CLASS IX - CBSE
Physics Study Material
(Updated for 2026–2027 Batch)

Name:

MOTION

Motion and Rest

Motion and **Rest** are fundamental concepts in physics that describe the state of an object with respect to its surroundings.

Definition of Rest

An object is said to be **at rest** if it **does not** change its position with respect to its surroundings over time. In other words, the object remains stationary relative to a chosen reference point.

Definition of Motion

An object is said to be **in motion** if it changes its position with respect to its surroundings over a period of time. The movement can be in a straight line, curved path, or rotational.

Important Note: Rest and motion are **relative terms**. An object may be at rest with respect to one observer but in motion with respect to another. For example, a passenger sitting inside a moving bus is at rest relative to the bus but is in motion relative to an observer standing outside the bus.

Summary:

- **Rest:** No change in position relative to the surroundings with time.
- **Motion:** Change in position relative to the surroundings with time.

Scalar and Vector Quantities

Scalar Quantity

A **scalar quantity** is a physical quantity that has only magnitude and no direction.
Examples: Temperature, mass, time, distance, speed

Vector Quantity

A **vector quantity** is a physical quantity that has both magnitude and direction.
Examples: Displacement, velocity, acceleration, force

Difference Between Scalar and Vector Quantities

Aspect	Scalar Quantity	Vector Quantity
Definition	Has only magnitude	Has both magnitude and direction
Representation	Numeric value with units	Arrow above symbol, e.g., $\vec{v}$ or boldface $\mathbf{v}$
Examples	Time, mass, speed, distance, temperature	Displacement, velocity, force, acceleration

Distance and Displacement

Definitions

Distance

Distance is the **total length of the path traveled** by an object, regardless of direction.

Displacement

Displacement is the **shortest straight-line distance** from the initial position to the final position of the object, including direction.

Explanation

Distance is a scalar quantity — it has only magnitude but *no direction*. Displacement is a vector quantity — it has both magnitude and direction.

Comparison Table

Feature	**Distance**	**Displacement**
Quantity Type	Scalar (only magnitude)	Vector (magnitude and direction)
Can be Negative?	**Never** negative; always zero or positive	Can be zero, positive, or **negative** depending on direction
Value When Start = End	Zero (if no movement) or positive	Always zero (since initial and final positions coincide)
Relation Between Values	Always greater than or equal to displacement ($d \geq \|\vec{s}\|$)	Always less than or equal to distance in magnitude
Measurement	Total length of the path covered irrespective of direction	Shortest straight-line path from start to end, considering direction
Direction	No direction involved	Has direction, indicated by an arrow in vector notation
Symbol	d	$\vec{s}$ or s
Examples	Distance traveled while walking 4 m east then 3 m north = 7 m	Displacement for same walk = $\sqrt{4^2+3^2} = 5$ m, direction north-east

Speed

Speed

Speed is defined as the **rate of change of distance with respect to time**. It tells us how fast an object is moving regardless of its direction.

Formula

Speed Formula

$$v = \frac{d}{t}$$

where,

- $v =$ Speed
- $d =$ Distance traveled
- $t =$ Time taken

Properties of Speed

Feature	**Description**
Quantity Type	Scalar quantity (only magnitude, no direction)
Symbol	v
SI Unit	Meter per second (m/s)
Other Units	Kilometers per hour (km/h), miles per hour (mph)
Can be Negative?	No, speed is always zero or positive
Direction Included?	No, speed does not have direction
Applied Example	The reading on a vehicle's speedometer indicates speed but not direction

Table 1: Key properties of speed

Examples

- If a car travels 100 meters in 5 seconds, its speed is:

$$v = \frac{100 \text{ m}}{5 \text{ s}} = 20 \text{ m/s}$$

- If you walk 3 kilometers in 1 hour, your speed is:

$$v = \frac{3 \text{ km}}{1 \text{ hr}} = 3 \text{ km/h}$$

- The speedometer in a vehicle indicates the speed but not the direction.

Average Speed

Definition of Average Speed

Average speed is defined as the total distance traveled divided by the total time taken to cover that distance.

$$\text{Average speed} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

Explanation

Average speed is a scalar quantity that gives an overall measure of how fast an object moves during its entire trip. It averages out any changes in speed or pauses during travel.

For a journey with multiple segments where speeds and times vary, average speed is calculated as:

$$v_{\text{avg}} = \frac{v_1 t_1 + v_2 t_2 + \cdots + v_n t_n}{t_1 + t_2 + \cdots + t_n}$$

Example

A train travels at 50 km/h for 2 hours and then at 70 km/h for 3 hours. Find the average speed.

$$\begin{aligned}
\text{Distance}_1(s_1) &= 50 \times 2 = 100 \text{ km} \\
\text{Distance}_2(s_2) &= 70 \times 3 = 210 \text{ km} \\
\text{Total distance} &= 100 + 210 = 310 \text{ km} \\
\text{Total time} &= 2 + 3 = 5 \text{ hours} \\
\text{Average speed} &= \frac{310}{5} = 62 \text{ km/h}
\end{aligned}$$

Uniform Motion

Definition

Uniform motion is a type of motion in which an object moves in a straight line with a **constant speed**, covering equal distances in equal intervals of time, no matter how small the time intervals are.

Key Characteristics

- The speed v remains constant throughout the motion.
- The object moves in a straight path without changing direction.
- There is no acceleration in uniform motion.
- Distance covered is directly proportional to time: doubling time doubles the distance.

Formula

Formula for Uniform Motion

$$s = vt$$

where,

- s = distance covered
- v = constant speed
- t = time elapsed

Examples

- A car moving at a constant speed of 60 km/h on a straight road for 2 hours covers a distance:

$$s = 60 \times 2 = 120 \text{ km}$$

- A train moving at a steady 100 km/h for 3 hours travels:

$$s = 100 \times 3 = 300 \text{ km}$$

- The blades of a ceiling fan rotating at a steady speed exhibit uniform circular motion as they cover equal angles in equal time intervals.

Graphical Interpretation

- A distance-time graph for uniform motion is a straight line with constant slope. - The slope of this line corresponds to the speed v

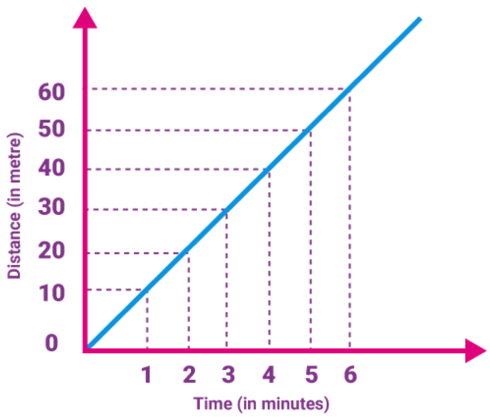


Figure 1: **Uniform motion (Can you calculate the speed?)**

Uniform Speed

- **Uniform speed** means an object covers equal distances in equal intervals of time, no matter how small the intervals.
- Mathematically:

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

- If speed is constant, the distance-time graph is a straight line with constant slope.
- **Example:** A car moving steadily at 60 km/h covers 60 km every hour.

Uniform Motion

- **Uniform motion** means moving with constant speed **and** constant direction (i.e., along a straight line).
- Here, velocity (speed and direction) remains constant.
- **If direction changes (even with constant speed), motion is not uniform.**
- **Example:** A car moving at 50 km/h along a straight road.

Problem:

Priya travels from her home to the market, which is 3 km away, at a speed of 6 km/h. After shopping, she returns home along the same route at a speed of 4 km/h. What is her average speed for the entire journey?

Solution:

- **Total distance travelled:**
$$3\,\text{km} + 3\,\text{km} = 6\,\text{km}$$
- **Time taken to go to the market:**
$$t_1 = \frac{\text{distance}}{\text{speed}} = \frac{3}{6} = 0.5\,\text{hr}$$
- **Time taken to return home:**
$$t_2 = \frac{3}{4} = 0.75\,\text{hr}$$
- **Total time taken:**
$$0.5\,\text{hr} + 0.75\,\text{hr} = 1.25\,\text{hr}$$
- **Average speed:**
$$\text{Average speed} = \frac{\text{Total distance}}{\text{Total time}} = \frac{6}{1.25} = 4.8\,\text{km/h}$$

Answer: Priya's average speed for the entire journey is 4.8 km/h.

Problem:

A cyclist travels on a straight road at a uniform speed of 12 km/h. How much distance will the cyclist cover in 2.5 hours?

Solution:

- **Given:**
Uniform speed = 12 km/h
Time = 2.5 hours
- **Distance formula:**
Distance = Speed × Time
- **Calculation:**
Distance = 12 km/h × 2.5 h = 30 km

Answer: The cyclist will cover 30 km in 2.5 hours at uniform speed.

Velocity?

Velocity is a physical quantity that describes both the **speed** and the **direction** of motion of an object. It tells us not just "how fast," but also "in which direction" an object is moving.

Definition

Velocity is the rate of change of displacement.
It is defined as the displacement covered by an object per unit time **in a particular direction**.

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time}}$$

How is Velocity Different from Speed?

- **Speed** is a scalar quantity; it only tells how much distance an object covers per unit time, regardless of direction.
- **Velocity** is a vector quantity; it tells how much displacement occurs per unit time *in a specific direction*.

Velocity Representation

- Velocity is denoted by $\vec{v}$. **(The arrow on v is not commonly used in 9th standard. You will learn more about vecotr quantities in class 11th)**).
- It is a vector, i.e., has both magnitude and direction.
- **Formula:** $\vec{v} = \dfrac{\text{Displacement}}{\text{Time}}$
- **SI unit:** m/s (meters per second)
- **Other units:** km/h, cm/s
- **Direction:** Always state the direction with the value (e.g., $25\,\text{m/s}$ east).
- **Graphical:** Represented by an arrow in the direction of motion.

Example

Suppose a person walks $50\,\text{m}$ east in $10\,\text{s}$ and then $30\,\text{m}$ west in the next $10\,\text{s}$.

- **Total distance** $= 50 + 30 = 80\,\text{m}$
- **Net displacement** $= 50 - 30 = 20\,\text{m}$ east
- **Average speed** $= \dfrac{80\,\text{m}}{20\,\text{s}} = 4\,\text{m/s}$
- **Average velocity** $= \dfrac{20\,\text{m east}}{20\,\text{s}} = 1\,\text{m/s east}$

Uniform (Constant) Velocity

Definition

A body has a uniform velocity if it travels in a specified direction in a straight line and moves over equal distances in equal intervals of time, no matter how small these time intervals maybe

Mathematically:

$$\vec{v} = \text{constant}$$

This means displacement changes at a uniform rate and in a fixed direction.

Ways the Velocity of a Body Can Change

- **Change in speed:** Magnitude of velocity changes, direction remains the same.
- **Change in direction:** Speed stays constant, direction changes (e.g., motion along a circular path).
- **Change in both speed and direction:** Both magnitude and direction of velocity change simultaneously.

Note: Any change in speed or direction means the velocity is changing.

Example: Calculating Speed and Velocity

A boy walks 120 meters east in 2 minutes, then 70 meters west in the next 1 minute. Calculate:

1. Total **distance** travelled
2. Total **displacement**
3. **Average speed**
4. **Average velocity**

Solution:

- **Total distance:**
$$120\,\text{m} + 70\,\text{m} = 190\,\text{m}$$
- **Total displacement:**
$$120\,\text{m (east)} - 70\,\text{m (west)} = 50\,\text{m (east)}$$
- **Total time:** $2\,\text{min} + 1\,\text{min} = 3\,\text{min} = 180\,\text{s}$
- **Average speed:**
$$\frac{190\,\text{m}}{180\,\text{s}} \approx 1.06\,\text{m/s}$$
- **Average velocity:**
$$\frac{50\,\text{m (east)}}{180\,\text{s}} \approx 0.28\,\text{m/s east}$$

Differences Between Speed and Velocity

Aspect	**Speed**	**Velocity**
Nature	Scalar quantity (no direction)	Vector quantity (has direction)
Definition	Rate of change of distance covered with respect to time	Rate of change of displacement with respect to time
Formula	Speed $= \dfrac{\text{distance}}{\text{time}}$	Velocity $= \dfrac{\text{displacement}}{\text{time}}$
Direction	No specific direction; only magnitude	Has both magnitude and specific direction
Value	Always positive or zero	Can be positive, negative, or zero
Zero condition	Zero only when the object is at rest	Zero if final displacement is zero (even if the object moved)
Path dependence	Depends on total path travelled	Depends only on initial and final position
SI unit	meter per second (m/s)	meter per second (m/s)

Differences Between Speed and Acceleration

Aspect	Speed	Acceleration
Nature	Scalar quantity (no direction)	Vector quantity (has direction)
Definition	Rate at which distance is covered	Rate of change of velocity per unit time
Formula	$\text{Speed} = \frac{\text{distance}}{\text{time}}$	$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time}}$
Direction	Only magnitude, no direction	Magnitude and direction both required
SI unit	meter per second (m/s)	meter per second squared (m/s^2)
Zero value	Zero if object is at rest	Zero if velocity is constant (not changing)
Physical meaning	"How fast" an object moves	"How quickly" its speed or direction changes
Measurement	Odometer or speedometer	Calculated from change in velocity and time

Differences Between Velocity and Acceleration

Aspect	Velocity	Acceleration
Nature	Vector quantity (has direction and magnitude)	Vector quantity (has direction and magnitude)
Definition	Rate of change of displacement per unit time	Rate of change of velocity per unit time
Formula	$\text{Velocity} = \frac{\text{displacement}}{\text{time}}$	$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time}}$
SI Unit	meter per second (m/s)	meter per second squared (m/s^2)
Physical meaning	"How fast and in which direction" an object moves	"How quickly the velocity of an object changes"
Zero value	Zero if object is at rest or returns to starting point	Zero if velocity remains constant
Measurement	Can be measured with displacement and time (direction required)	Calculated from velocity change and time interval

Equations of Motion for a Uniformly Accelerated Body

When an object moves in a straight line with a **constant acceleration**, its velocity changes at a uniform rate. The relationships between displacement, velocity, acceleration, and time can be described using mathematical formulas known as the **equations of motion**.

These equations are useful for:

- Calculating the velocity after a certain time
- Finding the total distance (displacement) covered in a given time
- Relating velocity, displacement, and acceleration even when time is not provided

The equations of motion are fundamental tools in physics for solving problems about linear motion when acceleration is constant.

First Equation of Motion

Let us derive the first equation of motion for an object moving with constant acceleration.

Let:

- u = Initial velocity (in m/s)
- v = Final velocity after time t (in m/s)
- a = Constant acceleration (in m/s^2)
- t = Time elapsed (in seconds)

Step 1: Definition of Acceleration

Acceleration is defined as the rate of change of velocity:

$$a = \frac{v - u}{t}$$

Step 2: Rearranging to Find Final Velocity

Multiplying both sides by t:

$$at = v - u$$

Adding u to both sides:

$$v = u + at$$

Step 3: Meaning of the Equation

The final velocity v after time t is equal to the initial velocity u plus the product of acceleration and time.

First Equation of Motion

$$v = u + at$$

- v = Final velocity (m/s)
- u = Initial velocity (m/s)
- a = Acceleration (m/s^2)
- t = Time (s)

Second Equation of Motion

Let us derive the second equation of motion for a body moving with constant acceleration.
Let:

- u = Initial velocity (in m/s)
- v = Final velocity after time t (in m/s)
- a = Constant acceleration (in m/s^2)
- t = Time elapsed (in seconds)
- s = Displacement (in meters)

Step 1: Average Velocity

If the acceleration is constant,

$$\text{Average velocity} = \frac{u+v}{2}$$

Step 2: Displacement as Average Velocity × Time

$$s = \text{average velocity} \times \text{time} = \frac{u+v}{2} \times t$$

Step 3: Substitute v from the first equation of motion ($v = u + at$)

$$s = \frac{u + (u + at)}{2} \times t$$

$$s = \frac{2u + at}{2} \times t$$

$$s = \left(u + \frac{at}{2}\right) t$$

$$s = ut + \frac{1}{2}at^2$$

Second Equation of Motion

$$s = ut + \frac{1}{2}at^2$$

- s = Displacement (m)
- u = Initial velocity (m/s)
- a = Acceleration (m/s^2)
- t = Time (s)

Third Equation of Motion

Let us derive the third equation of motion for a body moving with constant acceleration.
Let:

- u = Initial velocity (in m/s)
- v = Final velocity (in m/s)
- a = Constant acceleration (in m/s^2)
- t = Time elapsed (in seconds)
- s = Displacement (in meters)

Step 1: Start with the first equation of motion

From the first equation: $v = u + at$
Rearranging to find time:

$$t = \frac{v-u}{a}$$

Step 2: Use the second equation of motion

From the second equation: $s = ut + \frac{1}{2}at^2$

Step 3: Substitute the value of t

$$s = u\left(\frac{v-u}{a}\right) + \frac{1}{2}a\left(\frac{v-u}{a}\right)^2$$

Step 4: Simplify the first term

$$u\left(\frac{v-u}{a}\right) = \frac{u(v-u)}{a} = \frac{uv-u^2}{a}$$

Step 5: Simplify the second term

$$\frac{1}{2}a\left(\frac{v-u}{a}\right)^2 = \frac{1}{2}a \times \frac{(v-u)^2}{a^2} = \frac{(v-u)^2}{2a}$$

Step 6: Combine both terms

$$s = \frac{uv-u^2}{a} + \frac{(v-u)^2}{2a}$$

$$s = \frac{uv-u^2}{a} + \frac{v^2-2uv+u^2}{2a}$$

Step 7: Get common denominator

$$s = \frac{2(uv-u^2)}{2a} + \frac{v^2-2uv+u^2}{2a}$$

$$s = \frac{2uv-2u^2+v^2-2uv+u^2}{2a}$$

$$s = \frac{v^2-u^2}{2a}$$

Step 8: Rearrange to get the final form

Multiplying both sides by $2a$:

$$2as = v^2 - u^2$$

$$v^2 = u^2 + 2as$$

Third Equation of Motion

$$v^2 = u^2 + 2as$$

- v = Final velocity (m/s)
- u = Initial velocity (m/s)
- a = Acceleration (m/s^2)
- s = Displacement (m)

FORCE AND LAWS OF MOTION

What is force?

Force is a **push** or a **pull** acting on an object. It is an external agent capable of changing the state of rest or motion of a body, or changing its shape.

Force is needed to (or the effects of force):

- Move a stationary object.
- Stop a moving object.
- Change the direction of a moving object.
- Change the speed of a moving object.
- Change the shape or size of an object.

Mathematically:

When a force is applied to an object of mass m and it produces an acceleration a, then the force F is given by:

$$F = m \cdot a$$

where:

- F is the force (in newtons, N),
- m is the mass (in kilograms, kg),
- a is the acceleration (in $\mathrm{m/s^2}$).

Units of Force:

- SI unit of force is **newton (N)**.
- 1 newton is the force required to accelerate a 1 kg mass by 1 $\mathrm{m/s^2}$.

$$1\,\mathrm{N} = 1\,\mathrm{kg} \times 1\,\mathrm{m/s^2}$$

Conclusion: Force plays a fundamental role in all physical activities — from walking and running to launching rockets and lifting objects. Without force, motion cannot begin or change.

Here are some everyday examples where force is acting on a body:

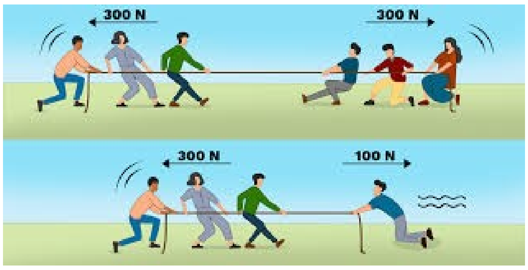
1. **Pushing a stalled car:** When you push a car that has broken down, you apply a force that tries to move it forward.
2. **Kicking a football:** Your foot applies a force to the ball, which sets it in motion.
3. **Pulling a drawer:** When you pull a drawer open, you apply a force that brings it towards you.
4. **Falling apple:** When an apple falls from a tree, the force of gravity pulls it toward the ground.
5. **Pressing a sponge:** When you press a sponge, the applied force changes its shape.
6. **Hitting a cricket ball with a bat:** The bat applies a force on the ball, changing its speed and direction.
7. **Braking a bicycle:** Applying brakes creates a force that slows down or stops the bicycle.

8. **Stretching a rubber band:** When you stretch it, you apply force that increases its length temporarily.

Note: In each case, the force either:

- Changes the state of motion of the object,
- Alters its speed or direction, or
- Deforms its shape.

Balanced and unbalanced forces



Balanced Forces

Definition:
If the resultant of all the forces acting on a body is zero, the forces are called, **balanced forces**.

Characteristics:

- Do not change the state of motion of the object.
- May change the shape of the object.
- Net force (**or resultant force**) = 0.

Example:

- A book resting on a table — the downward gravitational force is balanced by the upward normal force.
- Two people pushing a box from opposite sides with equal force — the box doesn't move.

Unbalanced Forces

Definition:
When the forces acting on an object do **not** cancel out (**or when the resultant is not 0**), they are called **unbalanced forces**.

Characteristics:

- Change the state of motion (start, stop, accelerate, or change direction).
- Can also change the shape of the object.
- Net force $\neq 0$.

Example:

- Kicking a stationary football — the force of the kick is unbalanced, so the ball moves.
- A person pushing a trolley — it starts moving in the direction of the greater force.

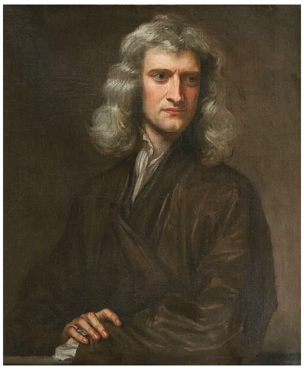
Summary Table

Balanced Forces	**Unbalanced Forces**
Do not change the state of motion	Change the state of motion
Net force is zero	Net force is non-zero
May change shape, but not motion	May change both shape and motion
Example: Book on a table	Example: Pushing a moving cart

NEWTON'S LAWS OF MOTION

Who was Newton?

Sir Isaac Newton was a great scientist and mathematician. In 1687, he proposed three fundamental laws that describe how objects move. These are known as **Newton's Laws of Motion**.



What are Newton's Laws of Motion?

Newton's Laws of Motion are three physical laws that form the foundation of classical mechanics. These laws explain how and why objects move (or don't move).

- **First Law** — Law of Inertia
- **Second Law** — Law of Acceleration ($F = ma$)
- **Third Law** — Action and Reaction

Why are Newton's Laws important?

- They help us understand the motion of objects in our daily life.
- They explain everything from why we stay at rest in a stationary bus, to why we get pushed back when it suddenly accelerates.
- These laws are used in engineering, construction, vehicle design, sports, and even space exploration!

Newton's First Law of Motion

Statement:

An object at rest stays at rest and an object in **uniform motion** continues to move with the same speed and in the same direction unless acted upon by an **unbalanced external force**.

Explanation:

This law is also known as the **Law of Inertia**. It means:

- A body will not change its state (rest or uniform motion) on its own.
- It will only change if an unbalanced force acts on it.

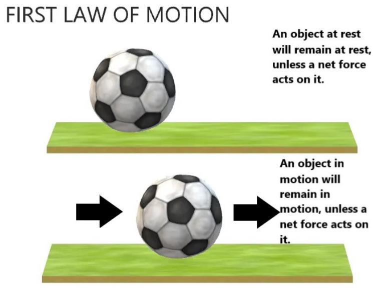
Examples:

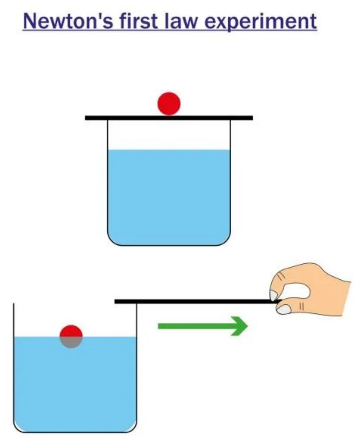
- A book lying on a table stays there unless you pick it up or push it.
- A moving bicycle continues to move even after you stop pedaling, until friction or brakes stop it.
- When a bus suddenly starts, passengers fall backward — their body was at rest and resisted the sudden motion.
- When a bus stops suddenly, passengers fall forward — their body was in motion and resisted stopping.

Inertia:
Inertia is the tendency of a body to resist changes in its state of motion. More the mass, more the inertia.
Types of Inertia:

1. **Inertia of Rest** – Tendency to remain at rest.
2. **Inertia of Motion** – Tendency to keep moving.
3. **Inertia of Direction** – Tendency to keep moving in the same direction.

Key Point:
Force is required to overcome inertia and change the state of motion of an object.





MOMENTUM

To understand Newton's Second Law of Motion, we must first understand the concept of momentum (specifically, linear momentum).

Let's begin with a simple thought experiment. Imagine your friend gives you two choices:

- Stand in front of a truck moving towards you at 30 km/h, **or**
- Stand in front of a housefly flying towards you at the same speed — 30 km/h.

What would you choose? A witty answer might be: *"Stop imagining!"* — but based on the concept of momentum, you'd obviously choose the housefly.

Why? Because the housefly has far less mass than the truck, and getting hit by it wouldn't hurt nearly as much.

Conclusion: The force required to stop a moving object is directly proportional to its **mass**.

Now let's take another example. Suppose a cricket ball is thrown at you twice:

- First, at a speed of 30 m/s
- Then again, at a speed of 20 m/s

Which one is harder to stop? Clearly, **more force** is required to stop the ball thrown at 30 m/s.

Conclusion: The force required to stop a moving object is also directly proportional to its **velocity**.

Putting both ideas together:

- The greater the **mass**, the greater the force required to stop it.
- The greater the **velocity**, the greater the force required to stop it.

This leads us to the concept of **momentum**.

Momentum is defined as the product of the mass and velocity of a body.

Momentum

$$p = m \times v$$

Where:

– p: momentum (kg·m/s)

– m: mass (kg)

– v: velocity (m/s)

From the above formula, it is clear that if the velocity of the body is 0 (or if the body is at rest), the body possesses **no momentum (0 momentum)**.

Since momentum depends on the mass and velocity of a body, a body will have large momentum:

1. if its mass is large,
2. if its velocity is large,
3. if both its mass and velocity are large.

Conservation of Linear Momentum

Let two objects of masses m_1 and m_2 move with initial velocities u_1 and u_2, and after collision, their velocities become v_1 and v_2, respectively.

Using Newton's Third Law:

When two bodies interact, the force exerted by one body on the other is equal and opposite:

$$\text{Force on } m_1 = -\text{Force on } m_2$$

If the time of interaction is t, then using Newton's Second Law:

$$\frac{m_1v_1 - m_1u_1}{t} = -\frac{m_2v_2 - m_2u_2}{t}$$

Multiply both sides by t:

$$m_1v_1 - m_1u_1 = -(m_2v_2 - m_2u_2)$$

Rearrange the terms:

$$m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2$$

Conclusion:

Law of Conservation of Linear Momentum

$$\boxed{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$$

The total momentum before collision is equal to the total momentum after collision if no external force acts on the system.

Units of Momentum

In the SI system, momentum is measured in:

$$\text{kilogram metre per second} \quad (\text{kg}\cdot\text{m/s})$$

Why? Because momentum is calculated as:

$$\text{Momentum} = \text{mass (kg)} \times \text{velocity (m/s)}$$

So the unit becomes:

$$\boxed{\text{kg}\cdot\text{m/s}}$$

This is a derived unit and does not have a special name, but is commonly used in physics.

Rate of Change of Momentum and Newton's Second Law

(An important derivation from exam P.O.V)

1. What is momentum?

Momentum is the quantity of motion of a moving object. It depends on its mass and velocity.

$$\text{Momentum} = \text{mass} \times \text{velocity}$$

2. What does rate of change of momentum mean?

It means how much the momentum changes in a given time interval.

3. How is it calculated?

If momentum changes from p_1 to p_2 in time $t_2 - t_1$, then:

$$\text{Rate of change of momentum} = \frac{p_2 - p_1}{t_2 - t_1}$$

Force applied on the object is directly proportional to the rate of change of momentum, and acts in the direction of the force:

$$F \propto \frac{p_2 - p_1}{t_2 - t_1}$$

4. If mass remains constant:

$$p_1 = m \times u \quad \text{and} \quad p_2 = m \times v$$

So the change in momentum is:

$$p_2 - p_1 = m(v - u)$$

Substitute into the earlier expression:

$$F \propto \frac{m(v - u)}{t_2 - t_1}$$

Since m is constant:

$$F \propto m \times \frac{v - u}{t_2 - t_1}$$

But we know:

$$\frac{v - u}{t_2 - t_1} = a \quad \text{(acceleration)}$$

Therefore:

$$F \propto m \times a$$

5. Newton's Second Law of Motion:

If we remove the proportionality by introducing a constant $k = 1$, we get:

$$\boxed{F = m \times a}$$

This is the mathematical form of Newton's Second Law: *"The force acting on an object is directly proportional to the product of its mass and acceleration."*

Units in Newton's Second Law

From Newton's Second Law, we have:

$$F = m \times a$$

Where:

- F is the force
- m is the mass (in kilograms, kg)
- a is the acceleration (in metres per second squared, m/s^2)

So, the unit of force becomes:

$$\text{Unit of Force} = \text{kg} \times \text{m/s}^2 = \text{kg·m/s}^2$$

This derived unit is called a **newton (N)**.

Definition:
One newton is the force required to accelerate a mass of 1 kg by 1 m/s^2.

$$1\,\text{N} = 1\,\text{kg} \times 1\,\text{m/s}^2 = 1\,\text{kg·m/s}^2$$

Applications of Newton's Second Law of Motion

Newton's Second Law helps us understand how force, mass, and acceleration are related. This law is used in many real-life situations.

1. **Pushing a Vehicle:**
   A small car accelerates more than a heavy truck when the same force is applied. To move a heavier vehicle, we need to apply more force.
2. **Kicking a Ball:**
   A football moves faster than a cricket ball when kicked with the same force because the football has less mass.
3. **Rocket Launch:**
   Rockets push gases downwards at high speed. By Newton's Second Law, this creates a large acceleration upwards, helping the rocket lift off.
4. **Car Crash and Airbags:**
   Airbags increase the time during which the passenger comes to a stop. This reduces acceleration and, therefore, reduces the force on the body.
5. **Helmets and Safety Gears:**
   Helmets reduce the force of impact by increasing the time taken to stop and spreading the force over a larger area, reducing injury.
6. **Catching a Cricket Ball:**
   When a fast-moving cricket ball is caught, its momentum reduces to zero. This means a force must be applied to stop the ball.

Case 1: Stopping suddenly
If the ball is stopped suddenly (in a short time), the time t is small. According to Newton's Second Law:

$$F = \frac{mv - mu}{t}$$

So when t is small, the force F is large. This can hurt your hands.

Case 2: Pulling hands backward
If you move your hands backward while catching, you increase the time t taken to stop the ball. This reduces the force:

$$F \propto \frac{1}{t}$$

As time increases, force decreases. This makes the catch softer and prevents injury.

Conclusion: Pulling hands backward while catching a ball increases the time of contact and reduces the force on your hands. This is a direct application of Newton's Second Law.

Newton's Third Law of Motion

Newton's Third Law of Motion states:
"For every action, there is an equal and opposite reaction."

$$\boxed{F_{12} = -F_{21}}$$

Here, F_{12} is the force exerted by object 1 on object 2, and F_{21} is the force exerted by object 2 on object 1.

Examples and Explanations

1. **Pushing Against a Wall**
   When you push on a wall with your hand, you exert a force on the wall (action). Even though the wall does not move, it exerts an equal and opposite force back on your hand (reaction). This reaction force is what you feel as resistance. If the wall did not push back, your hand would go through it.

2. **Swimming**
   A swimmer pushes water backward using her hands and feet (action). In response, the water pushes the swimmer forward with an equal and opposite force (reaction). This reaction force propels the swimmer through the water.

SOUND

Introduction

Sound plays a vital role in our daily lives, allowing us to communicate and interact with the world around us. **It is a form of energy that produces a sensation of hearing in our ears**. Whenever we hear music, voices, or environmental noises, we are experiencing the effects of sound waves traveling through different media.

What is Sound?

Sound is a type of energy produced due to the vibration of objects. These vibrations create disturbances in a material medium (such as air, water, or solids), which then travel in the form of waves. Our ears detect these waves, allowing us to hear different sounds.

Production of Sound

- Sound is generated when an object vibrates. For example, plucking a guitar string or striking a tabla causes its surface to vibrate, which produces sound.
- In humans, sound is produced when the vocal cords vibrate as air passes through them.
- Vibrations from sources such as tuning forks, drums, and flutes all lead to the generation of sound energy.

Propagation of Sound

- Sound requires a material medium (solid, liquid, or gas) for its propagation.
- Sound cannot travel through a vacuum because there are no particles to transfer the vibrations.
- Sound travels fastest in solids, followed by liquids, and slowest in gases.

Nature of Sound Waves

- Sound travels as waves in the medium. These are referred to as **mechanical waves** since they need a medium.
- The waves travel by the vibration of particles, causing alternate compressions and rarefactions in the medium.
- Such waves, in which the particles of the medium vibrate along the direction of propagation, are called **longitudinal waves**.

Key Points

- Sound is a form of energy produced by vibrating objects.
- A medium is required for sound to travel.
- Sound travels fastest in solids, slower in liquids, and slowest in gases.
- The sensation of hearing is a result of the energy carried by sound waves.

In this chapter, we will explore how sound is produced, how it travels, its characteristics (like pitch, loudness, and quality), and some of its practical applications in daily life.

Production of Sound

Sound is produced when an object vibrates. The vibrations set the surrounding medium (usually air) into motion and this alternation of compressions and rarefactions is detected by our ears as sound.

What Produces Sound?

Whenever an object moves to-and-fro (vibrates), it disturbs particles in the surrounding medium. These disturbances travel as waves, and on reaching our ears, are interpreted as sound.

- When a tuning fork is struck and placed near the ear, the prongs vibrate rapidly and produce sound.
- Plucking a stretched rubber band or a guitar string causes it to vibrate, resulting in the production of sound.
- Striking the membrane of a drum or tabla makes the membrane vibrate, producing sound waves.
- Vocal cords in humans generate sound by vibrating when air is pushed through the larynx.

Common Methods of Producing Sound

1. **By vibrating strings** (e.g., Sitar, Guitar, Violin)
2. **By vibrating air columns** (e.g., Flute, Trumpet, Shehnai)
3. **By vibrating membranes** (e.g., Drum, Tabla, Dholak)
4. **By vibrating plates or bells** (e.g., Metal bell, Bicycle bell)

Demonstration Activities

- Fix a plastic ruler to the edge of a table, bend and release it. The vibrating ruler produces sound.
- Strike a tuning fork and touch it to a small suspended pith ball; the ball jumps due to vibrations.
- Place your finger lightly on your throat and speak; you will feel vibrations in the vocal cords.
- There are two more activities given in the NCERT textbook - Class 9. The student is encouraged to go through those activities as well.

Key Points

- Sound is always produced by vibrations of objects.
- Energy needed for vibration may come from hand movement, wind, friction, or electrical impulses.
- The production of sound ceases when the vibrations stop.

Vibration and Oscillation

Both **vibration** and **oscillation** refer to repetitive back-and-forth or to-and-fro motion around a central position called the **equilibrium position or mean position.**

Definition of Oscillation

Oscillation is the periodic motion of an object moving repeatedly between two points or states around a central equilibrium position. The motion has a definite time period and frequency.

Definition of Vibration

Vibration is a specific type of oscillation characterized by rapid to-and-fro motion of an object or particles about an equilibrium position. Vibration usually involves higher frequency oscillations.

Key Differences

Aspect	Oscillation	Vibration
Definition	Repetitive back-and-forth motion around a central equilibrium position.	Rapid to-and-fro motion around an equilibrium point, often with higher frequency.
Frequency	Usually low frequency.	Usually high frequency.
Nature	Broad concept covering various periodic motions.	A type of oscillation with rapid motion, mostly in mechanical systems.
Examples	Pendulum swinging, tides, a swing moving back and forth.	Vibrating guitar string, tuning fork, mobile phone vibration.
Appearance	Smooth and slower motion.	Rapid trembling or shaking motion.
Scope	Can be physical or non-physical phenomena (including biological systems).	Primarily mechanical objects or particles vibrating.

Summary

- Oscillation usually refers to slower, periodic motion back and forth.
- Vibration refers to faster, often smaller, mechanical oscillations.
- Both involve repeated movement about a central or mean position.
- All vibrations are oscillations, but not all oscillations are vibrations. The difference mainly depends on the frequency and the system involved.

Propagation of Sound

Sound is produced by vibrating objects, which create disturbances in the surrounding medium. These disturbances travel as waves through the medium by alternatively compressing and expanding the particles, forming regions of **compression** and **rarefaction**.

How Sound Travels

When an object vibrates, it pushes nearby particles of the medium, causing them to move from their mean positions. These particles collide with adjacent particles, passing on the vibration energy. This chain reaction causes the sound to propagate through the medium without the particles themselves moving far from their equilibrium positions.

Why Sound Needs a Medium

Sound needs a material medium (solid, liquid, or gas) to travel because it is a mechanical wave. Mechanical waves require particles to transmit vibrations. In a vacuum, where there are no particles, sound cannot travel.

Speed of Sound in Different Media

The speed of sound depends on:

- **Elasticity:** How quickly particles return to their original position after being disturbed.
- **Density:** How closely packed the particles are.

Sound travels fastest in solids because their particles are tightly packed and can transmit vibrations quickly. It travels slower in liquids and slowest in gases where particles are farther apart.

Medium	Relative Particle Distance	Speed of Sound
Solids	Very close	Fastest (e.g., 5000 m/s in steel)
Liquids	Closer than gases	Moderate (e.g., 1480 m/s in water)
Gases	Far apart	Slowest (e.g., 340 m/s in air)

Table 2: Variation of Speed of Sound in Different Media

Additional Points

- The particles of the medium vibrate about fixed positions; they do not travel with the sound.
- Sound waves in the air are longitudinal waves consisting of compressions and rarefactions.
- Temperature and humidity can also affect the speed of sound in gases.

Compression and Rarefaction

When sound travels through a medium like air, it does so by creating regions where the particles are alternately pushed closer together and then pulled farther apart. These regions are called **compressions** and **rarefactions**.

Compression

Compression is the region in a sound wave where particles of the medium are pressed close together. This results in an increase in pressure and density in that region compared to the normal atmospheric pressure.

Rarefaction

Rarefaction is the region in a sound wave where particles are spread farther apart than normal. This leads to a decrease in pressure and density in that region.

How Compression and Rarefaction Occur

- When an object vibrates, it pushes nearby air particles forward, creating a compression.
- These particles then move back, creating a region of rarefaction.
- This process repeats, producing alternating compressions and rarefactions that move through the medium as longitudinal sound waves.

Properties

- Compressions correspond to regions of high pressure and density.
- Rarefactions correspond to regions of low pressure and density.
- The distance between two consecutive compressions or rarefactions is the wavelength (λ) of the sound wave.
- This pattern of compressions and rarefactions allows sound to propagate through solids, liquids, and gases.

What is a Medium?

In physics, a **medium** is a substance or material through which waves travel. It acts as a carrier for the transmission of energy from one place to another.

Definition of Medium

A medium is any material (solid, liquid, or gas) that allows mechanical waves, such as sound waves, to propagate by vibrating its particles.

Key Points

- Sound, being a mechanical wave, requires a medium to travel because it needs particles to carry vibrations.
- Different media affect the speed and quality of wave propagation.
- Examples of media include air (for sound waves), water (for water waves), and solids like steel (for seismic waves).
- Waves such as light can travel through a vacuum and do not necessarily require a medium.

  The medium is not the wave itself; it is just the material through which the wave travels from one point to another.

Longitudinal Waves

Definition: A longitudinal wave is a wave in which the particles of the medium vibrate back and forth in the same direction as the wave travels. The particle displacement is parallel to the direction of wave propagation.

Key Characteristics of Longitudinal Waves

- The particles of the medium move to and fro along the direction of wave propagation.
- The wave consists of alternating regions of **compression** (particles close together) and **rarefaction** (particles spread apart).
- The distance between two consecutive compressions or rarefactions is called the **wavelength** (λ).
- Longitudinal waves can travel through solids, liquids, and gases.

Examples of Longitudinal Waves

- Sound waves traveling through air or other media.
- Primary (P) waves produced during earthquakes.
- Vibrations in a stretched spring or slinky when pushed and pulled.

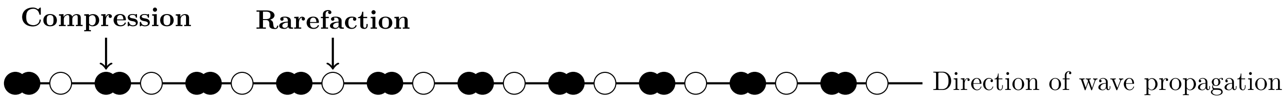


Figure 2: Longitudinal Wave Showing Compressions and Rarefactions

Difference between Longitudinal and Transverse Waves

Longitudinal Waves	**Transverse Waves**
Particles of the medium vibrate parallel to the direction of wave propagation.	Particles of the medium vibrate perpendicular to the direction of wave propagation.
Consist of compressions (high pressure) and rarefactions (low pressure).	Consist of crests (high point) and troughs (low point).
Can travel through solids, liquids, and gases.	Usually travel through solids and the surface of liquids.
Cannot be polarized.	Can be polarized.
Particles move back and forth along the wave's direction.	Particles move up and down or side to side, perpendicular to the wave's direction.
Examples include sound waves and primary (P) waves in earthquakes.	Examples include light waves, water waves, and secondary (S) waves in earthquakes.
Energy transfer is in the same direction as particle movement.	Energy transfer is perpendicular to particle movement.

Frequency

Definition: Frequency is the number of complete waves or vibrations produced in one second. It tells us how often a repeating event, such as a wave cycle, occurs in a given time period.

What is Frequency?

Frequency (denoted by f) is the number of complete oscillations or cycles of a wave passing through a point per second. ν (nu) represents how many oscillations or cycles occur per second in a wave.

Units of Frequency

- The SI unit of frequency is the **Hertz (Hz)**.
- 1 Hertz means one cycle per second.
- Other units include kilohertz (kHz), megahertz (MHz), and gigahertz (GHz) for larger values. For example, 1 kHz = 1000 Hz.

Frequency is the reciprocal of the time period T (time taken for one complete cycle):

$$\boxed{f(or)\nu = \frac{1}{T}}$$

Example

If a pendulum completes 40 oscillations in 20 seconds, its frequency is:

$$f = \frac{40}{20} = 2 \text{ Hz}$$

This means the pendulum completes 2 oscillations every second.

Frequency is a fundamental property of waves that helps us understand and describe their behavior.

Relation between Pitch and Frequency

Pitch is the quality of a sound that allows us to classify it as *high* or *low*. It is a subjective perception determined mainly by the frequency of the sound wave.

Pitch and Frequency Relationship

Pitch is directly proportional to frequency. This means:

- Higher the frequency, higher is the pitch (sound appears shrill).
- Lower the frequency, lower is the pitch (sound appears deep or faint).

For example:

- A whistle producing sound at around 1000 Hz has a high pitch.
- A drum producing sound at around 100 Hz has a low pitch.

Guitar Example: Pitch and Frequency

When you pluck a guitar string, it vibrates at a certain frequency, producing a sound of a specific pitch.

- **Thicker strings** vibrate more slowly with lower frequencies, producing lower-pitched sounds or bass notes.
- **Thinner strings** vibrate faster with higher frequencies, producing higher-pitched sounds or treble notes.

For example:

- The thickest string on a standard guitar (low E) vibrates at about 82 Hz, producing a low pitch.
- The thinnest string (high E) vibrates at about 330 Hz, producing a much higher pitch.

So, changing string thickness or tightening the string increases its vibration frequency, resulting in a higher pitch sound — exactly what you experience when tuning your guitar.

> *Guitar strings are a perfect real-life illustration of how frequency affects pitch. Faster vibrations mean higher notes, slower vibrations mean lower notes.*

Pitch is how our brain interprets the frequency of sound waves as high or low tones, making frequency a physical quantity and pitch a perceptual quality.

Knowing the wavelength is essential for understanding wave properties like frequency and speed, because they are all related by the formula:

$$v = f \times \lambda$$

where v is the wave speed, f is frequency, and λ is wavelength.

Wavelength and Its Unit

Wavelength (λ) is the distance between two consecutive points that are in phase on a wave, such as from one crest to the next crest or one trough to the next trough.

Wavelength Definition and Unit

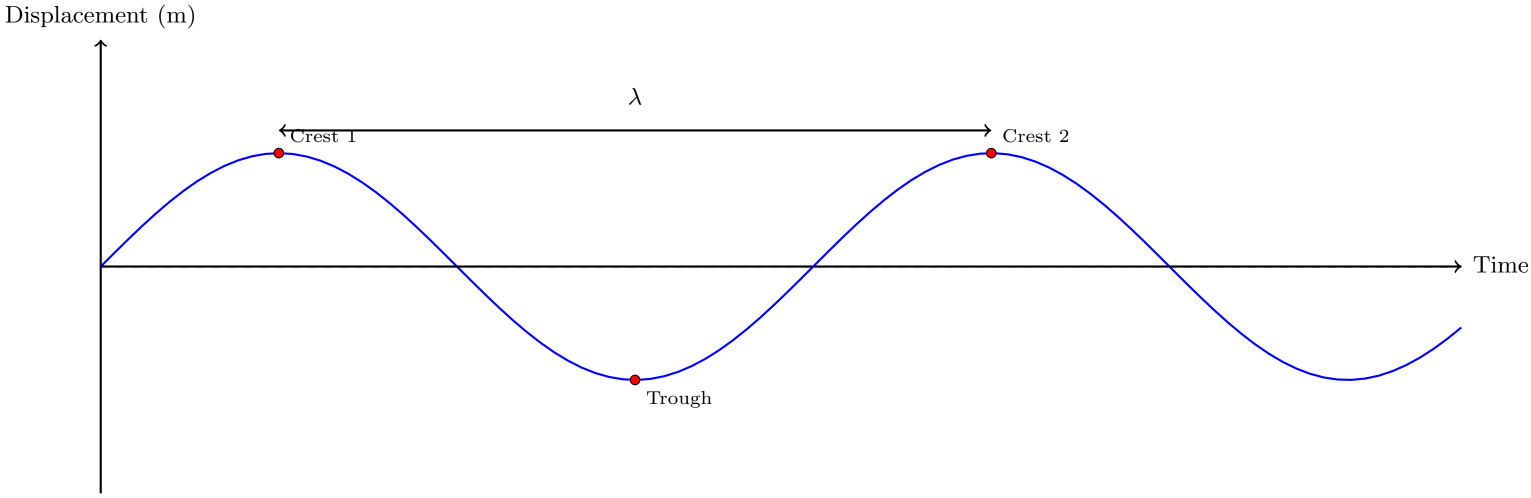
Wavelength is the length of one complete wave cycle. It is measured as the distance over which the wave's shape repeats.
The SI unit of wavelength is the **meter (m)** because wavelength is a measure of distance. Other units such as **centimeters (cm)**, **millimeters (mm)**, **nanometers (nm)**, and **angstroms (Å)** are also used depending on the type and scale of the wave.

Crests and Troughs

- **Crest:** The highest point on a wave, above the equilibrium position.
- **Trough:** The lowest point on a wave, below the equilibrium position.

Examples of Wavelength Units

- Sound waves in air: wavelength in meters (m).
- Visible light: wavelength in nanometers (nm), e.g. 400–700 nm.
- X-rays and atomic scales: wavelength in angstroms (Å), where 1 Å $= 10^{-10}$ m.



Amplitude of a Wave

Amplitude is the maximum displacement or distance of a vibrating particle from its **mean (rest) position**. It shows how far the particle moves away from the central position during vibration.

In a wave, amplitude represents the height of the **crest (peak)** or the depth of the **trough (lowest point)** from the mean position. It is a measure of the strength or intensity of the wave.

How is Amplitude Measured?
Amplitude is measured as the distance between the mean position of the vibrating particle and its maximum displacement (either the crest or trough). The unit of amplitude is the same as the unit of displacement, usually meters (m) or centimeters (cm).

In Sound Waves:
The amplitude of sound waves determines their **loudness**. Higher amplitude means louder sound, and lower amplitude means softer sound.

Loudness and Amplitude of Sound

The loudness or softness of a sound is mainly determined by the **amplitude** of the sound wave.

- The amplitude of a sound wave depends on the **force** with which an object is made to vibrate.
- For example, if we strike a table lightly, it vibrates with less force, producing a sound wave with small amplitude, leading to a soft sound.
- If we hit the table hard, it vibrates with greater force, producing a sound wave with larger amplitude, resulting in a louder sound.

When a sound wave travels away from its source, its amplitude and loudness decrease because the wave spreads out and loses energy.

- As sound travels farther from the source, the particles of the medium vibrate with smaller displacement, so the amplitude reduces.
- This causes the sound to become softer or less loud.
- Louder sounds with greater amplitude can travel larger distances because they carry more energy.

Summary:

- Larger amplitude $\Rightarrow$ More forceful vibration $\Rightarrow$ Louder sound.
- Smaller amplitude $\Rightarrow$ Less forceful vibration $\Rightarrow$ Softer sound.
- Amplitude decreases with distance, making the sound softer as it moves away from the source.

Speed of Sound

The speed of sound is defined as the distance traveled by a point on a sound wave, such as a compression or rarefaction, per unit time.

We know that speed (v) is given by:

$$v = \frac{\text{distance}}{\text{time}}$$

In the case of a sound wave, the distance traveled in one time period (T) is equal to the **wavelength** (λ) of the sound wave.

Thus,

$$v = \frac{\lambda}{T}$$

Since the frequency (ν) of a wave is the number of waves produced per second, it is the reciprocal of the time period:

$$\nu = \frac{1}{T}$$

Substituting this in the above equation, we get

$$v = \lambda \times \nu$$

This means

$$\boxed{\text{Speed of sound} = \text{Wavelength} \times \text{Frequency}}$$

The speed of sound remains almost constant for all frequencies in a given medium under the same physical conditions such as temperature and pressure.

Key Points:

- λ (wavelength) is the distance between two consecutive compressions or rarefactions in a sound wave.
- ν (frequency) is the number of sound waves produced in one second.
- v (speed) is how fast the sound waves travel through the medium.

Speed of Sound in Different Media

The **speed of sound** is the rate at which a sound wave travels through a medium. This speed depends on the type of material the sound wave moves through.

- Sound travels **fastest in solids**, slower in liquids, and slowest in gases.
- In solids, particles are packed very closely, so vibrations pass quickly from one particle to another.
- In gases, particles are far apart, so vibrations take longer to move from one particle to the next.

Typical values at room temperature:

Medium	**Speed of Sound (m/s)**
Air	343
Water	1482
Iron	5120

- Sound cannot travel in a vacuum because there are no particles to carry the vibrations.
- Temperature and humidity can slightly affect the speed of sound, especially in gases.

Summary: Sound travels fastest in solids, slower in liquids, and slowest in gases. The arrangement and closeness of particles in each medium affect the speed.

Reflection of Sound

Reflection of sound is the bouncing back of sound waves when they hit a solid or hard surface. Just like light reflects off a mirror, sound can reflect off walls, buildings, and other obstacles.

How does reflection of sound happen?

- When a sound wave strikes a hard surface, it cannot pass through easily and so bounces back into the original medium.
- The angle at which the sound hits the surface (angle of incidence) equals the angle at which it bounces off (angle of reflection), similar to the law of reflection for light (to be learnt in class 10^{th}).
- The reflected sound can sometimes be heard as a distinct repetition, called an echo.

Examples of Reflection of Sound:

- **Echo:** When you shout near a tall building or a mountain, the sound waves reflect back to you after a short time, and you hear your own voice again as an echo.
- **Speaking in a Big Hall:** In an empty hall, your voice often sounds louder and might seem to come back to you because the sound waves are reflecting off the walls.
- **Sonar:** Ships and submarines use the reflection of underwater sound waves (sonar) to detect objects or measure the depth of the sea.
- **Stethoscope:** In medical instruments like the stethoscope, sound from the body is reflected through the tubes so it can be heard more clearly by the doctor.

Summary: Reflection of sound lets us hear echoes and is used in many devices like sonar and stethoscopes. It occurs when sound waves hit hard surfaces and bounce back into the original medium.

Echo

Echo is the repetition of sound caused when sound waves reflect off a distant large and hard surface, such as a tall building or a mountain, and return to the listener after a short delay.

How does an echo occur?

- When you shout or clap near a suitable reflecting surface, the sound waves travel to the obstacle and reflect back to your ears.
- Your brain can distinguish the original sound from its echo only if the time gap between them is at least 0.1 seconds (the persistence of hearing).

Minimum Distance for Echo:

- The sound must travel to the reflector and back, covering a total minimum distance of (speed of sound) $\times$ (0.1 s).
- At 22°C, the speed of sound in air is about 344 m/s.
- Required total distance: $344\ \text{m/s} \times 0.1\ \text{s} = 34.4\ \text{m}$.

- So, the minimum distance of the reflector from the source should be $\frac{34.4 \text{ m}}{2} = 17.2$ m.
- This distance changes with the speed of sound, which depends on air temperature.

Other Facts:

- Echoes can occur more than once due to multiple reflections from various surfaces (rolling thunder is an example).
- Echoes help in measuring distances, e.g., bats use echoes for navigation and ships use echo-sounding techniques to measure ocean depths.

Example Problem:
A boy claps his hands near a cliff and hears the echo after 0.5 *seconds. If the speed of sound in air is* 340 *m/s, how far is the cliff from the boy?*
Solution:
Time to go to the cliff and back = 0.5 seconds.

$$\text{Total distance travelled} = \text{speed} \times \text{time} = 340 \text{ m/s} \times 0.5 \text{ s} = 170 \text{ m Distance to the cliff} \quad = \frac{170 \text{ m}}{2} = 85 \text{ m}$$

Thus, the cliff is 85 metres away from the boy.

Range of Hearing

The **range of hearing** describes the range of sound frequencies that humans can hear. This range is called the **audible range** and, for most people, it extends from about 20 Hz to 20,000 Hz (20 kHz).

- **Humans:** The normal audible range is 20 Hz to 20,000 Hz. With increasing age, people often lose the ability to hear higher frequencies.
- **Children and some animals:** Young children (under age 5) and animals like dogs can hear up to 25,000 Hz (25 kHz).

Infrasonic Sound (Infrasound):

- Frequencies **below** 20 **Hz**.
- Humans cannot hear infrasound, but some animals (such as rhinoceroses, elephants, and whales) use it to communicate.
- Examples: Vibrations of a pendulum and the low-frequency sounds produced by earthquakes are infrasound.
- Some animals can detect earthquakes early because they sense these infrasound waves.

Ultrasonic Sound (Ultrasound):

- Frequencies **above** 20,000 **Hz (20 kHz)**.
- Humans cannot hear ultrasound, but animals like bats, dolphins, and porpoises produce and detect such high-frequency sounds.
- Some moths can also detect ultrasonic sounds, which helps them escape from bats.

Summary Table:

Type of Sound	Frequency Range	Who can detect
Infrasonic	Below 20 Hz	Some animals (not humans)
Audible	20 Hz to $20,000$ Hz	Most humans
Ultrasonic	Above $20,000$ Hz	Some animals (not humans)

Key Point: Sounds too low (infrasonic) or too high (ultrasonic) for humans can still be used and detected by animals.

Applications of Ultrasound

Ultrasound refers to sound waves with frequencies higher than 20,000 Hz, which cannot be heard by humans. Ultrasound has many useful applications because these waves can travel through different materials and provide detailed information.

1. **Medical Imaging (Ultrasonography):**
   - Ultrasound is used in hospitals to create images of internal organs.
   - A probe sends ultrasound waves into the body, and the echoes are used to form pictures of organs or a baby during pregnancy.
   - It is safe and does not use harmful radiation.
2. **Cleaning Delicate Objects:**
   - Ultrasound is used to clean items like jewellery, watches, and dental tools.
   - The waves shake off dirt from tiny and hidden places without damaging the objects.
3. **Detecting Cracks and Flaws in Metals:**
   - Ultrasound checks metal parts (such as railway tracks or pipes) for hidden cracks.
   - Waves sent into the metal reflect back from flaws, revealing any damage inside.
4. **Measuring Distance and Depth (SONAR):**
   - Ships and submarines use ultrasound in SONAR to measure water depth and find objects underwater.
   - An ultrasound pulse is sent through water; the time taken for its echo to return tells the distance.
5. **Industrial Uses:**
   - Ultrasound improves manufacturing by mixing chemicals efficiently and removing air bubbles from products.

Summary: Ultrasound is useful in medicine, cleaning, safety checks, measuring distances, and industry because it can travel through various materials and reflect off surfaces.

Important Formulas

Formula	Description	Variables
$v = \dfrac{\lambda}{T}$	Speed = wavelength / time period	v = speed (m/s), λ = wavelength (m), T = time period (s)
$v = \lambda\nu$	Speed = wavelength × frequency	v = speed (m/s), λ = wavelength (m), ν = frequency (Hz)
$f = \dfrac{1}{T}$	Frequency as reciprocal of time period	ν = frequency (Hz), T = time period (s)
Amplitude (A)	Maximum displacement from rest position	A = amplitude (m or cm)

Introduction to Work, Power and Energy

In our daily life, we often say that we are "**doing a lot of work**" when we **study for exams**, **play a sport** or **help at home**. In **science**, however, the word **work** has a **special and precise meaning**. In this chapter, you will learn how **physicists** define **work**, **energy** and **power**, and how these ideas help us understand **moving objects**, **machines** and even our own **bodies**.

Whenever a **force** makes an object **move**, there is a **transfer of energy**. When you **lift** your school bag, **kick** a football, or **ride** a bicycle, you are doing **work** in the scientific sense. The **energy stored** in your body (from the food you eat) or in fuels (like petrol) gets converted into **mechanical energy** that produces motion and other effects such as **sound**, **heat** and **light**.

In this chapter, you will learn:

- The **scientific definition of work** and the **conditions** under which work is said to be done.
- How to **calculate work done** by a constant force using a simple **formula**, and understand **positive**, **negative** and **zero** work with examples.
- What is **energy**, why it is called the **capacity to do work**, and the **different forms of energy** (such as **kinetic** and **potential** energy).
- How to calculate the **kinetic energy** of a moving object and the **potential energy** of an object at a height, along with their **SI units**.
- The very important **law of conservation of energy** and simple situations where **one form of energy changes into another**.
- What is **power**, how it is related to **work** and **time**, and how to compare which machine or person is **more powerful**.
- How to use the practical unit **kilowatt-hour (kWh)** and understand the idea of **electric energy consumption** in homes.

Why is this chapter important?

- It explains how **machines** like **cranes**, **elevators**, **cars** and **bicycles** help us do work more **easily and quickly**.
- It helps you understand how **energy from food**, **fuels**, **waterfalls**, **wind** and **sunlight** is converted into useful **mechanical**, **electrical** and **heat** energy in daily life.
- It builds a base for higher classes, where you will study **work–energy theorem**, **more complex energy transformations** and **efficiency of machines** in detail.

Key ideas to keep in mind from the start:

- **Work**, **energy** and **power** are **related concepts** that help us measure and compare physical processes.
- **Energy can neither be created nor destroyed, it can only be transformed from one form to another** (**law of conservation of energy**).
- Every activity around you — from a **falling stone** to a **moving fan** — can be explained using the ideas of **work**, **energy** and **power**.

By the end of this chapter, you should be able to **define** these terms clearly, **use the formulas confidently**, and **solve numerical problems** based on **real-life situations** involving work, energy and power.

1 Work

In day-to-day life, we often use the word **work** for any activity that needs **effort** or makes us **feel tired**. We say that we are "working hard" when we prepare for exams, play for a long time, or help with household chores. In **science**, however, the term **work** has a **very specific meaning** and is not used for every kind of effort.

Consider the following situations:

- A student studies for hours, reads books, makes notes and solves problems.
- A person pushes hard against a heavy rock, but the rock does not move at all.
- A person stands still for a long time holding a heavy load on the head.
- You climb up a long staircase to reach the second floor just to enjoy the view.

In **everyday language**, we often say that the student and the person pushing the rock are doing a lot of **work** because they feel **tired** and are using a lot of **energy**. On the other hand, climbing stairs just for fun may not even be called "work" in common talk, even though you also get tired in doing it.

In **science**, whether **work is done or not** does *not* depend on how **tired** you feel, but on whether a **force** causes a **displacement** of an object in the direction of the force.

Now think again about the situations:

- While **studying**, your mind is active and you feel tired, but there is **no physical displacement of an object** by a force that you apply. So, in the **scientific sense**, **no work is done** on any external object.
- When you push a **huge rock** and it does **not move**, you may get completely exhausted. But since the rock has **no displacement**, the work done on the rock is **zero** according to physics.
- When you **stand still** with a heavy load on your head, your muscles are under strain and you get tired. However, the load is **not moving**, so the **displacement is zero**. Hence, **no work is done** on the load in the scientific sense.
- When you **climb up stairs** or a **tall tree**, your body is raised to a greater **height**. There is a clear **displacement** of your body in the direction of the force you apply on the steps. So, in physics, you are doing **work against gravity**, even if you are just doing it for fun.

Everyday work vs scientific work

- **Studying for exams**: Everyday language **work**, but **no scientific work** (no displacement caused by your force on an object).
- **Pushing a wall / rock that does not move**: Feels like work, but **no scientific work** is done on the wall or rock.
- **Carrying a load and walking on a level road**: In everyday life, this is work, but in physics, **no work is done on the load** because the force on the load (upward) is perpendicular to the horizontal displacement.
- **Lifting a bag or climbing stairs**: Both everyday and scientific sense agree that **work is done**, because a force causes displacement in its own direction.

1.1 Scientific Conception of Work

In science, we say that **work is done** only when a **force** acting on an object **produces a displacement** of that object. It is not enough to just push, pull or feel tired; the object must actually **move** because of the force.

Let us look at some simple situations:

- **Pushing a pebble:** A small pebble is lying on a table or floor. You push it gently with your finger. The pebble **starts moving** and shifts from its original position. Here, you applied a **force** on the pebble and the pebble **got displaced**. So, according to science, **work is done** on the pebble.
- **Pulling a trolley:** A girl pulls a small trolley or suitcase using a handle. As she pulls, the trolley **moves forward** across the floor. She applies a **force** on the trolley and the trolley **moves through a distance**. Therefore, **work is done** on the trolley.
- **Lifting a book:** You pick up a book from the floor and lift it to your desk or to a shelf. To do this, you must apply an **upward force** on the book. The book **rises** to a greater height. In this case, there is a **force** on the book and the book has **moved upward**. Hence, **work is done** on the book.

From these examples, we can extract the essential rule used in science.

Essential conditions for work (scientific view):

- A **force** must act on the object.
- The object must be **displaced** (it should move from its position).

If **any one** of these conditions is missing, then **no work is said to be done** on the object in the scientific sense.

Is work done when a bullock pulls a cart?
A bullock is pulling a cart along a road. The cart **moves forward**. The bullock exerts a **pulling force** on the cart through the yoke and rope. The cart **covers some distance** in the direction of this pull. Here:

- There is a **force** acting on the cart (due to the bullock), and
- There is a **displacement** of the cart in the direction of the force.

So, according to the scientific definition, **work is being done** on the cart by the bullock.

Thus, the **scientific conception of work** is very clear and strict: **force** alone is not enough, and **displacement** alone is not enough. **Both** must be present together for us to say that work is done in physics.

1.2 Work Done by a Constant Force

To **define work in science**, we first consider a simple situation where a **constant force** acts on an object and the object is **displaced in the same direction** as the force.

Suppose a constant force F acts on an object lying on a smooth surface. The object **starts moving** and is **displaced** through a distance s **in the direction of the force**. In this situation:

- the force on the object has a **fixed magnitude** and direction (it is **constant**),
- the object moves through a distance s **along the same straight line** as the force.

Let the **work done** by the force on the object be W. In physics, for this simple case, we **define** work as the **product of the force and the displacement** in the direction of the force.

Definition (Constant force along displacement)
If a constant force F acts on an object and produces a displacement s **in the direction of the force**, then the **work done** W by the force is:

$$W = F \times s$$

- W: work done by the force
- F: magnitude of the constant force
- s: displacement of the object in the direction of the force

Example: A constant horizontal force of $10\,\mathrm{N}$ acts on a box and moves it $3\,\mathrm{m}$ along a straight, horizontal floor in the same direction as the force.
Here, $F = 10\,\mathrm{N}$ and $s = 3\,\mathrm{m}$.

$$W = F \times s = 10 \times 3 = 30$$

So, the work done on the box by the force is 30 **units of work**. (In the next subsection, you will learn that the SI unit of work is the **joule**.)

Thus, whenever a **constant force** causes an object to move in **the same direction**, the work done is simply the **product of the force and the displacement**.

Thus, the **work done** by a force acting on an object is equal to the **magnitude of the force** multiplied by the **distance moved in the direction of the force**. In this simple case, **work has only magnitude and no direction**, so it is treated as a **scalar quantity**.

Using the formula

$$W = F \times s,$$

if we take $F = 1\,\mathrm{N}$ and $s = 1\,\mathrm{m}$, then the work done by the force is:

$$W = 1\,\mathrm{N} \times 1\,\mathrm{m} = 1\,\mathrm{N\ m}.$$

SI unit of work
The SI unit of work is the **newton metre** (N m), which is also called the **joule** (J).

$$1\,\mathrm{J} = 1\,\mathrm{N} \times 1\,\mathrm{m}$$

Definition of 1 joule:
One joule is the amount of work done on an object when a force of $1\,N$ displaces it by $1\,m$ along the line of action of the force.

Recall that, in physics, **work is done** by a force only when **both** of the following conditions are satisfied:

- A **force** acts on the object.
- The object is **displaced in the direction of the force**.

If any one of these conditions is **not** satisfied, the **work done is zero**.

1.2.1 Case 1: Force is zero

If the **force on the object is zero**, then, from the formula

$$W = F \times s,$$

we get

$$W = 0 \times s = 0.$$

So, when **no force** acts on an object, the work done on the object is **zero**, even if the object is moving on its own. For example, if a ball is already rolling on a smooth, frictionless surface and you do not push or pull it, you are doing **no work** on the ball because you are not applying any force.

1.2.2 Case 2: Displacement is zero

If the **displacement of the object is zero**, that is, the object **does not move** from its position, then

$$W = F \times 0 = 0.$$

This means that even if you apply a **large force**, the work done will still be **zero** if the object does not move. For example:

- Pushing a rigid wall with all your strength, but the wall does not move at all.
- Standing still for a long time with a heavy load on your head (the load remains at the same position).

In both these situations, you feel **tired** and use your **energy**, but the **displacement of the object is zero**, so, in the scientific sense, the **work done is zero**.

Zero work from the definition

$$W = F \times s$$

- If $F = 0 \Rightarrow W = 0$.
- If $s = 0 \Rightarrow W = 0$.

Therefore, whenever **either the force is zero** or the **displacement is zero**, the **work done is zero**, in agreement with the basic conditions for work.

1.2.3 Positive and Negative Work

The **sign** of work (positive or negative) depends on the **direction of force** compared to the **direction of displacement**.

- If force and displacement are in the **same direction**, work done is **positive**.
- If force and displacement are in **opposite directions**, work done is **negative**.

Consider an object moving with a **uniform velocity** along a straight line. Now a **retarding force** F (like friction or braking force) is applied in the **opposite direction** to its motion. The angle between the direction of motion and the direction of the force is 180°. Let the object **come to rest** after moving a further distance s.

In this situation:

- The **displacement** of the object is in the **forward** direction (direction of motion).
- The **retarding force** is in the **backward** direction, opposite to the displacement.

Since the force and displacement are in **opposite directions**, the work done by this retarding force is taken as **negative**. Numerically, we can show this as:

$$W = F \times (-s) = -F \times s.$$

Negative work

- When a force acts **opposite** to the direction of displacement, the work done by that force is **negative**.
- Negative work means the force is **removing energy** from the object (for example, slowing it down or stopping it).

Thus, the work done by a force can be **positive** (same direction), **negative** (opposite direction), or **zero** (no displacement or perpendicular).

Work Done for Different Values of θ

The work done by a constant force is given by

$$W = \vec{F} \cdot \vec{s} = Fs\cos\theta$$

where

- F = magnitude of the applied force
- s = displacement of the object
- θ = angle between the direction of force and displacement

The value of work depends on the value of θ. There are three important cases.

Case 1: $\theta = 0^\circ$ (Force and displacement in the same direction)

When the force acts in the **same direction as the displacement**, the angle between them is 0°.

$$W = Fs\cos 0^\circ$$

Since

$$\cos 0^\circ = 1$$

$$W = Fs$$

Therefore, the work done is maximum and positive.
Example: Pulling a cart forward with a rope.

Case 2: $\theta = 90°$ (Force perpendicular to displacement)

When the force acts **perpendicular to the displacement**, the angle between them is 90°.

$$W = Fs\cos 90°$$

Since

$$\cos 90° = 0$$

$$W = 0$$

Therefore, no work is done by the force.
Even though the force may act on the object, it does not contribute to displacement in that direction.
Example: The centripetal force acting on a body moving in a circular path.

Case 3: $\theta = 180°$ (Force opposite to displacement)

When the force acts in the **opposite direction to displacement**, the angle between them is 180°.

$$W = Fs\cos 180°$$

Since

$$\cos 180° = -1$$

$$W = -Fs$$

Therefore, the work done is negative.
Negative work means that the force opposes the motion of the object.
Example: Friction acting on a sliding block.

Summary:

Angle (θ)	Nature of Work	Example
0°	Positive Work	Pulling a cart
90°	Zero Work	Centripetal force
180°	Negative Work	Friction

2 Energy

Energy is the **capacity to do work**. Anything that can do work, or can cause changes like **moving objects**, **heating**, **lighting** or **producing sound**, is said to possess energy.

Life is impossible without energy. All living beings need a continuous supply of energy to **grow**, **move**, **breathe**, **think** and carry out all body activities. Machines and devices around us also need energy to run: fans, lights, mobile phones, cars, trains, computers and even satellites.

Why do we say the demand for energy is increasing?

- Population is increasing and more people need **electricity**, **transport** and **industry**.
- Our lifestyle uses more electrical and electronic devices than before (lights, ACs, gadgets, vehicles).

So, as our activities grow, the **demand for energy keeps rising**.

Where does all this energy come from? The **Sun** is the **biggest natural source of energy** for the Earth. Many of the energy sources we use are actually **derived from the Sun**:

- **Solar energy** directly in the form of sunlight.
- **Wind energy**, because winds are caused by unequal heating of the Earth's surface by the Sun.
- **Hydroelectric energy**, because the Sun drives the **water cycle**, lifting water that later falls as rain and fills rivers and dams.
- **Biomass and fossil fuels**, because plants trap solar energy by photosynthesis, and fossil fuels are ancient, stored forms of this energy.

Apart from the Sun, energy can also come from:

- **Nuclei of atoms** (**nuclear energy** from nuclear fission/fusion),
- The **interior of the Earth** (**geothermal energy**),
- The **oceans** (**tidal** and **wave** energy).

All these are different **sources of energy** that humans try to use for various purposes.

In this chapter, you will mainly study **mechanical energy** (like **kinetic energy** and **potential energy**) and how energy is **converted** from one form to another while doing **work**.

2.1 Meaning of Energy

The word **energy** is used very often in our daily life, but in science it has a **definite and precise meaning**. An object is said to possess **energy** if it has the **capacity to do work**.

Consider these situations:

- A **fast moving cricket ball** hits a **stationary wicket** and makes the wicket fall or move away. The moving ball had the **ability to do work** on the wicket and change its state. So, the fast moving ball **possessed energy**.
- When an object is **raised to a certain height**, it can do work while coming down. For example, a **raised hammer** can drive a nail into wood when it falls. The raised hammer has gained the **capability to do work** because of its **position** (height).

- When children **wind a toy car** using a key and then place it on the floor, the car starts moving on its own. By winding, energy gets stored in the **spring or mechanism** inside the toy, which later makes the toy move. Thus, the wound-up toy **possesses energy**.
- When a **balloon** is filled with air and **gently pressed**, its shape changes but it comes back to its original shape when the force is removed. If the balloon is **pressed very hard**, it may burst with a **loud sound**. In this case, the compressed air and stretched rubber had enough **stored energy** to do work and produce the bursting effect.

In all these examples, the objects acquire, through different means (like **motion**, **height**, **winding**, **compression** or **stretching**), the **capability of doing work**. This capability is what we call **energy**.

Definition of energy

*An object having a capability to do work is said to possess **energy**.*

Energy and transfer of energy

- The object which **does the work** (for example, the moving ball or the falling hammer) **loses energy**.
- The object on which the work is **done** (for example, the wicket or the nail) **gains energy**.

Thus, whenever work is done, **energy is transferred** from one object to another.

Therefore, **energy and work are closely related**: energy is the **capacity to do work**, and when work is done, energy is **used up** by one object and **gained** by another.

2.2 How Does an Object with Energy Do Work?

An object that **possesses energy** can **exert a force** on another object. When this happens, **energy is transferred** from the first object to the second, and the second object may start moving or changing its state. In this way, the object with energy can **do work**.

For example, a **moving ball** (which has energy) can hit another ball at rest and make it move. A **compressed spring** can push a block and set it in motion. In each case:

- The first object (ball or spring) **exerts a force** on the second object.
- The second object **gets displaced** and **work is done** on it.
- Energy is **transferred** from the first object to the second.

This shows that the first object had a **capacity to do work**, so it **possessed energy**.

Energy and its unit

- The **energy possessed by an object** is measured in terms of its **capacity of doing work**.
- Therefore, the **unit of energy** is the same as the unit of work, that is, the **joule (J)**.
- $1\,\text{J}$ is the **energy required** to do $1\,$joule of work.
- Sometimes a larger unit called the **kilo joule (kJ)** is used:

$$1\,\text{kJ} = 1000\,\text{J}.$$

Thus, any object that **possesses energy** can, in principle, **do work** by exerting a force and transferring energy to other objects.

3 Forms of Energy

The world around us provides energy in **many different forms**. In physics, we often group these forms of energy to understand how they are **stored**, **used** and **converted** from one form to another.

One important group is **mechanical energy**. Mechanical energy is the energy possessed by an object because of its **motion** and **position**. It is the sum of:

- **Kinetic energy** (energy due to motion),
- **Potential energy** (energy due to position or state).

So, mechanical energy = **kinetic energy + potential energy**.
Apart from mechanical energy, energy also appears in many other useful forms in nature and in technology:

- **Heat (thermal) energy**: Energy related to the **temperature** of a body; it is due to the motion of particles inside the object (for example, a hot cup of tea, a burning stove).
- **Chemical energy**: Energy stored in **chemical bonds** of substances (for example, food, fuels, batteries). It can be released during chemical reactions.
- **Electrical energy**: Energy associated with the **flow of electric charges** (current) in circuits; used in **fans, lights, motors, computers**, etc.
- **Light (radiant) energy**: Energy carried by **light and other electromagnetic waves**, such as sunlight, light from bulbs, lasers, etc.

Why many forms?
In real life, energy is **constantly changing** from one form to another. For example, in an electric bulb, **electrical energy** is converted into **light energy** and **heat energy**. In a car, **chemical energy** of fuel becomes **heat** and then **mechanical energy** of motion.

Thus, although energy has many forms, they are all just different ways in which nature **stores and transfers** the same physical quantity: **energy, the capacity to do work**.

3.1 How Do We Recognise a Form of Energy?

In science, we treat something as a **form of energy** if it can, **directly or indirectly**, be used to **do work** — that is, if it can exert a **force** and produce a **displacement**, or cause some observable **change**.

When you are not sure whether a certain "entity" (like light, heat, sound, electricity, etc.) is a form of energy, ask:

- Can it **make something move** or change its speed?
- Can it **lift** something or **change its position**?
- Can it **heat**, **light up**, **produce sound**, or **cause a chemical change**?

If the answer is "**yes**" to any of these, then it can **do work** in some way and is treated as a **form of energy**.

Discuss and test with examples

- **Light**: Can light cause changes? (e.g. make solar cells generate electricity, help plants make food, fade colours of cloth). If yes, it behaves as a **form of energy**.
- **Heat**: Can heat boil water, expand metals or drive steam engines? Then heat is a **form of energy**.
- **Electricity**: Can electric current run a fan or motor? Then electrical energy is clearly a **form of energy**.

You can discuss such examples with your **friends and teacher** and decide whether a given effect can be linked to the **ability to do work**.

In summary, whenever a physical quantity can **cause changes** or **do work** in some way, we recognise it as a **form of energy**.

4 Kinetic Energy

A **moving object can do work**. The energy that an object possesses because of its **motion** is called its **kinetic energy**.

Observe that:

- A **fast moving cricket ball** can knock down the stumps.
- **Blowing wind** can rotate the blades of a windmill.
- A **rotating wheel** can drive a machine.
- A **speeding stone** thrown from a catapult can break a glass pane.

All these moving objects are able to **do work** on other objects. This shows that they all **possess energy due to motion**, that is, **kinetic energy**.
Similarly, a **falling coconut**, a **speeding car**, a **rolling stone**, a **flying aircraft**, **flowing water**, **blowing wind** and a **running athlete** all have kinetic energy. In every case, the object is in **motion** and can **do work** (like hitting, pushing, turning or lifting something).

Definition of kinetic energy
Kinetic energy is the energy possessed by an object ***due to its motion****.*

The **faster** an object moves, the **more work** it can do in a given situation. For example, a fast car can cause more damage in a collision than a slow car of the same mass. This means that the **kinetic energy of an object increases with its speed**.

By definition in physics, the **kinetic energy** of a body moving with a certain velocity is taken to be **equal to the work done on it to make it acquire that velocity** (starting from rest).

In the next part of the chapter, this idea will be used to **derive a formula** for kinetic energy in terms of the **mass** of the body and the **square of its velocity**.

4.1 Derivation of the Formula for Kinetic Energy

We know that the **kinetic energy** of a body moving with a certain velocity is defined as the **work done on it** to make it acquire that velocity (starting from rest).

Consider a body of mass m initially at rest. A constant **unbalanced force** F acts on it and makes it move in a straight line. Let its velocity become v after it has moved through a displacement s.

- Initial velocity of the body $u = 0$ (starts from rest),
- Final velocity of the body v,
- Displacement of the body s,
- Constant acceleration produced a,
- Constant force applied F.

Step 1: Use the equation of motion

From the equation of motion,

$$v^2 = u^2 + 2as$$

Since $u = 0$, we get

$$v^2 = 2as \quad \Rightarrow \quad s = \frac{v^2}{2a}.$$

Step 2: Relate force and acceleration

From Newton's second law of motion,

$$F = ma.$$

The **work done** W by the force F in displacing the body through a distance s in the direction of the force is

$$W = F \times s.$$

Substitute $F = ma$ and $s = \dfrac{v^2}{2a}$:

$$W = ma \times \frac{v^2}{2a}.$$

The acceleration a cancels out:

$$W = m \times \frac{v^2}{2} = \frac{1}{2}mv^2.$$

Expression for kinetic energy

Since the work done on the body to bring it from rest to velocity v is equal to its **kinetic energy** K, we write

$$K = \frac{1}{2}mv^2.$$

Thus, the kinetic energy of a body of mass m moving with velocity v is

$$\boxed{K = \frac{1}{2}mv^2}.$$

Key points from the derivation

- Kinetic energy is **directly proportional** to the mass m.
- Kinetic energy is **proportional to the square of the velocity** v^2. If the speed becomes double, kinetic energy becomes **four times**.

(FROM EXAM P.O.V)

4.2 How Kinetic Energy Changes with Mass and Velocity

The kinetic energy of a body of mass m moving with velocity v is

$$K = \frac{1}{2}mv^2.$$

So, K is **directly proportional** to the mass m and to the **square of the velocity** v^2.

Let the **initial kinetic energy** be

$$K_0 = \frac{1}{2}mv^2.$$

(i) Velocity is halved

New velocity $v' = \frac{v}{2}$.

$$K' = \frac{1}{2}m\left(\frac{v}{2}\right)^2 = \frac{1}{2}m\frac{v^2}{4} = \frac{1}{4}\left(\frac{1}{2}mv^2\right) = \frac{1}{4}K_0.$$

When the velocity is **halved**, the kinetic energy becomes **one-fourth** of the original.

(ii) Mass is halved

New mass $m' = \frac{m}{2}$.

$$K' = \frac{1}{2}\left(\frac{m}{2}\right)v^2 = \frac{1}{4}mv^2 = \frac{1}{2}\left(\frac{1}{2}mv^2\right) = \frac{1}{2}K_0.$$

When the mass is **halved** (same velocity), the kinetic energy becomes **half** of the original.

(iii) Mass is doubled

New mass $m' = 2m$.

$$K' = \frac{1}{2}(2m)v^2 = mv^2 = 2\left(\frac{1}{2}mv^2\right) = 2K_0.$$

When the mass is **doubled** (same velocity), the kinetic energy becomes **twice** the original.

(iv) Velocity is doubled

New velocity $v' = 2v$.

$$K' = \frac{1}{2}m(2v)^2 = \frac{1}{2}m \cdot 4v^2 = 4\left(\frac{1}{2}mv^2\right) = 4K_0.$$

When the velocity is **doubled**, the kinetic energy becomes **four times** the original.

(v) Velocity is four times

New velocity $v' = 4v$.

$$K' = \frac{1}{2}m(4v)^2 = \frac{1}{2}m \cdot 16v^2 = 16\left(\frac{1}{2}mv^2\right) = 16K_0.$$

When the velocity is made **four times**, the kinetic energy becomes **16 times** the original.

(vi) Mass is $\frac{1}{4}$ of initial mass

New mass $m' = \dfrac{m}{4}$.

$$K' = \frac{1}{2}\left(\frac{m}{4}\right)v^2 = \frac{1}{8}mv^2 = \frac{1}{4}\left(\frac{1}{2}mv^2\right) = \frac{1}{4}K_0.$$

When the mass is $\frac{1}{4}$ of the initial mass (same velocity), the kinetic energy becomes **one-fourth** of the original.

(vii) Velocity is tripled

New velocity $v' = 3v$.

$$K' = \frac{1}{2}m(3v)^2 = \frac{1}{2}m \cdot 9v^2 = 9\left(\frac{1}{2}mv^2\right) = 9K_0.$$

When the velocity is **tripled**, the kinetic energy becomes **nine times** the original.

4.3 More Common Exam Cases on Kinetic Energy

Let the initial kinetic energy be

$$K_0 = \frac{1}{2}mv^2.$$

1. Mass doubled, velocity halved New mass $m' = 2m$, new velocity $v' = \dfrac{v}{2}$.

$$K' = \frac{1}{2}(2m)\left(\frac{v}{2}\right)^2 = \frac{1}{2} \cdot 2m \cdot \frac{v^2}{4} = \frac{mv^2}{4} = \frac{1}{2}\left(\frac{1}{2}mv^2\right) = \frac{1}{2}K_0.$$

Result: When mass is **doubled** and velocity is **halved**, kinetic energy becomes **half** of the original.

2. Mass doubled, velocity unchanged (Already implied, but asked frequently.)
New mass $m' = 2m$, $v' = v$.

$$K' = \frac{1}{2}(2m)v^2 = 2\left(\frac{1}{2}mv^2\right) = 2K_0.$$

Result: Mass **doubled** $\Rightarrow$ kinetic energy becomes **twice**.

3. Velocity tripled, mass unchanged New velocity $v' = 3v$.

$$K' = \frac{1}{2}m(3v)^2 = \frac{1}{2}m \cdot 9v^2 = 9K_0.$$

Result: Velocity **tripled** $\Rightarrow$ kinetic energy becomes **nine times**.

4. Both mass and velocity doubled New mass $m' = 2m, \quad v' = 2v$.

$$K' = \frac{1}{2}(2m)(2v)^2 = \frac{1}{2} \cdot 2m \cdot 4v^2 = 4mv^2 = 8\left(\frac{1}{2}mv^2\right) = 8K_0.$$

Result: Mass **doubled** and velocity **doubled** $\Rightarrow$ kinetic energy becomes **8 times**.

5. Speed made five times (same mass) New velocity $v' = 5v$.

$$K' = \frac{1}{2}m(5v)^2 = \frac{1}{2}m \cdot 25v^2 = 25K_0.$$

Result: Velocity made **5 times** $\Rightarrow$ kinetic energy becomes **25 times**.

6. Mass becomes one-third, velocity doubled New mass $m' = \frac{m}{3}, \quad v' = 2v$.

$$K' = \frac{1}{2}\left(\frac{m}{3}\right)(2v)^2 = \frac{1}{2} \cdot \frac{m}{3} \cdot 4v^2 = \frac{4}{6}mv^2 = \frac{2}{3}\left(\frac{1}{2}mv^2\right) = \frac{2}{3}K_0.$$

Result: Mass becomes $\frac{1}{3}$ and velocity is **doubled** $\Rightarrow$ kinetic energy becomes $\frac{2}{3}$ of the original.

7. Kinetic energy given, velocity changed Sometimes questions say: "Kinetic energy is 25 J at 5 m/s; what will it be when velocity is doubled / tripled?" Students should directly use the **ratio**:

$$\frac{K'}{K_0} = \left(\frac{v'}{v}\right)^2.$$

Shortcut: If velocity becomes n times, then kinetic energy becomes n^2 times (mass same).

5 Potential Energy

When work is done on an object and this work does *not* show up as a change in its speed or velocity, the energy given to the object is **stored inside it**. This stored energy is called **potential energy**.

For example:

- When you **stretch a rubber band**, you pull it and do **work** on it. The rubber band gets deformed but may not move from its place. The energy you give is stored as **elastic potential energy** in the stretched band.
- When you **wind the key of a toy car**, you do work in turning the key. Inside the toy, a **spring** is twisted and the energy you supply is stored in the spring as **potential energy**. When the toy is placed on the floor and released, this stored energy makes it move.

In all such cases, the object **gains energy** because of a change in its **position** or **configuration** (shape/arrangement of its parts), not because it is already moving fast.

Definition of potential energy

*The potential energy possessed by an object is the energy present in it by virtue of its **position** or **configuration**.*

Position vs configuration

- A stone kept at a height, or water stored in a dam: **potential energy due to position** (gravitational potential energy).
- A stretched bow, compressed spring, or stretched rubber band: **potential energy due to configuration** (elastic potential energy).

In both types, work was done **earlier**, and that work is now stored as **potential energy**, ready to be converted into other forms (often kinetic energy) when the object is allowed to move.

5.1 Potential Energy of an Object at a Height

When an object is **raised to a certain height** above the ground, **work is done** on it **against gravity**. This work done gets stored in the object as **gravitational potential energy**.

Gravity always pulls objects **downwards** towards the Earth. When you **lift** an object **upwards**, you have to apply a force **against** this pull of gravity. As you raise the object:

- You are **doing work** on the object.
- The object is **gaining energy** because of its **higher position**.

The energy stored in the object due to this **raised position** is called its **gravitational potential energy**.

Definition

The **gravitational potential energy** of an object at a point above the ground is defined as the **work done in raising it** from the ground to that point **against gravity**.

Everyday examples:

- Water stored in a **dam** high above the river has gravitational potential energy and can run **turbines** when allowed to fall.

- A book kept on a **high shelf** has more gravitational potential energy than the same book lying on the floor.
- A stone held **in your hand** at some height has gravitational potential energy and can do work (for example, dent the ground) if dropped.

In the next step, you will derive a simple expression for the gravitational potential energy of an object of mass m at a height h above the ground.

5.2 Expression for Gravitational Potential Energy

It is important to note that the **work done by gravity** depends only on the **difference in vertical height** between the initial and final positions, and **not** on the path taken by the object.

Suppose a block is raised from position A to position B by two different paths (for example, straight up or along a smooth ramp). Let the vertical height between A and B be

$$AB = h.$$

In both cases, the **vertical rise** is the same (h), so the **work done against gravity** is the same. Thus, in each situation, the work done on the object against gravity is mgh.

Derivation of $E_P = mgh$

Consider an object of mass m placed on the ground. Let it be raised vertically through a height h.

- The minimum upward force required to lift the object is equal to its **weight**, that is mg.
- The **displacement** in the direction of this force is the vertical height h.

Work done on the object against gravity,

$$W = \text{force} \times \text{displacement} = mg \times h = mgh.$$

This work done is stored in the object as **gravitational potential energy**. Therefore, the gravitational potential energy E_P of the object at height h is

$$E_P = mgh.$$

Thus,

$$\boxed{E_P = mgh}$$

is the expression for the gravitational potential energy of an object of mass m at a height h above the ground (near the Earth's surface, where g is constant).

Key point: Whether you lift a book **straight up** or carry it up a **ramp** to the same height, its gravitational potential energy at the top depends only on m, g and h, not on the path you used.

5.3 Energy Transformations in Daily Life

In most human activities and gadgets, **energy changes from one form to another**. The **total energy** is conserved, but its **form** changes (for example, from chemical to electrical, or electrical to heat and light).

Some common examples of energy conversion are listed below.

Activity / Gadget	Main Energy Conversion(s)
Electric bulb	Electrical energy → light energy + heat energy
Ceiling fan	Electrical energy → mechanical (kinetic) energy of rotating blades
Electric iron	Electrical energy → heat energy
Gas stove / candle	Chemical energy of fuel → heat energy + light energy
Human body (eating food, doing work)	Chemical energy in food → mechanical (muscular) energy + heat energy
Battery–torch	Chemical energy in battery → electrical energy → light energy + heat energy in the bulb
Hydroelectric power plant	Gravitational potential energy of stored water → kinetic energy of flowing water → electrical energy
Windmill	Kinetic energy of wind → mechanical energy of rotor → electrical energy (in a generator)
Solar panel	Solar (light) energy → electrical energy
Loudspeaker / earphones	Electrical energy → sound energy + a little heat
Car / bike	Chemical energy of petrol or diesel → heat energy → mechanical (kinetic) energy of the vehicle
Hydraulic lift / crane	Electrical energy → mechanical energy → gravitational potential energy of lifted load

Students can add more examples from daily life: mobile phones charging, mixers and grinders, electric heaters, solar cookers, etc., and identify the **input form of energy** and the **output form(s) of energy** in each case.

6 Law of Conservation of Energy

We have seen that energy can be **converted** from one form to another. But what happens to the **total amount** of energy?
Law of conservation of energy:
Energy can neither be created nor destroyed. It can only be converted from one form to another. The ***total energy*** *of an isolated system remains* ***constant****.*

This law holds for **all** physical processes and **all** types of energy transformations. Energy may appear in different forms (kinetic, potential, heat, light, etc.), but the **sum** of all forms of energy remains the **same** before and after the process.

Free fall of an object: PE $\leftrightarrow$ KE

Consider an object of mass m falling freely from a height h above the ground (ignoring air resistance).

- **At the start (at height h):**
  The object is just released from rest, so its velocity $v = 0$.
  Kinetic energy (KE) $= \frac{1}{2}mv^2 = 0$.
  Potential energy (PE) $= mgh$.
  Total energy $E = \text{PE} + \text{KE} = mgh + 0 = mgh$.
- **At some point during the fall (at height h'):**
  The object has fallen a bit and has velocity v.
  Potential energy $= mgh'$.
  Kinetic energy $= \dfrac{1}{2}mv^2$.
  Total energy $E = mgh' + \dfrac{1}{2}mv^2$.
- **Just before reaching the ground (height 0):**
  The object is about to hit the ground, so its speed is **maximum**.
  Potential energy $= mg \times 0 = 0$.
  Kinetic energy $= \dfrac{1}{2}mv_{\text{max}}^2$.
  Total energy $E = 0 + \dfrac{1}{2}mv_{\text{max}}^2$.

Total mechanical energy in free fall

At the top:

$$E_{\text{top}} = \text{PE} + \text{KE} = mgh + 0 = mgh.$$

At any intermediate point:

$$E = \text{PE} + \text{KE} = mgh' + \frac{1}{2}mv^2.$$

Just before hitting the ground:

$$E_{\text{bottom}} = 0 + \frac{1}{2}mv_{\text{max}}^2.$$

In the absence of air resistance, we find

$$mgh = mgh' + \frac{1}{2}mv^2 = \frac{1}{2}mv_{\text{max}}^2,$$

so

$$\text{PE} + \text{KE} = \text{constant}.$$

The sum of kinetic energy and potential energy of an object is called its **total mechanical energy**. During free fall, the **decrease in potential energy** at any point is exactly equal to the **increase in kinetic energy**. Thus, total mechanical energy remains **constant**.

Conclusion:

During the free fall of the object, there is a **continual transformation** of gravitational potential energy into kinetic energy. The **forms** of energy keep changing, but the **total mechanical energy** (PE + KE) remains **constant** throughout the motion.

6.1 Difference between Kinetic Energy and Potential Energy

Kinetic Energy (KE)	Potential Energy (PE)
Energy possessed by an object **due to its motion**.	Energy possessed by an object **due to its position or configuration**.
An object must be **moving** to have kinetic energy.	An object can have potential energy even when it is **at rest**.
Depends on **mass** and **square of velocity**: $K = \frac{1}{2}mv^2$.	Depends on **position** in a field (like height in gravitational field) or on **deformation** (stretching/compression).
Increases when the **speed increases**.	Increases when the object is taken to a **higher position** or more **stretched/compressed**.
Examples: moving car, flowing water, blowing wind, rolling ball.	Examples: water stored in a dam, stone at height, stretched bow, compressed spring.
Usually appears **during motion**, often after potential energy is released.	Usually represents **stored energy**, which can later convert into kinetic energy.

7 Rate of Doing Work (Power)

Different people and machines may do the **same amount of work**, but in **different times**. The quantity that tells us **how fast or how slow** work is done is called **power**.

For example:

- A **stronger person** may climb the same staircase in less time than another person.
- A **more powerful vehicle** completes a journey in a shorter time than a less powerful one.

In both cases, the total work done may be the **same**, but the rate of doing work is **different**. Machines and other agents that transfer energy do work at **different rates**.

Definition of power

Power is defined as the **rate of doing work** or the **rate of transfer of energy**.

If an agent does work W in time t, then

$$\text{Power} = \frac{\text{Work}}{\text{Time}} \quad \Rightarrow \quad P = \frac{W}{t}.$$

If an agent transfers energy E in time t, then

$$P = \frac{E}{t}.$$

Unit of power: The SI unit of power is the **watt** (symbol: W), named in honour of **James Watt (1736–1819)**.

- An agent has power 1 watt if it does work at the rate of 1 joule per second.
- That is,

$$1\,\text{W} = 1\,\text{J s}^{-1}.$$

Sometimes, we deal with much **larger** rates of energy transfer. Then we use the unit **kilowatt** (kW).

$$1\,\text{kW} = 1000\,\text{W} = 1000\,\text{J s}^{-1}.$$

Average power

If a machine or person does different amounts of work in different time intervals, it is useful to talk about **average power**.

Average power is defined as:

$$\text{Average power} = \frac{\text{Total work done (or total energy consumed)}}{\text{Total time taken}}.$$

Thus, power tells us **how quickly** work is done or energy is used. Higher power means work is done or energy is transferred **faster**.

Definition of 1 watt of power

1 watt is the power of an agent which does **1 joule of work in 1 second**.

$$1\,\text{W} = 1\,\text{J s}^{-1}$$

This means that if a device performs 1 J of work or consumes 1 J of energy every second, its power is 1 watt.

8 Simple Machines

Introduction

In everyday life, we often use tools to make our work easier. For example, we use a knife to cut vegetables, a ramp to push heavy loads, or a pulley to lift a bucket from a well. These devices help us perform tasks with less effort.
Such devices are called **machines**. A machine is a device that helps us do work more easily by changing the **magnitude**, **direction**, or **point of application** of a force.
The simplest forms of machines are known as **simple machines**. They form the basic building blocks of many complex machines used in daily life.

Definition

A **simple machine** is a mechanical device that makes work easier by multiplying force or changing the direction of force.

Examples of Simple Machines:

- Lever
- Pulley
- Inclined plane
- Wheel and axle
- Wedge
- Screw

8.1 Levers

Introduction

One of the most commonly used simple machines is the **lever**. A lever helps us lift or move heavy loads with less effort.
Many tools that we use in daily life such as **scissors, crowbars, bottle openers, and see-saws** work on the principle of a lever.

Definition of a Lever

A **lever** is a rigid bar that is capable of rotating about a fixed point called the **fulcrum**.

Every lever consists of three important parts:

- **Fulcrum (F)** – The fixed point about which the lever rotates.
- **Effort (E)** – The force applied to move the load.
- **Load (L)** – The weight or resistance that needs to be lifted or moved.

Principle of a Lever

A lever works on the principle of **moments**.
For a lever to be in equilibrium,

$$\text{Effort} \times \text{Effort Arm} = \text{Load} \times \text{Load Arm}$$

Classes of Levers

Levers are classified into **three types** depending on the relative positions of the **Fulcrum (F)**, **Effort (E)**, and **Load (L)**.

First Class Lever

In a **first class lever**, the **fulcrum lies between the effort and the load**.
Arrangement:

$$E \quad F \quad L$$

Examples:

- See-saw
- Scissors
- Crowbar

Second Class Lever

In a **second class lever**, the **load lies between the fulcrum and the effort**.
Arrangement:

$$F \quad L \quad E$$

Examples:

- Wheelbarrow
- Nutcracker
- Bottle opener

Third Class Lever

In a **third class lever**, the **effort lies between the fulcrum and the load**.
Arrangement:

$$F \quad E \quad L$$

Examples:

- Human forearm
- Fishing rod
- Tweezers

9 Mechanical Advantage

Why Do We Use Machines?

In daily life, we often need to lift or move heavy objects. Doing this directly may require a large amount of force.
Machines help us by **reducing the effort needed to perform a task**. In many cases, a machine allows a small effort to lift a much larger load.
The ability of a machine to multiply force is described by a quantity called **Mechanical Advantage**.

Definition

Mechanical Advantage (MA) is defined as the ratio of the **load lifted by the machine** to the **effort applied to the machine**.

$$\text{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}}$$

$$MA = \frac{L}{E}$$

Where

- L = Load (the resistance or weight lifted by the machine)
- E = Effort (the force applied to operate the machine)

Important Points

- Mechanical Advantage tells us how many times a machine multiplies the applied force.
- It is a **dimensionless quantity** because it is a ratio of two forces.
- A higher value of Mechanical Advantage means the machine reduces effort more effectively.

Interpretation of Mechanical Advantage

The value of Mechanical Advantage can tell us how useful a machine is.

Case 1: $MA > 1$

If the Mechanical Advantage is greater than 1, the machine **multiplies force**.
This means the effort applied is smaller than the load lifted.
Example: Using a crowbar to lift a heavy stone.

Case 2: $MA = 1$

If the Mechanical Advantage is equal to 1, the effort applied is equal to the load.
The machine only **changes the direction of the force** but does not multiply it.
Example: A fixed pulley used to draw water from a well.

Case 3: $MA < 1$

If the Mechanical Advantage is less than 1, the effort applied is greater than the load.
Such machines do not multiply force but help in **increasing speed or distance of motion**.
Example: Tweezers.

Example

Suppose a machine is used to lift a load of 200 N using an effort of 50 N.

$$MA = \frac{L}{E}$$

$$MA = \frac{200}{50}$$

$$MA = 4$$

This means the machine multiplies the applied force **four times**.

10 Inclined Plane

Introduction

Suppose you want to lift a heavy box onto a truck. One way is to lift it straight up. However, lifting a heavy object vertically requires a large force.
Instead, if we place a **ramp** between the ground and the truck, the box can be pushed upward along the slope with much less effort.
This sloping surface is called an **inclined plane**. It is one of the most important and widely used **simple machines**.

Definition

An **inclined plane** is a flat surface that is tilted at an angle to the horizontal. It is used to raise or lower heavy objects with less effort.

An inclined plane is simply a **sloping surface or ramp**. It helps us move objects from a lower level to a higher level more easily. Instead of lifting the object vertically, we push or roll it along the slope.

Using an inclined plane **reduces the effort required**, but the object must travel a **longer distance**.

Why Does an Inclined Plane Make Work Easier?

When an object is lifted vertically, the full weight of the object must be overcome.

However, when the object is moved along a slope:

- Only a part of the weight acts along the slope.
- Therefore, the effort required to move the object becomes smaller.
- However, the object must travel a greater distance along the slope.

Thus, an inclined plane makes work easier by **reducing the force required to lift an object**. [?, ?]

Examples of Inclined Planes

Inclined planes are commonly seen in everyday life.

- Ramps used to load goods into trucks
- Staircases
- Roads on hills or mountains
- Slides in playgrounds
- Ramps used in hospitals for wheelchairs

Important Idea

An inclined plane does not reduce the total work done.
It simply allows the same work to be done with a **smaller force acting over a larger distance**.

Mechanical Advantage of an Inclined Plane

The mechanical advantage of a machine is defined as

$$MA = \frac{\text{Load}}{\text{Effort}}$$

For an inclined plane,

$$MA = \frac{\text{Length of the slope}}{\text{Height of the plane}}$$

$$MA = \frac{L}{h}$$

where

- L = length of the inclined plane
- h = vertical height of the inclined plane

A longer and gentler slope gives a **greater mechanical advantage**. [**?**, **?**]

Example

An inclined plane has a length of 6 m and a height of 2 m.

$$MA = \frac{L}{h}$$

$$MA = \frac{6}{2}$$

$$MA = 3$$

This means the inclined plane multiplies the applied force **three times**.

D.P.P - I (Based on equations of motion)

1. A car accelerates from rest at $3\,\mathrm{m/s^2}$. Find its velocity after 5 seconds.
2. A train starts from rest and travels 500 meters in 20 seconds with uniform acceleration. What is its acceleration?
3. An object is moving with an initial velocity of $15\,\mathrm{m/s}$ and an acceleration of $4\,\mathrm{m/s^2}$. What is its velocity after 6 seconds?
4. A cyclist traveling at $10\,\mathrm{m/s}$ applies the brakes and stops after 20 meters. What is the acceleration?
5. A ball is thrown vertically upwards with a velocity of $18\,\mathrm{m/s}$. Calculate the maximum height reached. (Take $g = 9.8\,\mathrm{m/s^2}$.)
6. A car moves with a uniform velocity of $25\,\mathrm{m/s}$ for 12 seconds. Find the distance covered.
7. A bus starts with a velocity of $20\,\mathrm{m/s}$ and stops after 8 seconds with a uniform retardation of $2.5\,\mathrm{m/s^2}$. What is the distance covered before it stops?
8. A train moving at $40\,\mathrm{m/s}$ is brought to rest in 200 meters. What is the acceleration?
9. A stone, initially at rest, falls freely under gravity. What will be its velocity after 3 seconds? (Take $g = 9.8\,\mathrm{m/s^2}$.)
10. An object is moving with uniform acceleration of $5\,\mathrm{m/s^2}$. If its initial velocity is $7\,\mathrm{m/s}$, what distance will it cover in 10 seconds?

D.P.P - II (Based of Newtons laws of motion)

1. Define inertia. Give three examples from daily life showing inertia.
2. State Newton's first law of motion. Explain it with a suitable example.
3. An object of mass 5 kg is moving with a velocity of 10 m/s. Calculate the momentum of the object.
4. A force of 20 N acts on a body of mass 4 kg initially at rest. Calculate the acceleration produced and velocity attained in 5 seconds.
5. What is meant by the conservation of momentum? Derive the formula for conservation of linear momentum for two interacting bodies.
6. State Newton's third law of motion. Explain with the help of examples.
7. Why do passengers fall backward when a bus suddenly starts?
8. Why do passengers fall forward when a bus suddenly stops?
9. Explain the effect of force on a body with respect to its mass and acceleration.
10. A ball of mass 0.5 kg moving at 10 m/s collides with a stationary wall and rebounds with the same speed. Calculate the change in momentum.
11. Explain with examples how the force applied can bring about the change in shape of a body.
12. What is the SI unit of force? How is it defined?
13. Explain the terms balanced force and unbalanced force with suitable examples.
14. Write the formula for momentum and state its unit. How does momentum depend on velocity and mass?

15. Derive an expression for force using the concept of rate of change of momentum.
16. Why should safety belts in vehicles be fastened properly? Relate your answer to Newton's laws.
17. Explain the phenomenon of recoil in guns using Newton's third law.
18. Describe an activity to demonstrate the law of conservation of momentum.
19. Why does a gun recoil when a bullet is fired from it?
20. Explain with an example how the force applied can produce motion in an object initially at rest.
21. Calculate the force required to stop a car of mass 800 kg moving at 20 m/s in 10 seconds.
22. State Newton's laws of motion and give a practical example for each.

D.P.P - III (Based on Newtons second law of motion)

1. A force of 20 N is applied to a box of mass 4 kg. Calculate the acceleration produced in the box.
2. A car of mass 1000 kg accelerates uniformly from rest to 20 m/s in 10 seconds. Calculate the force applied on the car.
3. A force of 50 N produces an acceleration of $5\,m/s^2$ in an object. Find the mass of the object.
4. State and explain Newton's second law of motion using the concept of momentum.
5. A truck of mass 1500 kg is moving with an acceleration of $2\,m/s^2$. Calculate the net force acting on the truck.
6. If a force of 10 N acts on an object of mass 2 kg, find the acceleration produced.
7. Two boxes of masses 3 kg and 5 kg are pushed with equal forces. Which box will have greater acceleration? By what factor?
8. A cyclist applies a force of 100 N to accelerate his 80 kg bicycle and rider. Calculate the acceleration of the bicycle.
9. What does Newton's second law of motion state? Calculate the force needed to give an acceleration of 2 $\mathrm{m/s^2}$ to a body of mass 10 kg.

D.P.P - IV (SOUND)

1. **The wavelength of a sound wave is 0.85 m and its frequency is 400 Hz. Calculate the speed of the sound wave.**
2. **A sound wave travels with a speed of 340 m/s and frequency of 500 Hz. Calculate the wavelength.**
3. **If a sound wave travels 1.5 km in 5 seconds, find the speed of sound.**
4. **The time period of a sound wave is 0.002 seconds. Calculate its frequency.**
5. **The amplitude of a sound wave is 0.03 m. What does this amplitude signify?**
6. **A sound wave has a speed of 330 m/s and wavelength of 0.75 m. Find its frequency.**
7. **If a sound wave with frequency 600 Hz travels with a speed of 300 m/s, calculate its wavelength.**

8. **A sound wave in air has a wavelength of 1.2 m and a frequency of 285 Hz. What is the speed of this sound wave?**

9. **A sound wave travels at 350 m/s and has a time period of 0.004 seconds. Calculate its frequency.**

10. **If a sound wave covers a distance of 950 m in 2.5 seconds, what is its speed?**

11. **A sound wave in water has a frequency of 1500 Hz and a speed of 1500 m/s. Find its wavelength.**

12. **The frequency of a sound wave is 420 Hz and its wavelength is 0.82 m. Determine the speed of the sound wave.**

13. **A tuning fork produces sound waves of frequency 256 Hz that travel at 320 m/s. What is their wavelength?**

14. **If the amplitude of a sound wave increases, what happens to the loudness of the sound? Explain.**

15. **A sound wave has a velocity of 343 m/s and a wavelength of 0.98 m. Find its frequency.**

16. **What is the relationship between the frequency, wavelength, and speed of a sound wave? State the formula and explain each term.**

17. **A sound wave travels 450 m in 1.5 seconds. Calculate the speed of sound.**

18. **Read the passage below and answer the questions that follow:**

The speed of sound depends on the medium through which it is travelling. In air at room temperature ($20°C$), the speed of sound is about 343 m/s. Sound travels faster in liquids and even faster in solids because particles are packed more closely, allowing vibrations to pass quickly from particle to particle. The relationship between speed (v), frequency (ν), and wavelength (λ) of a sound wave is given by the formula:

$$v = \lambda\,\nu$$

For example, if a sound wave traveling in air has a wavelength of 0.5 m and a frequency of 686 Hz, its speed is 0.5 m $\times$ 686 Hz $=$ 343 m/s.

(a) What is the speed of sound in air at room temperature?
(b) Why does sound travel faster in solids than in gases?
(c) Write the formula that relates speed, wavelength, and frequency of a sound wave.
(d) If the frequency of a sound wave in water is 1500 Hz and its speed is 1500 m/s, what is its wavelength?
(e) What will happen to the speed of sound if the temperature of air increases?

D.P.P - V (Previous years Questions)

1. A ball projected vertically upwards with an initial velocity u goes to a maximum height h. What is its velocity at the highest point? **[2018]**

2. A ball is thrown vertically upwards and reaches a maximum height in 3 s. Find: **[2016]**

   (i) the velocity with which it was thrown upwards,

   (ii) the maximum height attained by the ball.
   Take $g = 10$ m s^{-2}.

3. A particle is released from rest from a height. **[2016]**

   (a) Find the distance it falls through in 1 s.

   (b) Find the distance it falls through in 3 s. Also, find the speed with which it strikes the ground after 3 s.

4. The successive crest and trough of a wave are 30 cm apart. Find the wavelength. Also, find the frequency of the wave if 10 crests and 10 troughs are produced in 2 s. **[2025]**