By Fundamental Nature (Elementary vs. Composite):

- **Elementary (or Fundamental) Particles:** These are particles that are not known to be composed of smaller constituents. They are the true "building blocks."
  - **Quarks:**
    - Six "flavors": Up (u), Down (d), Charm (c), Strange (s), Top (t), Bottom (b)
    - Carry fractional electric charges ($+2/3e$ or $-1/3e$)
    - Experience the **strong nuclear force** (mediated by gluons) due to a property called "color charge."
    - Never observed in isolation due to "color confinement."
  - **Leptons:**
    - Six types: Electron (e^-), Muon (μ^-), Tau (τ^-), and their corresponding neutrinos (electron neutrino ν_e, muon neutrino ν_μ, tau neutrino ν_τ)
    - Do not experience the strong nuclear force
    - Charged leptons (electron, muon, tau) have integer electric charge (−1e). Neutrinos are electrically neutral and have very tiny (but non-zero) mass
  - **Gauge Bosons (Force Carriers):**
    - **Photon (γ):** Mediates the **electromagnetic force**
    - **Gluons (g):** Eight types, mediate the **strong nuclear force**
    - **W and Z Bosons (W^+, W^-, Z^0):** Mediate the **weak nuclear force**
    - **Graviton (hypothetical):** Predicted to mediate the **gravitational force**, but not yet discovered and not part of the Standard Model
  - **Higgs Boson (H):**
    - A scalar boson (spin 0)
    - Responsible for giving mass to other elementary particles through the Higgs field
- **Composite Particles:** These are particles made up of combinations of elementary particles.
  - **Hadrons:** Particles composed of quarks held together by the strong nuclear force.
    - **Baryons:** Composed of three quarks (or three antiquarks) Examples:
    - **Proton (p):** uud (two up, one down quark)
    - **Neutron (n):** udd (one up, two down quarks)
    - **Mesons:** Composed of a quark and an antiquark. Examples:
    - **Pions (π):** e.g., ud (up and anti-down quark)
    - **Kaons (K):** contain a strange quark or antiquark



III. **By Generation (for Fermions):**

Both quarks and leptons are organized into three "generations" or "families." Each successive generation contains particles that are heavier versions of their counterparts in the previous generation, but they are less stable and decay rapidly into lighter particles.

- **First Generation:** Up quark, Down quark, Electron, Electron neutrino. (These are the particles that make up ordinary matter.)
- **Second Generation:** Charm quark, Strange quark, Muon, Muon neutrino
- **Third Generation:** Top quark, Bottom quark, Tau, Tau neutrino

This classification system, embodied in the Standard Model, provides a highly successful framework for understanding the fundamental nature of matter and forces in the universe.

MULTIPLE CHOICE QUESTIONS

- **Which of the following is NOT a component category within the Standard Model of particle physics?**

  (a) Quarks (b) Leptons (c) Gravitons (d) Bosons

Answer: (c) Gravitons **Explanation:** Gravitons are hypothetical particles for gravity, which is not fully integrated into the Standard Model. Quarks, leptons, and other bosons (gauge and Higgs) are part of it

- **The Standard Model effectively describes which of the following fundamental forces?**

  (a) Gravitational (b) Strong nuclear

  (c) All four fundamental forces (d) Only electromagnetic and strong

Answer: (b) Strong nuclear

Explanation: The Standard Model describes the strong, weak, and electromagnetic forces, but it does not fully incorporate gravity

- **A major limitation of the Standard Model is its inability to explain:**

  (a) The existence of quarks (b) The mass of the electron

  (c) Dark matter (d) Radioactive decay

Answer: (c) Dark matter

Explanation: The Standard Model successfully explains quarks, electron mass, and radioactive decay. Its limitations include not explaining dark matter, dark energy, or fully integrating gravity.

- **Within the Standard Model, matter particles are classified as:**

  (a) Bosons (b) Gauge bosons (c) Fermions (d) Force carriers

Answer: (c) Fermions **Explanation:** Fermions are the fundamental matter particles (quarks and leptons) in the Standard Model

- **The Higgs boson's role completes the Standard Model by explaining:**

  (a) The curvature of spacetime (b) The strong interaction between quarks

  (c) How particles acquire mass (d) The expansion of the universe

Answer: (c) How particles acquire mass **Explanation:** The discovery of the Higgs bosón and its mechanism for giving mass to other fundamental particles was the last major piece to be experimentally confirmed in the Standard Model

SLO BASED SHORT QUESTIONS & ANSWERS

- **What is the Standard Model of particle physics?**

Ans: The Standard Model is a comprehensive theory that describes the fundamental particles of matter and the three fundamental forces (strong, weak, and electromagnetic) through which they interact.

- **List the three main categories of particles that form the Standard Model.**

Ans: The three main categories are Fermions (matter particles: quarks and leptons), Gauge Bosons (force carriers), and the Higgs Boson

- **Name two fundamental forces that the Standard Model successfully describes.**

Ans: The Standard Model successfully describes the strong nuclear force, the weak nuclear force, and the electromagnetic force

- **What are two significant phenomena in the universe that the Standard Model does not fully explain?**

Ans: The Standard Model does not fully explain the existence of dark matter and dark energy, nor does it incorporate gravity

- **How does the Standard Model differentiate between "matter particles" and "force-carrying particles"?**

Ans: The Standard Model differentiates them by their classification as Fermions (matter particles like quarks and leptons) which have half-integer spin, and Bosons (force-carrying particles like photons, gluons, W/Z bosons) which have integer spin

* * *

TEXT BOOK EXERCISE WITH SOLUTION

MULTIPLE CHOICE QUESTIONS

Tick the correct answer.

12.1 Which one of the following is the fundamental particle?

(a) Proton (b) Neutron

(c) Electron (d) Meson

Explanation: Protons and neutrons are made of quarks (hadrons), mesons are also made of quarks (quark-antiquark pair). Electrons are leptons and are considered fundamental particles.

12.2 The first discovered anti-particle is:

(a) anti-proton (b) anti-neutrino

(c) anti-photon **(d) anti-electron**

Explanation: The positron (anti-electron) was the first anti-particle discovered by Anderson in 1932

12.3 Which one of the following pair of particles creates annihilation?

(a) proton-proton (b) proton-neutron

(c) neutron-photon **(d) electron-positron**

Explanation: Annihilation occurs between a particle and its corresponding anti-particle.

12.4 The strong nuclear force between the two particles is mediated by:

(a) gluons (b) photon

(c) mesons (d) gravitons

Explanation: Annihilation occurs between a particle and its corresponding anti-particle.

12.5 Which one of the following forces interacts between two particles through photons?

(a) Strong nuclear force (b) Weak force

(c) Electromagnetic force

(d) Gravitational force

Explanation: Photons are the exchange particles for the electromagnetic force.

12.6 When a neutron changes into a proton, then we will observe:

(a) β^--decay (b) β^+-decay

(c) γ-decay (d) α-decay

Explanation: Neutron decay $(n \rightarrow p + e^- + \nu)$ is beta-minus decay.

12.7 Baryon is formed by combination of:

(a) 2 quarks **(b) 3 quarks**

(c) 4 quarks

(d) A quark and an anti-quark

Explanation: Baryons consist of three quarks

12.8 Which one of the following forces has negligible effect between the elementary particles?

(a) Strong nuclear force

(b) Weak force

(c) Gravitational force

(d) Electromagnetic force

Explanation: Gravitational force is extremely weak at the subatomic level

12.9 Which particles are produced by strong interaction?

(a) Graviton (b) Leptons

(c) Hadrons (d) Mesons

Explanation: Hadrons (protons, neutrons, mesons) interact via the strong force

12.10 A strong nuclear force exists between the nucleons of:

(a) p-p (b) n-n

(c) p-n **(d) all of these**

Explanation: The strong nuclear force acts between all nucleons (protons and neutrons)

12.11 Which one of the following radiation/particles has the highest ionization power?

(a) α (b) β^-

(c) β (d) γ

Explanation: Alpha particles have the highest ionization power due to their large charge and mass.

12.12 Which one of the following radiation/particles has the highest penetrating power?

(a) α (b) β^-

(c) β **(d) γ**

Explanation: Gamma rays have the highest penetrating power because they are uncharged electromagnetic waves.

12.13 A change occurs in atomic number of a nucleus but its mass number remains the same by decay of:

(a) α **(b) β**

(c) γ (d) α and γ

Explanation: In beta decay, Z changes $(Z \rightarrow Z \pm 1)$ while A remains the same. Alpha decay changes both A and Z, gamma decay changes neither

12.14 In a nucleus, a neutron changes into a proton, the atomic number changes by one, the mass number will:

(a) decrease (b) increase

(c) remain the same (d) none of these

Explanation: This describes beta-minus decay $(n \rightarrow p)$, where A remains constant and Z increases by 1.

12.15 The electroweak theory was introduced by:

(a) Dirac (b) Einstein

(c) Anderson **(d) Dr. Abdul Salam**

Explanation: Abdus Salam, Sheldon Glashow, and Steven Weinberg are credited with the electroweak theory.

12.16 The asymmetry of matter and anti-matter is due to imbalance number of:

(a) hadron (b) lepton

(c) baryon (d) photons

Explanation: The asymmetry is largely attributed to the violation of baryon number conservation, leading to more baryons than anti-baryons.

12.17 Which one of the following particle is responsible for the mass of the fundamental particle?

(a) Quarks (b) Anti-quark

(c) Lepton **(d) Higgs boson**

Explanation: The Higgs boson is responsible for giving mass to other fundamental particles through its associated Higgs field.

12.18 A proton is composed of up and down quarks; the order of quarks is:

(a) udd (b)udu

(c)uud (d)dud

Explanation: A proton consists of two up quarks and one down quark (uud).

12.19 The number of quarks that composed of a neutron is:

(a) 2 **(b)3**

(c)4 (d)5

Explanation: A neutron is a baryon, composed of three quarks (udd).

SHORT ANSWER QUESTIONS

12.1 What do different isotopes of a given element have in common? How are they different?

Ans:

- **Common:** The isotopes of an element have same charge number, same proton number, same electron and same chemical properties.
- **Different:** The isotopes of an element have different mass number, different neutron number, different physical properties.

12.2 Identify the element that has 87 nucleons and 50 neutrons.

Ans: **Given:** Number of nucleons (Mass number) A = 87 Number of neutrons N = 50.

We know that A = N + Z, where Z is the atomic number (number of protons).

So, Z = A - N = 87 - 50 = 37

The element with atomic number 37 is Rubidium (Rb)

Answer: Rubidium (Rb)

12.3 What are the similarities and differences between the strong nuclear force and the electromagnetic force?

Ans: **Similarities:**

Both are fundamental forces

Both involve the exchange of force-carrying particles (bosons)

Differences:

Electromagnetic force	strong nuclear force
1. Weak force	1. Strong force
2. Long range force	2. Short range force
3. It governs a vast range of phenomena, from atomic structure, chemical bonding, electricity, magnetism, and light propagation.	3. It is responsible only for holding the nuclei of atoms together. They only exist inside the nucleus
4. Following inverse suare law	4. Not following inverse square law
5. The strong nuclear force acts on quarks and gluons, involving "color charge."	5. The electromagnetic force acts on electrically charged particles, involving electric charge.

12.4 Fill in the missing particle or nucleus:

(a) $^{45}_{20}Ca \rightarrow ? + e^{-} + \bar{\nu}$

(b) $^{58}_{29}Cu^{*} \rightarrow ? + \gamma$

a. This is a beta-minus decay. In beta-minus decay, a neutron transforms into a proton, increasing the atomic number (Z) by 1 while the mass number (A) remains the same. So, the daughter nucleus will have A = 45 and Z = 20 + 1 = 21. The element with Z=21 is Scandium (Sc).

b. This is a gamma decay, indicated by the emission of a gamma photon. Gamma decay occurs when an excited nucleus transitions to a lower energy state. The mass number (A) and atomic number (Z) of the nucleus do not change during gamma decay. So, the missing nucleus will have A = 58 and Z = 29. The element is Copper (Cu) Answer: $^{58}_{29}Cu^{*}$ (in an excited state, which then transitions to ground state $^{58}_{29}Cu$ = Copper)

12.5 Why neutrino must be released in the positron emission?

Ans: Neutrino released to conserve mass and energy

Positron emission (beta-plus decay) involves the decay of a proton into a neutron and a positron ($p \rightarrow n + e^{+} + \upsilon$). A neutrino ($\upsilon$) must be released to conserve fundamental quantities:

1. **Conservation of Lepton Number:** The electron lepton number must be conserved. Before the decay, there are no leptons. After the decay, a positron (e^{+}) is emitted, which has a lepton number of -1. To balance this, a neutrino (υ) with a lepton number of +1 must also be emitted, making the total lepton number zero on both sides.
2. **Conservation of Energy and Momentum:** The neutrino carries away a portion of the decay energy and momentum. Without it, the energy and momentum spectra of the emitted positrons would be discrete, which contradicts experimental observations (positrons have a continuous energy spectrum). The neutrino accounts for the "missing" energy and momentum.

12.6 Distinguish between fermions and bosons.

Ans:

- **Fermions:**
  - Particles with half-integer spins (e.g., 1/2,3/2, ...)
  - Obey the Pauli Exclusion Principle, which states that no two identical fermions can occupy the same quantum state simultaneously.
  - They obey Fermi-Dirac statistics
  - Examples: electrons, protons, neutrons, quarks, leptons.
- **Bosons:**
  - Particles with integer spins (e.g., 0 1,2, ...).
  - Do not obey the Pauli Exclusion Principle, multiple identical bosons can occupy the same quantum state.
  - They obey Bose Einstein statistics
  - Examples: photons, gluons, W and Z bosons, Higgs boson, mesons (which have integer spin).

12.7 How does strong force hold the nucleus?

Ans: The strong nuclear force holds the nucleus together by overcoming the electrostatic repulsion between positively charged protons. This force is intensely attractive and acts between all nucleons (protons and neutrons) over very short distances ($<10^{-15}$ m). It is mediated by particles called gluons and is responsible for the stability of atomic nuclei. Without the strong force, the nucleus would disintegrate due to proton-proton repulsion.

12.8 Can there be pair production for photons having energy 20 keV? Explain briefly.

Ans: No, pair production cannot occur for photons with an energy of 20 keV.

- **Explanation:** Pair production involves the creation of a particle-antiparticle pair, such as an electron-positron pair. According to the law of mass-energy equivalence, the minimum energy required for the creation of an electron-positron pair is equal to the sum of their rest mass energies, which is $2m_0c^2 = 1.02$ MeV
- Since 1 MeV = 1000 keV, 1.02 MeV=1020 keV
- A photon with energy 20 keV is significantly less than the required 1020 keV. Therefore, it does not possess enough energy to create an electron-positron pair.

12.9 What is the difference between beta particle and electron?

- **Electron:** A fundamental particle that orbits the nucleus of an atom. It is a lepton
- **Beta particle:** An electron (or positron in β^{+} decay) that is emitted from the nucleus during radioactive decay.

Key Difference: While physically identical (both are electrons), their origin is different. An orbital electron exists outside the nucleus, forming the electron shell. A beta particle is created *inside* the nucleus (from the decay of a neutron into a proton and an electron, or a proton into a neutron and a positron) at the moment of emission.

12.10. How do a proton and a neutron convert to each other?

A proton and a neutron can convert into each other through a process called beta decay. These transformations are mediated by the weak nuclear force and involve the emission or absorption of particles like electrons, positrons, and neutrinos.

1. Beta-minus decay (neutron converting to proton):

- In case of beta minus decay a neutron in nucleus decays into a proton and eject an electron and an antineutrino.

$$^{1}_{0}n \rightarrow ^{1}_{1}p + ^{0}_{-1}e + \bar{\nu}$$

- A neutron with composition udd can convert into a proton with composition uud by changing a down quark into an up quark.

2. Beta-plus decay (proton converting to neutron):

- In case of beta plus decay a proton in nucleus decays into a neutron and eject a positron and a neutrino.

$${}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e + \nu$$

- A proton with composition uud can convert into a proton with composition udd by changing an up quark into a down quark.

12.11 Why does beta-decay have a continuous energy spectrum and alpha-decay have a discrete energy spectrum?

Beta-decay beta decay have continuous energy spectrum due to the emission of three particles (beta particle, neutrino, and recoiling daughter nucleus) in the decay process and the energy share among the emitted particles in multiple ways.

Alpha decay alpha decay involves only two particles (alpha particle and daughter nucleus) and the energy distribute in a fixed way and result into a discrete spectrum.

12.12 Differentiate between hadron and leptons with examples.

- **Hadrons:**
    - Are composite particles made up of quarks.
    - Interact via the strong nuclear force.
    - Can be further classified into:
        - **Baryons:** Composed of three quarks (e.g., protons (uud), neutrons (udd)).
        - **Mesons:** Composed of a quark-antiquark pair (e.g., pions (π), kaons (K)).
- **Leptons:**
    - Are fundamental particles, meaning they have no internal structure (not made of quarks).
    - Do not interact via the strong nuclear force; they interact through the weak nuclear force and electromagnetic force (if charged).
    - Examples: electrons (e^-), muons (μ^-), tau particles (τ^-), and their corresponding neutrinos (ν_e, ν_μ, ν_τ).

12.13 Why electron-positron pair cannot decay into a single photon?

An electron-positron pair cannot decay into a single photon due to the principle of conservation of momentum.

- If an electron and a positron, both initially at rest or moving with equal and opposite momenta, were to annihilate into a single photon, the initial total momentum would be zero (or close to zero).
- However, a single photon always carries non-zero momentum ($p = E/c$).
- Therefore, the annihilation into a single photon would violate the conservation of momentum. To conserve both energy and momentum, an electron-positron annihilation must produce at least two photons moving in opposite directions, or possibly three photons if other interactions are involved.

12.14 State the role of Higgs Boson in the generation of mass in modem physics theories.

The Higgs boson's primary role, according to the Standard Model of particle physics, is to explain how other fundamental particles acquire mass. It does this by interacting with the widespread Higgs field that exists throughout space. Particles that interact strongly with this field experience a greater "drag" or resistance, effectively gaining more mass such as carriers of electroweak interaction i.e., W^+, W^- and Z bosons. Particles that do not interact with the Higgs field (like photons) remain massless. The strength of a particle's interaction with the Higgs field determines its mass.

12.15 What are Mesons? Give examples.

Mesons are a type of hadron, which means they are composite subatomic particles that interact via the strong nuclear force. They are composed of a quark and an antiquark pair. Mesons have integer spin, making them bosons.

Examples of mesons include:

- **Pions (π):** Like π^+ (made of ud), π^- (made of ud), and π^0 (made of uu or dd).
- **Kaons (K):** Contain a strange quark or anti-quark (e.g., K^+ made of us).

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