Chapter 12

1. What is the Universe?

The **universe** is the totality of space, time, matter, and energy. It includes:

- **Galaxies**, stars, planets, moons, black holes
- All forms of **radiation and dark matter/energy**
- Estimated age: **13.8 billion years**
- Contains **billions of galaxies**, each with millions to billions of stars

2. Importance of Gravitational Force in the Universe

Gravitational force is the fundamental force that:

- **Holds planets in orbit** around stars
- Binds **galaxies** and galaxy clusters together
- Controls the motion of celestial bodies
- Played a major role in the **formation of stars, galaxies**, and planetary systems
- Prevents matter in the universe from expanding forever unchecked

Without gravity, no stars, planets, or life could exist.

3. Study of the Universe (Cosmology)

The **scientific study of the universe** is called **cosmology**.
Scientists and astronomers use:

- **Telescopes** (optical, radio, space-based like Hubble)
- **Spectroscopy** (studying light spectra from stars/galaxies)
- **Satellites and space probes**
- Mathematical models and simulations

4. Big Bang Theory

- The most accepted **origin theory of the universe**

- States the universe began as a **singular point of infinite density** (~13.8 billion years ago)
- This point expanded rapidly – not an explosion, but a **rapid expansion of space itself**
- As expansion occurred, matter cooled and formed galaxies and stars

Evidence for Big Bang:

- Redshift of galaxies (expansion)
- Cosmic microwave background radiation (CMBR)
- Abundance of light elements (hydrogen and helium)

5. Hubble's Study Regarding the Universe

Edwin Hubble (1920s)

- Observed that **galaxies are moving away** from us.
- The farther a galaxy is, the **faster it moves away**.

This led to the formulation of **Hubble's Law**.

6. Hubble's Law

Hubble's Law:

$v = H_0 \times d$

Where:
v = recessional velocity
H_0 = Hubble's constant
d = distance of galaxy

Where:

- vvv = velocity at which a galaxy is receding
- H0H_0H0 = Hubble's constant (approx. 70 km/s per megaparsec)
- ddd = distance of the galaxy

Meaning:
The universe is **expanding**. Every galaxy is moving away from every other galaxy.

7. Possible Futures of the Universe

The fate of the universe depends on the balance between **expansion force** and **gravitational force**:

a. Continuous Expansion (Open Universe)

- Expansion continues forever
- Galaxies move farther and farther
- The universe becomes cold and dark

b. Slowing Expansion → Balance (Flat Universe)

- Expansion slows but never fully stops
- Critical density is just right
- Universe expands infinitely at a decreasing rate

c. Contraction (Closed Universe)

- Gravity overcomes expansion
- Universe eventually collapses → **Big Crunch**

8. Role of Centripetal & Centrifugal Forces in Existence of Heavenly Bodies

Centripetal Force:

- Pulls celestial bodies **towards the center**
- Provided by **gravitational attraction**

Centrifugal Force:

- Tendency of a rotating body to move **away from the center**
- Acts **outward**, due to orbital motion

These two forces are in **balance**, keeping:

- **Planets in orbit** around the sun

- **Moons** orbiting planets
- **Galaxies** stable

If centripetal > centrifugal → inward collapse
If centrifugal > centripetal → escape from orbit

9. Mean Density & Critical Density

Mean Density of the Universe:

The average density of all matter (including dark matter)

Mean Density of the Universe:

ρ_{mean} = (total mass of universe) / (volume of universe)

Critical Density:

- The exact density needed to **stop the expansion** of the universe over infinite time

Critical Density Formula:

$\rho_c = (3 \times H_0^2) / (8 \times \pi \times G)$

Where:
H_0 = Hubble's constant
G = Gravitational constant

10. Comparing Mean Density and Critical Density

Condition	Resulting Universe Type
$\rho_{mean} > \rho_c$	Closed Universe (collapses)
$\rho_{mean} = \rho_c$	Flat Universe (balanced)
$\rho_{mean} < \rho_c$	Open Universe (expands forever)

11. Types of the Universe (Based on Density)

Flat Universe

- Infinite, but gravity balances expansion
- Universe expands slowly forever

Open Universe

- Infinite and keeps expanding rapidly
- Cold, dark future

Closed Universe

- Finite and curves back on itself
- Eventually contracts → Big Crunch

Interesting Facts about the Universe

- The observable universe is **about 93 billion light years** across!
- **Dark energy** makes up ~70% of the universe, and it's driving the accelerated expansion.
- **Galaxies are not expanding themselves**, only **space between them** is.
- The **James Webb Space Telescope** allows scientists to study the earliest galaxies, close to Big Bang time.
- **Neutron stars** are so dense that 1 teaspoon of their material would weigh billions of tons on Earth.

Quick Revision

- **Universe:** All matter and energy
- **Gravity:** Binds structures in space
- **Big Bang:** Universe began as dense point
- **Hubble's Law:** Expansion → $v = H_0 \cdot d$
- **Fate of Universe:** Depends on mean vs critical density
- **Types of Universes:** Open, flat, closed