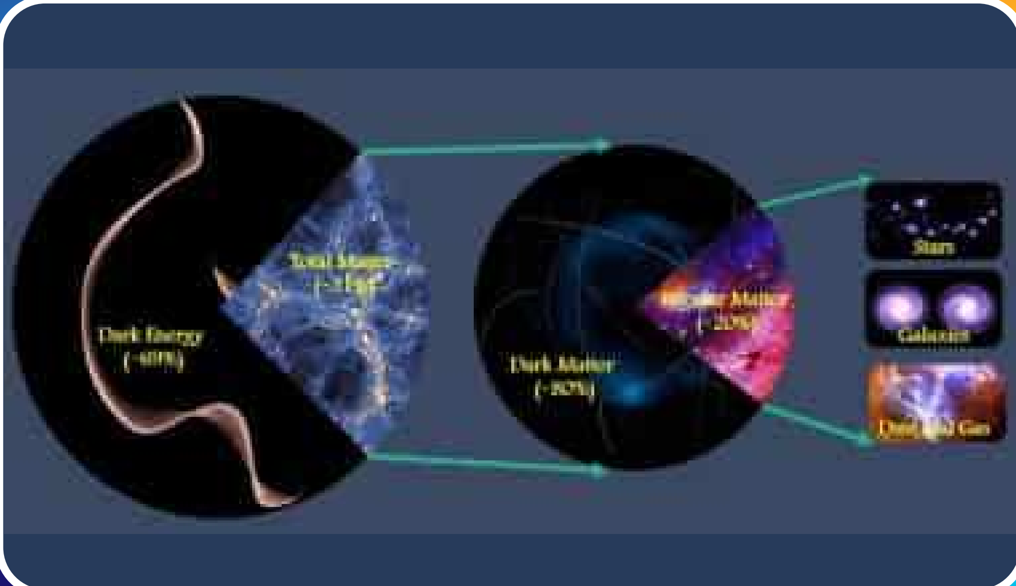
Unit 28

Particle Physics

Teaching Periods 03 **Weightage %** 02



In particle physics, Dark Matter and Dark Energy are mysterious entities that make up about 95% of the universe's mass-energy budget. Dark Matter is thought to be composed of Weakly Interacting Massive Particles (WIMPs), such as axions or neutralinos, which interact with normal matter only through gravity and the weak nuclear force, making them invisible to most detectors. Dark Energy, on the other hand, is believed to be a property of space itself, represented by a hypothetical field, like the Higgs field, that drives the accelerating expansion of the universe. Together, they form the "dark sector" of the universe, governing its large-scale structure and evolution, yet remaining elusive and invisible to direct detection, sparking intense research and debate in the particle physics community.

In this unit student should be able to:

- Describe the fundamental forces of nature and their field particles
- Describe the key features and components of the standard model of matter including hadrons, leptons and quarks.
- Describe the working principal, construction and use of Wilson Cloud Chambers
- Describe the working principal, construction and use of GM counter

Introduction:

Let's explore how our universe was formed and what holds everything together. People have been curious about these questions for a very long time. Originally, scientists believed that atoms were the smallest pieces that made up everything. But, in the 1800s, they discovered that atoms have smaller parts called electrons, protons, and neutrons.

Today, physics tells us about even tinier pieces that make up everything. These super small pieces are called "elementary" or "fundamental" particles, and they're so simple that they don't have any smaller parts inside them. Molecules, atoms, protons, and neutrons are not fundamental particles because these are made up of other particles, while electrons, quarks, and photons are fundamental particles. Studying all these elementary particles and understanding how they behave is the main goal of particle physics. Imagine these particles as tiny puzzle pieces that collectively form everything around us! To make sense of this cosmic puzzle, scientists have developed various theories. These theories aid in explaining the behavior and interactions of these particles. In this chapter, we will study one of the most crucial theories known as the **Standard Model**.

> **DO YOU KNOW?**
>
> Fundamental particles
> Those particles which are simple, structure less, and are not made up of other particles.

Particle Physics is the branch of Modern Physics which deals with the study and search of the ultimate constituents of matter (elementary particles) and their interactions.

28.1 The Standard Model:

Our universe is made up of two things: matter and energy (radiation). To understand them better, scientists have divided particles into two main groups: matter particles and force particles. Scientists have identified many elementary particles belonging to these categories. These particles are categorized and explained in detail in the Standard Model of Particle Physics, which is the best-known theory to date. It is a framework that explains three of the four fundamental forces (electromagnetism, the weak nuclear force, and the strong nuclear force) and all known elementary particles.

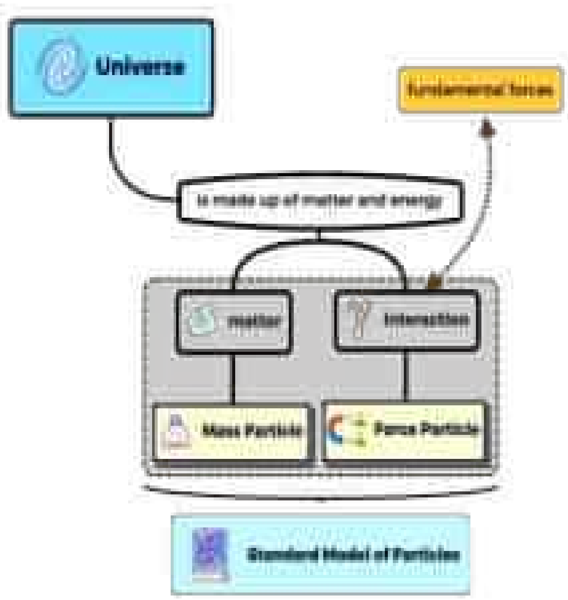


Figure 28.1:
The universe is made up of matter and energy.

The Standard Model classifies all known elementary particles into two main classes:

Fermions:

These are the matter particles, which make up everything in the universe.

Bosons:

These are the force-carrying particles, which mediate the interactions between fermions.

The Standard Model is a very successful theory. It has been able to predict the existence of many new particles, and it has been confirmed by a wide range of experiments. However, the Standard Model is not perfect. It does not explain gravity, which is the fourth fundamental force. It also does not explain dark matter and dark energy, which make up most of the universe.

28.1.1 Fundamental forces and their field particles:

The building block or brick of all matter is known as an elementary particle, but these particles cannot make up the whole structure of the universe by themselves. Just like a "brick" is the building block of our homes, we need cement as "glue" to give structure to our homes. Similarly, we need "glue" or "force particles" to build our universe. This glue is known as fundamental forces in the Standard Model. Each fundamental force has a field particle associated with it. A field particle is a virtual particle that mediates the fundamental force between two other particles. The Standard Model has kept all field particles in a class of "Boson."

The term "field particles" refers to particles associated with force fields. According to the Standard Model, bosons are often considered field particles because they are linked to force fields. For example, the photon is a field particle associated with the electromagnetic field.

Scientists have grouped all fundamental forces into four basic types. In order of increasing strength, these forces and their associated field particles are described as:

1. **Gravitational Force:**

It is the force that attracts two masses towards each other. It is the weakest of the four fundamental forces but acts over long distances.

Field Particle: The hypothetical particle associated with gravity is the graviton, although it has not been observed yet. The Standard Model doesn't explain gravity.

2. **Weak Nuclear Force:**

The weak force is responsible for radioactive decay, where unstable atomic nuclei break down into smaller, more stable nuclei. It's responsible for processes like beta decay and neutrino emission. This force is weaker than electromagnetic and strong nuclear forces but stronger than gravitational force.

Field Particle: There are three field particles associates with weak nuclear force. These are W^+, W^- and Z bosons. These short-lived bosons carry the force over very small distances, explaining the limited range of the weak force.

3. **Electromagnetic Force:**

This force is responsible for the interactions between charged particles, such as electrons and protons. It includes both electric and magnetic forces. The electromagnetic force is stronger than both gravitational and weak nuclear forces. It is also a long-range force, similar to the gravitational force.

Field Particle: The field particle of electromagnetic force is photon. It is mass less and chargeless particle. When ever charged particles interact, they exchange photons, causing the attractive or repulsive forces we observe.

4. Strong Nuclear Force:

The strong force binds quarks together to form protons and neutrons, and it holds atomic nuclei together. It is the strongest force among all forces and acts at subatomic levels.

Field Particle: Gluons are the field particles that mediate the strong force between quarks.

28.1.2 Particle zoo:

One way of studying elementary particles is to classify them into different categories based on certain behaviors and then to look for similarities or common characteristics among the classifications. We know that the Standard Model has classified all elementary particles and their interactions into two main groups according to their spins:

- Particles that carry force, called **boson s**having spin in integer values such as 0,1and 2.
- Particles that make up all matter, called **fermions** having spin in odd half integer values such as ½. 3/2 etc.

Bosons:

The arrangement of all elementary particles in the Standard Model constitutes a particle zoo. All bosons can be classified into two types: Elementary Boson and Composite Boson. Composite bosons consist of quark and anti-quark combinations while elementary bosons are not made up of other elementary particles.

Elementary Bosons:

Elementary bosons are the carriers of the fundamental forces in nature. For examples:

- Gluon
- W^+, W^-andZ^0 Bosons
- Photon
- Higgs Boson– *gives mass to all particles.*
- Graviton

The properties of elementary bosons are given in the table.

Table 28.1 The properties of elementary bosons

Force	Boson	Spin	Strength	Mass
Strong	Gluon	1	1	Massless
Electromagnetic	Photon	1	10^{-2}	Massless
Weak	W, Z	1	10^{-7}	80.91GeV
Gravity	Gravitation	2	10^{-39}	Massless

Composite Bosons:

Composite bosons are made up of an even number of fermions. For examples, **mesons** are composite bosons that composed of one quark and one antiquark. Mesons are intermediate mass particles that mediate the strong force between nucleons such as protons and neutrons.

Fermions:

All material particles are made up of fermions. We can further divide fermions in to two sub-classes: **elementary fermions** and **composite fermions**.

Elementary Fermions:

Elementary fermions are building blocks of all material particles. There are not made of any other particles. The fermions come in two types: **leptons** and **quarks**.

(a) Leptons:

Leptons are a group of elementary particles that do not experience the strong nuclear force. There are six types or flavors of leptons, which come in three pairs. The pairs are made up of three charged particles named electron, muon, and tau, along with their Partners called neutrinos (charge less). These all six leptons group into three generations:
Generation I, Generation II and Generation III as shown in the table. 28.2 Each generation consists of one pair of leptons (for example, electron with electron neutrino).

DO YOU KNOW?

- Our universe belongs to Generation I particles. Particles belonging to Generation II and Generation III are heavier than the particles belonging to Generation I.
- The heavier particles of Generations II and III undergo decay processes, transforming into Generation I particles.

Properties of leptons:

- **Electron:** Negatively charged; commonly found in atoms.
- **Muon and Tau:** Heavier counter parts of the electron.
- **Neutrinos:** Electrically neutral; they interact very weakly with matter.
- Leptons interact via weak and electromagnetic forces but not through the strong force.
- Leptons are stable particles and do not undergo decay under normal circumstances.
- Leptons exist alone and donot form groups.

Table 28.2 Generations of Leptons and Quarks

	Fermions			
	Charge	**Generation I**	**Generation II**	**Generation III**
Leptons	-1	electron (e)	muon (μ)	tau (τ)
	0	e-neutrino	μ-neutrino	τ-neutrino
Quarks	+2/3	up (u)	charm(c)	top(t)
	-1/3	down (d)	strange (s)	bottom(b)

Quarks:

Quarks are elementary particles that experience all three fundamental forces: strong nuclear force, weak nuclear force, and electromagnetic force. Quarks come in six types, or flavors: up (u), down (d), charm (c), strange (s), top (t), and bottom (b).

Quarks are a fundamental component of visible matter. All the matter around us, such as protons and neutrons, is made up of quarks. Similar to leptons, quarks also come in three generations, with each generation containing one pair of quarks. The up and down quarks are the only stable quarks in ordinary matter.

DO YOU KNOW?

Color force increases with increasing distance. The up and down quarks are the only stable quarks in ordinary matter.

Properties of Quarks:

- They carry fractional electric charges, either +2/3 or -1/3.
- Quarks interact strongly with the strong nuclear force, which is mediated by gluons. Quarks are never found as free particles in nature; they are always confined within larger particles called hadrons.
- Hadrons are particles made up of quarks held together by the strong nuclear force. Examples of hadrons include protons and neutrons.
- Quarks can undergo weak interactions, leading to processes such as beta decay. Weak interactions can change one type of quark into another. For example, a down quark can change into an up quark through weak decay processes.

DO YOU KNOW?

Hadron is Greek words means heavy. Meson has spin1, so they can also be placed in the class of boson.

Self-Assessment Questions:

1. Which particles don't participate in strong nuclear force?
2. Define the term "flavor" in the context of quarks and list the six quark flavors.

Color Charge:

1. Electric charge comes in only one type: positive (with its opposite negative). But strong charge (that deals with strong nuclear force) comes in three types: red, green, and blue. These color names are just labels and do not correspond to actual colors in the visual spectrum.
2. Quarks carry either one of the three color charges; and they can change their colors during particle interactions. Quarks of different colors are attracted to one another due to the strong nuclear force; it means red attracts green; blue attracts red, and so on. On the other hand, quarks of the same color repel one another.
3. Quarks always combine in ways that result in "color-neutral" or "white-color" particles. For example, a proton consists of three quarks: one red, one green, and one blue, making it color-neutral. Only white color combinations are permitted. This is why isolated quarks do not exist in nature. This is known as quark confinement. Therefore, all free particles have a color charge of zero.

Composite Fermions:

Composite subatomic particles such as protons, neutrons, alpha particles etc., are composed of two or more elementary particles. All composite particles are massive. The composite particles that are made of quarks are called hadrons. The two main categories of hadrons are baryons and mesons.

(a) Baryons:

Baryons are a class of hadrons that consist of three quarks. For example, protons and neutrons are the most well-known baryons, each composed of three quarks:

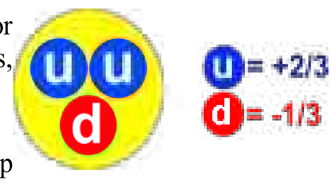


Figure 28.2 Proton Quarks

Proton:

It consists of two up and one down quarks ($\bar{u}\bar{u}\bar{d}$). Up (u) quark has +2/3 charge and down quark has -1/3charge. Therefore, net charge on proton has +1 charge:

$$Proton = \bar{u}\bar{u}\bar{d} = \frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1$$

$$Neutron = \bar{u}\bar{d}\bar{d} = \frac{2}{3} - \frac{1}{3} - \frac{1}{3} =$$

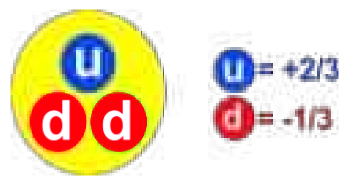


Figure 28.3 Neutron Quarks

Neutron:

It consists of three quarks: one up and two down quarks ($\bar{u}\bar{d}\bar{d}$). The net charge on neutron is zero:

(b) Mesons:

Mesons are another class of hadrons, but they consist of one quark and one anti quark. For example, pions (π) are common mesons. They carry the strong nuclear force, binding protons and neutrons together.

Quarks and Beta Decay:

β -decay is a type of radioactive decay process in which a neutron in an atomic nucleus is transformed into a proton. When a β^--decay occurs, a down quark emits a field particle called a W^--boson (a weak force carrying particle) and transforms into an up quark. The W^--boson quickly breaks up into an electron and an antineutrino. The process is shown in Figure.28.4.

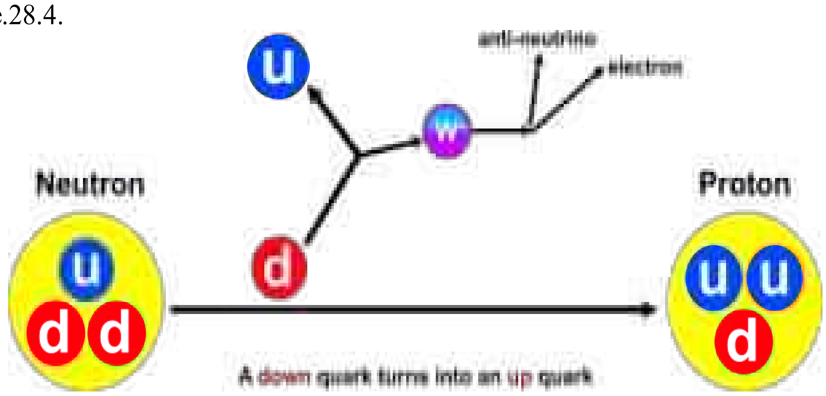


Figure 28.4 Quarks and β^-- beta decay

Electric charge is conserved during beta decay with the emission of an electron and an antineutrino.

β^+- decay is a type of radioactive decay process in which a proton is transformed into a neutron. In β^+-decay, an up quark emits a field particle called a W^+-boson and transforms into a down quark. The W^+-boson quickly breaks up into an anti-electron (positron) and a neutrino. The process is shown in Figure.28.4

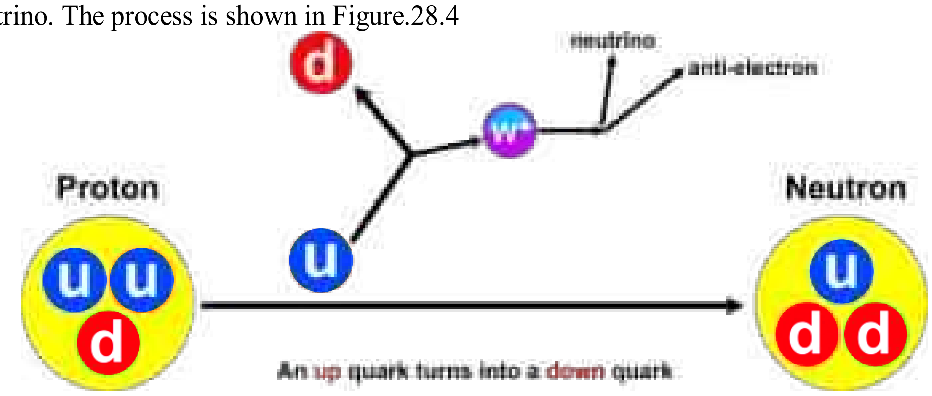


Figure28.5 Quarks and β^+- beta decay

The up quark can change into a down quark by emitting W+ weak particle. How could that trick be done? Explain.

Nature can create short-lived particles, like particle-antiparticle pairs, out of nothing by borrowing energy permitted by the uncertainty principle. This principle allows for a fluctuation in energy levels at any given moment, making it possible for particles to briefly come into existence before annihilating each other.

Imagine that there was created such a pair of particles: a down quark and anti-down quark in the neighborhood of the up quark:

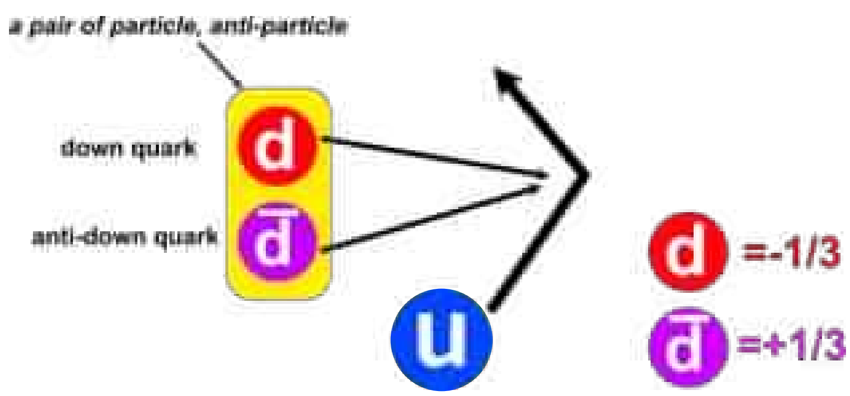


Figure 28.6 A pair of particles and anti-particles

Anti-down quark is represented by bar over symbol d: $\bar{d}$. The charge on anti-down is +1/3. Therefore, net charge on the pair is zero. Next, imagine the down quark replacing the up quark. The up quark could then join up with the remaining anti-down quark to make the W^+ particle:

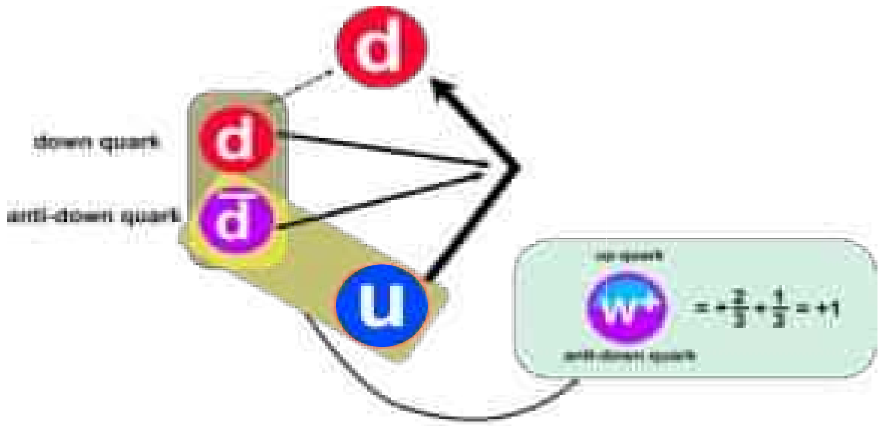


Figure 28.7 up quark and anti-down quarks

The net charge on W^+ is +1. The W^+ boson can vary its constituents and it can consist of a pair of positron-neutrino. The net charge is again +1. Now the W^+ boson decays into positron and neutrino as shown in diagram.

28.2 Radiations Detectors:

Radiations Detectors or Particle Detectors are devices that detect, track, and identify ionizing particles produced by nuclear decay, cosmic radiation, or particle accelerator reactions. In addition to reporting the presence of a particle, detectors can measure its energy and other properties such as momentum, spin, charge, and identify particle type. Particle detectors are classified into numerous types, including ionization detectors, scintillation detectors, Cherenkov light detectors, transition radiation detectors, and others.

Many particle detectors work by measuring the ionization produced when charged particles pass through a medium. The detectors based on the loss of energy caused by the ionization of atoms are called **gaseous detectors**, such as the **Wilson cloud chamber** and the **GM counter**.

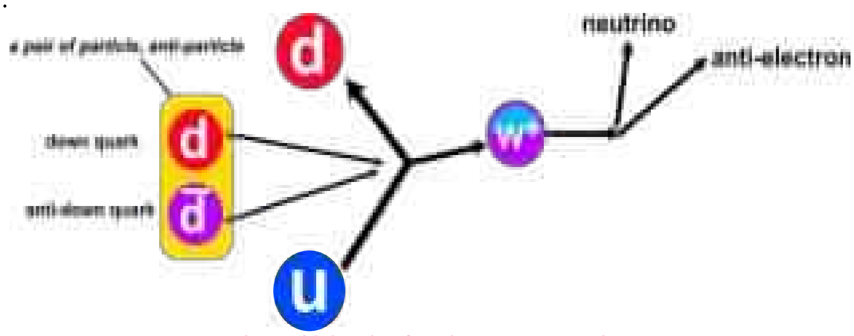


Figure 28.8 Pair of Positron and Neutrino

Gaseous detectors are a crucial tool in detecting and analyzing electronic signals. They convert the ionization produced by a charged particle through a gas into an electronic signal, providing accurate measurements of a particle's position or trajectory, therefore, they are also known as **tracking detectors**. Wilson cloud chamber is a type of tracking detector.

28.2.1 Wilson cloud chambers:

A Wilson cloud chamber is a type of tracking detector which works on the principle of ionization. It is a class of gas detector that is used in particle physics and nuclear physics to visualize the tracks of subatomic particles such as electrons, positrons, alpha particles, and cosmic rays. It was invented by Scottish physicist Charles Thomson Rees Wilsonin1912 and played a crucial role in the early discoveries of subatomic particles.

Figure 28.9 Wilson cloud Chambers

Working Principle:

The Wilson Cloud Chamber consists of a sealed container filled with a supersaturated vapor, typically water or ethanol. When a particle passes through the chamber, it ionizes the vapor, creating a trail of droplets that condense around the ionized path. This creates a visible cloud-like track that can be photographed and analyzed.

Construction:

The schematic diagram of Wilson cloud chamber is shown in figure 28.10, which consists of a large cylindrical chamber A, with walls and a ceiling made of glass. It contains dust-free air saturated with water vapor. P is a piston working inside the chamber. When the piston moves down rapidly, adiabatic expansion of the air inside the chamber takes place. The piston is connected to a large evacuated vessel F through a valve V. When the valve is opened, the air under the piston rushes into the evacuated vessel F, thereby causing the piston to drop suddenly. The wooden blocks WW reduce the air space inside the piston. Water at the bottom of the apparatus ensures saturation in the chamber. The expansion ratio can be adjusted by altering the height of the piston.

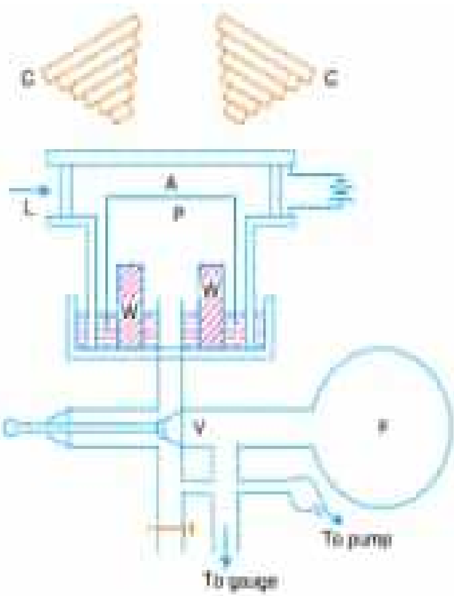


Figure 28.10 Schematic diagram of Wilson Cloud Chamber

As soon as the gas in the expansion chamber is subjected to sudden expansion, the ionizing particles are shot into the chamber through a side window. A large number of extremely fine droplets are formed on all the ions produced by the ionizing particles. These droplets form a track of the moving ionizing particles. At this stage, the expansion chamber is profusely illuminated by a powerful beam of light L and two cameras CC are used to photograph the tracks as shown in figure 28.10. The process of expansion, shooting of the ionizing particles into the expansion chamber, illuminating the chamber and clicking the camera must all be carried out in rapid succession in order to get satisfactory results. The type of ionizing particle can be identified by its track in the cloud chamber. Alpha particles, being relatively massive, travel in straight, thick, and clearly defined paths. Beta particles, being lighter, are easily deflected and create thin, curved paths. The cloud chamber has been instrumental in discovering many elementary particles, such as the positron and meson.

Use of Wilson Cloud Chambers:

- **Particle Identification:** Wilson cloud chambers were historically instrumental in the identification and study of subatomic particles. By observing the curvature of particle tracks in a magnetic field and the nature of the tracks themselves, scientists could identify and classify various particles.
- **Nuclear Physics Research:** Cloud chambers have been used to study the behavior of particles in nuclear reactions and to investigate the structure of atomic nuclei.
- **Cosmic Ray Studies:** Wilson cloud chambers are also used in cosmic ray research. These instruments can detect and track the passage of cosmic rays, which are high-energy particles originating from space.
- **Education and Outreach:** Cloud chambers are often used as educational tools in physics classrooms and science museums to help students and the general public visualize the behavior of subatomic particles.

Geiger-Muller counter:

A Geiger-Muller counter (GM counter) is a type of gas radiation detector used to measure ionizing radiation. It is a portable and versatile device commonly employed for detecting the presence and intensity of various types of ionizing radiation, including alpha particles, beta particles, and gamma rays. The Geiger-Muller (GM) counter was invented by two German scientists, Hans Geiger and Walther Muller, in 1928.

Figure 28.11 GM Counter

Construction:

The GM counter consists of a hollow metallic chamber as shown in the figure 28.11 that acts as a cathode.

A thin wire anode is also placed along its axis.

The chamber has a sealed window, through which the radiation enters the chamber.

The chamber is filled with an inert gas at low pressure.

There is a counter connected to this system to measure the radiation.

Working:

The chamber is filled with an inert gas (helium, neon, or argon) at low pressure. A high voltage is applied to this chamber. The metallic chamber will conduct electricity. When radiation enters the chamber through the window, the photons in the radiation will ionize the inert gas inside the chamber. This will make the gas conductive. The electrons produced due to ionization are accelerated due to the potential that we applied and these electrons cause even more ionization. The ionized electrons travel towards the anode. The anode is connected to a counter. The counter counts the electrons reaching the anode. This is how we measure radiation.

Resultant Curve: Geiger Plateau

The performance of a GM counter is typically illustrated by the Geiger Plateau curve, which shows the count rate versus the applied voltage.

1. **Initial Region:**
   At low voltages, no significant ionization occurs, so the count rate is very low.
2. **Threshold Region:**
   As voltage increases, the counter starts to detect ionizing events. The count rate begins to rise sharply.
3. **Geiger Plateau:**
   At a certain voltage range, the count rate levels off and remains relatively constant. This is the operational region of the GM counter. The plateau indicates that each ionizing event is creating a detectable pulse, and the counter is functioning reliably.
4. **Continuous Discharge Region:**
   If the voltage is increased too much, continuous discharge occurs, where the counter no longer operates correctly, and the count rate rises rapidly again.

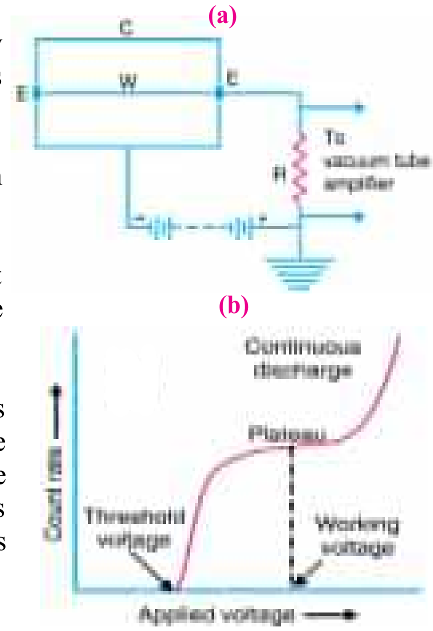


Figure 28.12 (a, b)
applied voltage vs counter rate graph

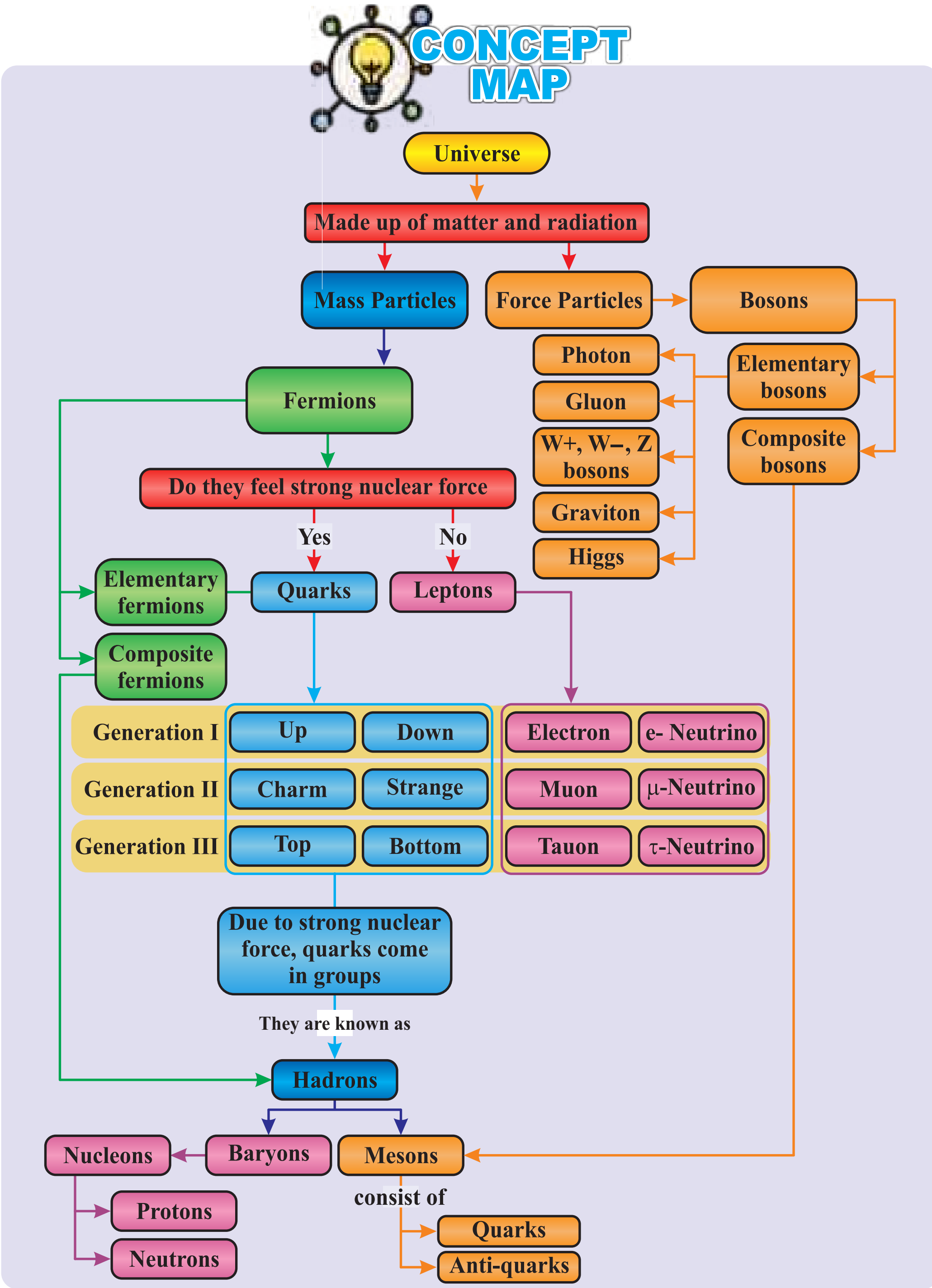
Use of GM Counter:

Geiger-Muller counters have a wide range of applications, including:

- **Radiation Monitoring:**
  They are commonly used for radiation monitoring in nuclear power plants, laboratories, and industrial settings to measure radiation levels and ensure the safety of workers and the environment."
- **Environmental Monitoring:**
  GM counters are employed for environmental radiation monitoring to assess background radiation levels and detect any abnormal increases in radiation.
- **Health Physics:**
  Health physicists use GM counters to monitor radiation exposure of individuals working with radioactive materials or in radiation-prone environments.
- **Education:**
  Health physicists use GM counters to monitor radiation exposure of individuals working with radioactive materials or in radiation-prone environments.
- **Radiological Emergencies:**
  In the event of radiological emergencies or accidents involving radioactive materials, GM counters can be used to assess radiation contamination levels.

SUMMARY

- ✓ Gravitational Force it is weakest, acts on mass, mediated by the hypothetical graviton.
- ✓ Electromagnetic it is a force acts on electric charge, mediated by the photon.
- ✓ Strong Nuclear Force is a strongest force; it acts on quarks and gluons within hadrons mediated by gluons.
- ✓ Weak Nuclear Force is responsible for radioactive decay, mediated by W and Z bosons.
- ✓ Standard Model of Matter Hadrons is composite particles made up of quarks, including baryons (e.g., protons and neutrons) and mesons.
- ✓ Leptons are fundamental particles are not made of quarks, including electrons, muons, taus, and their associated neutrinos.
- ✓ Quarks are fundamental particles that combine to form hadrons, come in six flavors (up, down, charm, strange, top, bottom).
- ✓ Radiation Detectors is devices used to detect and measure ionizing radiation for safety, environmental monitoring, and scientific research.
- ✓ Wilson Cloud Chambers
  - Working Principle: It visualizes paths of charged particles through supersaturated vapor, forming condensation trails.
  - Construction: Sealed chamber with alcohol vapor and cooled base.
  - Use: Detecting and studying the tracks of ionizing particles, observing particle interactions.
- ✓ Geiger-Müller (GM) Counter
  - Working Principle: Detects ionizing radiation by ionizing gas within a tube, generating electrical pulses.
  - Construction: Tube filled with inert gas, central wire anode, outer cathode, high voltage applied.
  - Use: Measuring radiation levels, monitoring radioactive contamination, ensuring safety in nuclear facilities and laboratories.


CONCEPT MAP
Universe
Made up of matter and radiation
Mass Particles
Force Particles
Bosons
Photon
Gluon
W+, W–, Z bosons
Graviton
Higgs
Elementary bosons
Composite bosons
Fermions
Do they feel strong nuclear force
Yes
No
Quarks
Leptons
Elementary fermions
Composite fermions
Generation I
Up
Down
Electron
e- Neutrino
Generation II
Charm
Strange
Muon
μ-Neutrino
Generation III
Top
Bottom
Tauon
τ-Neutrino
Due to strong nuclear force, quarks come in groups
They are known as
Hadrons
Nucleons
Baryons
Mesons
Protons
Neutrons
consist of
Quarks
Anti-quarks

EXERCISE

Section (A): Multiple Choice Questions (MCQs)

Choose the correct answer:

1. The Standard Model classifies elementary particles into two main groups:
   (a) Baryons and Leptons (b) Fermions and Bosons
   (c) Quarks and Gluons (d) Hadrons and Mesons
2. The following is NOT a flavor of quark:
   (a) Up (b) Down (c) Electron (d) Top
3. The charge of an up quark is:
   (a) +1/2e (b) -1/2 e (c) +2/3e (d) -2/3e
4. The concept of "quark confinement" implies that:
   (a) Quarks cannot exist as free particles outside of hadrons.
   (b) Quarks are always found in pairs with opposite charges.
   (c) Quarks have a strong affinity for gluons.
   (d) Quarks are the fundamental building blocks of all matter.
5. The primary role of the Higgs boson in the Standard Model is:
   (a) Mediating electromagnetic interactions (b) Providing mass to other particles
   (c) Transmitting the strong nuclear force (d) Creating dark matter
6. According to the Standard Model, the term "color" refers to:
   (a) Visible light spectrum (b) Charge property of quarks
   (c) Mass of particles (d) Spin of particles
7. A particle made up of a quark and an antiquark is called:
   (a) Lepton (b) Baryon
   (c) Meson (d) Neutrino
8. An elementary particle that feels all three fundamental forces (electromagnetic, weak, and strong nuclear forces) is:
   (a) Lepton (b) Quark
   (c) Electron (d) Neutrino
9. The primary function of a Geiger-Müller counter in particle physics is to:
   (a) Measure the velocity of particles
   (b) Detect and count ionizing radiation
   (c) Create antimatter particles
   (d) Generate magnetic fields
10. In a Geiger-Müller counter, the gas commonly used to detect ionizing radiation is:
   (a) Oxygen (b) Neon (c) Argon (d) Helium

Section (B): **CRQs (Short Answered Questions):**

1. Explain the difference between bosons and fermions and their roles in mediating fundamental forces.
2. Compare and contrast the properties of quarks and leptons, the two main categories of fermions in the Standard Model.
3. Define the term "lepton" and provide examples of leptons. Explain their fundamental properties and role in the Standard Model of particle physics.
4. Explain the concept of color charge in quarks and its significance in the strong nuclear force. How does the combination of quarks contribute to the color-neutral nature of protons and neutrons?
5. Describe the structure of a proton and neutron in terms of its quark composition. How do quarks combine to form a proton and a neutron, and what are the specific types of quarks involved?

Section (C): **ERQs (Long Answered Questions):**

1. Explain the structure of the Standard Model, including the different types of particles and their relationships. How does the model classify fundamental forces?
2. Describe in detail all fundamental forces and their associated field particles. What is a boson, and why are bosons referred to as field particles?
3. Describe the operating principle of a Geiger-Müller counter. How does it detect and quantify ionizing radiation, and what are its limitations in terms of measurement range and types of radiation detected?
4. Discuss the uses of a Wilson cloud chamber in particle physics experiments. How does it visualize charged particle tracks, and what factors can affect its performance?