CHAPTER 4: DYNAMICS – II

1. INTRODUCTION

In *Dynamics – I*, we studied force and Newton's laws of motion.
In **Dynamics – II**, we study the **different effects of force**, such as:

- Turning effect of force (rotation)
- Stability of bodies
- Role of centre of mass and centre of gravity
- Friction and its effects
- Circular motion and centripetal force
- Orbital motion and satellites

This chapter explains how forces not only move objects in straight lines but also **rotate, balance, topple, slow down, or make objects move in circles**.

2. FORCES ON BODIES

2.1 Line of Action of a Force

- The **line of action of a force** is the straight line along which a force acts.
- The **effect of a force depends not only on its magnitude and direction but also on its line of action**.
- When several forces act on a body simultaneously, both **net force** and **line of action** become important.

Example:
When two people push a heavy cupboard, the ease of motion depends on whether their forces act along the same or different lines.

2.2 Parallel Forces

When forces act in parallel directions, they are called **parallel forces**.

- **Like parallel forces**
  Forces acting in the same direction.
- **Unlike parallel forces**
  Forces acting in opposite directions.

Examples:

- Pushing a cart with both hands → like parallel forces
- Turning a bicycle handle → unlike parallel forces

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3. MOMENT OF A FORCE (TORQUE)

3.1 Definition

- The **turning effect of a force** about a fixed point or axis is called **moment of force** or **torque**.
- Torque is a **vector quantity**.
- SI unit: **newton metre (N m)**

Force produces **translational motion**, while moment of force produces **rotational motion**.

3.2 Axis of Rotation

- **Axis of rotation** is a fixed line about which an object rotates.
- Examples:
  - Hinges of a door
  - Centre of a nut when using a wrench
  - Earth's axis of rotation

3.3 Moment Arm

- The **moment arm** is the **perpendicular distance** between the axis of rotation and the line of action of force.
- Torque depends on:

- Magnitude of force
- Length of moment arm

If the line of action of force passes through the axis of rotation, **moment arm = 0**, hence **no rotation occurs**.

3.4 Clockwise and Anticlockwise Moments

- **Clockwise moment** → taken as **negative**
- **Anticlockwise moment** → taken as **positive**

A longer handle produces more torque for the same applied force (reason for long spanners).

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4. CENTER OF MASS AND CENTER OF GRAVITY

4.1 Center of Mass (CM)

- The **center of mass** is the point at which the mass of a body is considered to be concentrated.
- Motion of the body can be described by tracking the motion of its center of mass.

If a force passes through the center of mass, it **does not produce rotation**.

4.2 Center of Gravity (CG)

- The **center of gravity** is the point at which the entire weight of a body appears to act.
- For small objects, **CM and CG coincide**.
- For very tall objects, CM and CG may differ slightly because gravity varies with height.

4.3 CM/CG of Regular and Irregular Bodies

- For uniform objects:
  - Sphere, cube → geometric centre
  - Rod → midpoint

- For irregular objects:
    - Found by suspending the object from different points and drawing vertical lines
    - Intersection point gives CG

CM/CG may lie **outside the material of the body**, depending on shape and orientation.

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5. EQUILIBRIUM

5.1 Definition

A body is said to be in **equilibrium** when:

- Net force on it is zero
- Net torque on it is zero

Such a body does not accelerate or rotate.

5.2 Conditions of Equilibrium

First Condition of Equilibrium

- The vector sum of all forces acting on a body is zero.
- Ensures **no linear acceleration**.

Second Condition of Equilibrium

- The vector sum of all torques acting on a body is zero.
- Ensures **no angular acceleration**.

For complete equilibrium, **both conditions must be satisfied**.

5.3 Principle of Moments

The second condition of equilibrium is also called the **principle of moments**:

> *For a body in equilibrium, the sum of clockwise moments about a pivot equals the sum of anticlockwise moments about the same pivot.*

This principle is used in:

- Seesaws

- Balances
- Levers

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6. TYPES OF EQUILIBRIUM

6.1 Static Equilibrium

- Body is at rest.
- Example: A book resting on a table.

6.2 Dynamic Equilibrium

- Body moves with constant velocity.
- Two types:
    - **Dynamic translational equilibrium** (constant linear speed)
    - **Dynamic rotational equilibrium** (constant angular speed)

Examples:

- Paratrooper falling at terminal velocity
- Ceiling fan rotating at constant speed

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7. STABILITY

7.1 Stability of a Body

Stability is the ability of a body to **return to its original position** after being disturbed.

Stability depends on:

- Height of center of gravity
- Area of base of support

7.2 Types of Stability

Stable Equilibrium

- Body returns to original position after disturbance.
- CM rises when displaced.
- Example: Book lying flat on table.

Unstable Equilibrium

- Body moves farther away from original position.
- CM falls when displaced.
- Example: Pencil balanced on its tip.

Neutral Equilibrium

- Body remains in new position.
- CM neither rises nor falls.
- Example: Ball on a flat surface.

7.3 Improving Stability

Stability can be increased by:

- Lowering the center of mass
- Increasing the base area
- Using both methods together

Self-righting toys use this principle.

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8. FRICTION

8.1 Definition

- **Friction** is the force that opposes relative motion between two surfaces in contact.
- It always acts **opposite to motion**.
- Unit: newton (N)

8.2 Microscopic Origin of Friction

- Surfaces are not perfectly smooth.
- Microscopic irregularities interlock, producing friction.

8.3 Advantages of Friction

- Enables walking
- Helps vehicles move
- Allows brakes to work
- Holds nails and screws in place

8.4 Disadvantages of Friction

- Causes wear and tear
- Produces heat
- Wastes energy

8.5 Methods of Reducing Friction

- Polishing surfaces
- Using lubricants
- Using ball bearings (convert sliding friction into rolling friction)

8.6 Rolling Friction

- Occurs when an object rolls over a surface.
- Much smaller than sliding friction.
- Reason for invention of wheels.

8.7 Fluid Friction (Drag)

- Occurs when an object moves through a fluid (liquid or gas).

- Depends on:
    - Shape and size of object
    - Speed of object
    - Nature of fluid

8.8 Terminal Velocity

- When drag force equals weight, acceleration becomes zero.
- Object moves with constant maximum speed called **terminal velocity**.
- For humans:
    - Without parachute ≈ 53 m/s
    - With parachute ≈ 5–10 m/s

8.9 Frictional Dissipation

- Friction converts mechanical energy into heat.
- Examples:
    - Rubbing hands
    - Shooting stars burning in atmosphere

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9. CENTRIPETAL FORCE

9.1 Uniform Circular Motion

- Speed remains constant but direction changes continuously.
- Causes acceleration towards the centre.

9.2 Centripetal Force

- The force that keeps an object moving in a circular path.
- Always directed towards the centre.

- Examples:
  - Tension in string
  - Gravitational force on planets
  - Friction on turning vehicles

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10. ORBITAL MOTION

10.1 Satellite Motion

- An orbit is a closed path around a massive body.
- Satellites move due to gravitational centripetal force.
- Artificial satellites must be given correct tangential speed.

10.2 Orbital Speed

- Speed required to keep a satellite in circular orbit.
- Depends on radius of orbit, not mass of satellite.

10.3 Orbital Period

- Time taken by satellite to complete one orbit.
- Farther objects have longer orbital periods.

ALL FORMULAE (COLLECTED AT END)

1. Torque (Moment of Force)

$$\tau = F \times d$$

2. First Condition of Equilibrium

$$\sum F = 0$$

3. Second Condition of Equilibrium

$$\sum \tau = 0$$

4. Principle of Moments

$$\sum \text{Clockwise moments} = \sum \text{Anticlockwise moments}$$

5. Centripetal Force

$$F_c = \frac{mv^2}{r}$$

6. Average Orbital Speed

$$v = \frac{2\pi r}{T}$$

7. Terminal Velocity Condition

$$\text{Weight} = \text{Drag force}$$

