Engineer Meligy

2nd Secondary

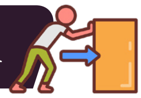
Physics
Main Book

2026

— 2nd Term —

Chapter 1: Work and Energy

Lesson 1: Work



- In our daily life, we use the word "work" to describe any activity that occupies a person and captures their attention.
- This activity may be:
  - **Mental work**, such as completing homework or studying.
  - **Physical work**, such as visiting a sick person or doing any physical activity.
- Sometimes, the word **work** is used to refer to any activity at all, whether it is mental or physical.
- However, in Physics, the word work has a specific scientific meaning that is different from its everyday use.

For work to be done on an object a **force** must act on the object and the object **must move** through a certain displacement as a result of that force. If the object does not move, then **no work is done,** no matter how large the applied force is.

Work

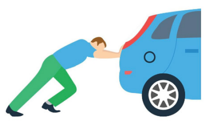
The process by which a force moves an object in the direction in which the force acts.
Or The scalar product of the force vector and diplacements vector.

Conditions for Doing Work

- For work to be done, two conditions must be satisfied:

1. A **certain force** must act on the object.
2. The object must **move** through a certain displacement in the **same direction** as the **force**.

- If any of these conditions is missing, then no work is done.

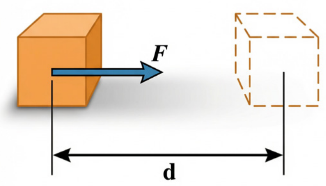
Examples Illustrating the Conditions of Work	
Cases Where Work Is Not Done	**Cases Where Work Is Done**
- If an object exerts a force or effort but **does not move**, then no work is done. - Examples: • A man pushing a wall • A student studying  	- If an object exerts a force or effort and the object **moves**, then work is done. - Examples: • A man pushing a car • A man lifting weights upward  

Calculating Work (W)

- If a force (F) acts on an object and moves it through a displacement (d) in the line of action of the force, then the work done can be calculated by the **scalar product of the force and displacement vectors.**

$$W = \vec{F} \cdot \vec{d}$$

- Where:
- **W = work done**
- **F = force**
- **d = displacement**



- When the displacement is in the same direction as the force, the equation becomes:

$$W = F\ d$$

Units of Work

- Work is measured in **joules (J)**, named after the English **scientist James Joule**.
- **One Joule** is equal to the **work** done when a **force** of **1 newton** moves an object through a displacement of **1 meter** in the direction of the force.
- So:

$$1\,J = 1\,N \cdot m$$

Unit of work:

$$N \cdot m = J$$

Unit of force

$$N = kg \cdot m/s^2$$

- Substituting in the unit of work:

$$J = N \cdot m$$

$$J = (kg \cdot m/s^2) \cdot m$$

$$J = kg \cdot m^2/s^2$$

- So: $J = kg \cdot m^2/s^2$

Formula for the Dimensions of Work

$$[ML^2T^{-2}]$$

Joule

One joule is the work done by a force of magnitude 1 N in moving an object through a displacement of 1 m in the direction of the line of action of the force.

Work and Force

- You might think that work is a vector quantity because both force and displacement are vector quantities.
- However, work is a scalar quantity, **Why?**
  - **Because work is calculated using the scalar product of force and displacement vectors.**

Note

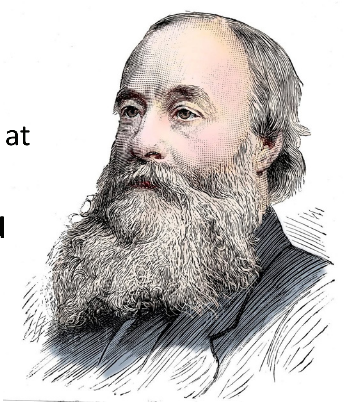
- Work is a scalar **(non-vector)** quantity.
- When you pull a suitcase and it moves 5 meters from east to west, you do work on the suitcase.
- It does not matter in which direction the suitcase moves.
- The work done is the same if it moves 5 meters from north to south.
- Direction does not affect the value of work, only the magnitude of force and displacement matter.

Apply With Mr. Meligy

- Calculate the work done by a girl lifting her backpack of mass 5 kg from the ground to a height of 1.4 m, given that: $g=10 m/s^2$

Answer:

James Joule (Joule)

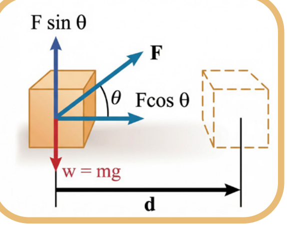


- James Joule was an English scientist who devoted most of his life to **performing experiments** to show the conversion of **mechanical work** into **internal energy**.
- In one of his famous experiments, he discovered that the **temperature** of **water** at the **bottom** of a waterfall is **higher** than its temperature at the **top**.
- This proved that part of the **mechanical energy of the falling water is converted into heat energy**, which is a form of internal energy.
- Because of his great contributions, the **unit of work and energy is named after him: the joule (J)**.

Calculating Work When the Force Makes an Angle (Θ) with the Displacement

- When a force F acts on an object and the displacement d is not in the same direction as the force, but makes an angle θ (theta) with it, the force must be resolved into two perpendicular components.
We resolve the force F into:

- **F1=Fcosθ**
- **F2 =Fsinθ**



The Component Near the Angle 1

$$F_1 = F\cos\theta$$

- This component is **parallel to the displacement (d).**
- It is responsible for causing the motion of the object.
- Therefore, **only this component does work.**
- So, the work done is: $W = F_1 \cdot d$

$$W = Fd\cos\theta$$

- This is the general equation for work when the force is applied at an angle:

$$\boxed{W = Fd\cos\theta}$$

The Component Far from the Angle 2

$$F_2 = F\sin\theta$$

- This component is **perpendicular to the displacement.**
It is in equilibrium with the weight of the body.
Its line of action is in the same straight line as the weight but in the opposite direction.
They are **equal in magnitude and opposite in direction**, so they cancel each other.
Therefore:

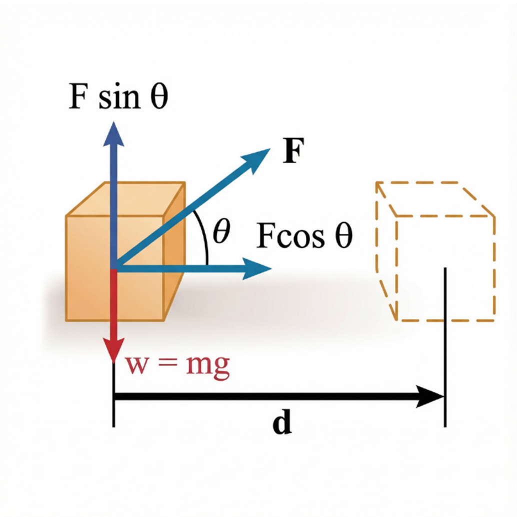
- **F sinθ does not cause motion**
- **F sinθ does no work**

General Formula of Work with Inclined Force

$$\boxed{W = F \cdot d\cos\theta}$$

- Where:

- **W = work done**
- **F = applied force**
- **d = displacement**
- **θ = angle between force and displacement**



Factors on Which the Work Done Depends

- - The work done by a force is given by the equation: ***W=Fdcosθ***

- From this equation, the work done depends on three factors:

- **The magnitude of the force *F***
- **The displacement *d***
- **The angle θ between the direction of the force and the displacement, through cos θ**

- Each factor can be studied while keeping the other two constant, and this is represented graphically.

Effect of Force F

- When the displacement (d) and the angle (θ) *between (F) and (d)* are constant:

$$W = Fd\cos\theta$$

$$W \propto F$$

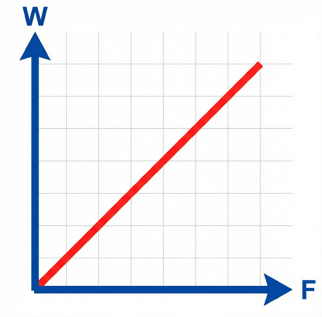
- This is a direct relationship.

- Law:

$$W = Fd\cos\theta$$

- Slope of the graph:

$$\text{slope} = \frac{\Delta W}{\Delta F} = d\cos\theta$$



Effect of Displacement d

- When the force (F) and the angle (θ) *between (F) and (d)* are constant:

$$W = Fd\cos\theta$$

$$W \propto d$$

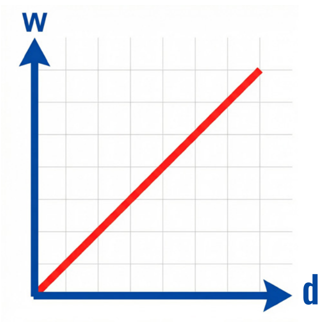
- This is a direct relationship.

- Law:

$$W = Fd\cos\theta$$

- Slope of the graph:

$$\text{slope} = \frac{\Delta W}{\Delta d} = F\cos\theta$$



Effect of the Angle Between Force and Displacement (cosθ)

- When the force (F) and the displacement (d) are constant:

$$W = Fd\cos\theta$$

$$W \propto \cos\theta$$

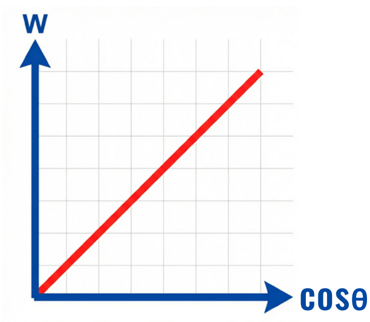
- This is a direct relationship.

- Law:

$$W = Fd\cos\theta$$

- Slope of the graph:

$$\text{slope} = \frac{\Delta W}{\Delta(\cos\theta)} = Fd$$

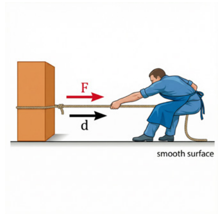
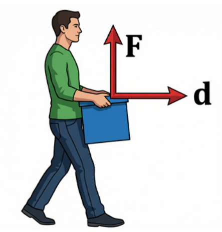
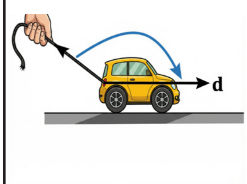
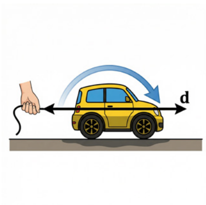


Effect of the Angle of Inclination (θ) on the Value of the Work Done

- The work done by a force is given by:

$$W = Fd\cos\theta$$

- So, the value and sign of work depend on the value of the angle θ between the direction of the force and the direction of displacement.

Value of the angle θ	Value of Work	Mathematical form	Cause	Examples	
$\theta=0^o$	Positive maximum value	$\cos\theta=1$ $W=+Fd$	- The force is in the same direction as the displacement. The force is along the line of action of the displacement.	A person pulls an object and moves it on a smooth surface in the same direction of the force.	
$0^o<\theta<90^o$	Positive value	$W=+Fd\cos\theta$	- The force is inclined at an acute angle to the line of action of the displacement. The person is doing work on the object.	Pulling an object with a force inclined at an acute angle to the displacement	
$\theta=90^o$	Zero work	$\cos90^o=0$ $W=0$	- The force is perpendicular to the line of action of the displacement.	A person carrying an object (like a bucket) while walking horizontally	
$90^o<\theta<180^o$	Negative value	$W=F.d\cos\theta$ (negative because $\cos\theta$ is negative)	- The force is inclined at an obtuse angle to the line of action of the displacement. The object is doing work on the person.	A person trying to pull an object while it is moving in the opposite direction to the force.	
$\theta=180^o$	Negative maximum value	$\cos180^o=-1$ $W=-F.d$	- The force is in the opposite direction to the displacement.	The force is inclined at an acute angle to the line of action of the displacement. The person is doing work on the object. - Work done by frictional forces. - Work done by the braking force on a car.	

Note

- When the angle between the force and the displacement is 60^o, the work done by the force is **half of its maximum value.** $(\cos60^o=1/2)$
- Because the maximum work occurs when:
$\theta=0^o$ **$W_{max}=fd$**
- So at 60^o: $w=\frac{1}{2}\,w_{max}$

1. The dimensional formula of work is ....
   a) ML^2T^{-2} b) MLT^{-2} c) MLT d) MLT^{-1}

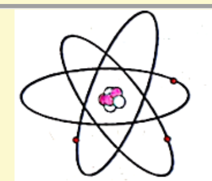
2. The unit **Joule** is equivalent to:
   a) N/m b) N.m c) $kg \cdot m^2/s^2$ d) Both (b) and (c)

3. The work done by a force acting at an angle θ with the displacement is given by:
   a) F·d b) F·d·sinθ c) F·d·cosθ d) F·cosθ

4. The work done by a force is **zero** when the angle between the force and the displacement is:
   a) 0° b) 60° c) 45° d) 90°

5. When the force acts on a body and the angle between the force and the displacement is **60°**, the work done is:
   a) Maximum b) Half of maximum c) Zero d) Negative

6. The work done by an electron moving in a circular path is:
   a) Zero b) Maximum in Level one
   c) Maximum in Last level d) Equal in all Levels

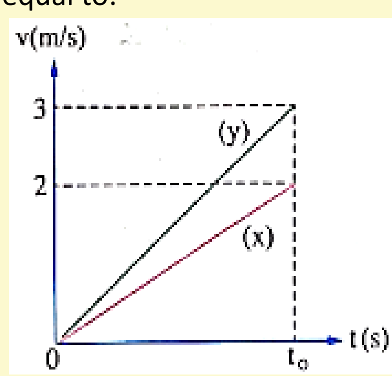


7. The force of friction does .... work.
   a) Zero b) Positive c) Negative d) No correct answer

8. Two bodies **(X)** and **(Y)** have the same mass and start moving from rest on a smooth horizontal surface under the action of different resultant horizontal forces.
   The adjacent graph represents the relationship between the velocity **(v)** and time **(t)** for each body. Find the ratio between the amounts of work done on the two bodies by the resultant force $\left(\frac{W_x}{W_y}\right)$

   (1) When both bodies cover the same displacement, the ratio is equal to:
   a) 2⁄3 b) 3⁄2
   c) 4⁄9 d) 9⁄4

   (2) During the time interval from **0** to $\mathbf{t_o}$, the ratio is equal to:
   a) 2⁄3 b) 3⁄2
   c) 4⁄9 d) 9⁄4



Work Done by Different Forces in Special Cases

Lifting an Object Vertically

- When an object is lifted through a certain distance, two forces act on it, and each force does work:

1. **The upward force (lifting force):**
   - Acts in the same direction as the motion.
   - The work done by this force is positive.
2. **The force of gravity (weight of the object):**
   - Acts downward.
   - It is opposite to the direction of motion.
   - The work done by this force is negative.

- So, during lifting:
  - The lifting force does **positive work**.
  - Gravity does **negative work**.

Motion in a Circular Path

- When an object moves in a circular path, the force acting on it is always perpendicular to the direction of motion.
- Since:

$$W = Fd\cos\theta$$

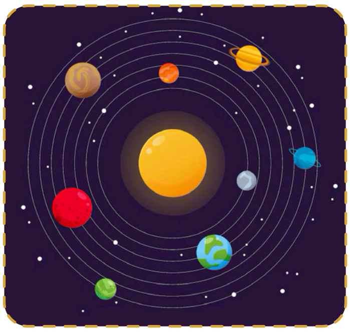
- and when the force is perpendicular to displacement:

$$\theta = 90^\circ, \quad \cos 90^\circ = 0$$

- So, no work is done.

$$W = 0$$

- Examples:
  - Motion of an electron around the nucleus
  - Motion of planets around the Sun
  - Motion of moons around planets
  - Motion of satellites



Pushing vs Pulling

- The work done in pushing an object is greater than the work done in pulling it.
This is because of the vertical component of the applied force Fsinθ.

(a) In the Case of Pushing

(b) In the Case of Pulling

(a) In the Case of Pushing

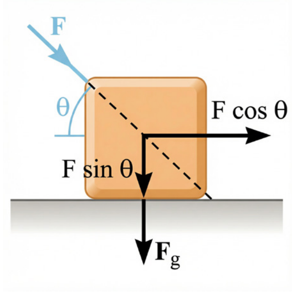
- The applied force makes an angle θ downward with the horizontal.

Components of the force:

Fcosθ → horizontal component (causes motion)

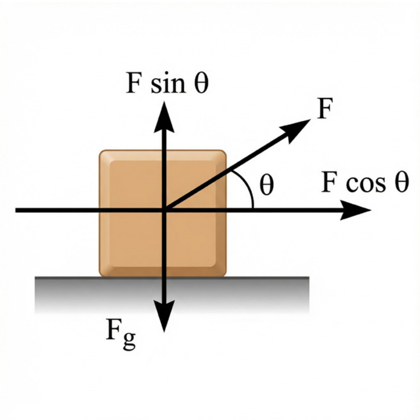
Fsinθ → vertical component

- Here:
  - F sin θ acts in **the same direction as the weight of the object.**
  - This increases the normal reaction.
  - This increases the frictional force.
  - Therefore, the work required to move the object **increases**.
- So:
  - F sin θ increases friction
  - Work required increases



(b) In the Case of Pulling

- The applied force makes an angle θ upward with the horizontal.
- Components of the force:
  - F cos θ → horizontal component (causes motion)
  - F sin θ → vertical component
- Here:
  - Fsinθ acts **in the opposite direction to the weight.**
  - This reduces the normal reaction.
  - This reduces the frictional force.
  - Therefore, the work required to move the object **decreases.**
- So:
  - F sin θ reduces friction
  - Work required decreases



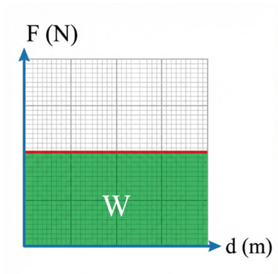
Determining Work Graphically

- Work can also be calculated graphically using a force–displacement curve.

When plotting a graph between force (F) and displacement (d), and the displacement is in the same line of action as the force ($\theta = 0^{o}$):

The graph is a straight line parallel to the displacement axis.

- Since: $W = F \times d$
- Then, graphically: $\text{Work} = \text{Length} \times \text{Width}$
- Which means: $\boxed{\text{Work graphically} = \text{Area under the force–displacement curve}}$



- So:

<u>The area under the (force–displacement) graph represents the work done by the force.</u>

Apply With Mr. Meligy

1) A force of 200 N acts on an object and moves it through a distance of 5 m.

*** Calculate the work done by this force in each of the following cases:**

1. When the force is in the same direction as the motion.
2. When the force makes an angle of 60° with the direction of the object's motion.
3. When the force is perpendicular to the direction of motion.

Answer:

*** What if the angle between the force and displacement decrease while keeping F & d constant, what will happen to work done by the force?**

2) Calculate the work done in each of the following cases

I) A girl is carrying a bucket of mass 300 g and moves it a distance of 10 m in the horizontal direction.

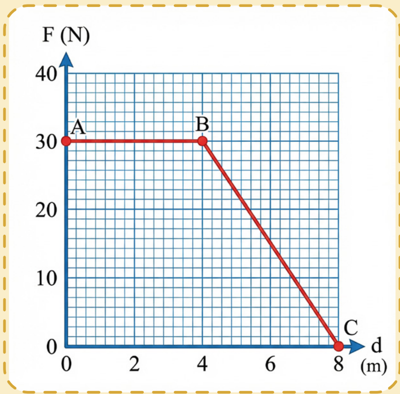
II) A boy lifts a bucket of the same mass 300 g through a distance of 10 cm in the vertical direction.

Answer:

3) A horizontal force acts on an object, and its magnitude changes with the displacement, as shown in the figure.

*** Calculate the work done by this force when the object moves horizontally from the starting point (zero displacement) through a displacement of 8 m.**

Answer:



Ch1 L2 - Energy

If a body is capable of doing work, then this body possesses energy.
For example, the ability of a person to do work to push a box means that he possesses energy.

Energy

Energy

The ability to do work.

- **Types of Energy:** Thermal Energy, Mechanical Energy, Potential Energy, Kinetic Energy.
- **Unit of measurement:** Joule (J) - (Same unit used to measure work)
- **Equivalent units:**

  $N \cdot m$ & $kg \cdot m^2/s^2$
- **Dimensions of energy:**

  ML^2T^{-2}

Energy has many forms. In this lesson, we will study **two forms** in detail:

1. Kinetic Energy (KE)
2. Potential Energy (PE)

1. Kinetic Energy

Kinetic Energy:

The energy possessed by a body due to its motion.

When a force (F) acts on a body initially at rest, causing it to move through a displacement (d) in the direction of the force, the work done by the force (Fd) is transformed into a form of energy known as kinetic energy (KE).

Examples of kinetic energy:

- An electron revolving around the nucleus
- Water flowing through a dam
- A moving car
- A running person

Calculating kinetic energy:

The kinetic energy of a body of mass (m) moving with speed (v) is given by:

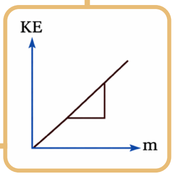
$$KE = \frac{1}{2}mv^2$$

Factors affecting the kinetic energy of a body:

1. Mass of the body

At constant speed, kinetic energy is directly proportional to the mass of the body.

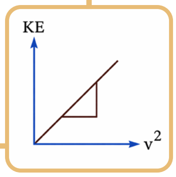
$$\text{slope} = \frac{\Delta \text{KE}}{\Delta m} = \frac{1}{2}v^2$$



2. Speed² of the body

At constant mass, kinetic energy is directly proportional to the square of the speed.

$$\text{slope} = \frac{\Delta \text{KE}}{\Delta v^2} = \frac{1}{2}m$$



How to find Kinetic energy formula?! (Derivation)

- If a force (F) acts on a body of mass (m) initially at rest, causing it to move with uniform acceleration (a) until its velocity becomes (v) after moving a displacement (d):

1. Displacement:

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

2. Average velocity:

$$\bar{v} = \frac{v_f + v_i}{2}$$

3. Acceleration:

$$a = \frac{v_f - v_i}{t} \Rightarrow t = \frac{v_f - v_i}{a}$$

* Substituting:

$$d = \frac{v_f + v_i}{2} \cdot \frac{v_f - v_i}{a}$$

$$d = \frac{v_f^2 - v_i^2}{2a}$$

* Since the body starts from rest:

$$v_i = 0 \Rightarrow v_f = v$$

$$d = \frac{v^2}{2a}$$

* Multiplying both sides by (F):

$$Fd = \frac{F}{2a}v^2$$

* From Newton's Second Law::

$$F = ma \Rightarrow \frac{F}{a} = m$$

$$Fd = \frac{1}{2}mv^2$$

- Where:
  - Fd represents the work done by the force.
  - ½mv² represents kinetic energy produced from the work done.

* Thus:

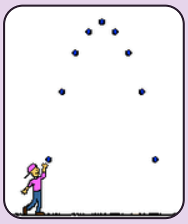
$$\text{KE} = \frac{1}{2}mv^2$$

NOTES!

- Kinetic energy is a scalar quantity, as it is defined by magnitude only, since it is the product of two scalar quantities (mass and square of speed).

$$KE = \frac{1}{2}mv^2$$

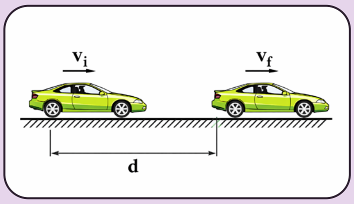
- The kinetic energy of a body doubles when its mass doubles.
- The kinetic energy of a body becomes four times greater when its speed doubles.
- The kinetic energy of a body becomes one quarter when its speed is reduced to half.
- The kinetic energy of a body doubles when its speed doubles and its mass is reduced to half.
- The kinetic energy of a body is reduced to half when its mass doubles and its speed is reduced to half.
- When a body is thrown upward, its kinetic energy decreases and becomes zero at the highest point, and when it falls downward, its kinetic energy increases.



-The kinetic energy can be related to the momentum by the following relation:

$$K.E. = \frac{1}{2}mv^2 = \frac{1}{2}mv\,v = \frac{1}{2}pv$$

- In the illustrated example, a car of mass (m) moves along a straight line under a constant resultant force (F), changing its speed from v_1 to v_2 while covering a displacement (d).



The work done is: $$W = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 = \Delta(KE)$$

So: $$Fd = \Delta(KE)$$

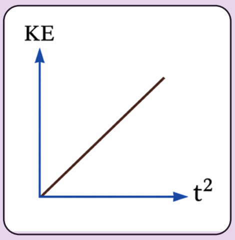
If a body starts moving from rest with uniform acceleration, its kinetic energy at any instant is proportional to the square of time, where:

$$\therefore \quad a = \frac{v_f - v_i}{t} = \frac{v_f - 0}{t} = \frac{v_f}{t}$$

$$\therefore \quad v_f = at$$

$$\therefore \quad KE = \frac{1}{2}mv_f^2 = \frac{1}{2}m(at)^2 = \frac{1}{2}ma^2t^2$$

$$\therefore \quad KE \propto t^2$$



Life Applications:

- When stopping a car of mass (m) moving at speed (v) by applying the brakes, a force (F) acts opposite to the direction of motion, and the car travels a stopping distance (d).

From:

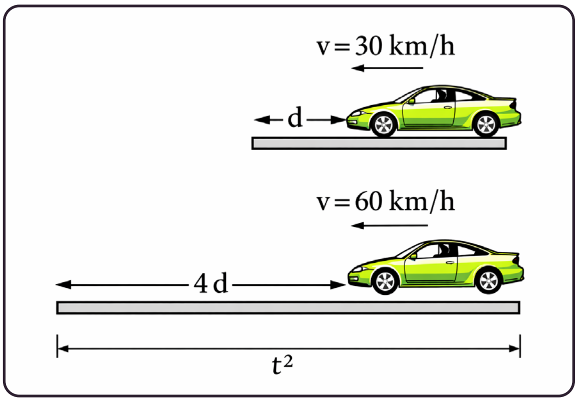
$$Fd = \frac{1}{2}mv^2$$

If (F) and (m) are constant, then:

$$d \propto v^2$$

* Example:

- At 30 km/h, stopping distance = d
- At 60 km/h, stopping distance = 4d



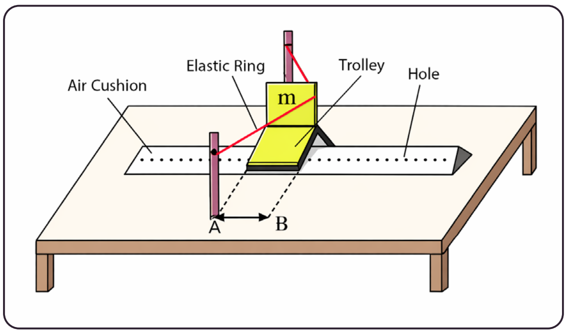
Think with Mr. Meligy

A car of mass 2000 kg is moving with a speed of 72 km/h. The kinetic energy of the car is equal to:

Practical Experiment: Determining the Kinetic Energy of a Body

- **Aim:**

To determine the kinetic energy of a moving body.



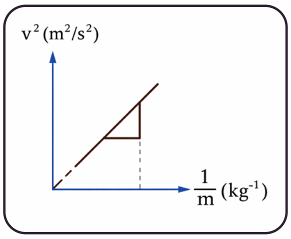
- **Apparatus**
  1. A trolley of mass m moving on an air track
  2. A rubber string
  3. A photoelectric cell
  4. An electronic timer or stopwatch
- **Procedure:**
  1. Pull the trolley from position A to B by stretching the rubber string.
  2. Release the trolley and allow it to move freely.
  3. Measure the time taken to travel distance AB.
  4. Calculate the speed using:

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

  5. Repeat the experiment for different masses and record results in this table:

Trolley mass m (kg)	Time t (s)	Velocity v (m/s)	$\frac{1}{m}$ (kg^{-1})	v^2 (m^2/s^2)
....	....	....	....	....
....	....	....	....	....
....	....	....	....	....

  6. Using the previous table, draw a graph showing the relationship between the square of the velocity v^2 on the vertical axis and the reciprocal of the mass $\frac{1}{m}$ on the horizontal axis. You will find that it is a straight line, as shown in the figure.



* From this, it is clear that:

$$v^2 \propto \frac{1}{m}$$

$\therefore$

$$\text{slope} = \frac{\Delta v^2}{\Delta(1/m)} = 2\text{KE}$$

Think with Mr. Meligy

1. A body has kinetic energy of 8 J and momentum of 4 Kg.m/s, calculate its velocity and mass.

2. If the speed of a body doubles and its mass becomes one quarter, then the kinetic energy

a) Doubles
b) Does not change
c) Becomes half
d) Becomes one quarter

3. The first body has double the mass of the second body, and its speed is half the speed of the second body.
The kinetic energy of the first body is ……… the kinetic energy of the second body.

a) Half
b) Double
c) One quarter
d) Four times

4. When the speed of a car doubles, its kinetic energy ………

a) Becomes half
b) Becomes double
c) Increases to four times
d) Remains constant

5. A body has a kinetic energy of 4 J.
If its speed doubles, its kinetic energy becomes ………

a) 0.8 J
b) 4 J
c) 8 J
d) 16 J

6. A car of mass 1200 kg starts moving from rest along a horizontal road. The work done by the resultant force acting on the car to increase its speed to 10 m/s is equal to:

a) 6×10^3 J
b) 4.5×10^4 J
c) 6×10^4 J
d) 9×10^4 J

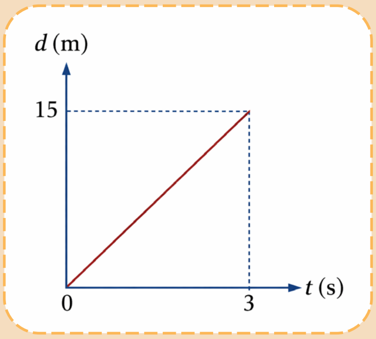
Think with Mr. Meligy

7. A car is moving along a straight line with a constant speed of 15 m/s. When the driver applies the brakes, the car comes to rest after traveling a distance of 20 m from the moment the brakes are applied .If the driver applies the brakes with the same braking force while the car is moving at a speed of 30 m/s, then the distance traveled by the car before stopping is:

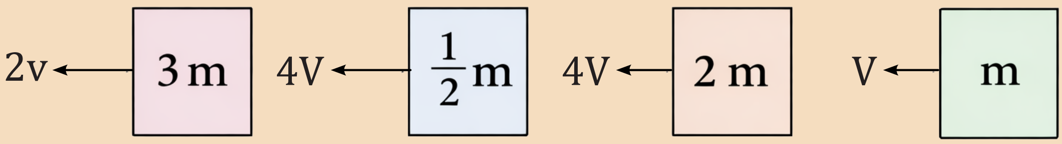
a) 5 m
b) 20 m
c) 40 m
d) 80 m

8. The adjacent graph shows the displacement–time (d–t) graph for the motion of a body. If the mass of the body is 10 kg, then the kinetic energy of this body is equal to:

a) 25 J
b) 50 J
c) 125 J
d) 225 J



9. Which of the following diagrams represents a body with the greatest kinetic energy?



(A) **(B)** **(C)** **(D)**

2. Potential Energy

Potential Energy

The energy possessed by a body due to its position or configuration.

When work is done on a body to change its position, this work is stored inside the body in the form of energy called potential energy (PE).

Types of Potential Energy

1. Elastic P.E

Stored when a spring or elastic string is stretched or compressed.

2. Gravitational P.E

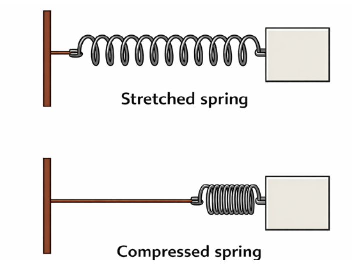
Related to the position of a body relative to the Earth's surface.

A. Elastic Potential Energy

Elastic P.E.

It's the energy stored in a body due to its extension or compression

Examples of elastic potential energy:



- **Stretching or compressing a spring:**
  - This causes its parts to store energy.
    This energy is called **elastic potential energy**.
  - When the force that caused the spring's extension or compression is removed, the spring does work in order to get rid of this stored energy, so that it returns to its stable (equilibrium) position.
- **Stretching a rubber string:**
  - Stretching a rubber string causes its particles to store elastic potential energy.
    When the force acting on the string is removed, the string moves in such a way as to release this energy and return to its stable (original) position.

Think with Mr. Meligy

What factors do you think affect the amount of potential energy stored in a spring when it is stretched or compressed?

B. Gravitational Potential Energy

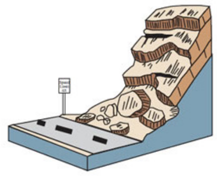
Gravitational P.E.

It's the energy possessed by a body due to its position relative to the Earth's surface (with respect to the gravitational field).

Examples of gravitational potential energy:

- **When a body is lifted above the Earth's surface:**
  - It gains gravitational potential energy;
    as the height of the body above the Earth's surface increases,
    the stored gravitational potential energy increases..

- **Landslips or rockslide:**
  - This means that it possessed gravitational potential energy, which was converted into kinetic energy during its fall.



Derivation of the Gravitational Potential Energy:

- When a body of mass **(m)** is lifted through a vertical height **(h)** above the Earth's surface, the work done **(W)** is given by the relation:

$$W = Fh$$

* Where **(F)** is the minimum force required to lift the body upward against the Earth's gravitational attraction, and it is equal to the body's weight **(w)**:

$$F = w = mg$$

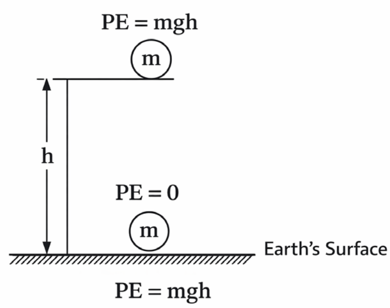
* Where (g) is the acceleration due to gravity and is approximately equal to **9.8 m/s²**.

* Therefore;

$$W = mgh$$

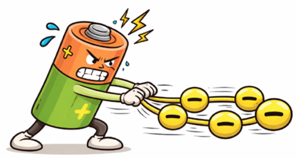
* The work done is stored inside the body in the form of potential energy **(PE)**.

$$\text{PE} = mgh$$



C Electrical Potential Energy

- **Electrical potential energy stored in the electrons inside the battery:**
  - Electrons move when the battery is connected and the circuit is closed. energy and return to its stable (original) position.



Factors affecting the Potential energy of a body:

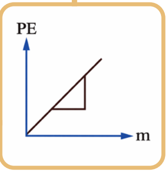
$$\mathrm{PE} = mgh$$

1. Mass of the Body:

At constant:
- Height above the Earth's surface.
- Gravitational acceleration.

The gravitational potential energy of a body is **directly proportional** to its **mass**.

$$\text{slope} = \frac{\Delta \mathrm{PE}}{\Delta m} = gh$$



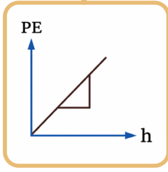
2. Gravitational Acceleration:

The acceleration due to gravity varies slightly with distance from the Earth's surface.

3. Height above the Earth's Surface:

At constant:
- Mass.
- Gravitational acceleration.

The gravitational potential energy of a body is **directly proportional** to its **height** above the Earth's surface

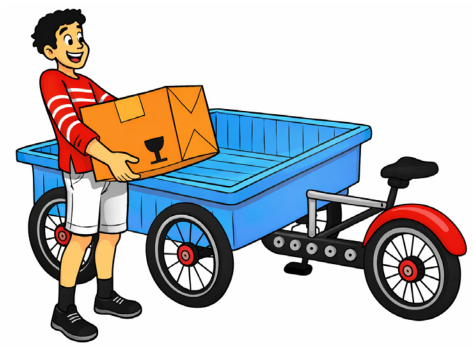


$$\text{slope} = \frac{\Delta \mathrm{PE}}{\Delta h} = mg = w$$

Life Application

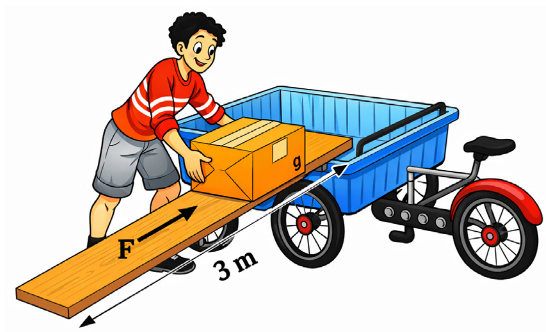
Case 1

- When lifting a box of weight 450 N vertically upward through a height of 1 m.



Case 2

- When lifting the same box through the same vertical height (1 m) using a smooth inclined plane of length 3 m.



The **work** done is the **same** in both cases

$$W = wh = 450 \times 1 = 450 \text{ J}$$

- **Force** Required (for **Vertical** Lifting) is **equal** to the weight of the box:

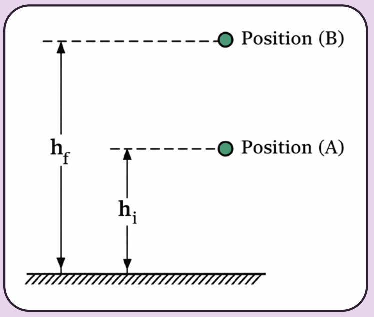
$$F = \frac{W}{d} = \frac{450}{1} = 450 \text{ N}$$

- **Force** Required (Using the **Inclined** Plane) is **less than** the weight of the box, but the box must be moved through a greater distance:

$$F = \frac{W}{d} = \frac{450}{3} = 150 \text{ N}$$

NOTES!

1. When a body of mass m is lifted from position (A) to position (B), as shown in the figure:



- The work done (W) on the body is equal to the change in the gravitational potential energy of the body, and is calculated from the relation:

$$W = mgh_f - mgh_i = mg(h_f - h_i) = mg\,\Delta h$$

* Therefore;

$$W = \Delta(\text{PE})$$

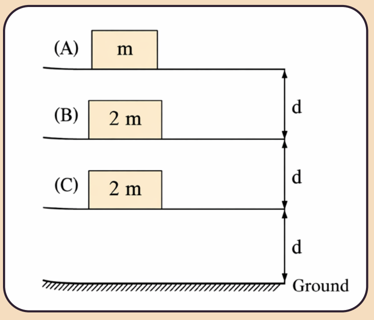
2. The gravitational potential energy of a person going up the stairs is the same as the gravitational potential energy of the same person going up in an elevator.

3. The gravitational potential energy of a body increases as its height above the Earth's surface increases.

4. The gravitational potential energy of a body is zero when it is on the Earth's surface or when it **return** back to the Earth's surface.

Think with Mr. Meligy

1. Three boxes (A, B, C) of different masses are placed on different heights, as shown in the figure. What is the correct order of the gravitational potential energy stored in each box?



A) A > B > C
B) C > B > A
C) B > A > C
D) B > C > A

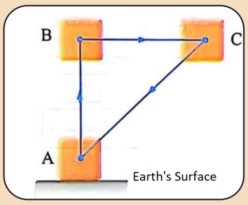
2. A body of mass 5 kg is thrown vertically upward with a speed of 80 m/s and reaches a height of 275 m.
Calculate its gravitational potential energy.
(Given that the acceleration due to gravity = 10 m/s²)

Think with Mr. Meligy

3. A body of mass 2 kg falls from a height of 120 m.
Calculate its gravitational potential energy in the following cases:

I) When it just starts to fall.
II) After it has fallen a distance of 80 m from the starting point.
III) Just before it reaches the Earth's surface.
(Given that the acceleration due to gravity = 10 m/s^2)

4. Calculate the work done against gravity to move a body of mass m along the path (ABCA). What do you conclude?



5. A man reaches his apartment by going up the stairs once and using the elevator another time. Which of the following statements is correct?

a) The man's gravitational potential energy is greater when using the stairs.
b) The man's gravitational potential energy is greater when using the elevator.
c) The man has no gravitational potential energy when using the elevator.
d) The man's gravitational potential energy is the same in both cases.

6. The energy stored in a compressed spring is ……… energy.

a) Potential
b) Kinetic
c) Nuclear
d) Repulsive

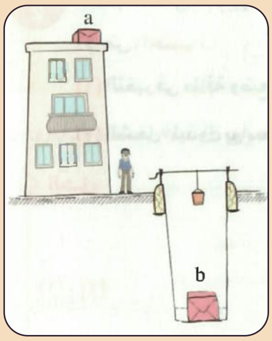
7. If a body is thrown vertically upward, which physical quantity becomes zero at the highest point?

a) Gravitational force
b) Acceleration
c) Potential energy
d) Speed

Think with Mr. Meligy

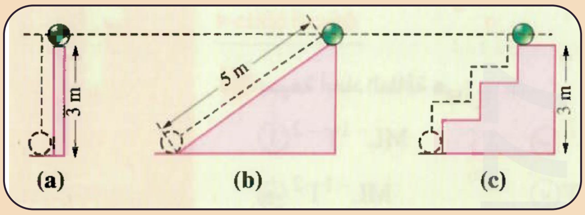
8. Two bodies (X) and (Y) have the same mass.
Body (X) is placed at a height h_x above the Earth's surface, and body (Y) is placed at a height h_y above the Moon's surface. If the two bodies have the same gravitational potential energy, then the ratio: (h_x/h_y) equals ....
(Given that the acceleration due to gravity on Earth is **six times** that on the Moon)

9. In the opposite figure, a person is standing on the Earth's surface. Next to him there is a building of height 10 m, and a well of depth 10 m below ground level.If a body (a) of mass 2 kg is placed on top of the building, and another body (b) of mass 4 kg is placed at the bottom of the well, then the gravitational potential energies of bodies (a) and (b) relative to the Earth's surface are ....
(Given that g = 10 m/s²)



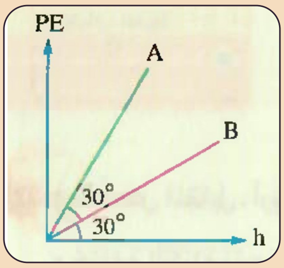
10. The opposite figures show three different paths (friction is neglected) that a ball at rest on the ground can follow to reach the same height.
In which path is the work done to lift the ball the greatest?

a) Path (a)
b) Path (b)
c) Path (c)
d) Equal in the three paths



11. The graph represents the relationship between gravitational potential energy (PE) and height (h) for two bodies A and B above the Earth's surface.
The ratio of their weights: (WA/WB) = ...

a) 2/1
b) 1/2
c) 1/3
d) 3/1



Ch 1 - L 3: Law of Conservation of Energy

- We learned before that energy is the ability (or potential) to do work.
- Energy exists in many different forms.
- For example:
  - Coal, gasoline, and other fuels contain stored chemical energy.
  - After chemical combustion, this energy can be converted into mechanical work.
  - This mechanical work appears in the motion of:
  - Cars
  - Trains
  - And other moving objects
- So, energy changes from one form to another, but it is never lost.

Law of Conservation of Energy

Energy cannot be created nor destroyed, but it can be converted from one form to another.

Example

- The burning of coal produces energy.
- This energy is converted into mechanical work.
- The mechanical work causes motion, such as:
  - Moving a train
- So:

$$\text{Chemical Energy} \rightarrow \text{Mechanical Work} \rightarrow \text{Motion}$$

Law of Conservation of Mechanical Energy

- When an object moves under the influence of gravity alone (neglecting air resistance), it is affected only by its weight.
- A body is subjected to a constant downward force equal to its weight (mg), and this type of motion is called free fall.
- The body moves with a uniform acceleration called the acceleration due to gravity (g).

Mechanical Energy

The sum of the potential energy and the kinetic energy of an object.

That is: $\text{Mechanical Energy} = \text{Potential Energy} + \text{Kinetic Energy}$

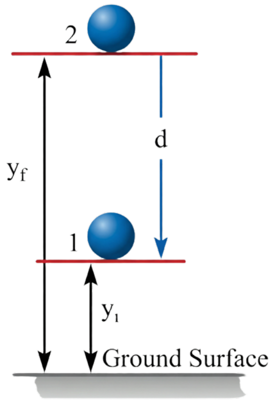
Law of Conservation of Mechanical Energy

The sum of the potential energy and the kinetic energy of an object remains constant.

Explanation Law of Conservation of Mechanical Energy

- If a body of mass m is thrown upward against the direction of gravity:
  - Its initial velocity is vi at point (1).
  - Its final velocity is vf at point (2), as shown in the figure.
- During this motion:
  - The **potential energy (PE)** increases as the height increases.
  - The **kinetic energy (KE)** decreases as the velocity decreases.
- So:
  - Increase in potential energy ↔ Decrease in kinetic energy

- At Earth's surface: $g=10 m/s^2$



Statement of the Law

- When an object moves under the influence of a force of a particular type, such as gravity or elastic force, the sum of its potential energy and kinetic energy remains constant.

Mathematical Form

- At point (1): $PE_1 + KE_1$
- At point (2): $PE_2 + KE_2$
- According to the law: $PE_1 + KE_1 = PE_2 + KE_2$
- Substituting the expressions: $mgy_f + \frac{1}{2}mv_f^2 = mgy_i + \frac{1}{2}mv_i^2$
- Rearranging: $\frac{1}{2}mv_i^2 - \frac{1}{2}mv_f^2 = mgy_f - mgy_i$
- Which means: $\Delta KE = -\Delta PE$

- That is:
  - Any decrease in kinetic energy is equal to the increase in potential energy, and vice versa.

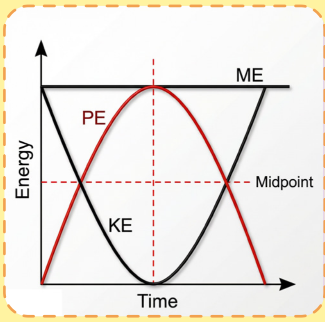
Important Conclusions

- The motion of a body is powered by mechanical energy.
- Energy changes between:
  - Potential Energy (PE)
  - Kinetic Energy (KE)
- But their **sum remains constant**.
-So: $\boxed{ME = PE + KE = \text{constant}}$

Note

- When an object is thrown vertically upward:
  - Its potential energy (PE) increases because its height increases.
  - Its kinetic energy (KE) decreases because its speed decreases.
  - Its mechanical energy (ME) remains constant, provided that air resistance is neglected.

$$ME=PE+KE=constant$$



- When an object falls downward:
  - Its potential energy (PE) decreases because its height decreases.
  - Its kinetic energy (KE) increases because its speed increases.
  - Its mechanical energy (ME) also remains constant.

$$ME=PE+KE=constant$$

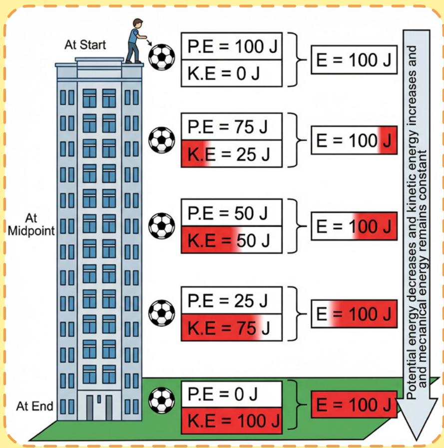
- At the Earth's surface:
  - The reference level is usually chosen so that:

$$PE=0$$

  - Therefore, the mechanical energy becomes:

$$ME=KE$$

- which means that all the mechanical energy is kinetic energy only.



- At the maximum height reached by the object:
  - The object momentarily stops, so:

$$KE=0$$

  - Therefore, the mechanical energy becomes:

$$ME=PE$$

- which means that all the mechanical energy is potential energy only.
- At the midpoint of the maximum height:
  - The potential energy equals the kinetic energy:

$$PE=KE$$

  - Since:

$$ME=PE+KE$$

  - then:

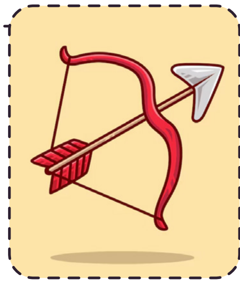
$$PE=KE=\frac{1}{2}ME$$

- So, at this point, each form of energy is half of the total mechanical energy.

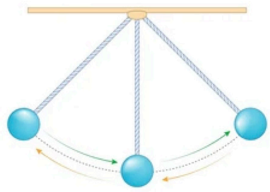
Examples of Conversion Between Potential Energy and Kinetic Energy

- Roller coaster:
  - At the top → maximum **potential energy**.
  - Going down → **potential energy** changes into **kinetic energy**.
- Pole vault (high jump):
  - Energy is stored as **potential energy** in the pole, then changes into **kinetic energy** to lift the athlete.v

More Examples



- Bow and arrow:
  - The **stretched bow stores potential energy**.
  - When **released**, it becomes **kinetic energy** of the **arrow**.
- Hammer:
  - When **raised** → **potential energy.**
  - When **falling** → **kinetic energy**.
- Pendulum:
  - At the **highest** point → **potential energy**.
  - At the **lowest** point → **kinetic energy**.
- Waterfall:
  - Water at a **height** → **potential energy.**
  - **Falling** water → **kinetic energy**.



Apply With Mr. Meligy

- A body is at rest at a height of 30 m above the Earth's surface. Its gravitational potential energy = 1470 J. When the body is released, it falls freely under the effect of gravity only, so air resistance is neglected. Given: $g=9.8 m/s^2$

Calculate:

- The kinetic energy of the body when it reaches a height of 20 m above the Earth's surface.
- The speed of the body at the moment it hits the Earth's surface.

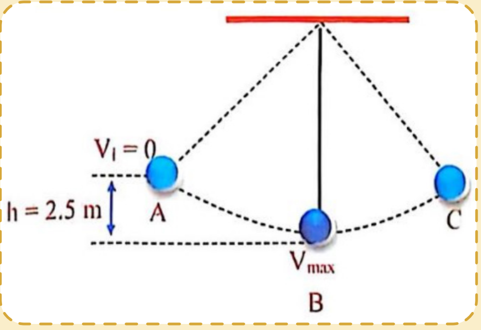
- If the object is thrown vertically downwards from the same height instead of being released from rest, which values calculated in the example would change?

Answer:

Apply With Mr. Meligy

- The figure opposite shows a ball suspended by a string swinging freely in a given plane. If the mass of the ball is m and air resistance is negligible, what is the maximum speed the ball reaches while swinging? ($g=9.8 m/s^2$)

Answer:



Note

- **Some students think** that the greater the mass of a ball, when it rolls down from the top of a smooth inclined plane, the faster it will reach the bottom.

- **But this belief is incorrect:** increasing the mass of the ball only increases its kinetic energy at the bottom of the incline, while its speed at the bottom remains constant and does not depend on mass, as long as the ball starts from the same height and moves on the same smooth inclined plane.

Apply With Mr. Meligy

- A body has potential energy equal to 100 J at its maximum height. What is its mechanical energy at the Earth's surface?

Answer:

- At the maximum displacement of a pendulum ball, how does the potential energy compare with the mechanical energy?

Answer:

- When a body is thrown vertically upwards, what happens to its mechanical energy (neglecting air resistance)?

Answer:

Investigating the Law of Conservation of Energy

- Purpose of the experiment is to prove that:
  - Mechanical energy = Potential energy + Kinetic energy = constant
- **Materials**:
  - Tennis ball
  - Adhesive tape
  - Digital balance
  - Stopwatch

- **Steps**:
  1. Measure the mass of the tennis ball using the digital balance in grams, then convert it into kilograms.
  2. Using adhesive tape, stick marks on the wall at different heights:
     - 1 m
     - 2 m
     - 2.5 m
  3. Drop the tennis ball from the height of 1 m and measure the time it takes to reach the ground using the stopwatch.
  4. Repeat this step three times and record the readings.
  5. Find the average time for this height.
  6. Repeat steps (3), (4), and (5) for the other heights (2 m and 2.5 m).
  7. Record the results in a table:

Height (m) h	Time (s) t		
	First attempt (t_1)	Second attempt (t_2)	Third attempt (t_3)
1			
2			
2.5			
Averege			

- **Calculations**:
  1. Calculate the potential energy at each height using the relation:

$$P.E. = mgh$$

  2. Calculate the final velocity of the ball just before hitting the ground using the first equation of motion:

$$V_e = V_i + at$$

  - Since the ball is dropped from rest:

$$V_i = 0$$

  - So:

$$V_e = at$$

  3. Calculate the kinetic energy at the moment of impact using:

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

  4. Record the values in another table:

Height (m) h	Potential Energy (P.E.)	Kinetic Energy (K.E.)
1		
2		
2.5		

- **Conclusion**:

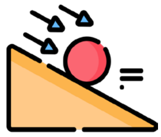
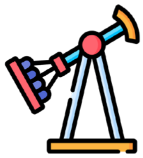
1. As the height increases, the potential energy increases.
2. The potential energy at the maximum height equals the kinetic energy at ground level.
   - That is:

     Mechanical energy = Potential energy + Kinetic energy = constant
3. This experiment proves the Law of Conservation of Mechanical Energy.

Chapter 2
Lesson 1

Oscillatory Motion

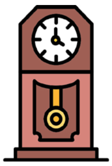
- You have studied that motion can be classified into two types:

	Translational Motion	Periodic Motion
Definition	- It is a motion between two different points. a starting point and an end point.	- It is a motion that gets repeated regularly through equal intervals of time.
Examples	- Motion in a straight line. - Motion in a curved path (Projectile motion). 	- Oscillatory motion. - Wave motion. 

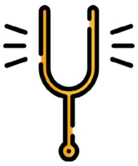
- In this chapter, we will study the wave motion, but first, we need to explore some important concepts through studying the oscillatory motion.

Oscillatory Motion

- If a body moves periodically on both sides of a fixed point. whether its motion is in a straight line or in a curved path, this motion is called an oscillatory motion such as the oscillation of:

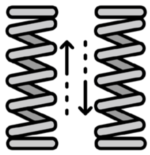


Simple pendulum (Clock pendulum)



Vibrating tuning fork

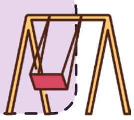
Vibrating string (Violin strings)



Plumb or bob suspended to a spring (Yoyo)

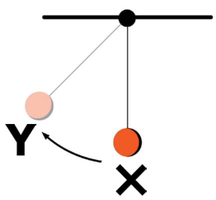
The Oscillatory Motion

It is the motion of a vibrating body about its rest position or its equilibrium position that gets repeated through equal intervals of time.



- In the following, we will study the oscillatory motion through studying the motion of a simple pendulum:

  * When a bob (suspended weight) of a pendulum is displaced sideways its resting position (point X) towards point Y, it will be subjected to a restoring force due to gravity, therefore when releasing the pendulum, it vibrates back and forth on both sides of its equilibrium position and repeats its motion in regular time intervals.



- To study oscillatory and wave motions, we need to explore some initial terms and concepts related to oscillatory motion, these physical concepts can be explained using a simple pendulum as follows:

1. Displacement (d)

- When a pendulum is oscillating, its bob moves sideways its rest position (**point X**) towards any point in its path of motion such as point **O or Q** where the distance between this point and the equilibrium position is called displacement **(d)**.

The Displacement of a Vibrating Body

It is the distance travelled by an oscillating body from its rest or equilibrium position at any moment.

- It is a **vector quantity.**
- Its measuring unit is **meter (m).**

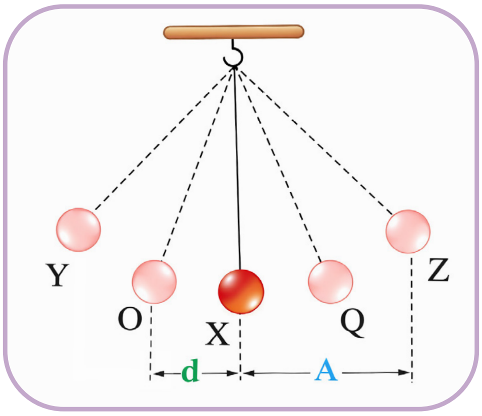
2. Amplitude (A)

- When the weight of the pendulum is displaced from **point X** to point **Y or Z** and left to oscillate, so it moves between the two points **(Y, Z)** where the maximum displacements of the pendulum away from its equilibrium position are equal in both sides **(XY = XZ)** and is called the amplitude **(A)**.

The Amplitude (A)

It is the maximum displacement of an oscillating body away from its rest or equilibrium position.

- It is a **scalar quantity.**
- Its measuring unit is **meter (m).**

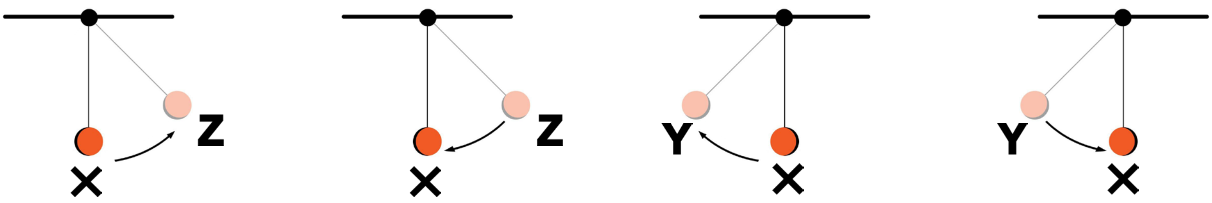


Apply With Mr. Meligy

- Can you state the difference between displacement andamplitude?

3. Complete Oscillation

- When observing the motion of the pendulum bob starting from point X in a certain direction until it returns back to the same point again moving in the same direction, so the pendulum has made a complete oscillation where its path of motion can be represented as follows:



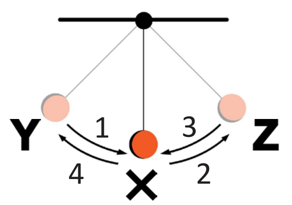
- Hence, we can notice that the pendulum bob passes by point X two successive times in the same direction with the same velocity, i.e. the body has the same phase.
- If the motion of the body has been observed starting from:

Point (Y) ⟶ **Point (Z)**

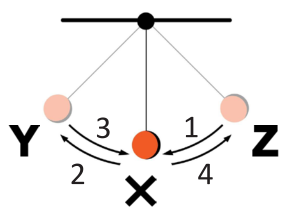
-It makes one complete oscillation at the instant of passing again through:

Point (Y) ⟶ **Point (Z)**

As follows



Y⟶X⟶Z⟶X⟶Y



Z⟶X⟶Y⟶X⟶Z

- Thus, the complete vibration (oscillation) can be defined as:

Complete Oscillation

It is the motion of an oscillating body during a period of time when it passes through a certain point in its path of motion two successive times in the same direction.

4. The Periodic Time (T)

The Periodic Time (T)

The time taken by a vibrating body to pass by the same point two successive times in the same direction (to make a complete oscillation).

Formula

$$T = \frac{t \text{ (Total time in seconds)}}{N \text{ (Number of complete oscillations)}} = 4 \times \text{The time of an amplitude}$$

The Measuring Unit

Second (s) which is equivalent to Hertz^{-1} (Hz^{-1})

5. The Frequency (υ)

The Frequency (υ)

The number of complete oscillations made by a vibrating body during one second.

Formula

$$\upsilon = \frac{\text{N (Number of complete oscillations)}}{\text{t (Total time in seconds)}} = \frac{1}{\text{4 x The time of an amplitude}}$$

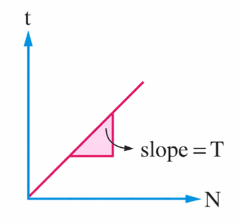
The Measuring Unit

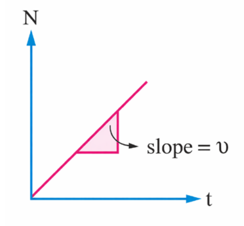
Hertz (Hz) which is equivalent to second^{-1} (s^{-1})

The Relation between Frequency (υ) and Periodic Time (T)

$T = \frac{t}{N} = \frac{1}{\upsilon}$ **OR** $\upsilon = \frac{N}{t} = \frac{1}{T}$

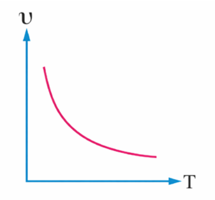
Frequency = The reciprocal of the periodic time, so frequency is inversely proportional to periodic time.



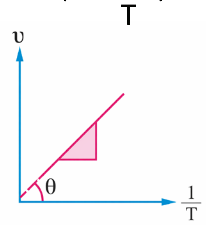


- From the previous, we can represent the graphs of:

Frequency VS Periodic Time (υ -T)



Frequency versus the reciprocal of the periodic time $(\upsilon - \frac{1}{T})$

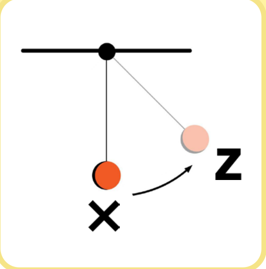


$$\text{Slope} = \frac{\Delta \upsilon}{\Delta (\frac{1}{T})} = 1$$

Notice that: The angle (θ) = 45° only if the two coordinates are drawn with the same scale.

Note

1. The motion of the pendulum bob from point X to point Z represents a quarter of a complete oscillation.
2. The time taken by the bob of the pendulum to move from point X to point Z equals the $\frac{1}{4}$ periodic time.
3. The displacement of the pendulum bob from point X to point Z equals the amplitude.



Phase

It is the position and direction of motion of a particle of the medium at a particular instant..

Apply With Mr. Meligy

1. A vibrating body performs ¼ of a complete oscillation in 1/80 of a second.

Calculate:

(a) The periodic time.

(b) The frequency.

2. A simple pendulum makes 1200 oscillations per minute, and in each complete oscillation it covers a distance of 20 cm.

Calculate:

(a) The amplitude of oscillation of the pendulum.

(b) The frequency.

(c) The periodic time.

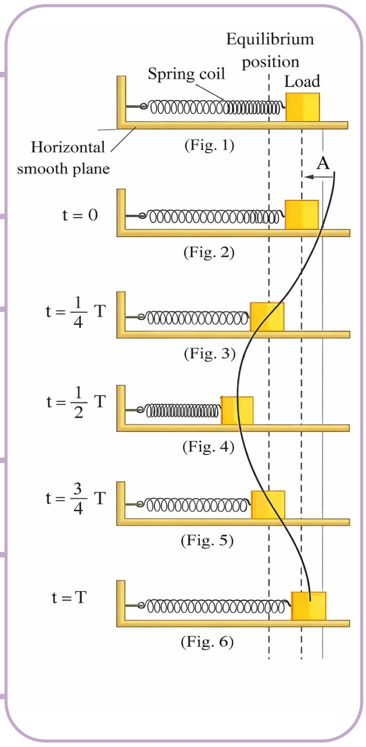
3. A vibrating body has a periodic time equal to ¼ of its frequency.

Calculate:

Its frequency and its periodic time.

Simple harmonic motion (SHM)

- Simple harmonic motion is a type of periodic motion, such as the motion of a simple pendulum or a body fixed by a spring coil, which can be represented by a sine curve (sine wave), as demonstrated by the following experiment:



Step One

- Put a load on a horizontal smooth plane and attach one end of a spring to the load and the other end to the wall (fig. 1).

Step Two

- At pulling the load to the right, the spring gets displaced a distance A and gets elongated (fig. 2).

Step Three

- When you release the load, the spring exerts a force on the load, pulling it towards the equilibrium position (fig. 3).

Step Four

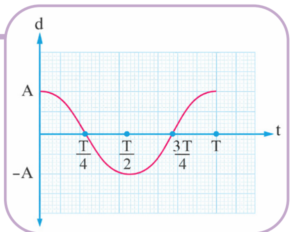
When the load reaches the equilibrium position, its velocity becomes a maximum value and the load exceeds the equilibrium position and completes its motion, due to its inertia hence the spring is compressed and the velocity of the load decreases till it reaches zero when the load reaches a displacement (A) equal to its initial displacement (A) in step (2) (fig. 4).

Step Four

When the spring is compressed, the force resulted from the compression of coil turns causes the load to return again to the equilibrium position at which its velocity becomes a maximum value (fig. 5), then the load passes the equilibrium position to make a displacement A for another time (fig. 6).

Step Four

This motion gets repeated in equal intervals of time, so the relation between the displacement of the load (d) from the equilibrium position and the time (t) can be represented by a sine wave function as shown in the opposite graph.



Apply With Mr. Meligy

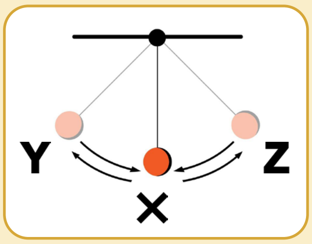
1. In the opposite figure: If the time taken by the pendulum to move from X to Z is 0.8 s, calculate:

(a) The periodic time.

(b) The frequency.

(c) The number of complete oscillations through 16 s.

(d) The time required to make 50 oscillations.



Answer:

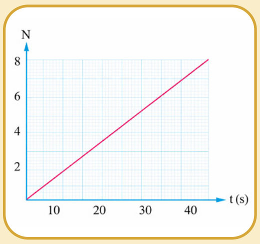
2. The opposite graph represents the relation between the number of complete oscillations (N) and the time (t), then the frequency of motion of this body equals

(a) 0.2 Hz.

(b) 2 Hz.

(c) 5 Hz.

(d) 40 Hz.



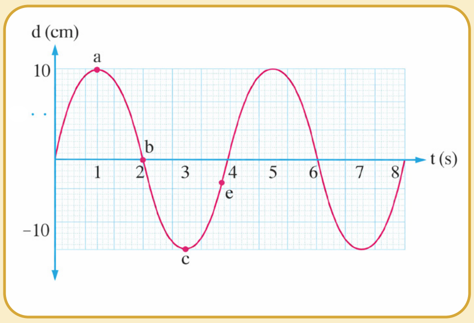
Answer:

Apply With Mr. Meligy

3. The opposite graph represents the relation between the displacement (d) of an oscillating body and the time (t), then Calculate:

(a) The amplitude.

(b) no. of oscillations in one minute.



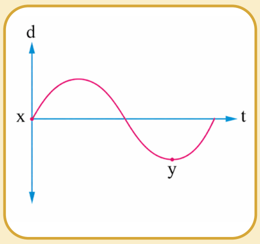
4. The opposite graph represents the relation between the displacement (d) and the time (t) for a mass tied to a spring and vibrating with frequency 60 Hz, then the time taken by the mass to pass between the two points x, y is.......... .

(a) 4×10^{-3} s.

(b) 8×10^{-3} s.

(c) 12.5×10^{-3} s.

(d) 25×10^{-3} s.



Energy transformations during the motion of simple pendulum

- Before studying the energy transformations in a simple pendulum, let us remember the concepts of kinetic energy, potential energy and mechanical energy:

Kinetic Energy

The energy possessed by the body due to its motion.
Example: A running man.

$KE = \frac{1}{2} mv^2$

Potential Energy

The energy stored in the body due to its state or position.
Example: Elongation and compression of a spring.

$PE = mgh$

Mechanical Energy

The summation of the potential energy and the kinetic energy of the body.
Example: Pole vault.

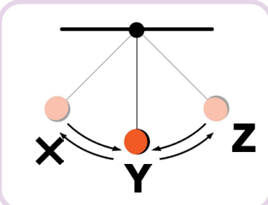
$E = PE + KE$

- In the following, we will discuss the transformations of energy in a simple pendulum so that when the pendulum bob shown in the opposite figure moves starting from position X, hence:

At Position X

- The pendulum bob has the maximum height relative to its equilibrium position.

$v = 0$, $KE = 0$, $E = PE$.



During its Motion from Position X to Y

- The vertical height of the pendulum bob decreases gradually, hence its potential energy decreases.
- Its kinetic energy increases as its velocity increases.

i.e. The potential energy gets converted gradually into kinetic energy since the mechanical energy is constant at all positions.

$E = KE\uparrow + PE\downarrow$

At Position Y (The Equilibrium Position)

- The potential energy of the bob has been completely converted into kinetic energy.
- The velocity of the bob at this position has a maximum value.

$PE = 0$, $v = v_{MAX}$, $E = KE$

During the Motion from Position Y to Z

- The height of the pendulum bob increases gradually from its equilibrium position, hence its potential energy increases.
- The velocity of the pendulum decreases gradually as its kinetic energy decreases, hence the kinetic energy gets converted gradually into potential energy since the mechanical energy is constant at all positions.

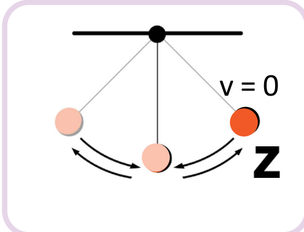
$$E = PE\uparrow + KE\downarrow$$

At Position Z

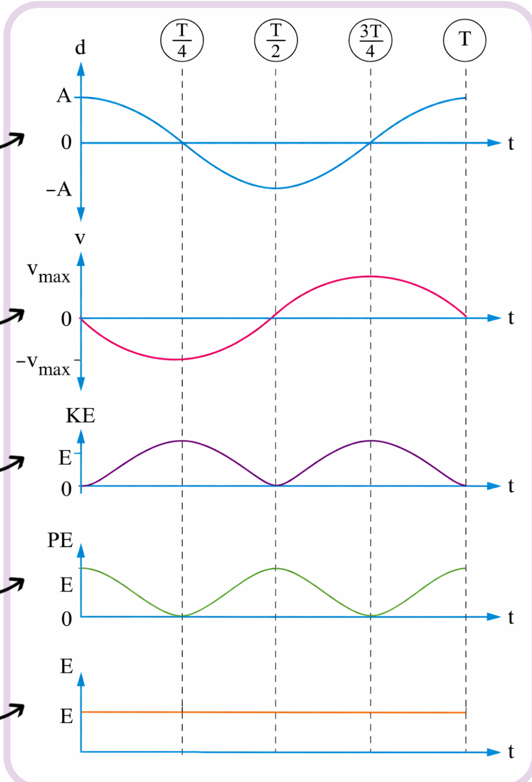
- The kinetic energy gets converted completely into potential energy.

$$v = 0,\quad KE = 0,\quad E = PE$$

- In the opposite figure, when the pendulum moves starting from point Z, the following graphs represent the variations of some physical quantities related to the motion of this pendulum as time (t) passes through one complete oscillation:

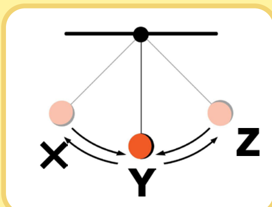


1. The displacement (d) away from the equilibrium position versus time (t).
2. The velocity (v) versus time (t).
3. The kinetic energy (KE) versus time (t).
4. The potential energy (PE) versus time (t).
5. The mechanical energy (E) versus time (t).



Note

- In the opposite pendulum when the pendulum bob is displaced from point Y to X then left to vibrate;
  1. The velocity of the pendulum at point Y is a maximum value.
  2. The velocity of the pendulum at each of the two points X and Z vanishes.



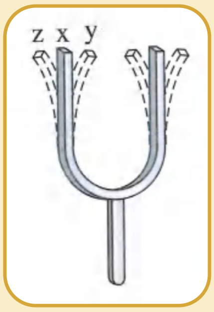
- Hence, we can define the amplitude as follows:

The Amplitude

It is the distance between two successive points in the path of motion of an oscillating body whose velocity becomes a maximum value at one of them and zero at the other.

Apply With Mr. Meligy

1. The opposite figure represents an oscillating tuning fork, so the speed of the fork's arm increases then decreases when it moves from.......... .



(a) z to x.

(b) x to y.

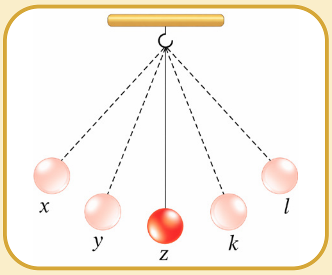
(c) y to z.

(d) x to z then to x.

Answer:

2. The opposite figure shows the motion of a simple pendulum where xy = yz = zk = kl. If the pendulum takes time (t) to move from x to y,

(1) the periodic time is.......... .



(a) a equal to 8 t.

(b) less than 8 t.

(c) greater than 8 t.

(d) indeterminable.

Apply With Mr. Meligy

3. The product of frequency and periodic time equals ....

(a) Amplitude of oscillation

(b) One complete oscillation

(c) Frequency

(d) Unity (one)

4. When the source vibrates with a certain frequency, the particles of the medium vibrate......

(a) With a different frequency

(b) With the same frequency

(c) With a frequency smaller than the source frequency

(d) With a gradually decreasing frequency

5. At the maximum displacement of the vibrating body, the speed of the vibrating body is ....

(a) Maximum speed

(b) Half of the maximum speed

(c) Zero

(d) One third of the maximum speed

6.If the time taken by a vibrating body to perform one complete oscillation is 0.1 s, then the number of complete oscillations performed by the vibrating body in 100 s is .... oscillations.

(a) 10

(b) 100

(c) 1000

(d) 10000

7. Increasing the amplitude of a wave propagating in a medium leads to ....

(a) Increase in speed

(b) Increase in frequency

(c) Increase in wavelength

(d) Increase in intensity

8. Frequency is measured in all of the following units except ....

(a) s-1

(b) cycle/s

(c) s

(d) Hz

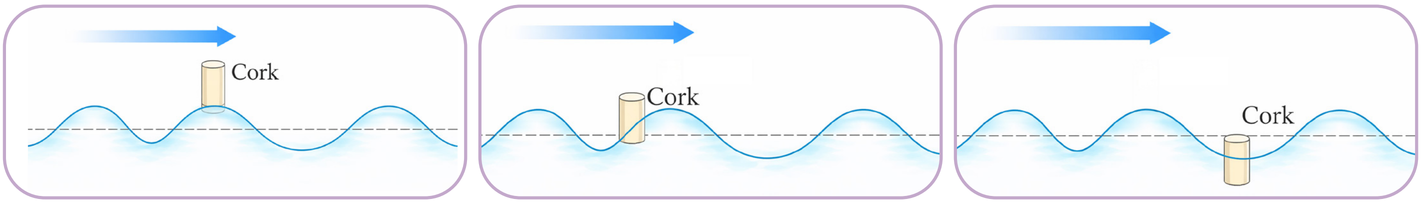
Chapter 2
Lesson 2
Wave Motion

- **When a stone is dropped into water (as in the figure):**
  1. The collision of the stone with water becomes a source of disturbance.
  2. This disturbance propagates on the surface of water in the shape of uniform concentric circles, whose center is the position at which the stone falls.
  3. These circles transfer energy in the same direction of their propagation.
  4. These circles are called water waves and their propagation represents a wave motion.
- **From the previous, we can define the wave as follows:**

The Wave

It is a disturbance that propagates and transfers energy in the direction of propagation.

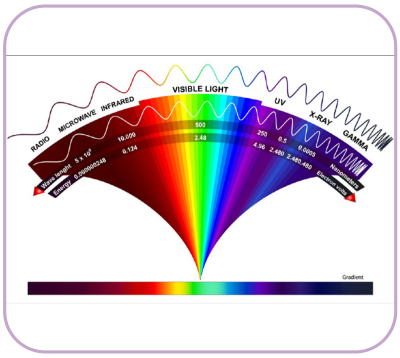
- When a wave propagates in a medium, the particles of the medium vibrate about their equilibrium positions without moving away from their equilibrium positions.
- This becomes clear when placing a piece of cork on the surface of water and causing a disturbance in the water.
- We find that the piece of cork moves up and down without moving from its position as in the following figures but the waves propagate in the water and thus energy is transmitted.



- Many forms of waves exist around us, some waves can be seen such as water waves, other waves cannot be seen but we can detect them such as radio and X-ray waves.
- In this chapter we will study waves, and the **two main types** of waves are :

1. Mechanical Waves

2. Electromagnetic Waves



1. Mechanical Waves

Source:

- Mechanical waves are produced due to the vibration of a body in a medium, so the vibration (disturbance) propagates from the body through the medium.

Propagation :

- They need a medium through which they can propagate.

Examples :

- Water waves. - Sound waves. - Waves that propagate in strings during their vibrations.

Conditions of Obtaining Mechanical Waves:

1. The existence of a vibrating source:

- Like:
  * A vibrating string
  * The vibrating arms of a tuning fork.

2. The occurrence of a disturbance that transfers from the source to the medium:

- Like:
  * The formed disturbances when the arms of a tuning fork gets vibrating.

3. The existence of a medium to transmit the disturbance:

- Mechanical waves (like sound waves) need a medium through which they can travel because the particles of the medium vibrate about their equilibrium positions without moving away from their positions to transfer the mechanical energy of the wave, so they can not propagate in space.

NOTES!

- Since sound is a mechanical wave, it cannot propagate in empty space, so:

1. The sounds of cosmic explosions that happen in the outer space cannot be heard.
2. Astronauts use wireless devices to communicate in space.

Types of Mechanical Waves

1. Transverse Waves
2. Longitudinal Waves

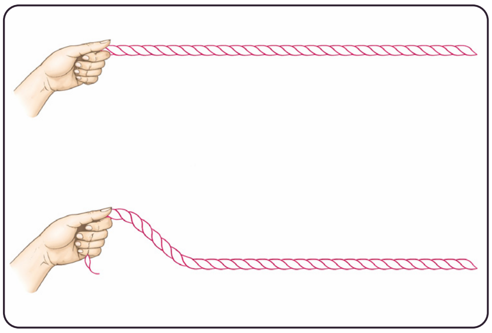
1. Transverse Waves

- To describe the nature of transverse waves, we carry out the following experiment:

Practical Experiment (1)

- **Step:**

1. Bring a long rope and fix its end to a vertical wall.
2. Hold the other end of the rope with your hand.
3. Move the end of the rope with your hand up and return it to the original position once.



- **Observation:**

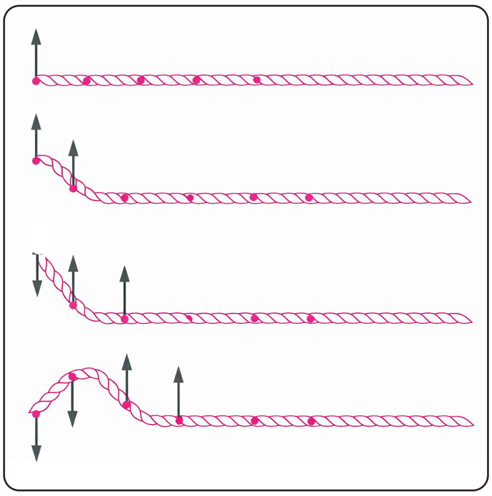
- A pulse wave is generated through the rope.

A Pulse

It is a single disturbance in the form of a half wave.

- **Explanation:**

1. Energy gets transferred from the source to its adjacent part in the rope, hence this part moves upward.
2. The tension force in the rope brings this part downwards, hence the energy gets transferred to next adjacent part, so this part moves upward and so on.
3. The parts of the rope vibrate up and down successively.



- **Step :**

4. Continue in moving the end of the rope up and down with a constant rate.

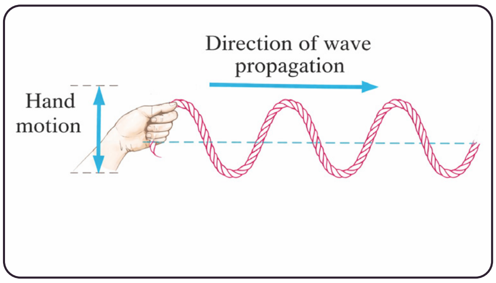
- **Observation:**

- The end of the rope moves upwards and downwards in a simple harmonic motion that transfers along the rope as continuous wave pulses (transverse wave train).

- **Conclusion:**

(1) The direction of propagation of the wave through the rope is:

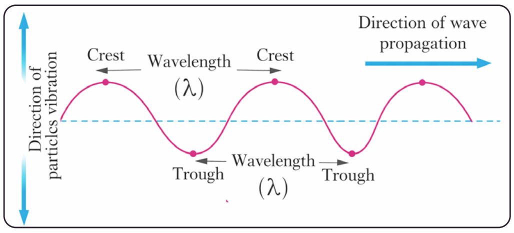
- The direction of energy propagation.
- Perpendicular to the direction of motion (vibration) of the medium particles (the rope) about their equilibrium positions.



A transverse Wave:

It is a wave in which the directions of medium particles vibrations about their equilibrium positions are perpendicular to the direction of wave propagation.

(2) The transverse wave consists of crests and troughs as shown in the following figure:



1. Crest:

- The position that represents the maximum displacement of the medium particles in the positive direction (positive pulse).

2. Trough:

- The position that represents the maximum displacement of the medium particles in the negative direction (negative pulse).

3. Wavelength (λ):

- The distance between two successive crests or two successive troughs or any two successive points along the direction of propagation that are in the same phase is called the wavelength of the transverse wave (λ).

NOTES!

- A medium particle has the same phase at a definite position, when it passes through that position two successive times with the same velocity (including magnitude and direction).

Examples of Transverse Waves:

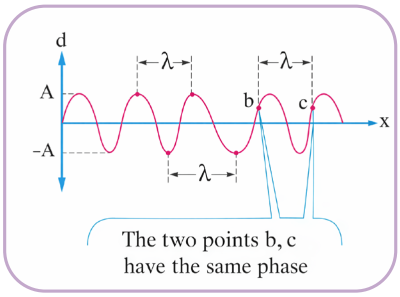
1. Water surface waves.
2. Battle rope waves.

Graphical Representation of Transverse Waves:

- The motion of the particles of the medium in which the transverse wave propagates can be represented through the graphs of:

1. The displacement of the particles of the medium (d) versus the horizontal distance (x) covered by the wave at a certain instant.

***From this,** we obtain a sine wave curve:

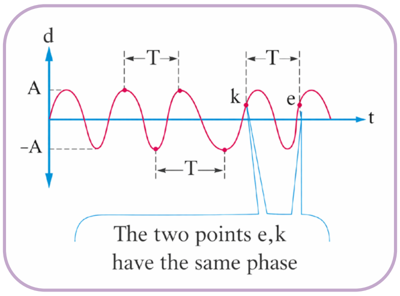


*** From this** sine curve we find that:

$$\lambda = \frac{x \text{ (Total distance)}}{\text{N (Number of waves)}}$$

2. The displacement of one of the medium particles (d) versus time (t).

***From this,** we obtain a sine wave curve:



*** From this** sine curve we find that:

$$\upsilon = \frac{\text{N (Number of waves)}}{\text{t (Time in seconds)}} = \frac{1}{T}$$

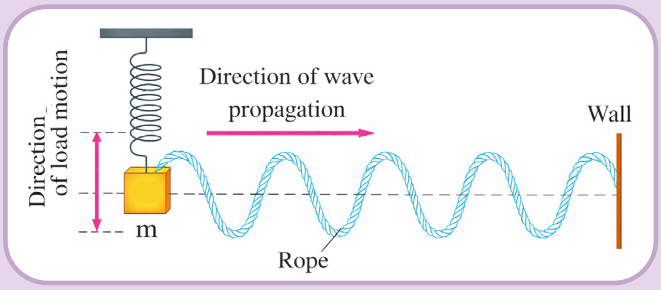
- From the previous, we can define the wave amplitude (A) as follows:

The Wave Amplitude (A)

It is the maximum displacement of the vibrating medium particles away from their equilibrium positions.

NOTES!

1. Transverse waves can be obtained by using a load held to a vertical spring that can vibrate up and down about its equilibrium position. The load is attached to a horizontal rope whose other end is fixed to a vertical wall, as the following figure:



In such case, the frequency of the transverse wave that propagates in the rope equals the frequency of the oscillatory motion of the load that is suspended to the spring.

(2) The amplitude of a transverse wave propagating in a stretched string depends on the work done by the vibrating source (the hand or a vibrating load) and that work gets transferred through the particles of the string in the form of:

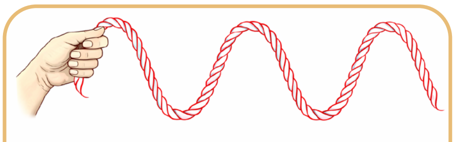
- Potential energy as a tension in the rope.
- Kinetic energy as a vibration in the rope.

(3) The amplitude of the wave doesn't depend on any of the frequency or the wavelength of the wave.

Enrichment Information

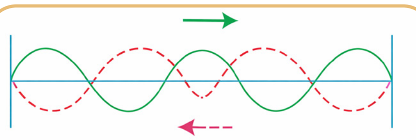
- **Travelling waves and standing waves can be distinguished from each other as follows:**

1. Travelling wave:
   - The wave that propagates in one direction continuously moving away from its source.



A travelling wave in a rope

2. Standing wave:
   - The wave that results from the overlap of waves that get reflected repetitively between two points.

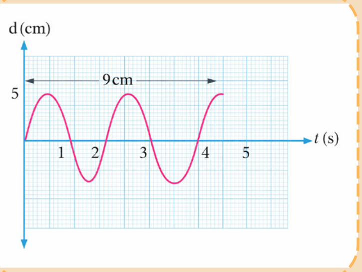


A standing wave on a string stretched between two clamps

Think with Mr. Meligy

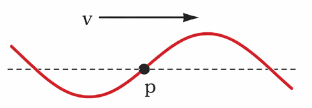
1. The opposite graph represents a transverse wave, calculate:

a) The amplitude.
b) The frequency.
c) The periodic time.
d) The wavelength.

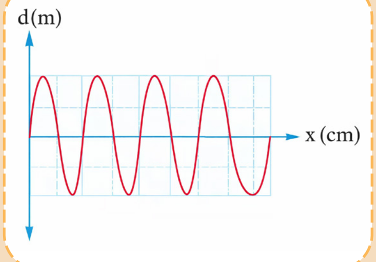


2. In the adjacent figure, transverse waves are moving toward the right. What is the direction of the instantaneous velocity of the particles of the medium at point (P)?

(a) Upward
(b) Downward
(c) To the right
(d) To the left



3. The opposite graph represents the relation between the displacement (d) of the medium particles in which a transverse wave is travelling at a certain instant and the distance (x) travelled by the wave, if the distance between the first trough and the seventh crest is 5.5 cm, the wavelength of the wave equals.........

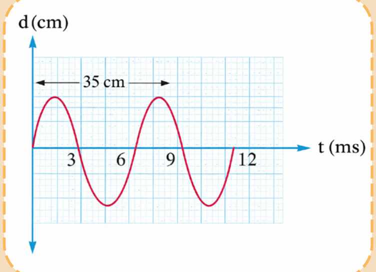


a) 5.5 cm.
b) 5 cm.
c) 1 cm.
d) 0.5 cm.

4. The opposite graph represents a transverse wave,

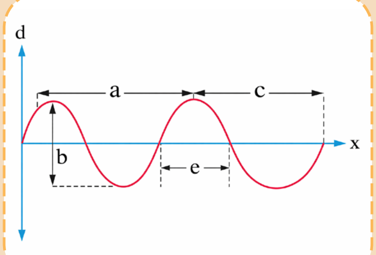
calculate:

a) The periodic time.
b) The frequency.
c) The wavelength.



Think with Mr. Meligy

5. The opposite graph represents the relation between the displacement (d) and the time (t) for a transverse wave, then:



(i) The wavelength for this wave is........ .

a) 2 c.
b) 0.5 b.
c) 2e.
d) 2 a.

(ii) The amplitude of this wave is................. .

a) c. b) e. c) 0.5 a. d) 0.5 b.

(iii) Increasing the wavelength to the double leads to.............. .

a) 2 c.
b) 0.5 b.
c) 2e.
d) 2 a

6. A transverse wave has a distance between the first crest and the sixteenth crest equal to 105 m, and the time interval between the passage of the first crest and the sixteenth crest is 0.375 s.

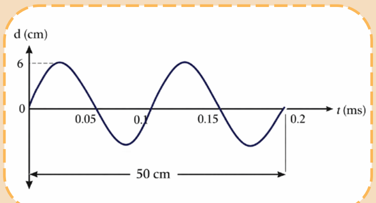
Calculate:

1. The wavelength. 2. The wave frequency. 3. The periodic time.

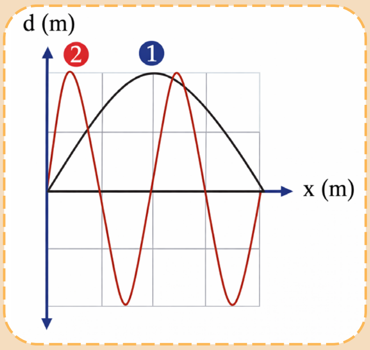
Think with Mr. Meligy

7. From the adjacent figure, calculate:

1. The wavelength. **2. The frequency.** **3. The amplitude of oscillation.**



8. (i) The adjacent figure represents two transverse waves. The ratio between their wavelengths $\frac{\lambda_1}{\lambda_2}$ is ....

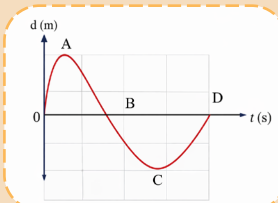


(a) 1/2
(b) 2/1
(c) 1/4
(d) 4/1

(ii) In the adjacent figure, the ratio between the amplitudes of the two waves $\frac{A_1}{A_2}$ is..........

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

9. The wave shown in the figure has a frequency of 25 Hz.
The time interval between points B and C in the figure is ....



(a) $\frac{2}{25}$ s
(b) $\frac{1}{25}$ s
(c) $\frac{1}{50}$ s
(d) $\frac{1}{100}$ s

2. Longitudinal Waves

- To describe the nature of longitudinal waves, we carry out the following experiment:

Practical Experiment (2)

- **Steps and observations:**

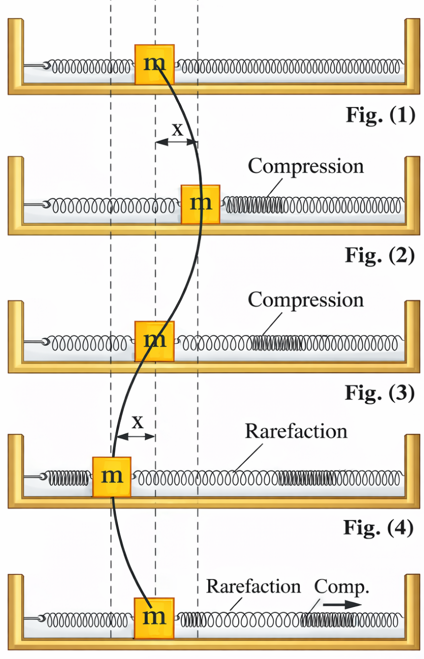


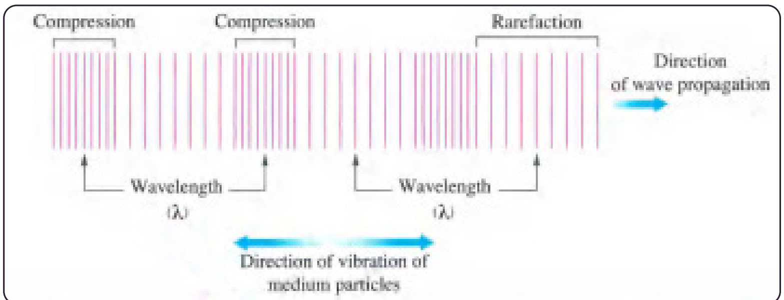
Fig. (1) Fig. (2) Fig. (3) Fig. (4) Fig. (5)

1. Put a load (m) on a smooth horizontal plane and attach the load between two springs, one of them is longer than the other and each of them is attached to a wall (figure 1).
2. Pull the load to a distance x to the right side.
3. A part of the spring which is adjacent to the load gets compressed at the right side forming a pulse of a compression (figure 2).
4. Leave the load free, so the load returns to its equilibrium position by the effect of the force generated in the spring at the left of the load, while the pulse of compression travels through the spring to the right of the load (figure 3).
5. The load exceeds the equilibrium position, moving to the left, creating a rarefaction in the spring towards the right (figure 4).
6. The motion of the load gets repeated to the right and the rarefaction pulse travels to the right (figure 5).

- **Conclusion:**

1. During the vibration of the load, a wave propagates in the spring where the direction of vibration of the medium particles is along the same line of the wave propagation, such wave is called longitudinal wave.
2. The longitudinal wave consists of a group of compressions and rarefactions which transfer along the spring as shown in the following figure:

   1. Compression:
   - The region where the particles of the medium become close to each other.



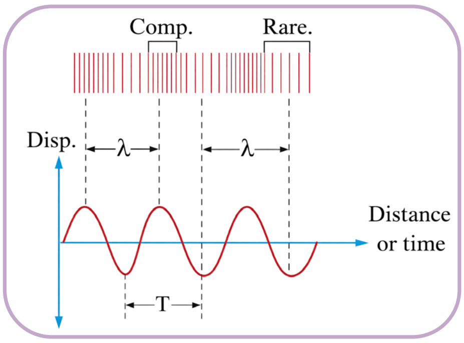
2. Rarefaction:
   - The region where the particles of the medium become far from each other.
3. Wavelength (λ):
   - The distance between the centers of two successive compressions. two successive rarefactions or any two successive points along the direction of propagation that are in the same phase is called the wavelength of the longitudinal wave.

Examples of Longitudinal Waves:

1. Sound waves in gases.
2. Waves inside water.

Graphical Representation of Longitudinal Waves:

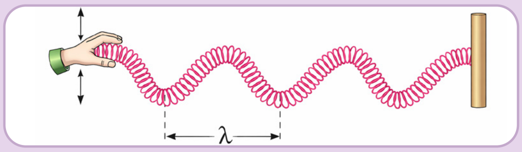
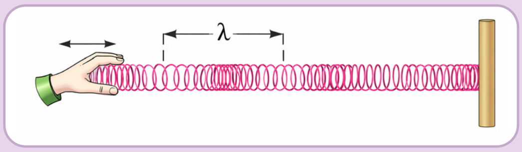
- When we plot the relation between the displacement of the medium particles and the distance travelled by the wave at a given instant or between the displacement and the time for the motion of the medium particles in which the longitudinal wave propagates, we get a sine wave curve as shown in the opposite figure, hence all the concepts and the laws of the transverse wave are applicable to this curve.



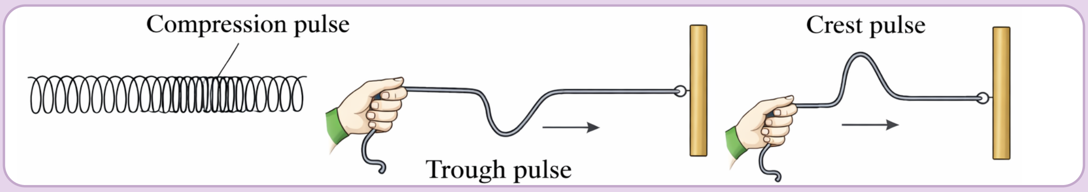
NOTES!

1. We can get transverse and longitudinal waves using a long spring coil:

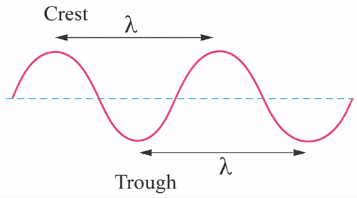
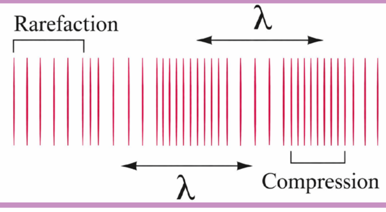
- A transverse wave or a longitudinal wave can be produced in a long spring coil depending on the direction of the vibration of the wave source (a vibrating body) where the particles of the medium vibrate in the same way as the vibrating source, when fixing a spring coil horizontally from one of its ends while moving the other end of the coil:

Up and Down	Back and Forth
The Formed Wave Will Be	
Transverse	Longitudinal
	

2. The pulse can be defined as a single disturbance forming a single half wave such as a single crest, a single trough, a single compression or a single rarefaction.



- From the previous, we can compare between the two types of mechanical waves (transverse and longitudinal) as follows:

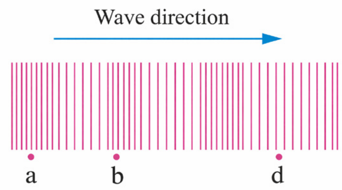
	Transverse Wave	Longitudinal Wave
Wave Form		
Direction of Vibration of Medium Particles	- Perpendicular to the direction of wave propagation.	- Along the line of wave propagation.
Wavelength	- The distance between two successive crests or two successive troughs.	- The distance between the centers of two successive compressions or the centers of two successive rarefactions.
Examples	- Propagating waves in strings. - Waves on water surface.	- Sound waves in gases. - Waves inside water.

Think with Mr. Meligy

1. The opposite figure represents a longitudinal wave. If the distance between the two points a and b is 1.7 m and the time taken by the wave to travel from (c) to (d) is 0.015 s, calculate:

(a) The wavelength of the longitudinal wave.

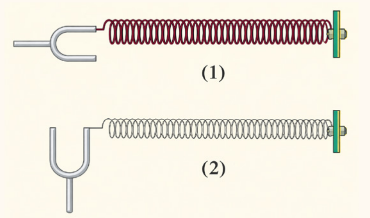
(b) The frequency of the wave.



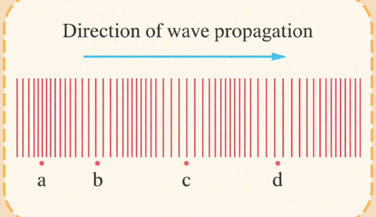
Think with Mr. Meligy

3. The opposite figures show two tuning forks attached to two springs.

What is the type of wave that will be produced in each case when the forks vibrate?



4. The opposite figure represents a longitudinal wave, then the ratio between the two distances $\frac{X_{ac}}{X_{de}}$ is................ .



a) $\frac{1}{2}$

b) $\frac{2}{1}$

c) $\frac{3}{2}$

d) $\frac{3}{1}$

5. The distance traveled by the wave during one periodic time (T) equals ....

(a) One quarter of a wavelength
(b) Half a wavelength
(c) Double the wavelength
(d) The wavelength

6. The distance between a compression center and the following rarefaction center is 8 cm. The wavelength equals ....

(a) 4 cm
(b) 8 cm
(c) 16 cm
(d) 32 cm

Think with Mr. Meligy

7. Half the vertical distance between the crest and the trough of a transverse wave is called ....

(a) Frequency
(b) Wavelength
(c) Displacement
(d) Amplitude of oscillation

8. If the horizontal distance between a crest and the following trough is 10 cm, then the wavelength equals .... cm.

(a) 5 cm
(b) 10 cm
(c) 20 cm
(d) 40 cm

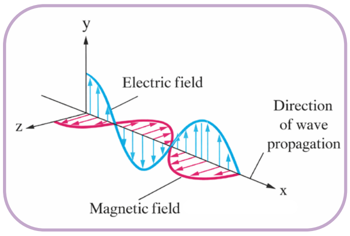
9. If the distance between the first crest and the fifth crest of a transverse wave is 24 cm, then its wavelength equals ....

(a) 6 cm
(b) 12 cm
(c) 4 cm
(d) 14 cm

2. Electromagnetic Waves

Concept:

- They are waves that originate from the vibration of electric and magnetic fields with the same frequency where both fields are in the same phase perpendicular to each other and to the direction of their propagation.



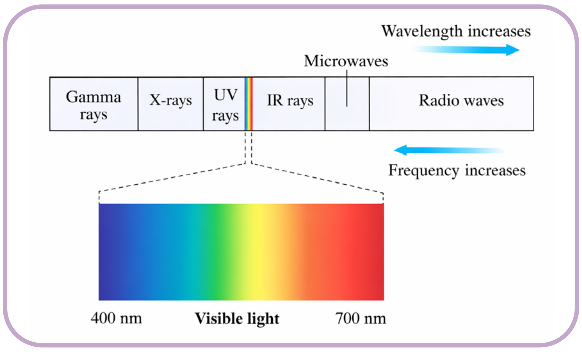
Propagation:

- They travel either in physical media or in empty space where their speed in space reaches its maximum constant value that equals 3×10^8 m/s.

Types:

- Transverse waves only.

Electromagnetic Spectrum:



- From the previous, we can compare between mechanical and electromagnetic waves as follows:

	Mechanical Waves	Electromagnetic Waves
Concept	- Waves originated from the vibration of medium particles either perpendicular to the direction of wave propagation or along the line of the wave propagation.	- Waves originated from the vibration of electric and magnetic fields perpendicular to each other and to the direction of the wave propagation.
Propagation	- They require a medium through which they can propagate.	- They don't require a medium to propagate, so they can travel through empty space.
Types	- Transverse and longitudinal waves.	- Transverse waves only.
Examples	• Water waves. • Sound waves. • Propagating waves in strings.	• Radio waves. • X-ray waves. • Light waves.

Wave Speed (v)

It is the distance travelled by the wave in one second in the direction of propagation.

Deducing The Speed of Propagation of The Waves:

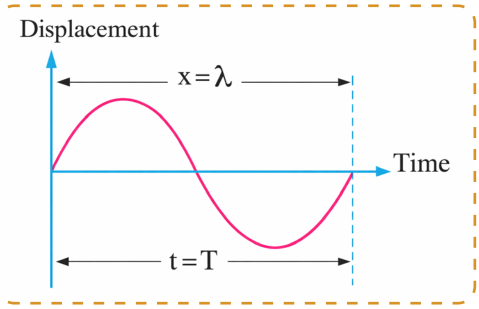
- If a wave has travelled a distance x through a time interval t,

the speed of the wave (v) is calculated from the relation:

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

- So, if the distance equals its wavelength (λ),

then the wave takes a time equal to its periodic time (T).



$$\therefore x = \lambda, t = T$$

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

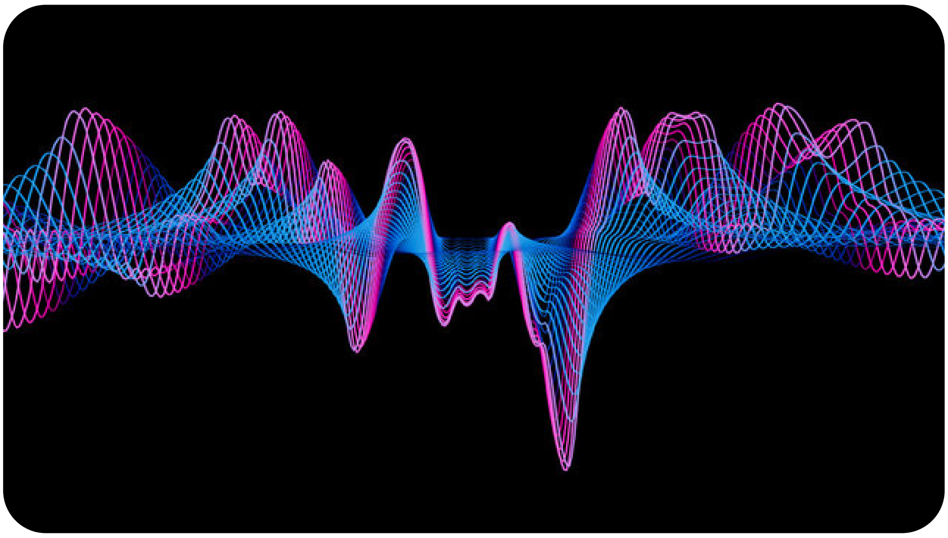
$$\therefore \upsilon = \frac{1}{T}$$

$$\therefore v = \lambda\upsilon$$

- This relation is applicable to all types of waves (mechanical or electromagnetic).

The Factors That Affect the Speed of a Wave in a Medium:

1. The type of wave (mechanical or electromagnetic).
2. Type of the medium material (solid, liquid, gas).
3. The physical properties of the medium material (such as the density, elasticity, temperature).
4. It does not depend on the frequency of the wave, its wavelength or its amplitude.



NOTES!

When applying the relation of $v = \lambda \upsilon$ on:

(A) Two waves of the same type propagating in the same medium.

(B) A wave travelling from one medium to another.

(A)

- The speed of the two waves will be the same because the wave speed depends only on the medium type.

$$v_1 = v_2$$
$$\lambda_1 \upsilon_1 = \lambda_2 \upsilon_2$$
$$\therefore \frac{\lambda_1}{\lambda_2} = \frac{\upsilon_2}{\upsilon_1}$$

(B)

- The frequency of the wave remains constant because the wave frequency depends on the source frequency.

$$\upsilon_1 = \upsilon_2$$
$$\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2}$$
$$\therefore \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$$

Where

- λ_1 and υ_1 are the wavelength and the frequency of the first wave, λ_2 and υ_2 are the wavelength and the frequency of the second wave.

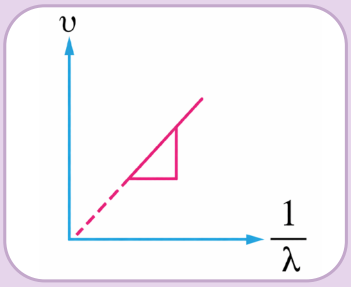
- λ_1 and v_1 are the wavelength and the speed in the first medium, λ_2 and v_2 are the wavelength and the speed in the second medium.

i.e.

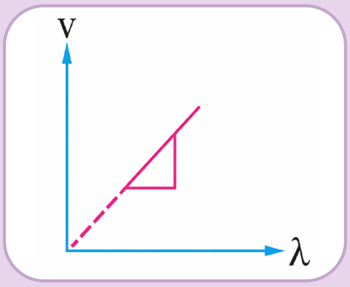
- The wavelength is inversely proportional to the frequency (υ) at constant wave speed (v).

- The wavelength is directly proportional to the wave speed (v) at constant frequency (υ).

Graphical Representation



$$\frac{\Delta \upsilon}{\Delta (\frac{1}{\lambda})} = v$$

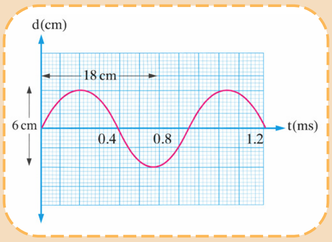


$$\frac{\Delta v}{\Delta \lambda} = \upsilon$$

Think with Mr. Meligy

1. Electromagnetic waves propagate in space at a speed c = 3x10^{8}m/s. If the wavelength of an electromagnetic wave is 5000 Å, what is the frequency of this wave?

(Given that: 1 Angstrom (Å) = 10^{-10}m)



2. The opposite graph represents the relation between the displacement (d) of one of the particles of a medium and the time (t) for a longitudinal wave propagating in this medium, then the speed of propagation of this wave in the medium equals................ .

a) 150 m/s.
b) 200 m/s.
c) 225 m/s.
d) 300 m/s.

3. A sound wave of wavelength λ propagates in air with a speed of 330 m/s, if it has travelled to another medium in which its speed is 990 m/s, then its wavelength increases by............ .

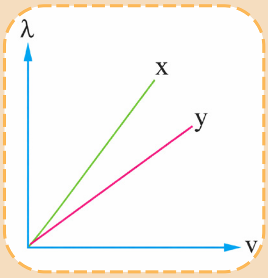
a) 1 λ. b) 2 λ. c) 3 λ. d) 4 λ.

4. Two tones, whose frequencies are 340 Hz and 212 Hz, travel in air. If the wavelength of one of them is longer than the other by 60 cm, then the speed of sound in air equals................ .

a) 337.9 m/s.
b) 430 m/s.
c) 342.1 m/s.
d) 343.2 m/s.

Think with Mr. Meligy

5. The opposite graph represents the relation between the wavelength (λ) for two waves (x, y) propagating in different media and the speed (v) of these two waves in each of these media, so which of the following relations is correct?



a) $T_x < T_y$.
b) $\upsilon_x > \upsilon_y$.
c) $T_x > T_y$.
d) $\upsilon_x = \upsilon_y$.

6. If a sound wave has travelled from one medium to another so that the ratio between its wavelengths ($\frac{\lambda_1}{\lambda_2}$) in the two media equals $\frac{2}{3}$, then the ratio between the speeds of sound in the two media $\frac{v_1}{v_2}$ equals................ .

a) $\frac{3}{4}$ b) $\frac{4}{3}$ c) $\frac{1}{1}$ d) $\frac{2}{3}$

7. If the ratio between the frequency of a man's sound and that of a girl's sound is $\frac{3}{4}$, then the ratio between the speeds of the sounds of the man and the girl in air equals............ .

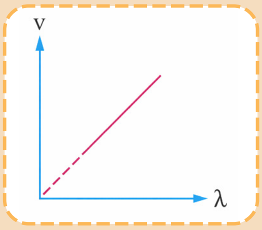
a) $\frac{3}{4}$ b) $\frac{4}{3}$ c) $\frac{1}{1}$ d) $\frac{16}{9}$

8. A vibrating string produces a sound wave of frequency υ, wavelength A and speed v, if the frequency of this string is increased, what will happen for each of the wave speed and the wavelength?

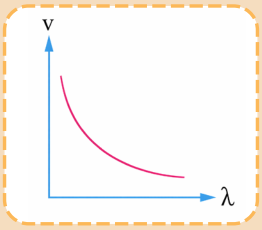
	The wave speed	The wavelength of the wave
(a)	Increases	Increases
(b)	Increases	Decreases
(c)	Doesn't change	Increases
(d)	Doesn't change	Decreases

Think with Mr. Meligy

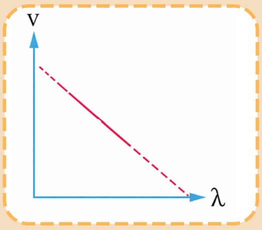
9. Which of the following graphs represents the relation between the speed (v) of multiple sound waves propagating in air and the wavelength (λ) of these waves?



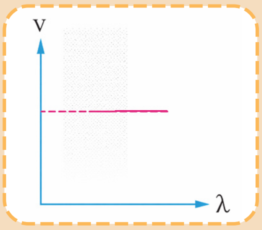
(a)



(b)



(c)



(d)