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ECZ GRADE 10 PHYSICS SUMMARISED NOTES (PURE) FOR 5124 AND 5054.

ESKULU ZM

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G10 PHYSICS NOTES AND EXERCISES (WITH PRACTICAL QUESTIONS) WITH ANSWERS

Here you will find Physics notes, exam tips, practical questions and exercises with answers designed for passing ECZ exams.

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SCIENTIFIC MEASUREMENTS

BASE AND DERIVED QUANTITIES

- A **Physical Quantity**; consists of a numerical **magnitude** and a **unit.**
- All physical quantities can be grouped under **base quantities** and **derived quantities**
- There are 7 base quantities;
  1. Length
  2. Time
  3. Mass
  4. Temperature
  5. Current
  6. Luminous Intensity
  7. Amount of substance (the mole)
  - Most units commonly used are in combination of the **base quantities/units** they are known as derived quantities. Examples; Velocity(m/s), Acceleration(m/s^2), Force(Kgm/s^2), Energy(Kgm^2/s^2)
  - The internationally accepted metric system used is called the **System of Units (SI Units)**

SI UNITS

The number(or value) of a physical quantity is written as a number followed by a suitable unit.

Base Quantity	SI Unit	Symbol Used
Length	Metre	m
Time	Second	s
Mass	Kilogram	Kg
Temperature	Kelvin	K
Current	Ampere	A

SCALARS AND VECTORS

Scalars

Definition	**Scalars** refer to physical quantities having magnitude only
e.g	length, time, mass, distance, speed, volume, density, energy

Vectors

Definition	**Vectors** refer to physical quantities with both magnitude and direction
e.g	displacement, velocity, acceleration, weight, force, moment

- Vectors can be represented by arrows
- The length of the arrow represents the magnitude. The arrow head represents the direction. Eg;

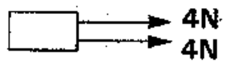
- Two vectors can be added to form a resultant vector
- There are two methods for addition of vectors;

Simple Addition Method

This is used when both vectors are parallel(same or opposite directions)

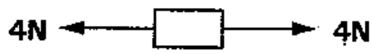
- Direction of vectors : When both vectors are parallel (same or opposite direction)

e.g. ❶



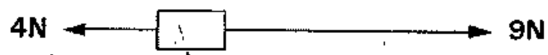
Resultant force = 8 N to the right

e.g. ❷



Resultant force = (−4 N) + 4 N = 0 N (opposite direction becomes negative)

e.g. ❸



Resultant force = 5 N to the right

Parallelogram Method

- This is used when both vectors are not in the same straight line.
- The resultant vector is represented in both magnitude and direction by the diagonal of a parallelogram with two given vectors as adjacent sides.
- That is, joining the two tails of the vectors first, then complete the parallelogram and lastly draw the diagonal

Example

Find the resultant force acting on the portrait suspended using two ropes as shown in Fig 5.11.

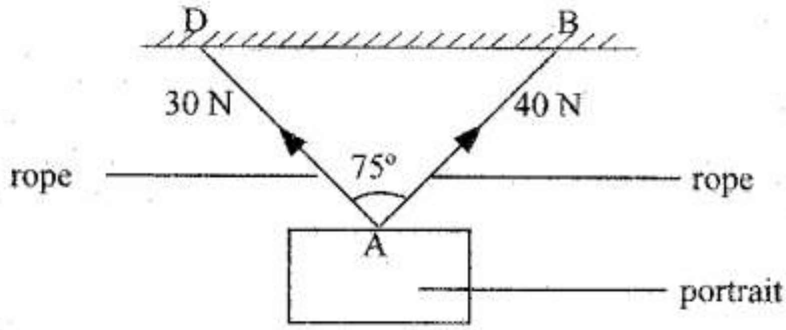
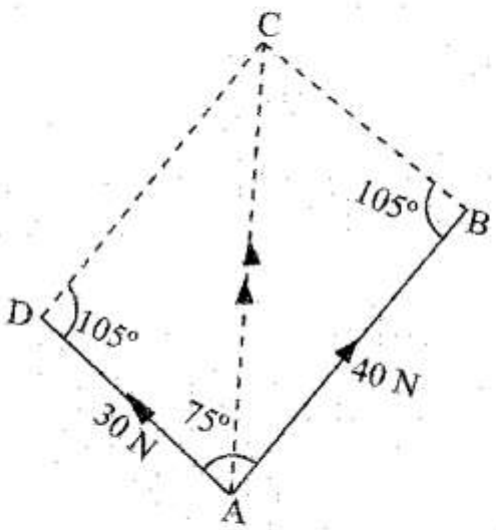


Fig. 5.11: Portrait suspended using two ropes

To find the resultant of the two forces, we first sketch a parallelogram of which the sides of 30 N and 40 N are adjoining (Fig. 5.12).



ABCD is a parallelogram

AD // to BC

AB // to DC

angle ADC = 180° – 75 = 105°

angle ABC = <ADC = 105

AC is the resultant force.

Fig. 5.12: Parallelogram of forces

To locate the resultant force AC, we draw a parallelogram ABCD as follows using a scale of 1 cm to represent 10 N.

Draw AB = 4 cm.
Draw angle BAD = 75° and measure AD = 3 cm.
Draw angle ABC = 105° and prolong line BC.
Draw line DC such that angle ADC = 105. Prolong the line to intersect line BC at C.
Join A to C with a straight line.
Measure AC and convert to newtons using the scale.
Measure angle BAC in Fig. 5.13.

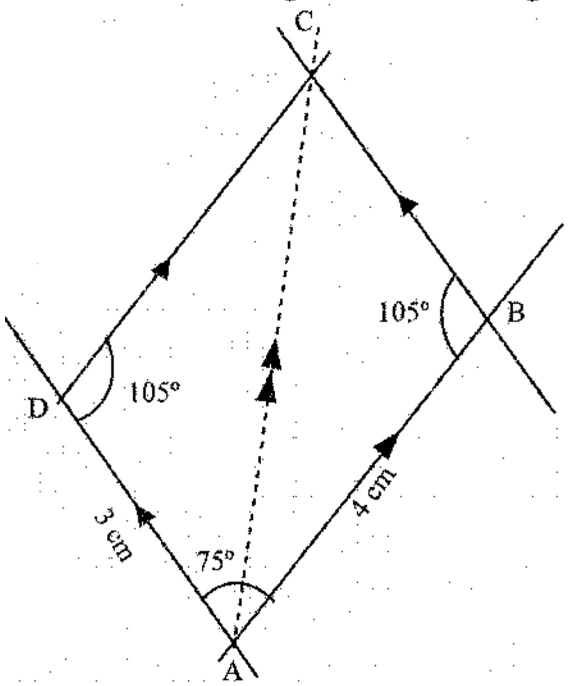


Fig. 5.13: Parallelogram drawn to scale

We obtain Fig. 5.13.

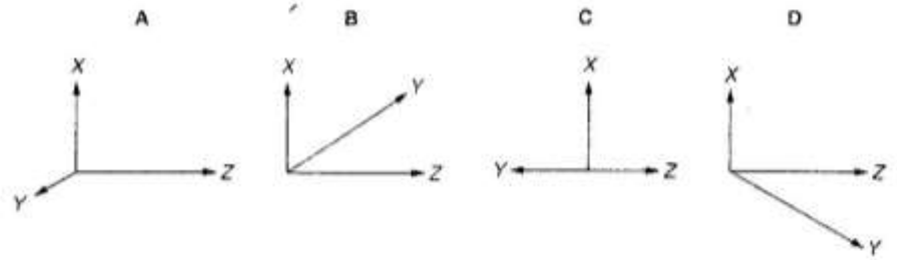
AC is the resultant force.

AC = 5.6
= 5.6 × 10 N
= 56 N

<CAD = 44°

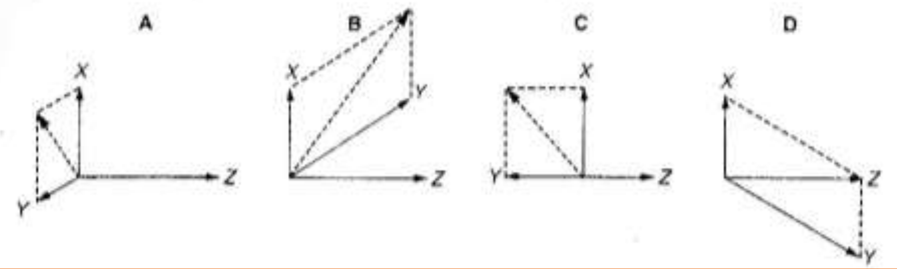
Thus, the resultant force is 56 N acting at an angle of 44° to the 30 N

[Q] Which diagram represents the directions of vectors X and Y and their resultant Z?



[Ans] D By the parallelogram law, the resultant of two forces is the diagonal of the parallelogram with the two forces as the adjacent sides.

After drawing the parallelogram, there are two diagonals. The resultant force is the diagonal which starts from the same point as the two forces.

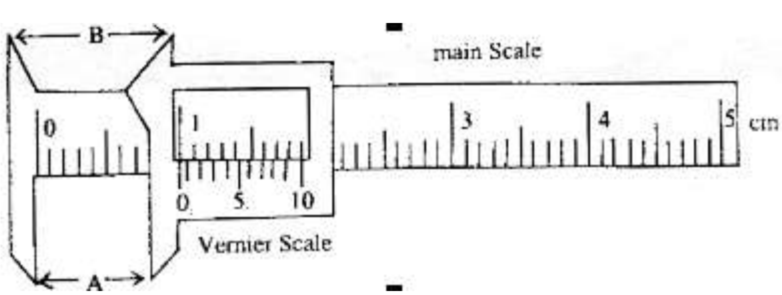


LENGTH

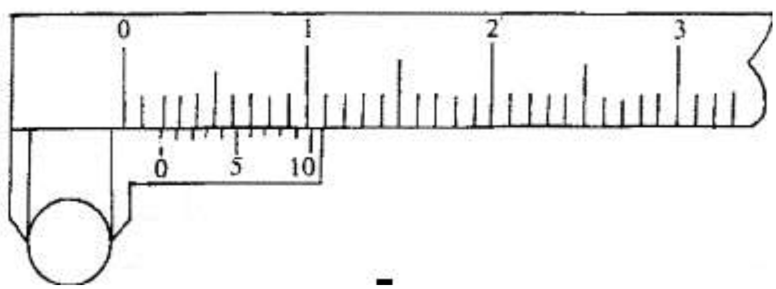
The Metre Rule

- The millimetre is its smallest division.
- It can be used to measure lengths of more than 1mm.

Vernier Callipers



- Used for measurements accurate to 0.1mm.
- It consists of two scales; **main scale** and **Vernier scale**
- Can be used to measure the diameter of balls and cylinders.
- The jaws marked **A** are used for measuring outer diameters whereas those marked **B** are for internal diameters of tubes
  - Enables us to take measurements up to 0.1 of the smallest division of the main scale.
  - Each division on the Vernier scale is 0.09mm.

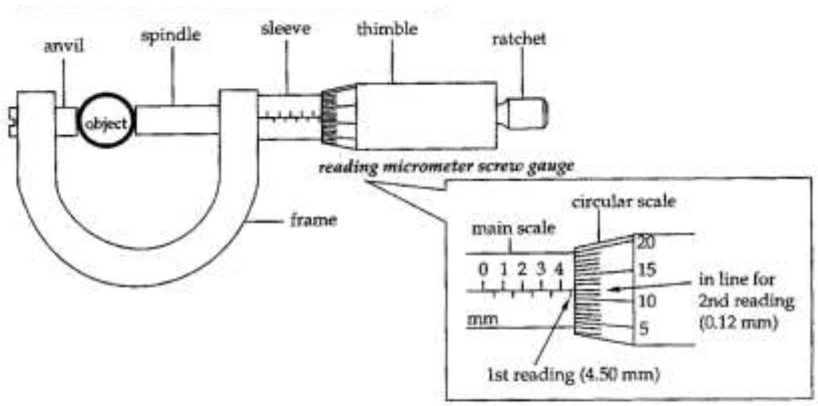


Procedure:

1. First find the value of the Main scale that appears just before the zero of the Vernier scale. (**1mm)**
2. Then find the value of the line on the main scale that coincides with a line on the Vernier scale and write it as a decimal point. The diameter is therefore (**1.6mm)**

Micrometer Screw Gauge

- Measures with an accuracy of 0.01mm.
- It can measure the diameter of hair.
- It consists of two scales; **main scale** on the **sleeve** and **circular scale** on the **thimble.**
- Each division represents a distance of 0.01mm.



Procedure:

1. Turn the thimble until the object is held gently.
2. Read the main scale on the sleeve for the 1st place of decimal. (**4.50mm)**
3. For the second place of the decimal, look at the marking on the thimble scale that coincides with the horizontal line of the main scale. (**0.12mm**)
4. Simply add the two decimal numbers. Hence, the correct reading for the object is **4.62mm.**

MEASURING TIME INTERVALS

- SI unit of time: second (s)

Simple Pendulum

- The time taken for the bob to complete one swing(**oscillation**), i.e A-B-C and back to A depends on the length of the thread.
- This time is called the period ***T*.**

$T = \frac{t}{n}$ where t = time taken; n = number of swings

Example:

In an experiment to determine the period of a pendulum, the time for 20 oscillations is found to be 30 seconds. What is the period of the pendulum?

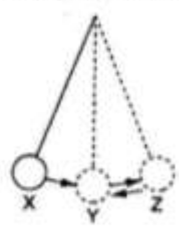
Solution:

$$T = \frac{t}{n}$$

$$T = \frac{30}{20}$$

$$T = 1.5s$$

[Q] The diagram shows a pendulum oscillating between positions X and Z. It takes 1.5 s to go from X to Z and back to the mid-point Y. What is the period of the pendulum?



A 0.5 s
B 1.0 s
C 1.5 s
D 2.0 s

[Ans] D Time for the pendulum to go from X to Z and back to Y is 3 quarters of an oscillation. Therefore period = 1.5 × 4/3 = 2.0 s

PRACTICAL 1- FACTORS THAT AFFECT THE PERIOD OF A SIMPLE PENDULUM

Apparatus

- A pendulum bob
- 1 metre string
- A stop watch

Procedure

- Set up the apparatus as shown below. Displace the pendulum through a small angle θ ($\theta < 10^o$) and release it. Use a stop watch to time 20 oscillations (complete cycles) of the pendulum.

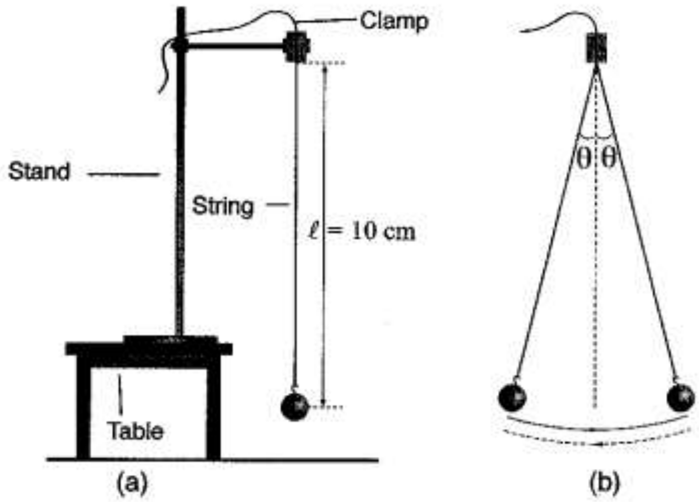


Fig. 2.28: To determine the acceleration due to gravity using a simple pendulum

- Repeat the experiment a second time and calculate the average time for 20 oscillations. Repeat the process for lengths 20 cm, 30 cm, 40 cm, 50 cm, 60 cm and 70 cm. Record your results in a table (see Table 2.4)

Table 2.4

Length, (l) of the string in (cm)	10	20	30	40	50	60	70
Time (t) for 20 oscillations in (s)							
Period $T(t) = \frac{t}{20}$ (s)							

- Draw a graph of period, T (s) against length, l, (cm) and comment on the nature of the graph.
- Draw a graph of T^2 (s^2) against length, l (cm).

From the graph, (Fig. 2.29 (a)) the period of the pendulum increases as the length increases. This can only happen, if the mass of the pendulum bob and amplitude remain constant. Fig. 2.29 (b) a graph of $T^2(s^2)$ against L, is a straight line graph passing through the origin i.e. period squared is directly proportional to the length of the pendulum string.

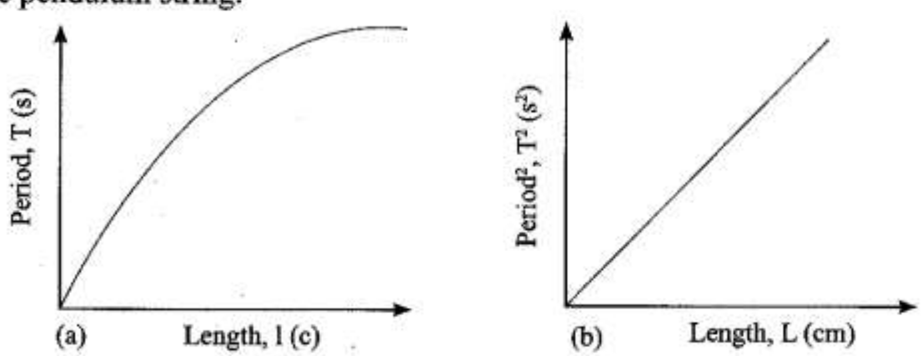


Fig. 2.29

For a simple pendulum oscillating with a small amplitude, the period (T) is given bt $T = 2\pi\sqrt{\frac{l}{g}}$,

Where, T is the period, l, the length of the pendulum and g the acceleration due to gravity.

Squaring both sides of the equation, $T = 2\pi\sqrt{\frac{l}{g}}$, we get

$$T^2 = \frac{4\pi^2 l}{g} \quad \text{.............(i)}$$

Making g the subject of the formula in equation (i), we get

$$g = \frac{4\pi^2 l}{T^2}$$

Therefore, acceleration due to gravity is given by $g = \frac{4\pi^2 l.}{T^2}$

If the values of T^2 and the corresponding values of l obtained through an experiment are plotted in a graph, we can determine the value of g as follows:

Comparing equation (i) and the general equation of the straight line i.e.

$T^2 = \frac{4\pi^2 l}{g}$ and $y = mx + c$,

Where T^2 and l correspond to y and x respectively, we note that

$\frac{4\pi^2 l}{g} = m$ (the gradient of the graph).

Making g the subject, we get that g is given by

$g = \frac{4\pi^2 l}{m}$ i.e. $g = \frac{4\pi^2 l}{\text{gradient of the graph}}$

Using the set up in Fig. 2.28, displace the pendulum through angle, $\theta = 10^\circ$ and release it. Use a stopwatch to time 20 oscillations (cycles) of the pendulum. Holding the length and mass constant repeat the experiment a second time and calculate the average time for 20 oscillations. Repeat the experiment for amplitudes, $\theta = 15^\circ, 20^\circ, 25^\circ, 30^\circ$ and 35°. Record your results in a table (see Table 2.5)

Table 2.5

Amplitude, θ (°)	10	15	20	25	30	35
Time, t_1, for 20 oscillation						
Time, t_2, for 20 oscillation						
Average time, t_{av} for 20 oscillation, $t_{av} = \frac{t_1 + t_2}{2}$						
Period $T(s) = \frac{t_{av}}{20}$ (s)						

- Draw a graph of period, T (s) against the Amplitude, θ (°) and comment on the nature of the graph.

Discussion

Fig. 2.28 is a graph of period, T(s) against the amplitude, θ (°)

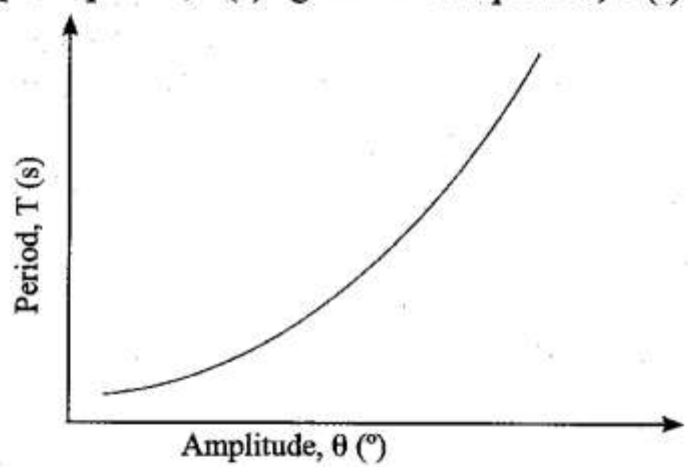


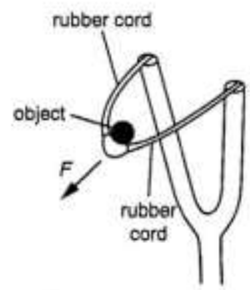
Fig. 2.29: A graph of period, T, against amplitude, Θ

From Fig. 2.29, the period, T of the pendulum increases asymptotically (does not touch the period or amplitude axis) or to infinity with the increase of Amplitude, θ.

Note: In both experiments, two readings of time are taken for each result and averaged to improve on the level of accuracy.

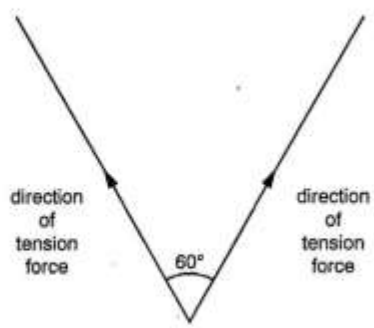
CHALLENGING QUESTIONS WITH ANSWERS - 1

1. The figure shows a catapult used to project an object. Force F pulls back the object, creating tension in the rubber cords.



(a) The tension force in each rubber cord is 20 N and the two cords are at 60° to each other. The figure below shows the direction of the two tension forces acting on the object.

By making a scale drawing on the figure, or otherwise, find the resultant of these two tension forces acting on the object. If you draw a scale drawing, state the scale that you use. [3]



(b) When the object is pulled back, the average value of the force F is 16 N and the object moves a distance 0.20 m in the direction of F. Calculate the work done. State clearly the equation that you use. [2]

2. Force is a vector quantity.

(a) State which two of the following are also vector quantities.

Acceleration, distance, mass, speed, velocity [1]

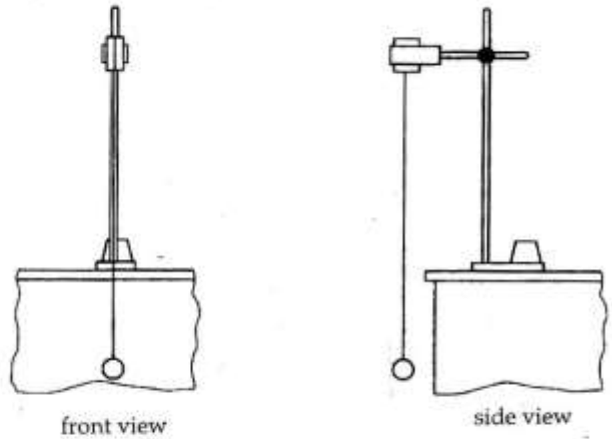
(b) When two forces of 5 N are added, they may produce a resultant force that has any value between 0 and 10 N.

(i) Describe how it is possible to produce a zero resultant force from two forces of 5 N.

(ii) Describe how it is possible to produce a resultant force of 10 N from two forces of 5 N.

(iii) Draw a vector diagram to show how a resultant force of about 5 N may be obtained from the two 5 N forces. Clearly label the forces and the resultant. [4]

3. The figure below shows a simple pendulum suspended from a clamp.



(a) Describe briefly how you would use a stopwatch or a stopclock to determine, as reliably as possible, the period of oscillation of the pendulum. [3]

(b) A student obtains the following values for the time for 20 complete oscillations of a pendulum.

14.6 s 14.7 s 14.5 s 14.6 s 14.7 s

Determine the period of the pendulum. [3]

SOLUTIONS:

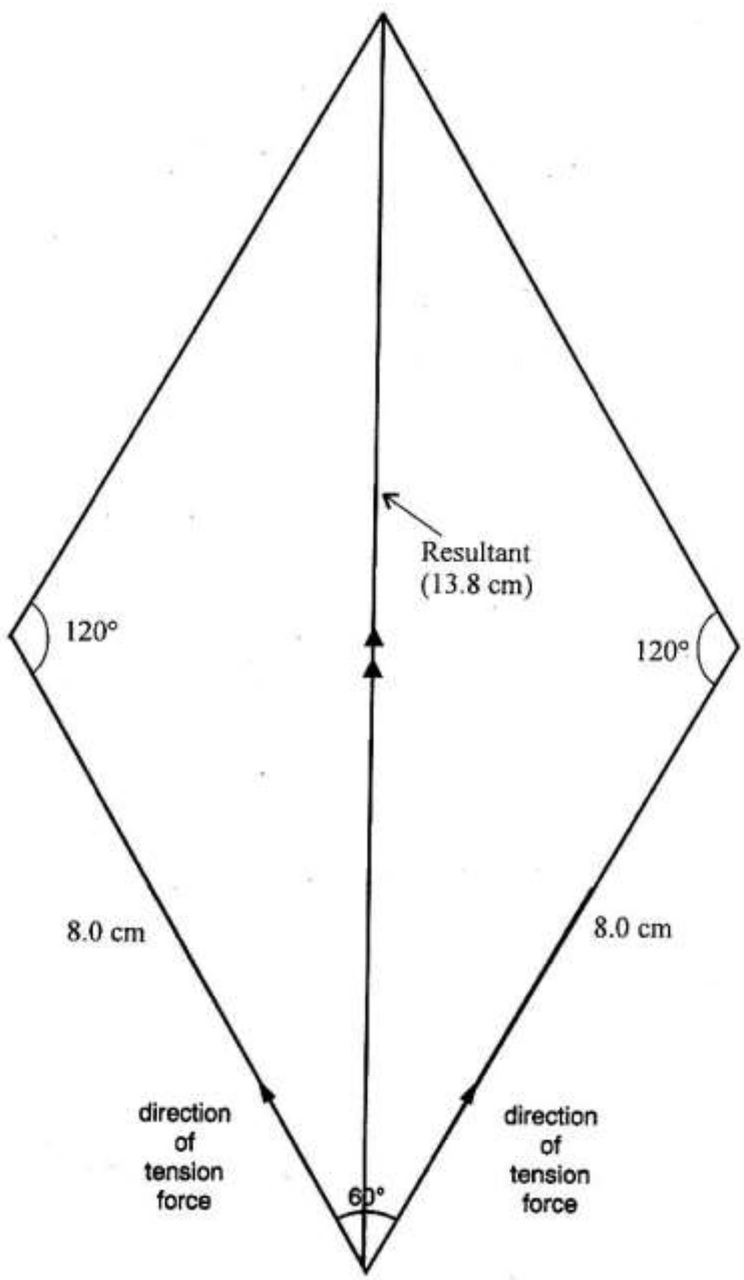
1. (a) Scale: 1 cm represents 2.5 N

Resultant force $= 13.8 \times 2.5 = 34.5$ N

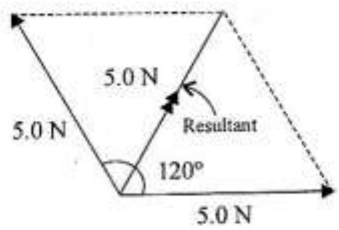
(b) Work done $=$ force $\times$ distance moved

$= (16)(0.20)$

$= 3.2$ J



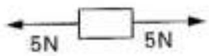
2. (a) acceleration and velocity
   (b) (i) Both forces are in directly opposite directions.
   (ii) Both forces are in the same direction.
   (iii)



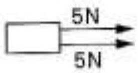
ExamTip

(a) Only acceleration and velocity have both magnitude and direction. The other quantities have only magnitude.

(b) (i)



(ii)



(iii) To obtain a resultant of 5.0 N, the diagonal of the parallelogram must be 5.0 N. Since the two forces are also 5.0 N, two equilateral triangles are formed. For an equilateral triangle, each angle is 60°. Hence the angle between the two 5.0 N is 120°.

3. (a) Measure the time taken for twenty oscillations using the stopwatch and record it as t. Period of the pendulum = $\frac{t}{20}$. Repeat the experiment to obtain several readings and calculate the average.

(b) Average time for 20 complete oscillations

$$= \frac{14.6 + 14.7 + 14.5 + 14.6 + 14.7}{5}$$

$$= 14.62$$

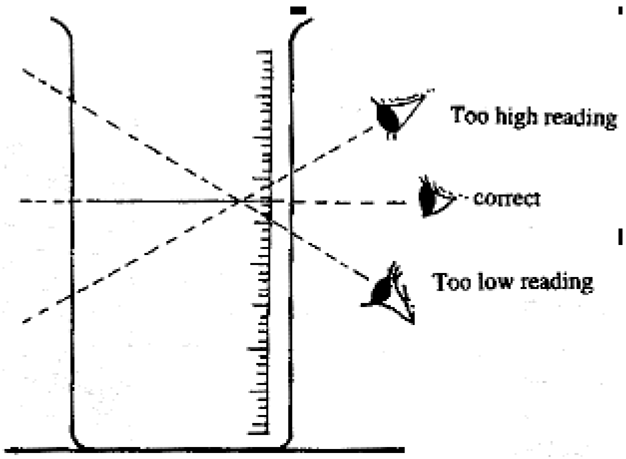
$$\text{Period of pendulum} = \frac{14.62}{20} = 0.73\text{ s}$$

VOLUME

Volume is the amount of space an object occupies. The unit of volume is the cubic metre (m^3)

The Volume of a Liquid

- Apparatus that can be used to measure volume of a liquid; measuring cylinder, pipette, burette, etc.
- How to take correct readings for the volume of a liquid:

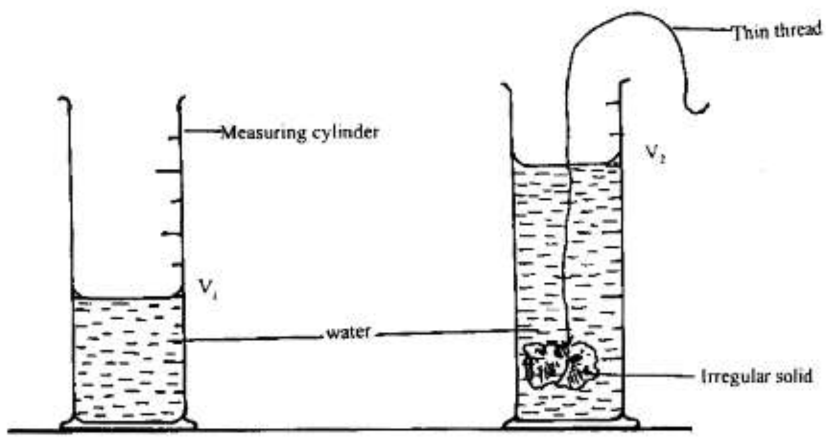


- Take the reading from the meniscus.

The Volume of a Solid

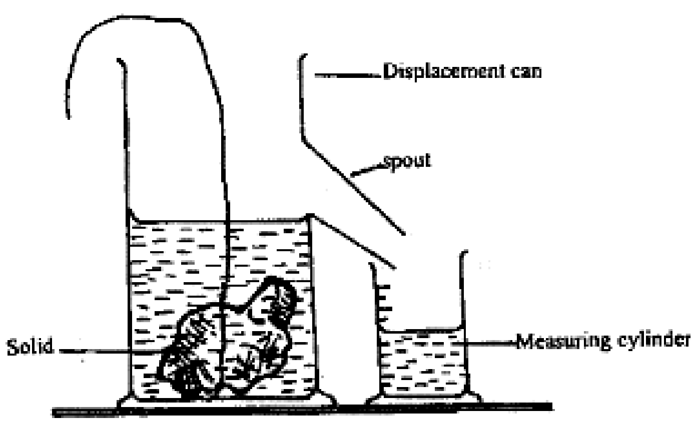
- The volume of a regular solid can be found using the following formula;
  Volume **=** Base Area **x** Height
  Or
  Volume = Length **x** Width **x** Height
- For irregular solids, the above formula above cannot work.
- The displacement method is used to find the volume of small irregular solids.

- The following describes this method; Calculations are shown here;



Volume of water before solid is put in = V_1
Volume of water after solid is put in = V_2
Volume of water displaced = Volume of Solid
Volume of Solid = $V_2 - V_1$

- Another method is the **displacement can** method described below



MASS, WEIGHT AND DENSITY

MASS

- Mass is the amount of matter a substance contains. It is measured in Kilogram.
- **Inertia** of a body refers to the tendency of not changing its state of rest or motion.
- A stationary object tends to remain at rest by itself. Such tendency is called **inertia. Inertia** is a Latin word for "laziness".
- A moving body keeps on moving with the same magnitude and direction. Such tendency is called **inertia.**
- Examples of inertia:
    1. When a bus stops suddenly, the passengers continue to move forward.
    2. A fat person can easily lose his balance if he tries to run in a zigzag manner.
    3. A bus with a mass of 7000 Kg has a larger inertia than a car with a mass of 1200 Kg.

Unit	Symbol	Volume
Tonne	t	10^3 Kg
Gramme	g	10^{-3} Kg
Milligramme	mg	10^{-6} Kg

Measurement of Mass

- Mass can be measured using a **beam balance**.

- The most common balance is the **triple beam balance**.

(a) Traditional beam balance (b) Triple beam balance (c) Digital beam balance

- **Cautions;** Ensure to Zero the balance and ensure that the pan and beams are clean.

Determining the Mass of a Liquid

The following formula is usually used;

Mass of liquid = Mass of container containing liquid - Mass of container only

Determining the Mass of Air

The following formula is usually used;

Mass of air = Mass of container containing air - Mass of container only

WEIGHT

Weight is a vector quantity that **measures the amount of gravity acting on a body**.

- All objects are attracted by the gravitational pull of Earth.
- An object with more mass experiences greater gravitational force acting on it.
- According to **Newton's 2nd Law of Motion**, weight can be calculated by simply multiplying **mass by acceleration due to gravity**

  W = mg

- g is also known as **gravitational field strength** which has the same magnitude of 9.81 but different SI Unit, ie. NKg^{-1}

Differences Between Mass and Weight

MASS	WEIGHT

Definition	measure of the amount of matter contained	attractive forced exerted due to gravity
Quantity	scalar	vector
SI Unit	kilogram (Kg)	newton (N)
Measurement	using a beam balance or electronic balance	using a spring balance or compression balance
Property	cannot be changed by changing its location, shape or speed	weight changes depending on location

The following shows the mass and weight of an astronaut when he travels from Earth to Earth's Moon:

On Earth	On Moon	In Outerspace
Mass = 84 Kg **Weight = 840 N** **(Gravity of Earth is about 10N/Kg)**	Mass = 84 Kg Weight = 140 N (Gravity of moon is about one-sixth of value on Earth. About **1.6N/Kg**)	Mass = 84 Kg Weight = 0 N (No gravity in outer space, weightlessness)

[Q] The gravitational field strength on the surface of the Moon is 1.6 N/kg. Which values of mass and weight are correct for an object placed on the Moon's surface?

	Mass / kg	Weight / N
A	10	1.6
B	10	16
C	16	10
D	16	160

[Ans] B Weight = mass × gravitational field strength = $10 \times 1.6 = 16$ N

Since mass of the object is not given, check the values for mass and weight to find out for which pair of values the relationship W = mg is held.

CENTRE OF MASS

- Bodies on Earth experience the pull gravity. This force of gravity is always directed towards the earth's centre and is called the weight of the body.
- The **centre of mass** is the point in a body where all the mass of the body seems to be concentrated.

PRACTICAL 2 – FINDING THE CENTRE OF MASS OF AN IRREGULAR LAMINA USING A PLUMBLINE

Apparatus

- An irregular lamina
- A drawing pin
- Plumbline

Procedure

- Make three holes P, Q and R on an irregularly shaped lamina as close as possible to the edges and far away from each other. The holes should be large enough to allow the lamina turn freely when supported by a drawing pin.
- Suspend the lamina on the clamp using the drawing pin each hole at a time.
- Suspend a plumbline (a thin thread with a small weight at one end) from the point of support, P as shown in Fig. 3.5(a) and draw the line of the plumbline on the lamina by marking two points A and B far apart and joining them.
- Repeat the procedure with the support Q and mark the point M where the two lines intersect.
- Check the accuracy of your method by suspending the lamina at R.

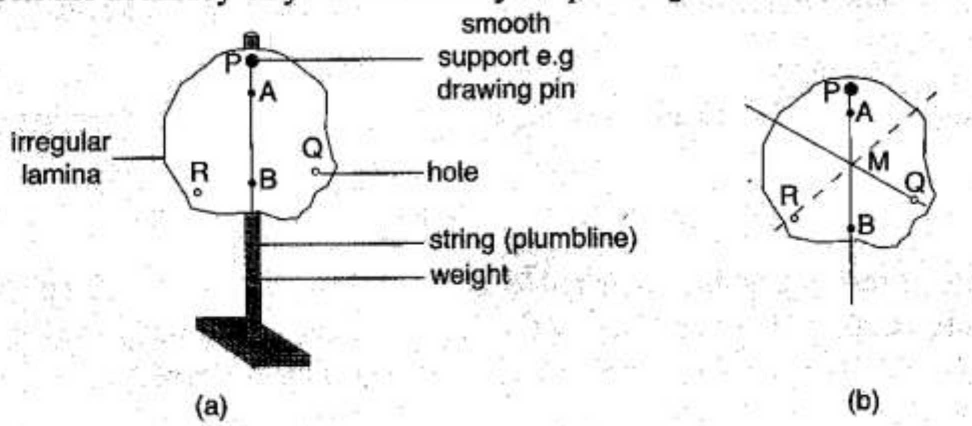


Fig. 3.5: Locating centre of mass of a lamina using a plumbline

The plumbline pass through M (Fig. 3.5 (b)). Check the results again by balancing the lamina about point M.

Observation

The lamina be balances horizontally. Point M is the centre of mass of the lamina.

Conclusion

The experiment above also proves that *when a body is freely suspended it rests with its centre of mass vertically below the point of suspension.*

DENSITY

- **Density** is a measure of how closely the particles of a substance are packed together.
  Density of a substance is its ***mass per unit volume***

$$\rho = \frac{m}{v}$$

- **Where** ρ = Density, m = Mass, v = Volume

Determining the Density of a Liquid

- Weight a clean beaker on a balance and run into it a measures volume of liquid.
- Use the following to calculate the density;

$$\textbf{Density of liquid} = \frac{\textbf{Mass of beaker with liquid – Mass of beaker only}}{\textbf{Volume of liquid}}$$

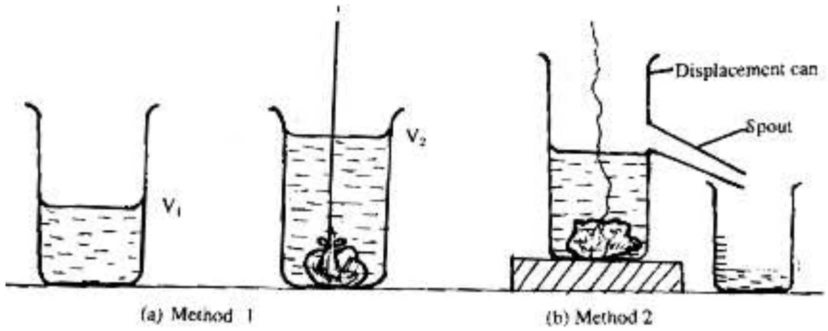
$$\rho = \frac{m_1 - m_2}{V}$$

- 1 Kg = 1000 g ; 1 m = 100 cm; 1 $m^3 = 10^6 cm^3$

Determining the Density of an Irregular Solid

- For example, we are finding the density of a stone. We will use the following formula.

$$\rho = \frac{mass\ of\ stone}{volume\ of\ water\ displace\ by\ stone}$$



Relative Density

- As long as the mass of equal volumes of water and the liquid whose density is to be determined are known, the density of the liquid can be determined as follows:

$$Relative\ Density = \frac{mass\ of\ liquid}{mass\ of\ equal\ volume\ of\ water}$$

- **Relative Density** is the ratio of the mass of any volume of a substance to the mass of an equal volume of water.

- If the relative density of a liquid is 0.80 its density is 0.80 g/cm^3.

Example

The density of the copper 8.93 g/cm³. Find the relative density of copper.

$$\text{Relative density of copper} = \frac{\text{density of copper}}{\text{density of water}}$$

$$= \frac{8.93 \text{ g/cm}^3}{1.0 \text{ g/cm}^3}$$

$$= 8.93$$

Relative Densities of Some Solids and Liquids

RELATIVE DENSITIES OF SOLIDS		RELATIVE DENSITIES OF LIQUIDS	
Aluminium	2.7	**Alcohol(Ethanol)**	0.79
Brass	8.5	**Benzene**	0.90
Copper	8.9	**Glycerine**	1.26
Cork	0.2 to 0.25	**Mercury**	13.6
Glass	2.5 to 2.9	**Methylated Spirit**	0.80
Gold	19.3	**Milk**	1.031
Ice	0.92	**Paraffin**	0.85
Iron	7.86	**Petrol**	0.66 to 0.69
Lead	11.3	**Sea Water**	1.02
Marble	2.6	**Sulphiric Acid**	1.84
Platinum	1.4		
Silver	10.5		
Sulphur	2.0		
Tin	7.3		
Zinc	7.1		

Uses of Density

We can use densities to identify substances and even determine their purity. Chemicals in industry can be separated by using their different densities. This is done in the separation of oils in the petroleum industry.

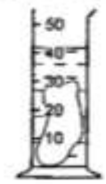
[Q] A student is trying to find the density of a stone, but he has mixed up the instruction cards.

Find the mass of the stone using a mass balance

Card 1

Read the new level of the liquid in the measuring cylinder

Card 2

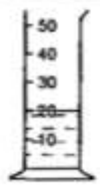


Put the stone into the liquid

Card 3

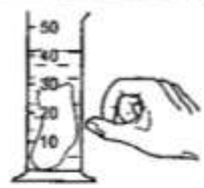
Divide the mass of the stone by its volume to find the density

Card 4



Put some liquid into a measuring cylinder and read the level of the liquid

Card 5



Flick the cylinder to get rid of any air bubbles

Card 6

Subtract the original volume of liquid from the volume of liquid plus the stone

Card 7

What order should the cards be in?

A $5 \rightarrow 3 \rightarrow 6 \rightarrow 2 \rightarrow 1 \rightarrow 4 \rightarrow 7$

B $1 \rightarrow 5 \rightarrow 3 \rightarrow 6 \rightarrow 2 \rightarrow 7 \rightarrow 4$

C $5 \rightarrow 6 \rightarrow 3 \rightarrow 2 \rightarrow 1 \rightarrow 7 \rightarrow 4$

D $1 \rightarrow 4 \rightarrow 5 \rightarrow 3 \rightarrow 6 \rightarrow 2 \rightarrow 7$

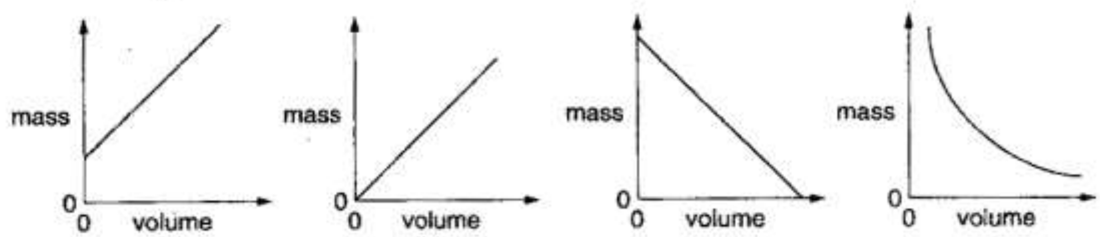
[Ans] **B** It is easier if you look at the choices given rather than work out the answer by rearranging the cards.

To find the density of a stone, we need to apply the formula density = mass/volume. The mass is measured by using a mass/electronic balance. The volume is obtained by the displacement method.

[Q] Some students want to calculate the density of a type of wood. They measure the masses and volumes of different sized samples of the wood.

Which graph shows their results?

A B C D



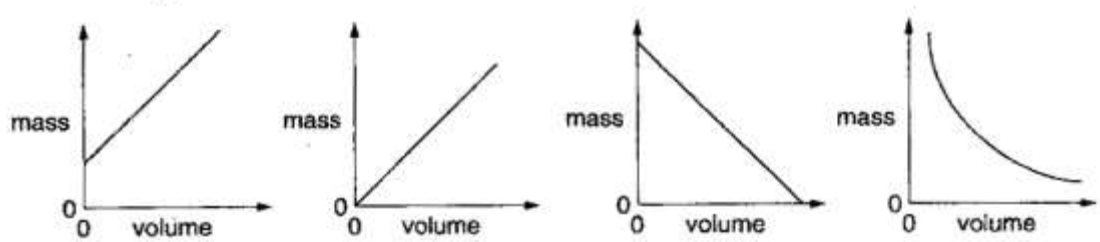
Ans] **B** For same substance, mass is directly proportional to volume.

The graph should start at the origin.

[Q] Some students want to calculate the density of a type of wood. They measure the masses and volumes of different sized samples of the wood.

Which graph shows their results?

A B C D



Ans] **B** For same substance, mass is directly proportional to volume.

The graph should start at the origin.

[Q] A quantity of gas in a sealed balloon is cooled down.

No gas is allowed to enter or leave the balloon.

How do the listed properties of the gas change?

	Mass	Volume	Density
A	decreases	stays the same	increases
B	increases	stays the same	decreases
C	stays the same	decreases	increases
D	stays the same	increases	decreases

[Ans] C When the temperature decreases, the gas contracts. The density will decrease as the volume is smaller but the mass is a constant.

For this type of question, candidates should bear in mind that the mass of the gas is a constant as no gas is allowed to enter or leave the balloon. The volume of the balloon is not a constant as it can expand or contract.

PRACTICAL 3 – DENSITY OF FLOATING WOOD

Apparatus

- A piece of wood
- An overflow can or Eureka can
- A compression balance
- A measuring cylinder
- Water

Procedure

- Measure the volume, (V_{wood}) of a piece of wood by immersing it into water in measuring cylinder using a sinker. (Measuring volume by displacement of the water).
- Fill an overflow can (eureka can) with water. Allow the excess water to flow out through the sprout.
- Place an empty beaker on a compression balance under the spout and record the weight, W of the empty beaker (see Fig 4.1)

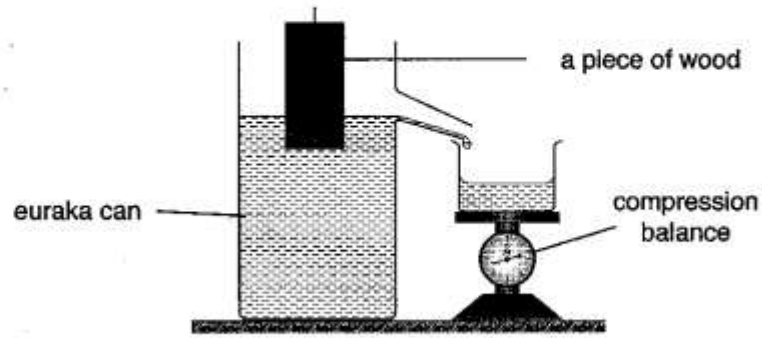


Fig. 4.1: Density of a piece of wood by displacement

- Place the piece of wood to float on the water in the eureka can and collect the water that flows out through the spout into the beaker. Record the weight W_2 of the beaker and displaced water.
- Calculate the weight, W_{water} of water displaced using; $W_{water} = W_2 - W_1$

Discussion

Since, weight of a floating wood = weight of a fluid displaced by the wood.

So $W_{wood} = W_{water} = W_2 - W_1$ .... (i)

From $W = m \times g \Rightarrow m = \frac{W}{g}$, we divide g on both sides of the equation (i) to get,

$$m_{wood} = m_{water} = m_2 - m_1$$

where, $m_2 - m_1$ is mass of water displaced.

The density of the floating wood is given by:

$$\text{Density of floating wood} = \frac{\text{mass of the wood}}{\text{volume of a water displaced}} = \frac{\text{mass of the wood}}{\text{volume of the wood}}$$

$$= \frac{m_2 - m_1}{V_{wood}}$$

CHALLENGING QUESTIONS WITH ANSWERS - 2

1. A measuring cylinder contains 30 cm^3 of liquid. When a stone of weight 0.92 N is dropped into the liquid, it sinks to the bottom and the liquid level rises to the 70 cm^3 graduation.

   Taking the weight of 1 kg to be 10 N, calculate

   (i) the mass of the stone, [1]

   (ii) the density of the stone. [2]

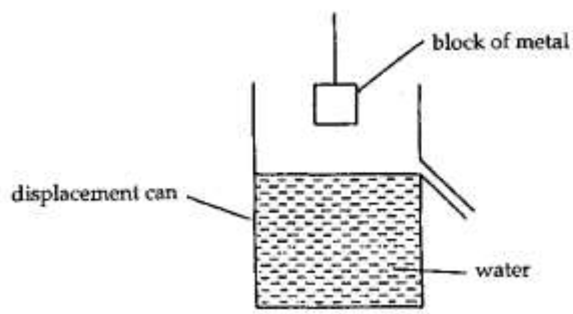
   Explain why it would not be possible to use this method to determine the density of cork which would float in the liquid. [1]

2. (a) When a block of metal is hung in air from a spring balance, the reading is 9.6 N.

   (i) What is the weight of the block of metal?

   (ii) Assuming that the weight of a 1 kg mass is 10 N, what is the mass of the block of metal? [2]

   (b)



   The above diagram shows a displacement can which has been filled with water.

   When the block of metal in (a) is lowered into the can until it is totally immersed in the water, 110 cm^3 of water overflows. Calculate the density of the metal. [2]

3. The mass of 600 spherical lead pellets is found to be 66 g and the total volume of the pellets is found to be 5.7 cm^3. Calculate

   (i) the total weight of the pellets,

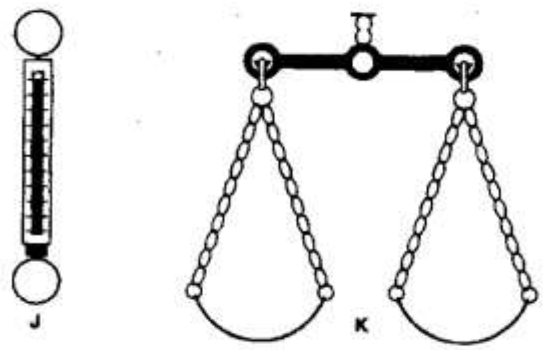
   (ii) the volume of one pellet,

   (iii) the density of the pellets in kg/m^3,

   (iv) the number of pellets which has a mass of 1.00 kg. [The force of gravity acting on a mass of 1.00 kg is 10.0 N] [7]

4. (a) The acceleration of free fall near the surface of the Earth is $9.8\ m/s^2$.
The acceleration of free fall near the surface of the Moon is $1.6\ m/s^2$.
Calculate the weight of an object of mass 5.0 kg
(i) near the surface of the Earth,
(ii) near the surface of the Moon. [3]

(b) You have available a balance J and a balance K, as shown in the figure.



State and explain which you would use to measure
(i) mass,
(ii) weight. [3]

SOLUTIONS:

1. (i) Mass, $m = W/g = 0.92/10 = 0.092$ kg

(ii) Volume of stone = change of reading on measuring cylinder
$= 70 - 30$
$= 40\ cm^3$

Density of stone = mass of stone / volume of stone
$= 92 / 40$
$= 2.3\ g/cm^3$

To find the volume of the cork accurately, it needs to be immersed completely into the liquid. Since the cork floats in the liquid, the volume of liquid displaced would not be equal to the volume of the cork. Thus it would not be possible to use this method to determine the density of cork.

2. (a) (i) The weight of the metal block is the reading of the spring balance.
9.6 N

(ii) Mass, m $= W / g$
$= 9.6 / 10$
$= 0.96$ kg

(b) Volume of the metal block is the volume of water displaced = 110 cm^3

Density $= \text{mass} / \text{volume}$
$= 960 / 110$
$= 8.73 g / cm^3$

ExamTip

(a) (i) Spring balance is used to measure weight which is a force. Beam balance is used to measure mass which is the amount of matter.

(ii) Again, candidates have to apply W = mg several times during examinations.

(b) Students are able to describe how to determine the volume of an object by displacement method.

3. (i) weight of the pellets $= mg$
$= (66 / 1000) \times 10$
$= 0.66$ N

(ii) volume of one pellet $= 5.7 / 600$
$= 9.5 \times 10^{-3}$ cm^3
$= 9.5 \times 10^{-9}$ m^3

(iii) density of the pellets $= \text{total mass} / \text{total volume}$
$= 66 / 5.7$
$= 11.6 \text{ g} / \text{cm}^3$
$= 11.6 \times 10^3 \text{ kg} / \text{m}^3$

(iv) number of pellets $= 1.00 / (0.066 / 600)$
$= 9090$ (3 sig. fig.)

ExamTip

(i) The mass of pellets is given in g. The unit of gravitational field strength is N/kg. It should be noticed that there is an inconsistency in the unit of mass. Candidates need to change the unit of mass from g to kg.

(ii) It is optional to change the unit of volume to m^3 here.

(iii) Density can also be found by $\frac{\text{mass of one pellet}}{\text{volume of one pellet}}$.

(iv) A common mistake here is that some students use the answer in (i) to find the mass for one pellet. They are not sure about the difference between mass and weight. Mass should be used for this question but not the weight (answer in part (i)).

4. (a) (i) weight near the surface of the Earth $= mg_{Earth} = 5.0 \times 9.8$
$= 49 \text{ N}$

(ii) weight near the surface of the Moon $= mg_{Moon} = 5.0 \times 1.6$
$= 8.0 \text{ N}$

(b) (i) Balance **K**. Its working principle does not depend on the value of acceleration due to gravity.

(ii) Balance **J**. Its readings depend on the value of acceleration due to gravity.

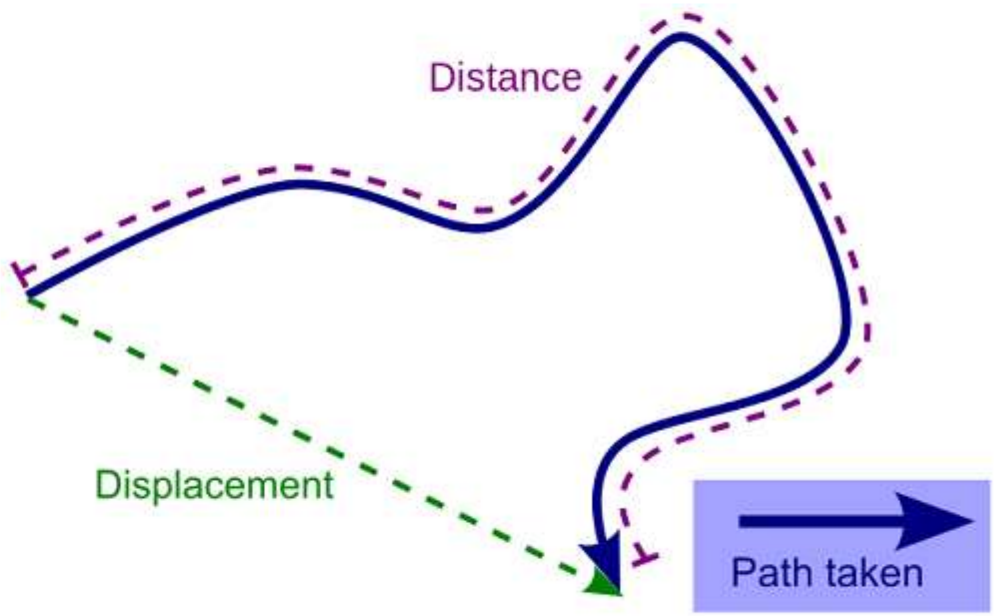
ExamTip

(a) This is a straightforward question, but it shows that the weight is not a constant. It depends on the distance and also the gravitational field strength.

(b) Balance K is to compare masses to show readings whereas balance J uses the gravitational pull to show a reading.

LINEAR MOTION

- Scalar quantities: **Distance** and **Speed**.
  Vector quantities: **Displacement** and **Velocity**.
- **Displacement** incudes direction. **Distance** only has magnitude.
- **Velocity** incudes direction. **Speed** only has magnitude.
- ***For motions in a straight line, there is no difference between distance and displacement (therefore, speed and velocity are the same thing).***



SPEED

Speed is the rate of increase of distance moved with time.

$$Speed = \frac{Total\ Distance}{Total\ Time}$$

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

VELOCITY

Velocity is the rate of change of displacement with time and it involves the idea of direction. Constant velocity means that the speed is not changing, and it is in a constant, specified direction.

ACCELERATION

- When a resting object starts to move and increases its speed, we say it is accelerating.
- When a moving object slows down and finally comes to a stop, we say it is **decelerating.**
- **SI Unit of acceleration:** metre per second squared (ms^{-2})

$$Acceleration = \frac{final\ velocity - initial\ velocity}{time\ taken}$$

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

The Motion in a Straight Line of a Moving Object

- **At rest: speed is zero**, **acceleration is zero.**
- If there is **increasing** speed, it may be:
- If there is **increasing** speed, it may be:
  - **Uniform** for a period or
  - **Non-uniform** for a period.
- The object can also move with **constant** speed for a period. (No change in speed, acceleration is zero)
- If there is **decreasing** speed, it may be:
  - **Uniform** for a period or
  - **Non-uniform** for a period.

Equations of Uniformly Accelerated Linear Motion

If we use '**a**' to represent acceleration, '**u**' for initial velocity, '**v**' for final velocity, '**s**' for displacement and '**t**' for time, the following equations of motion can be used.

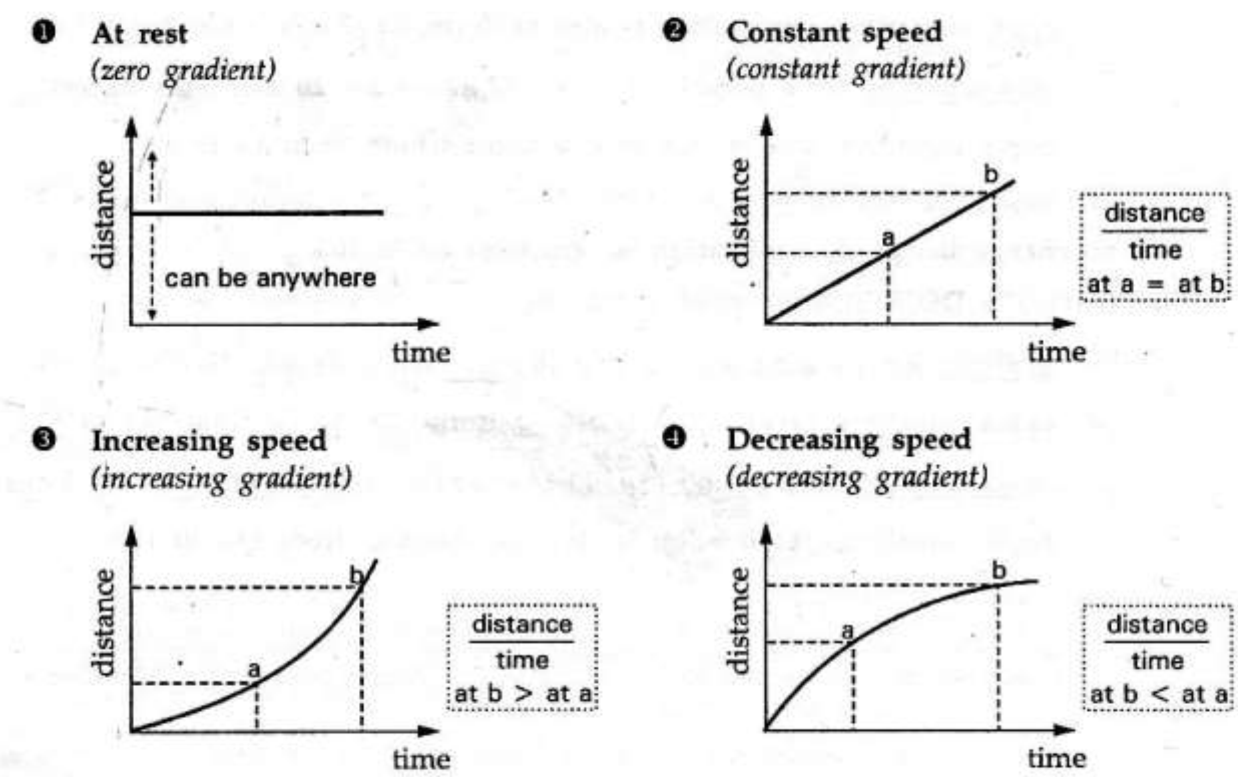
$$v = u + at \quad \text{---}(1)$$

$$s = ut + \frac{1}{2}at^2 \quad \text{---}(2)$$

$$v^2 = u^2 + 2as \text{---}(3)$$

DISTANCE –TIME GRAPH

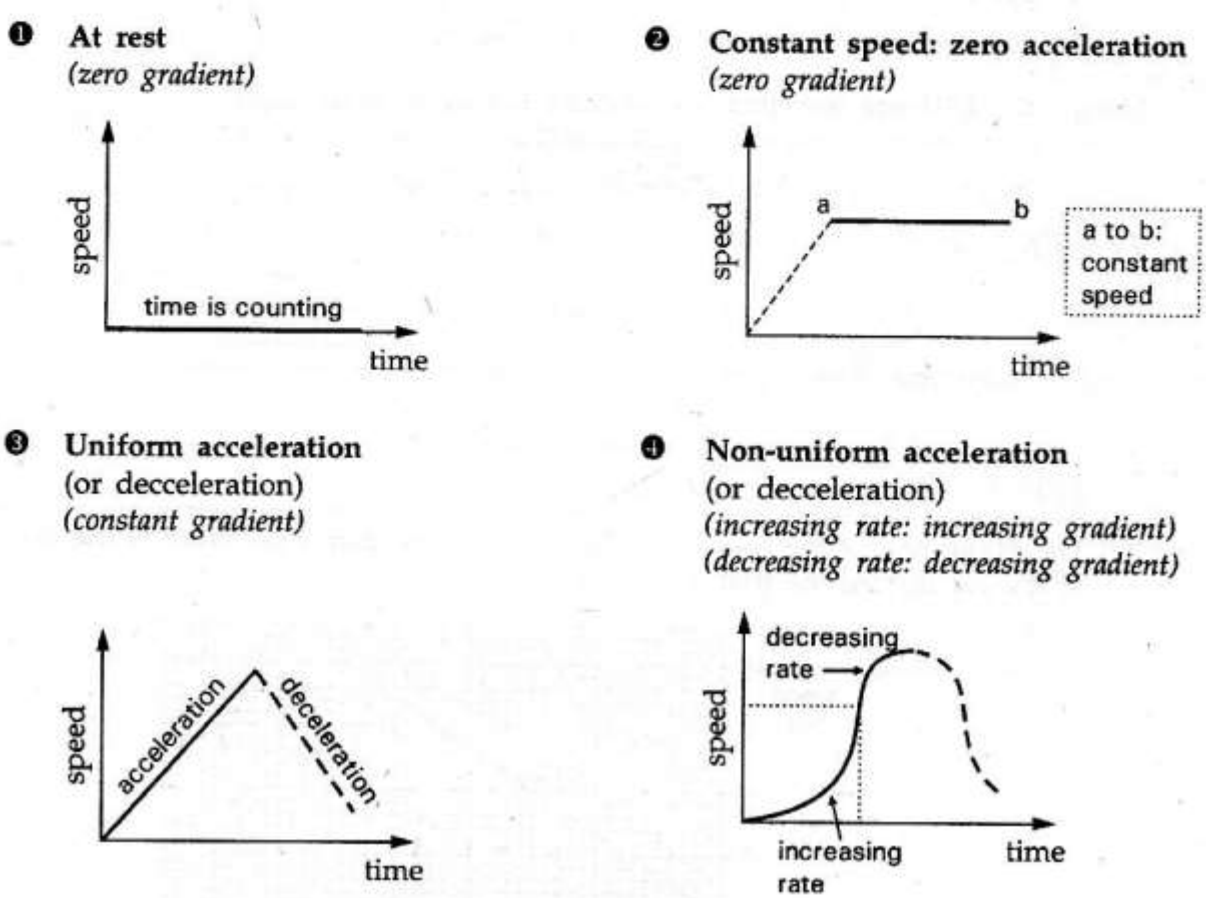
- The following figure shows the different kinds of motion of an object's **distance-time** graph.
  - When at rest, the graph is a horizontal straight line.
  - For constant speed, the graph is an upward sloping straight line.
  - For increasing or decreasing speed, the graph is a curve.
  - There is **no** downward sloping for a distance-time graph



The speed is the gradient(amount of slope) of the graph

VELOCITY-TIME GRAPH

- For motions in a **straight** line, the **speed-time (or velocity-time)** graph shows an object's acceleration.
- The following figure shows different kinds of motion
  - When **at rest** or moving at **constant** speed, the graph is a horizontal straight line: **both have zero acceleration.**
  - When moving at **uniform** speed, the graph is an upward or a downward sloping straight line:
  - **Uniform acceleration (or deceleration)**
  - When moving at **non-uniform** (increasing or decreasing) speed, the graph is an upward or a downward sloping curve.
  - When moving at **non-uniform** speed, the graph is an upward or a downward sloping curve.



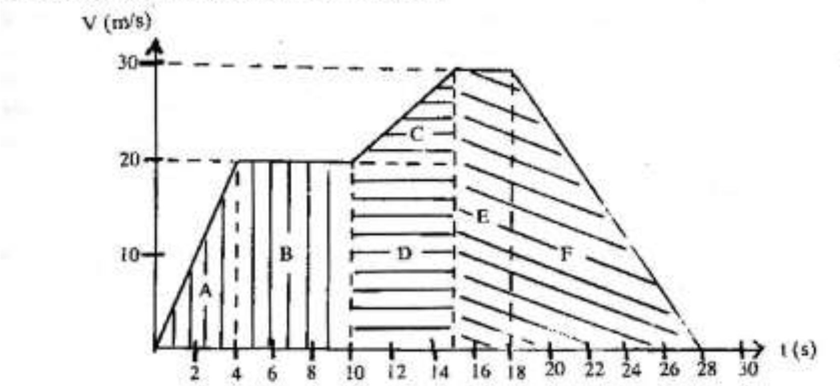
- **In the exam, candidates should be able to describe the different kinds of motion of an object by reading distance-time or speed-time graph.**

Example

A body moving from rest acquires a velocity of $20ms^{-1}$ in 4s. It moves with this velocity for 6 seconds and again accelerates to 30m/s in 5s. It travels for 3s at this velocity and then comes to rest with uniform retardation in 10s. Draw a velocity-time graph and use it to calculate (a) the acceleration while the velocity changes from 0 to 20 m/s (b) the acceleration while it changes from 20 to 30m/s (c) the retardation (d) the total distance covered (e) the average speed of the whole motion.

Solution

The velocity-time graph is shown below.



(a) $a = \frac{v}{t} = \frac{20 - 0}{4} = 5m/s^2$

(b) $a = \frac{30 - 20}{5} = 2m/s^2$

(c) $a = \frac{0 - 30}{10} = -3m/s^2$

(d) The total area may be obtained by adding the areas of sections A, B, C, D, E and F which are triangles and rectangles, or the shaded areas which are trapezia. Using the latter, we get total distance = First shaded area + Second one + Third one

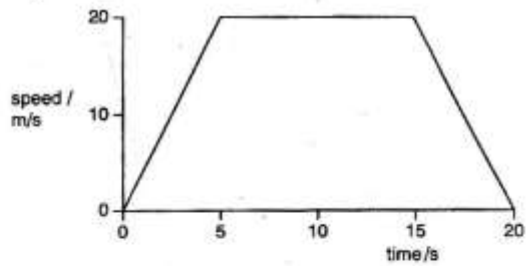
$= \frac{1}{2}(10 + 6) \times 20 + \frac{1}{2}(30 + 20) \times 5 + \frac{1}{2}(13 + 3) \times 30$

$= 160 \text{ m} + 125 \text{ m} + 240 \text{ m} = 525\text{m}.$

(e) Average speed $= \frac{\text{Total distance covered}}{\text{Total time taken}} = \frac{525}{28s} = 18.75\text{m/s}$

more examples…

[Q] The speed of a body during 20 s of motion is represented by the speed-time graph shown.



Which distance does the body travel during this motion?

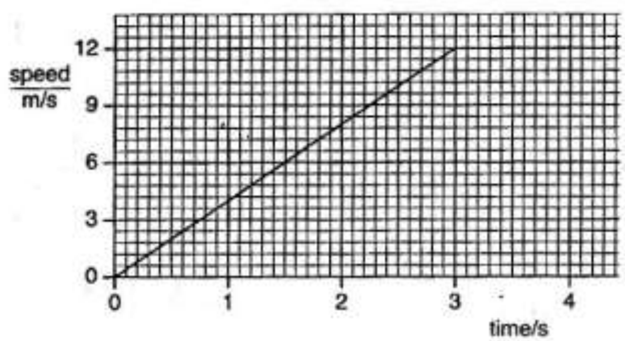
A 200 m
B 250 m
C 300 m
D 400 m

[Ans] C Distance travelled = area under the speed - time graph

$= \frac{1}{2}(10 + 20)20$

$= 300$ m

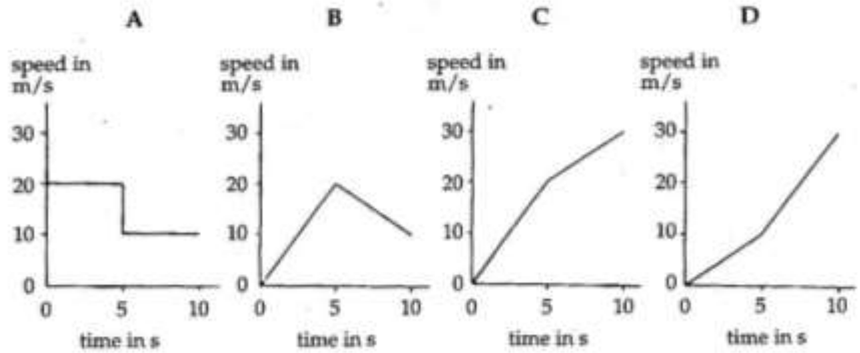
[Q] The graph shows the speed of a car as it moves from rest. What is the average speed of the car during the first 3 s?



A 4 m/s
B 6 m/s
C 18 m/s
D 36 m/s

[Ans] B Average speed $= \dfrac{\text{total distance}}{\text{time}} = \dfrac{\frac{1}{2}(12 \times 3)}{3} = 6$ m/s

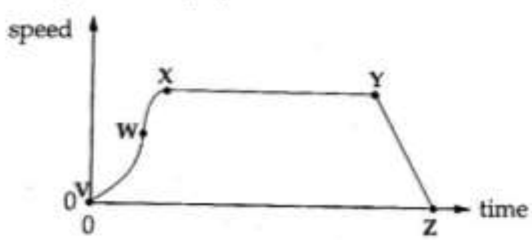
[Q] A skier is travelling downhill. The acceleration on hard snow is 4 m/s² and on soft snow is 2 m/s². Which graph shows the motion of the skier when moving from hard snow to soft snow?



Ans] C The skier is accelerating uniformly at a decreasing rate on soft snow.
By applying equation: $(20-0)/5 = 4\ m/s^2$ and $(30-20)/5 = 2\ m/s^2$.
B is out because the second part is negative, i.e. deceleration.

Acceleration of the skier is the gradient of the speed-time graph. The first part of the graph should be steeper than the second part as the acceleration on hard snow is greater than that on soft snow.

[Q] The diagram shows a speed-time graph.



In which region is the acceleration decreasing?

A V to W

B W to X

C X to Y

D Y to Z

Ans] B From W to X, the non-uniform acceleration is decreasing.

The gradient of the speed-time graph is the acceleration. From V to W, the acceleration is increasing (increasing gradient). From W to X, the acceleration is decreasing (decreasing gradient). From X to Y, the acceleration is zero (zero gradient). From Y to Z, the deceleration is uniform (constant gradient).

ACCELERATION DUE TO GRAVITY

- The force of gravity pulls down all objects.
- A **free falling** object experiences gravity as the only force acting on it.
- All free falling objects, regardless of shape, size or mass will accelerate at the same constant rate **downwards.**
- When released from the same **same height,** they will reach the ground at the **same time**.
- Applying the equation $s = ut + \frac{1}{2}at^2$, the distance '**x**' fallen by the body in time '**t**' is given by x = $ut + \frac{1}{2}gt^2$, where '**g**' is the acceleration due to gravity.

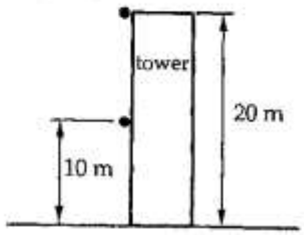
  Since, **u = 0** for free fall,

  $$\text{Then, } x = \frac{1}{2}gt^2$$

  $$\text{Hence, } g = \frac{2x}{t^2}$$

- For convenience in calculations, a value of **g = 10 m/s²** is usually used for objects on Earth.

[Q] Two similar cricket balls are released from a 20 m tower at the same time. One falls from the top, the other from half way up, as shown.



Which quantity is the same for both balls?

A acceleration

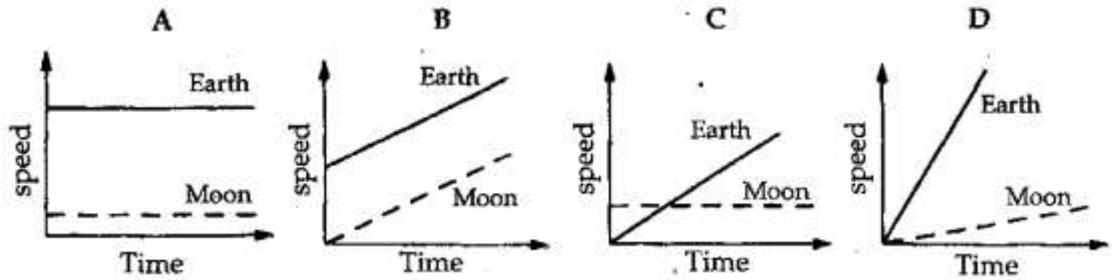
B final speed

C increase in velocity

D time of travel

[Ans] A Both balls are free falling body. The acceleration for both of them is the acceleration due to gravity, $10\ ms^{-2}$.

[Q] When someone on Earth drops a rock, it accelerates at about 10 m/s². When a rock is dropped on the Moon, the rock accelerates at about 1.6 m/s². Which diagram shows the speed-time graphs for rocks dropped on the Earth and on the Moon?



[Ans] D The gradient of the speed-time graph is the acceleration of the rock. Since the acceleration of the rock on Earth is greater, the speed-time graph of the rock on Earth is steeper compared to that on Moon.

Equations of Motion under Gravity

$v = u - gt$ ---(1)

$H = ut - \frac{1}{2}gt^2$ (for upward motion)--------------------(2)

$H = \frac{1}{2}gt^2$ (for downward motion)----------------(3)

$u^2 = -2gh$ (for upward motion)--------------------(4)

$v^2 = 2gh$ (for downward motion)----------------(5)

Example

A body is thrown vertically upwards with an initial velocity of 20 m/s. Given that the gravitational pull $g = 10\ m/s^2$, find:

(i) the time the body takes to reach the maximum height;

(ii) the maximum height, H reached above the starting point;

(iii) the total time of flight.

Solution

(i) For motion upwards $u = 20\ m/s$, $v = 0\ m/s$ and $g = 10\ m/s^2$

Using the equation, $v = u - gt$

$$0 = 20 - 10t$$
$$10t = 20$$
$$t = 2 \text{ seconds}$$

(ii) Using the equation, $H = ut - \frac{1}{2}gt^2$

$$= 20 \times 2 - \frac{1}{2} \times 10 \times 2 \times 2$$
$$= 40 - 20$$

maximum height = 20 m

(iii) The total time of flight = time taken from starting point to maximum height + time taken from the maximum height to the starting point.

From (i) above time for upward motion = 2 seconds

Using the equation $H = \frac{1}{2}gt^2$, time for downward motion will be,

$$H = \frac{1}{2}gt^2, H = 20 \text{ m from (ii) above}$$
$$20 = \frac{1}{2} \text{ x } 10 \times t^2$$
$$20 = 5t^2$$
$$t^2 = 4$$
$$t = 2 \quad \therefore t = 2 \text{ seconds}$$

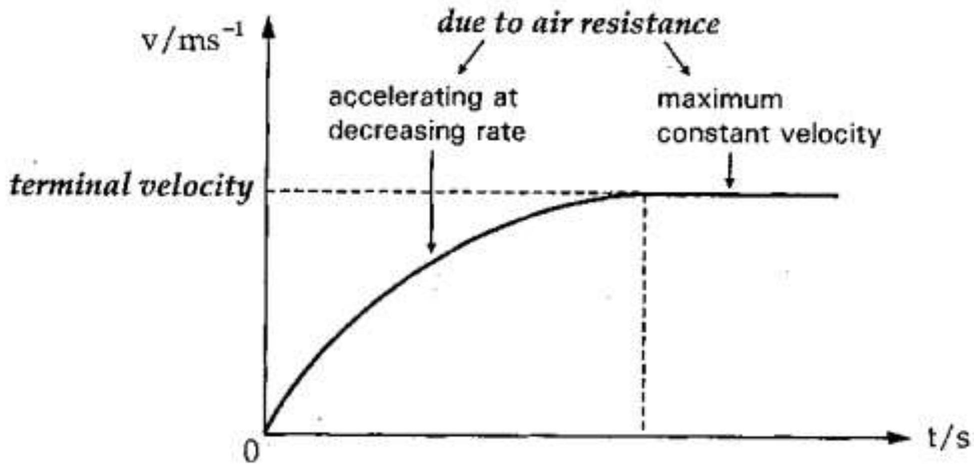
total time of flight = 2 + 2 = 4 seconds

Effect of Air Resistance

- There is always **air resistance** acting on the moving object in a direction **opposite** the direction of motion.
- Air resistance is a **frictional force** which:
  - Increases as the size of the surface area of the object increases.(directly proportional)
  - Increases as the speed of the object increases.(directly proportional)
  - Increases with the density of air.

Terminal Velocity

- Air resistance increases with the uniform increasing speed of the free-falling object.
- At first, the amount of air resistance is less than the weight of the free-falling object.
- The speed of the falling object gets higher and higher. Therefore, air resistance also get higher and higher.
- The weight of the object is constant. Therefore the resultant force keeps decreasing and decreasing.
- Eventually, the resultant force reaches **zero**, i.e acceleration of the object drops to zero.
- The object falls with a **constant** speed called **terminal velocity**.
- **Terminal velocity** is therefore defined as the **maximum downward velocity possible for a particular object falling through a fluid.**


v/ms^{-1}
due to air resistance
accelerating at decreasing rate
maximum constant velocity
terminal velocity
0
t/s

PRACTICAL 4 – THE MOTION OF A BODY FALLING IN A FLUID

Aim: To investigate the motion of a body falling in a fluid.

Apparatus

- Burette
- 3 steel balls
- clamp funnel
- glycerine
- complete stand

Procedure:

- Clamp the burette vertically. Carefully fill the burette with glycerine using a funnel (**NB:** ensure the tap is closed before putting glycerine).
- Carefully drop one steel ball from just above the liquid surface. (NB: ensure the ball does not slide along the walls of the burette.)
- Observe the movement of the ball through the glycerine.
- Repeat this experiment two more times using the other remaining steel balls.

Observation

Initially the speed of the ball increases and eventually becomes constant.

Discussion

When an object is falling in air or any other fluid, three forces act on it. These forces are: *weight of the body (W)*, *upthrust (U)* and *viscous drag* (fluid friction F_r) as shown in Fig. 6.36.

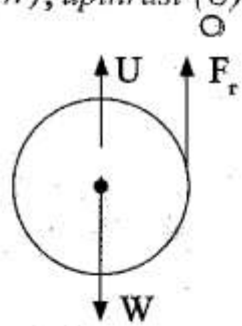


Fig. 6.36

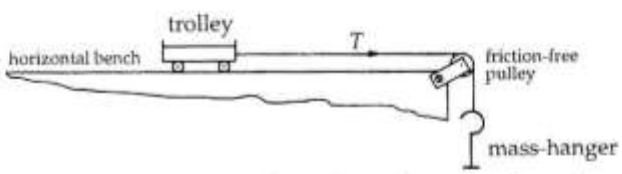
The viscous drag increases with increase in speed of the falling body.

Initially, W > (U + F_r) hence the body accelerates downwards. As viscous drag (F_r) increases, it reaches a point where U + F_r = W

There being no resultant force, the body moves at uniform (constant) velocity. This constant velocity is called terminal velocity (V_t). *Terminal velocity is therefore defined as the maximum downward velocity possible for a particular object falling through a fluid.*

CHALLENGING QUESTIONS WITH ANSWERS – 3

1. The figure below shows a trolley being pulled along a horizontal bench by means of the tension T in the thread fastened to the front of the trolley. The other end of the thread is attached to a mass-hanger.



A group of students times the motion of the trolley after it has been given a small initial push. They obtain the following data.

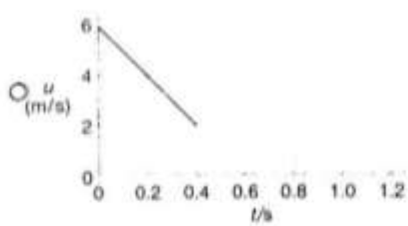
distance travelled/m	0.60	1.20	1.80
time/s	2.2	4.6	6.4

(a) Describe, in a few words, the motion of the trolley. Justify your answer. [3]

(b) Determine the average speed of the trolley. [2]

(c) The mass of the trolley is 1.4 kg and that of the mass-hanger is 15 g. The gravitational force on a mass of 1.0 kg is 10 N. Name and determine the magnitude of each of the four external forces acting on the trolley after it has been given the initial push. You may give your answers in any order. [2]

2. The figure below shows the variation of speed u with time t of a ball thrown vertically upwards into the air. Only the first 0.4 s of the graph has been plotted. In this question, air resistance can be neglected.



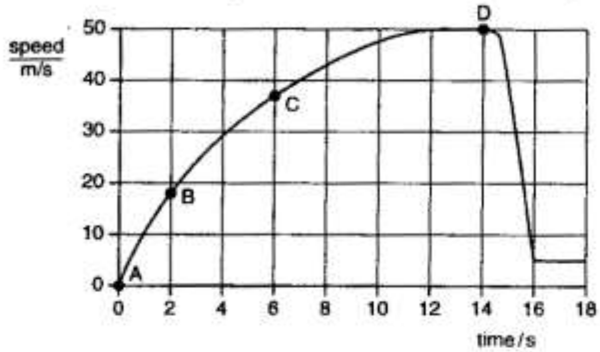
(a) State what is meant by the *speed* of the ball. [1]

(b) Complete the figure to show the variation of the speed u with time t between t = 0.4 s and t = 1.2 s. [2]

(c) State the value of the time when the ball is at its highest point above the ground. [1]

(d) Determine the vertical distance covered by the ball in the first 0.4 s of its motion. [3]

3. A parachutist jumps from an aircraft and falls through the air. After some time, the parachute opens.



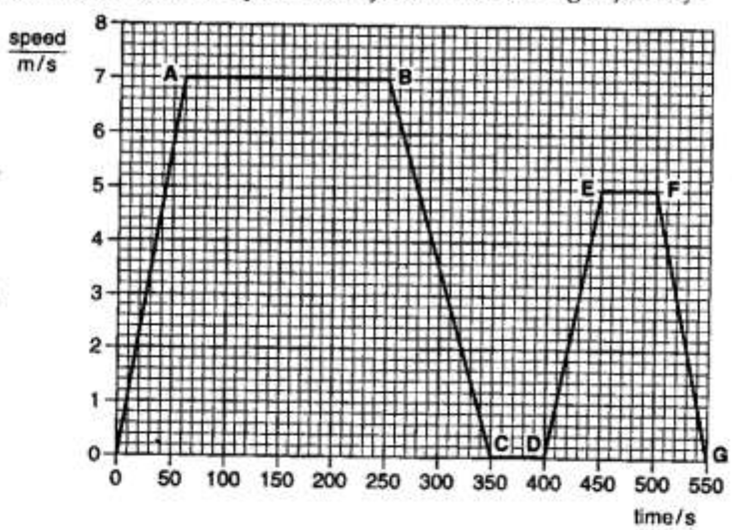
The figure above shows how the speed of the parachutist varies with time.

(a) Describe the motion of the parachutist between A and D. [3]

(b) State the value of the terminal velocity before and after the parachute opens. [1]

(c) Calculate the average value of the acceleration between B and C. [2]

4. The figure below shows how the speed of a cyclist varies during a journey.

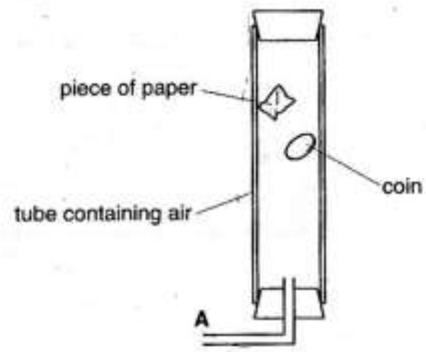


(a) Describe the motion of the cyclist between points B and C. [2]

(b) State which parts of the graph show the cyclist moving with constant speed. [1]

(c) Calculate the distance travelled by the cyclist in the first 250 s of the journey. [3]

5. The figure shows apparatus that demonstrates how a coin and a piece of paper fall from rest under gravity.



(a) State the initial value of the acceleration of the coin as it falls from rest. [1]

(b) The coin and paper are at the positions shown in the figure. Explain, in terms of the forces acting, why

(i) the paper falls with constant speed, [1]

(ii) the coin still accelerates. [1]

(c) A vacuum pump is connected to A and the air in the tube is removed. The coin and paper fall differently in a vacuum from the way they fall in air. State two of these differences. [2]

SOLUTIONS:

1. (a) The trolley has a uniform speed and no acceleration. If experimental errors are taken into account, the distance travelled per unit time remains almost constant.

(b) Average speed $= \frac{1.80}{6.4} = 0.28$ m / s

(c) Tension in string $= \frac{15}{1000} \times 10\text{ N} = 0.15\text{ N}$

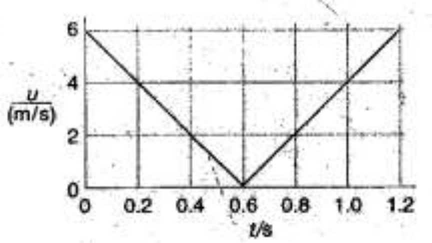
Frictional force on trolley = 0.15 N

Weight of the trolley = 1.4 × 10 N = 14 N

Normal Reaction on trolley = 14 N

2. (a) Speed is the distance travelled per unit time.

(b)



(c) time = 0.60 s

(d) distance covered = area under the speed - time graph $= \frac{1}{2}(6+2)(0.4) = 1.6$ m

3. (a) The speed of the parachutist increases and then becomes constant.
The acceleration of the parachutist decreases from some fixed positive value to zero.

(b) Before the parachute opens, terminal velocity = 50 m/s

After the parachute opens, terminal velocity = 5 m/s

(c) $a = \dfrac{v-u}{t}$

$= \dfrac{37-18}{6-2}$

$= 4.75 \text{ m/s}^2$

(a) When candidates are asked to describe the motion of an object, they need to describe the changes in speed and acceleration of the object. The marks allocation will tell how many points are required in your answer.

(c) From the speed-time graph, it is noticed that the acceleration from B to C is not uniform. However, when average value is calculated, we assume that the acceleration is constant. This also applies to average speed.

4. (a) The speed of the cyclist decreases uniformly. The deceleration of the cyclist is constant.

(b) AB and EF

(c) Distance travelled = area under speed - time graph

$= \frac{1}{2}(190+250)(7)$

$= 1540 \text{ m}$

(a) Describe the changes in speed and acceleration. The constant negative gradient shows that it is a constant deceleration.

(b) Moving with constant speed means no acceleration. The gradient of the speed-time graph is zero. This will result in horizontal lines in the speed-time graph.

(c) Candidates should read carefully the readings when they determine the area under the speed-time graph. Do not make careless mistakes when they find the lengths.

5. (a) 10 ms^{-2}

(b) (i) The resultant force acting on the paper is zero as the weight is equal to the upward force (air resistance).

(ii) There is a downward resultant force acting on the coin as the weight is greater than the air resistance.

(c) 1. Both the coin and paper accelerate throughout the fall.

2. Both the coin and paper fall at the same rate and reach the bottom of the tube together.

(a) The initial air resistance is 0 N. Therefore the coin is a free-falling body and its initial acceleration is the acceleration due to gravity.

(b) Air resistance increases with the speed of a falling body. As the paper is very light, the air resistance will soon equal the weight.

(c) When air in the tube is removed, there is no air resistance. Both the coin and the paper are free-falling objects and hence accelerate at 10 ms^{-2}.

FORCES

WHAT ARE FORCES?

- A **force** is a push or pull.
- A force is a **vector quantity.**
- The SI Unit is **Newton (N),** named after the famous Physicist **Sir Isaac Newton.**

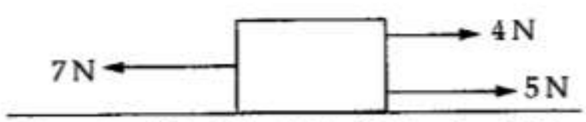
Effects of Forces

- A force can change **motion**, i.e it can cause an object to start or stop moving, increase or decrease speed and maintain or change direction.
- A force can distort or change the shape of an object. E.g a rubber band or a spring when compressed by a force.
- Can make objects turn about a point or cause a rotation

Unbalanced Forces

- If there are two or more forces acting on a body, there is a **resultant force.**
- If the **resultant force** is **zero** we say that the forces are **balanced.**
- If the resultant force is not zero, we say the forces are **unbalanced**.

e.g.



7 N to the left, 4 N + 5 N = 9 N to the right

There is a resultant force. The unbalanced force is 2 N to the right.

NEWTON'S FIRST LAW OF MOTION

- **A BODY WILL CONTINUE IN ITS STATE OF REST OR OF UNIFORM MOTION IN A STRAIGHT LINE UNLESS AN EXTERNAL FORCE IS APPLIED TO IT.**

NEWTON'S SECOND LAW OF MOTION

- **AN UNBALANCED FORCE ACTING ON A BODY PRODUCES AN ACCELERATION IN THE DIRECTION OF THE FORCE. THIS ACCELERATION IS DIRECTLY**

PROPORTIONAL TO THE FORCE AND INVERSELY PROPORTIONAL TO THE MASS OF THE BODY.

- This can be represented as follows:

$$Force = mass \times acceleration$$
$$F = ma$$

$$Weight = mass \times gravity$$
$$W = mg$$

Examples

[Q] A sledge of mass 25 kg is pulled across level ground with a horizontal force of 60 N. The constant force of friction is 20 N.

What is the acceleration of the sledge?

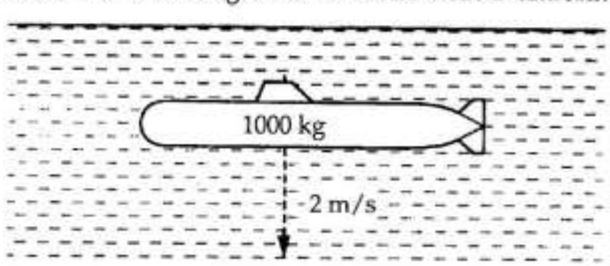
A $0.63\ m/s^2$ C $2.4\ m/s^2$

B $1.6\ m/s^2$ D $3.2\ m/s^2$

[Ans] B By Newton's 2nd Law

$$F = ma$$
$$60 - 20 = 25(a)$$
$$a = 1.6\ m/s^2$$

[Q] A small submarine of mass 1000 kg sinks in water with a uniform speed of 2 m/s.



What is the resultant force exerted on the submarine as it sinks?

A 0 N C 2000 N downwards

B 500 N downwards D 10000 N downwards

[Ans] A When an object is moving at constant speed, there is no acceleration. The resultant force is 0 N when acceleration is zero.

more examples…

1. A force of 350N acts on an object of mass 17.5 kg. What acceleration does it produce?

Solution

a = 350N/17.5 kg = 20 m/s^2.

2. A motorcycle and its rider have a mass of 500 kg. When moving on a level road at 20 m/s the rider disengages the gears, switches the engine off and comes to rest after 50 m. Calculate the retardation and the average frictional force that stops the rolling motorcycle.

Solution

$$v^2 = u^2 + 2ax$$

$$0 = 20^2 + 2a \times 50$$

$$a = \frac{-400\text{m}}{100\text{s}^2} = -40 \text{ m/s}^2$$

$$F = ma = 500 \times 4 = 200\text{N}$$

3. A bullet of mass 5g and travelling at 300 m/s strikes a wall and lodges 1 cm inside the wall. Calculate its retardation and the average force of resistance of the wall.

Solution

$$v^2 = u^2 + 2ax$$

$$0^2 = 300^2 + 2a \times 0.01$$

$$a = \frac{-90\ 000}{0.02} = -4\ 500\ 000 \text{ m/s}^2$$

$$F = ma = 0.005 \times 4\ 500\ 000 = 22\ 500\text{N}$$

PRACTICAL 5 – DEMONSTRATING INERTIA WITH CARD AND COIN

Experiment 8.1: Card being pulled slowly and suddenly to demonstrate inertia

Apparatus

- A coin
- A beaker
- A smooth cardboard

Procedure

- Place a coin on a smooth cardboard and place it over a beaker. Pull the card away slowly (Fig. 8.1 (a)). Observe what happens to the coin.
- Repeat the experiment but this time pull the card away suddenly (Fig. 8.1 (b)).

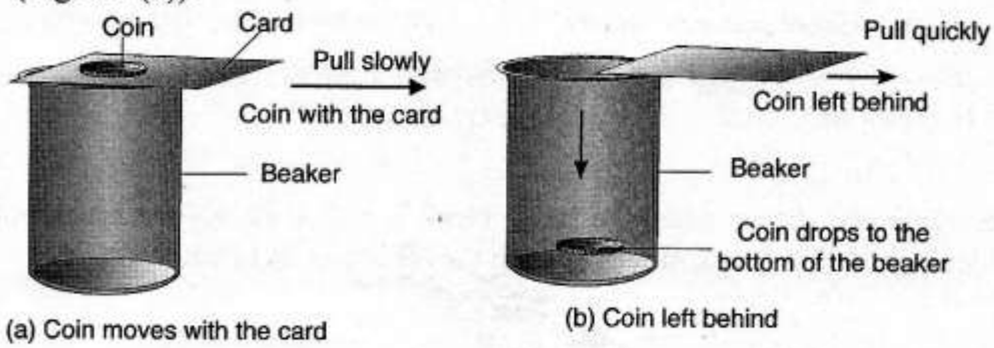


Fig. 8.1: Card with coin pulled (a) slowly (b) suddenly

Observation

When the card is pulled slowly the coin moves together with the card. However, when the card is pulled suddenly, the coin is left behind and drops vertically down into the beaker.

Discussion

When the card is pulled slowly, the frictional force between the card and the coin makes the two to move together. However, when the card is moved suddenly the coin resists motion and does not move with the card and hence drops vertically downwards into the beaker. The coin resists changing its state of rest but due to lack of support from below falls into the beaker.

MASS AND INERTIA

- A body with larger mass has greater inertia. Therefore, a lighter object is easier to start or stop moving. A heavier object is harder to stop or start moving.
- **Mass can be defined as the measure of inertia.**

PRACTICAL 6 – RELATIONSHIP BETWEEN ACCELERATION AND FORCE.

Experiment 8.5: To investigate the relationship between the acceleration of a body and the force applied on it

Apparatus

- A trolley
- Ticker timer
- Elastic cord
- A runway

Procedure

- Raise a runaway slightly to compensate for friction. Attach one end of elastic cord to the rod at the back of the trolley.
- Stretch the cord until the length is about twice the original length while holding the trolley in position. Release the trolley so that the cord exerts force F_1 on it.
- Keeping the length of the cord constant, repeat the experiment by stretching the cord thrice the original length and four times the original length. Release the trolley so that the cord exert forces 3 F and 4 F in Fig. 8.6. Observe and record the result.

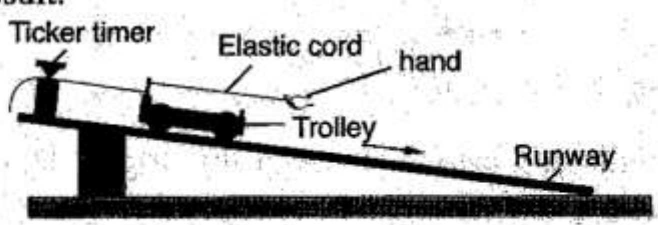


Fig. 8.6: Relationship between force and acceleration.

Observation

The tape obtained in each case appear as shown in Fig. 8.7 (a), (b) and (c).

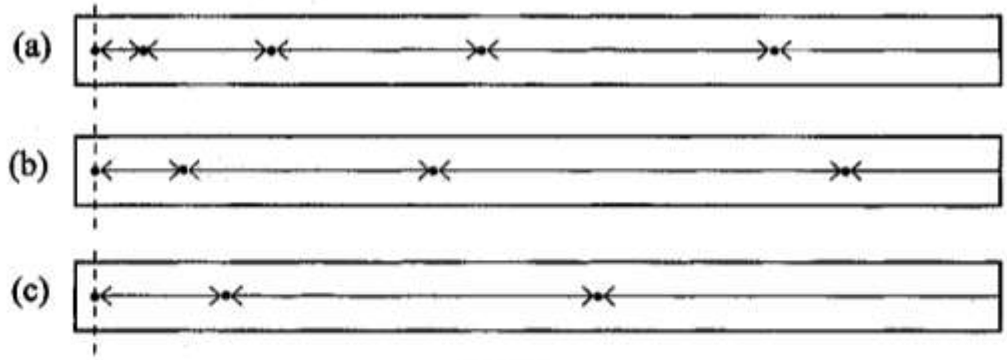


Fig. 8.7

From Fig. 8.7, we observe that the acceleration of tape in (a) is less than those in other tapes. Acceleration increases from tape in (a) to tape in (c).

The acceleration of tapes in (a), (b) and (c) in Fig. 8.7 and their corresponding values of forces exerted by the cords are tabulated as in Table 8.1.

Table 8.1

Force (F) exerted in Newton	F	2F	3F	4F
Acceleration a, of the trolley in m/s^2				

Plot a graph of acceleration a, (m/s^2) against force, F (N).

Discussion

If stretching the elastic cord ones produces a force F, stretching it twice, thrice and four times produce force equal $2F$, $3F$ and $4F$ respectively. A graph of acceleration against the force F (is shown in Fig. 8.8).

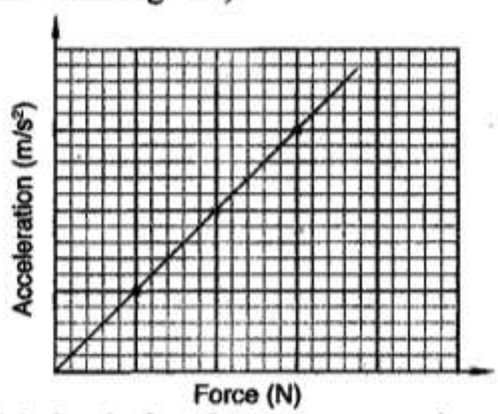


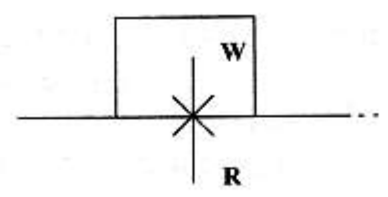
Fig. 8.8: Graph of acceleration, a, against force, F

The graph is a straight line passing through the origin. This shows that, the acceleration, a is directly proportional to the applied force, F i.e.

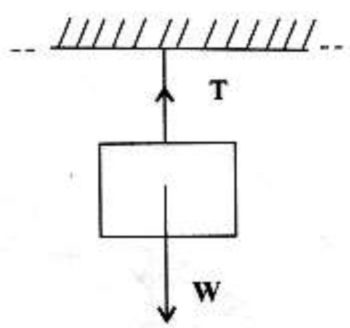
$a \propto F$ (mass is constant)

NEWTON'S THIRD LAW OF MOTION

- **FOR EVERY ACTING FORCE THERE EXISTS A REACTING FORCE THAT IS EQUAL IN MAGNITUDE BUT OPPOSITE IN DIRECTION.**
- **W = WEIGHT ; R = NORMAL REACTION FORCE:**



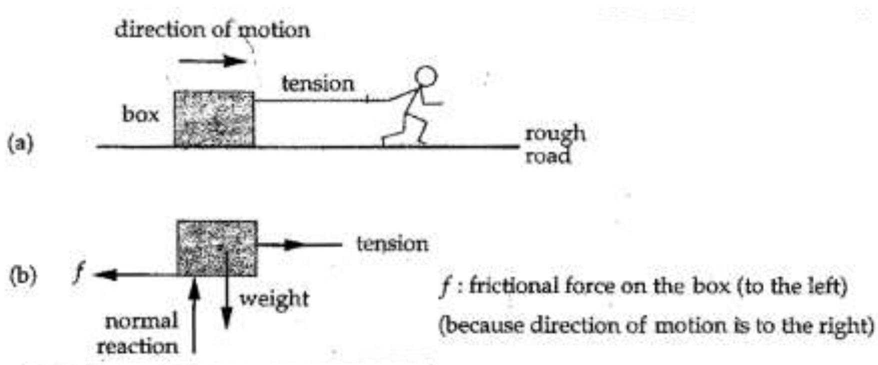
- When an object hangs by a string, the weight of the object is opposed by an equal force called tension in the string



- **TENSION = T; WEIGHT = W**

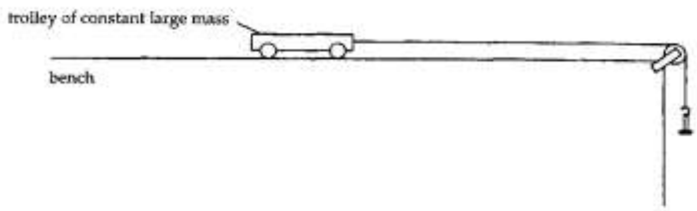
FRICTION

- **Friction force** always opposes the motion of an object.
- There is no surface that is completely smooth and this is why friction exists.
- Lubrication reduces friction.
- For example, a man uses a string to pull a box. Tension causes the box to move. There is friction between the box and the rough road and its direction is opposite to the direction of motion.



CHALLENGING QUESTIONS WITH ANSWERS – 4

1. The figure below shows an arrangement for demonstrating the relationship between force and acceleration.



(a) Draw a diagram of the trolley and, on your diagram, draw arrows to represent all the external forces acting on the trolley when it is accelerating along the bench. Label each force. [3]

(b) In one particular experiment, the mass of the trolley was kept constant. The time t for the trolley to move a distance of 1.00 m from rest was determined for various values of the pulling force F. The acceleration a was then calculated using the equation $s = \frac{1}{2}at^2$, where s = 1.00 m. The following values were obtained.

F / N	0.40	0.80	1.20	1.60	2.00
a / (m / s²)	0.08	0.22	0.43	0.57	0.74

(i) Plot a graph of F/N (y-axis) against a/(m/s²) (x-axis); start your axes at the point F/N = 0, a/(m/s²) = 0. Draw the best straight line through your points.

(ii) Determine the gradient of your graph.

(iii) Use your graph to determine the value of F when the acceleration is 0.

(iv) Use your answer to (a) to explain why a pulling force is needed to give zero acceleration. [10]

(c) State and explain the effect on the gradient of the graph if the mass of the trolley were to be doubled. [2]

2. (a) The table below shows the variation with time t of the distance s travelled by an aircraft as it starts moving along a runway.

t/s	0	1	2	3	4	5
s/m	0	1	6	17	37	67

State, giving your reasons,

(i) whether the speed of the aircraft is increasing, decreasing or remaining constant,

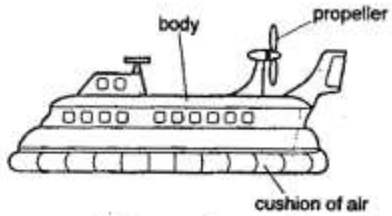
(ii) whether the acceleration of the aircraft is increasing, decreasing or remaining constant. [4]

(b) A parachutist falls from an aircraft which is flying horizontally. The parachute opens some time after the start of the fall.

(i) State why the initial vertical acceleration of the parachutist is approximately $10\ m/s^2$.

(ii) State and explain what happens to the vertical speed of the parachutist after the parachute opens. [4]

3. A hovercraft moves on a cushion of air which is trapped underneath it, as shown in the figure below. The trapped air reduces friction.

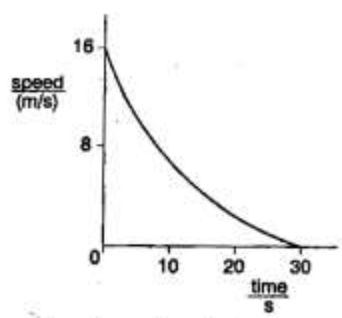


(a) The hovercraft starts from rest and, as it starts, the propeller produces a forward force F of 22 000 N. The mass of the hovercraft is 25 000 kg.

Calculate the initial acceleration of the hovercraft. You may assume there is no friction. [3]

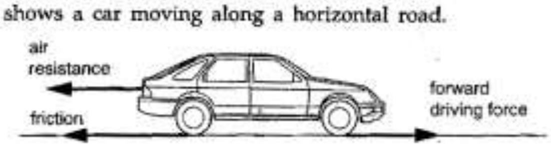
(b) Some time later, the hovercraft reaches a steady speed, even though the force F is unchanged. Suggest, in terms of the forces acting on the hovercraft, why the speed is now constant. [2]

(c) When the hovercraft is travelling at a speed of 16 m/s, the force F is switched into reverse and the hovercraft gradually slows down. Figure shown below is a graph of the variation of speed with time.



State how the graph shows that the acceleration is not constant. [1]

4. The figure below shows a car moving along a horizontal road.



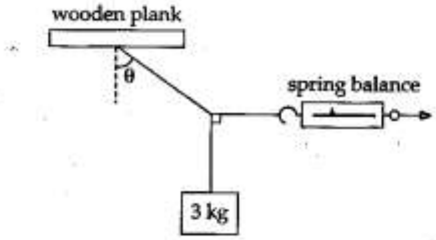
The car has mass 800 kg. At one point in its motion, when the combined forces of air resistance and friction acting backwards are 400 N, its acceleration is $1.4\ m/s^2$.

(a) Calculate the forward driving force required to accelerate the car. [3]

(b) With the engine working at constant full power, the car's acceleration decreases as it goes faster.

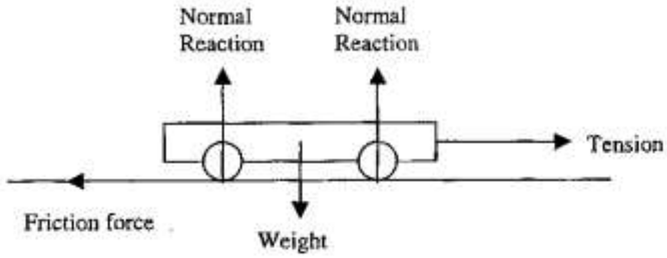
Explain why this is so. [2]

5. A block of mass 3 kg is hanging by a string from a flat wooden plank. A horizontal force pulls the block aside and the whole system is in equilibrium when the reading in the spring balance is 40 N.

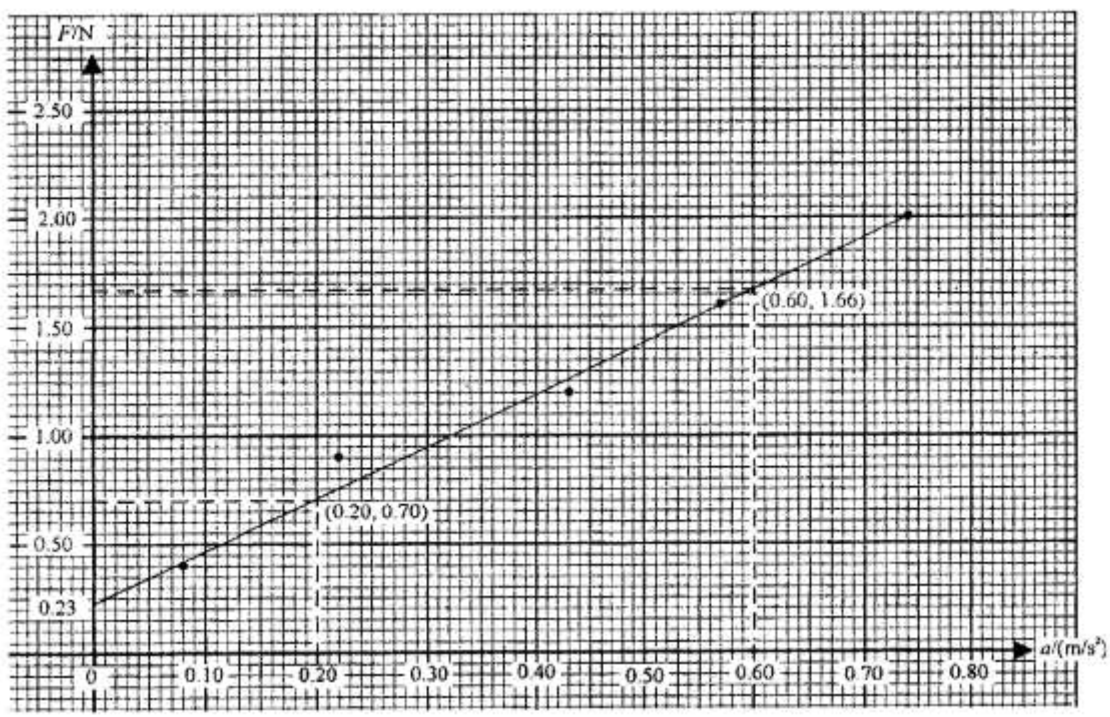


Draw a force diagram with a scale of 1 cm to 5 N to find the tension in the string and the angle of the string to the vertical.

1. (a)



(b) (i)



(ii) gradient $= \dfrac{1.66 - 0.70}{0.60 - 0.20} = 2.40$ kg

(iii) When the acceleration is 0, F is 0.23 N.

(iv) A pulling force equal to the frictional force is needed to give a zero resultant force. This gives rise to zero acceleration.

(c) The gradient is doubled because it represents the mass of the trolley.

2. (a) (i) The speed of the aircraft is increasing. It is because the distance travelled every one second is increasing.

(ii) The acceleration of the aircraft is increasing. The change of speed every one second is increasing.

(b) (i) Initially, there is no air resistance acting on the parachutist in the vertical direction.

(ii) The speed increases until it reaches a constant maximum value. At first, the air resistance is less than the weight of the parachutist. There is a downward resultant force and so the parachutist accelerates. As the speed increases, the air resistance increases until it is equal to the weight of the parachutist. The resultant force becomes zero and the acceleration of the parachutist is $0\ m/s^2$.

3. (a) By Newton's 2^{nd} Law,

$a = F/m = 22000/25000 = 0.88\ m/s^2$

(b) The forward force F is now equal to the frictional force acting on the hovercraft. The resultant force is zero and the craft has no acceleration.

(c) The gradient of the speed-time graph is not a constant.

(a) If an object starts from rest, its initial speed is zero. There is no friction.

(b) Candidates should take note that the frictional force increases with speed.

(c) Gradient of speed-time graph represents the acceleration. Acceleration is constant only when the gradient of the speed-time graph is constant (straight line).

4. (a) Let F_d be the forward driving force

By Newton's 2^{nd} Law

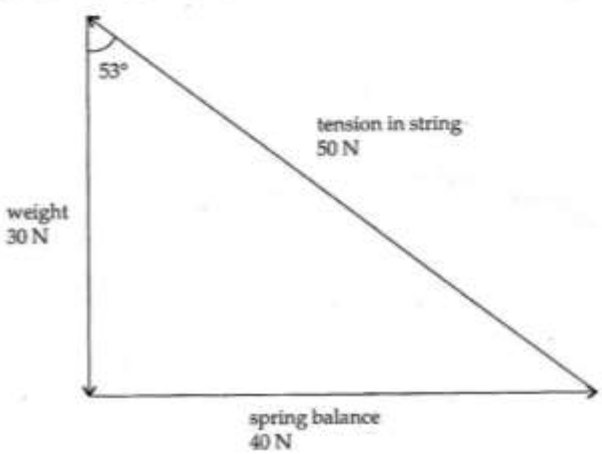
$$F = ma$$
$$F_d - 400 = 800 \times 1.4$$
$$F_d = 1520\ N$$

(b) As the car goes faster, the air resistance increases. When the engine is working at constant full power, the driving force is constant. This results in a decreasing resultant force acting on the car. Hence the car's acceleration decreases.

(a) When an object is moving horizontally, its weight does not affect its motion because it is a vertical force. For Newton's 2^{nd} Law, mass m is used but not the weight W. Many candidates tend to use the weight $W = m \times 10$ N/kg instead of m.

(b) Engine at constant full power means a constant driving force. Again, the air resistance acting on an object increases with speed of the object is tested. It explains why the acceleration of an object is changed during its motion. It is an important point in Dynamics.

5. Scale: 1 cm represents 5 N



The tension in the string is 50 N.
The angle of the string to the vertical is 53°.

Since the system is in equilibrium, the resultant force acting on the block is zero. When a vector diagram is drawn, the three forces form a triangle. This happens when there is no unbalanced force from the three forces acting on the object.

FORCE AND ELASTICITY

PRACTICAL 7 – RELATIONSHIP BETWEEN THE EXTENSION PRODUCED IN A SPRING AND THE FORCE APPLIED

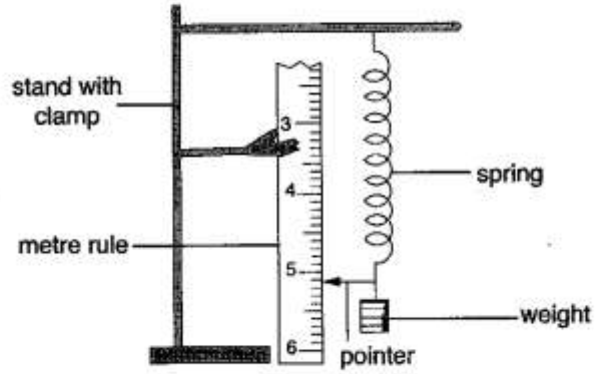


Fig. 9.1: Stretching a spring.

- Load the spring with a 50 g mass and record the new pointer reading. Unload the spring and observe what happens to the pointer.
- Repeat the experiment with 100 g, 150 g, 200 g, 250 g, 300 g, 350 g masses and record the readings on a table (Table 9.1).

The initial pointer reading x = ________cm

Table 9.1

Mass (g)	Force (N)	Final reading y (cm)	Extension, e y – x (cm)
50			
100			
150			
200			
250			
300			
350			

- Draw a graph of applied force against extension produced.

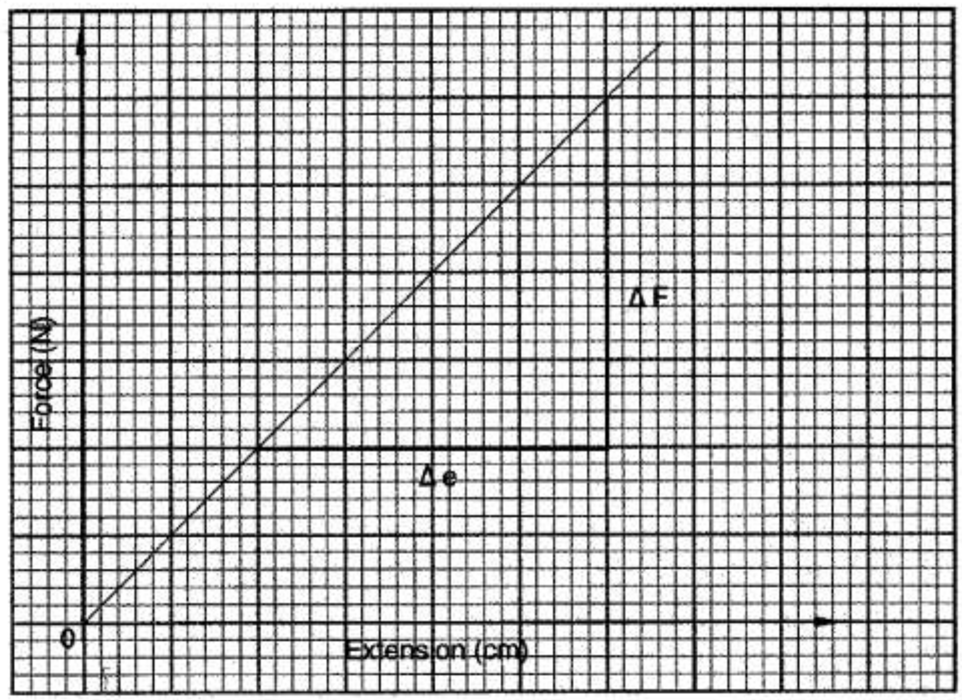


Fig. 9.2: Force-extension graph for a spring.

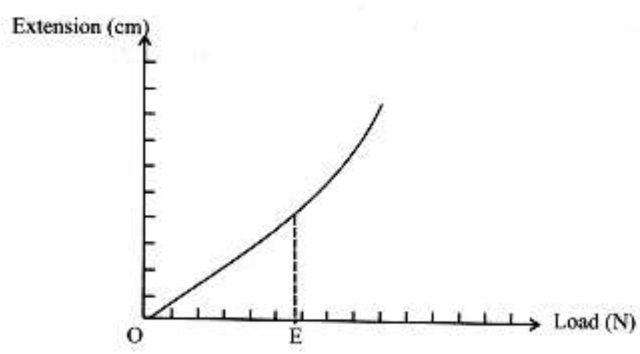
A graph of extension against force gives a straight line graph passing through the origin.
It can be seen from the graph that *the extension produced is directly proportional to the force applied*. Each time the spring is unloaded the pointer returns to its original position.

- **Hooke's Law states that; provided the elastic limit is not exceeded, the extension of a spring is directly proportional to the load applied on the spring**
- Where "**k**" is the constant of proportionality called the **spring constant**;

$$k = \frac{Force}{Extension}$$

$$k = \frac{F}{e}$$

- The SI unit of **K** is N/m
- The **gradient of the graph = spring constant**

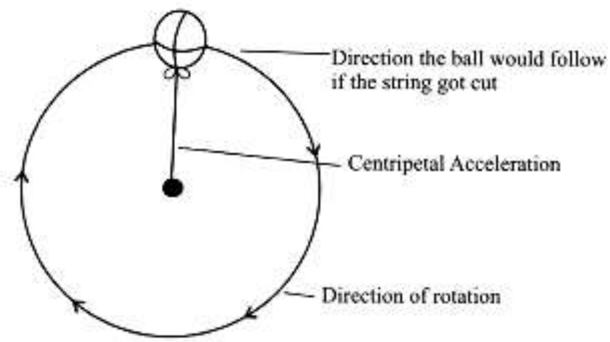


- The spring undergoes **elastic deformation** and obeys **hookes law** from O to E. Beyond E, it undergoes **plastic deformation** hence it does **not** obey **hookes law**

FORCE AND CIRCULAR MOTION

CIRCULAR MOTION

- The motion of an object at constant speed along a circular path is **uniform circular motion**.



- The ball above is whirled at a **constant speed**.
- Its direction changes continuously.
- Therefore, its velocity changes in **direction** but the **magnitude remains the same.**
- This results in **centripetal acceleration** towards the centre of the circle.

Centripetal acceleration is given by:

$$a_c = \frac{v^2}{r}$$

Where **'v'** Is the linear speed and **'r'** the radius of the circle.

- As the ball is whirled around, **a force is being exerted on the ball through the string towards the centre.** This force is called **centripetal force**.

$$F = ma = \frac{mv^2}{r}$$

$$thus\ the\ formula\ of\ centripetal\ force;$$

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

- **F = centripetal force; r = radius; m = mass; v = linear speed.**
- The ball exerts an equal and opposite force on the string away from the centre. This force is called **centrifugal force.**

PRACTICAL 8 – RELATIONSHIP BETWEEN FORCE AND THE SPEED OF REVOLUTION

Apparatus

- A glass or 1.5 m long string
- A crocodile clip
- A Paper clip
- A mass

Procedure

- Obtain a glass or plastic tube of length 15 cm and diameter about 1 cm, (e.g. casing of a biro pen). Tie a body of mass *m* to the end of a thick string of length 1.5 m. Pass the free end of the string down through the tube and attach a hanger of known mass *m*.
- Attach a long paper clip or a crocodile clip to the vertical portion of the string which can act as an indicator to keep the radius of the circular path constant and to check that the motion is steady. (Fig. 11.4)

  Precaution: Make sure that mass *m* is tied securely to the string and the area around you is clear of other students and other things.
- Adjust the position of the paper clip so that the radius of the circular path is 1 m, i.e. the length of the horizontal portion of the string is 1 m. Grip the tube with one hand and swing the hand above the head, so that mass *m* moves in a horizontal circle of radius 1 m. (Fig. 11.4)

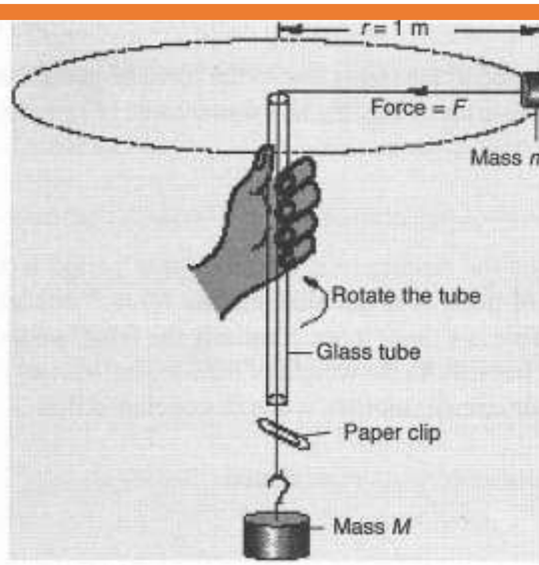


Fig. 11.4: A mass moving in a horizontal circle

- Note the number of revolutions made by the mass *m* in a certain time. Calculate the frequency of revolutions *f*, i.e. the number of revolutions made by mass *m* in 1 second. Determine the periodic time T (= $1/f$). Calculate the linear speed (v) of revolution of the mass *m* from the equation, $v = 2\pi r/T$.
- Keeping the mass *m* constant and the radius of the circular path as 1 m, add slotted masses M to the hanger and rotate the tube faster each time. Determine the frequency of revolution and the speed, *v* of mass *m*. Record your observations in a table (Table 11.1.)

Table 11.1

Mass of the hanger and the slotted masses (*M*) (kg)	Number of revolutions made in time *t* (N)	Frequency (*f*) $f = \frac{N}{t}$ (Hz)	*T*(s)	Speed v (r = 1 m)

- Deduce the relationship between masses *M* in the hanger and the speed of revolution *v* of the mass (*m*).

Discussion

The tension developed in the string due to the force of gravity on the hanger and the slotted masses (*Mg*) provides the horizontal force (*F*) needed to keep mass *m* in a circular path.

Conclusion

It is seen that when the frequency is doubled (time period is halved) the speed of revolution (*v*) of mass *m* is doubled and the force *F* needed to maintain the same radius as before is *4 times* more. Similarly the force needed is 9 times more, when the speed is trebled. As the weight of the hanging masses (*Mg*) provides the required force *F* for circular motion, it can be concluded that *the force F required to keep the body in a circular path of constant radius is directly proportional to the square of the speed of revolution*. Hence

$F \propto v^2$

Examples

Example

A 5 kg mass moves at uniform speed of 18 m/s in a circular path of radius 0.5 m. Calculate the centripetal force acting on the mass.

Solution

$$\text{Centripetal force, } F = m\frac{v^2}{r} = 5 \times \frac{18^2}{0.5} = 3\,240\text{ N}$$

Example

A car of mass 1 200 kg has to make a circular turn of radius 30 m. If it is moving with a uniform speed of 10 m/s, calculate the centripetal force acting on the car.

Solution

$$\text{Centripetal force, } F = m\frac{v^2}{r} = \frac{1\,200 \times 10^2}{30} = 4\,000\text{ N}$$

APPLICATIONS OF UNIFORM CIRCULAR MOTION

A Car Going Round a Curve

The maximum safe speed for the motorist not to skid off the road is given by the following formula;

$$v_{max} = \sqrt{F \times \frac{r}{m}}$$

More Applications

-Centrifuge

-Conical Pendulum

-An aircraft taking turn

TURNING EFFECT OF FORCES

MOMENT OF A FORCE

- The turning effect of a force about a pivot is called **moment** or **torque.**
- We can measure **moment of a force** if we know:
    1. The magnitude of the force applied.
    2. The perpendicular distance between the line of action of the force and the pivot
- **The moment of a force about a pivot is the product of the force and the perpendicular distance of its line of action from the pivot.**
- Hence;
- $Moment\ of\ a\ force = F\ \times d$

$$where:$$
$$F: force(N);\ d: perpendicular\ distance\ from\ pivot$$

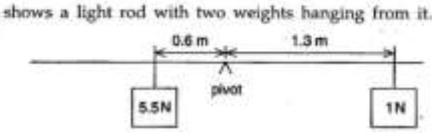
SI Unit of Moment of Force

- **Newton Metre (Nm).**
- **Moment of force is a vector quantity.**

PRINCIPLE OF MOMENTS

- It states that, **when a body is in equilibrium under the action of forces, the sum of clockwise moments about any point is equal to the sum of anticlockwise moments about the same point.**

[Q] The diagram shows a light rod with two weights hanging from it.



A third weight is to be added to bring the system into equilibrium so that the rod is balanced. What weight is required and where should it be placed?

	weight	position
A	1 N	2 m to the left of the pivot
B	1 N	3 m to the right of the pivot
C	2 N	1 m to the left of the pivot
D	2 N	1 m to the right of the pivot

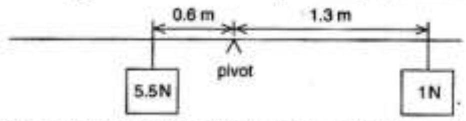
[Ans] D Before the additional weight is added,

anticlockwise moment = 5.5 × 0.6 = 3.3 Nm

clockwise moment = 1 × 1.3 = 1.3 Nm

For the light rod to be in equilibrium, we need a clockwise moment of 2.0 Nm from the additional weight. It should be placed on right hand side of the pivot.

[Q] The diagram shows a light rod with two weights hanging from it.



A third weight is to be added to bring the system into equilibrium so that the rod is balanced. What weight is required and where should it be placed?

	weight	position
A	1 N	2 m to the left of the pivot
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C	2 N	1 m to the left of the pivot
D	2 N	1 m to the right of the pivot

[Ans] D Before the additional weight is added,

anticlockwise moment $= 5.5 \times 0.6 = 3.3$ Nm

clockwise moment $= 1 \times 1.3 = 1.3$ Nm

For the light rod to be in equilibrium, we need a clockwise moment of 2.0 Nm from the additional weight. It should be placed on right hand side of the pivot.

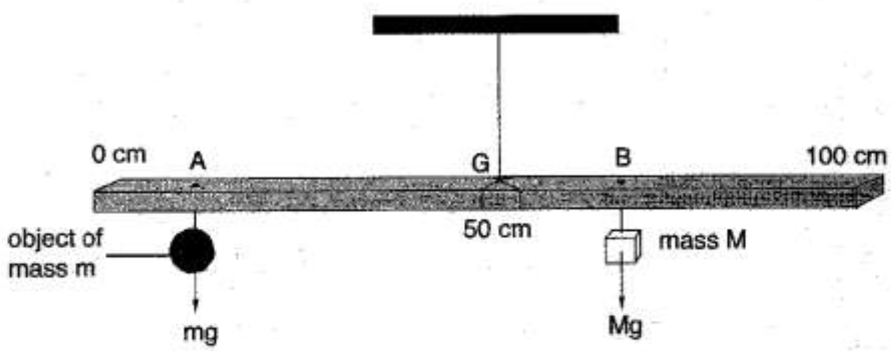
PRACTICAL 9 – FIND MASS USING THE PRINCIPLE OF MOMENTS.

Apparatus

- A metre rule
- A known mass
- An unknown mass

Procedure

- Suspend a uniform metre rule at its mid point G. Suspend the object of mass m, using a string, from a point A. Suspend a known mass M on the other side of the metre rule and adjust the position of the mass M till the metre rule is horizontal as shown in Fig. 12.12.



- Record the distances GA and GB. Repeat the experiment by changing the position of the object or the mass M. Enter the readings of M, GA and GB in a tabular form as shown in Table 12.2.

	Mass M(g)	GA(cm)	GB(cm)	$m = \frac{M.GB}{GA}$ (g)
1				
2				
3				
			Mean m	

- Calculate the mean value for the mass of the object from the last column.

Discussion

Taking moments about G,

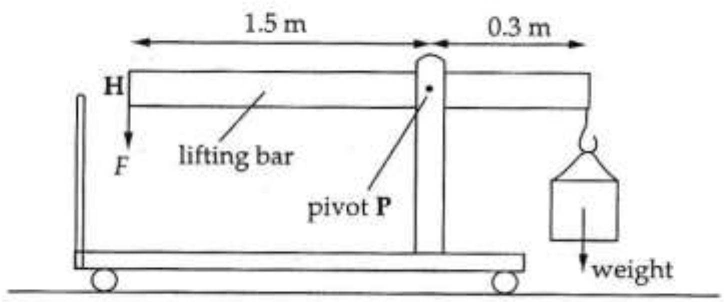
$$(mg) \times GA = (Mg) \times GB,$$

$$m \times GA = M \times GB, \quad \text{(g cancels out)}$$

$$\therefore m = \frac{M \times GB}{GA}$$

CHALLENGING QUESTIONS – 5

1. The diagram shows the essential features of a trolley used for lifting and transporting heavy buckets in a factory. The force to lift a bucket is derived from the downward force the operator exerts at the handle **H** at the end of the lifting bar. The centre of gravity of the lifting bar is at **P**.



(a) By taking moments, calculate the force *F* necessary to hold steady, in the position shown, a bucket and contents of total mass 60 kg. (Take the weight of 1 kg to be 10 N.) [3]

(b) Calculate the work done in lifting the mass of 60 kg through a vertical height of 0.12 m. [2]

(c) Calculate the power needed to complete this lifting operation in 4.0 s. [2]

Suggest a reason why the power actually developed by the operator during the 4.0 s must be greater than your calculated value. [1]

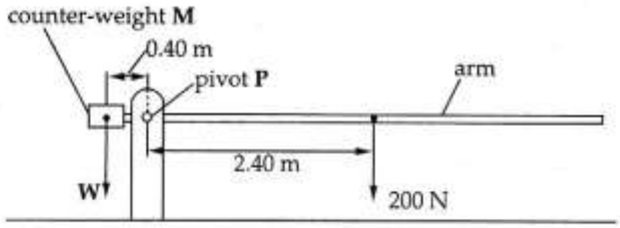
(d) State, with a reason in each case, why the device is designed so that the bar **PH** is 1.5 m long rather than

(i) 0.3 m,

(ii) about 5.0 m. [2]

2. (a) Explain what is meant by the moment of a force. Write down a unit in which it can be measured. [3]

(b) The figure below shows an electrically operated railway-crossing barrier. The barrier is pivoted at **P** and, in order to make it easier to raise the arm of the barrier, the weight of the arm is balanced by the counter-weight **M**.



The weight of the arm is 200 N and its centre of mass is 2.40 m from **P**. The centre of mass of **M** is 0.40 m from **P**. Calculate **W**, the weight of **M**, assuming that it just balances the weight of the arm. Show clearly how you arrived at your answer. [4]

3. Fig. 3.1 below shows a long, rigid, curved pole balanced at its midpoint **M** on a taut horizontal wire. One end of the pole is pushed upwards slightly by means of a vertical force F, as shown in Fig. 3.2.

The cross, labelled C, shows the position of the centre of mass of the pole in each diagram.

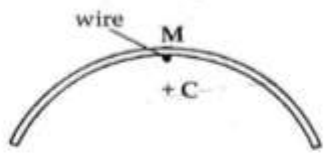


Fig. 3.1

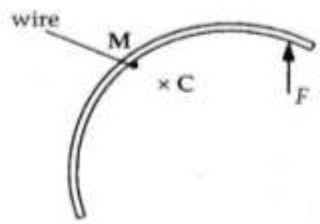


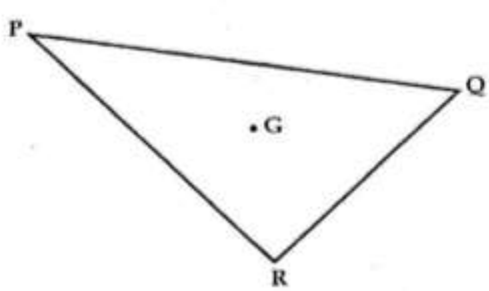
Fig. 3.2

(a) (i) On Fig. 3.1, draw an arrow to show the direction of weight of the pole with the arrow starting the point at which the weight acts.

(ii) In Fig. 3.2, the pole is balanced by force F and two more forces. On Fig. 3.2, draw arrows to show the positions and directions of these two forces. [3]

(b) Force F is now taken away. State and explain what will happen to the pole as soon as force F is taken away. [2]

4. The diagram shows a cross-section through the centre of a triangular prism. **G** shows the position of the centre of mass of the prism.



The prism is laid on one of its rectangular faces on a horizontal table. On which side, **PQ** or **QR** or **RP**, should the prism be placed for maximum stability? State your reasons for your answer. [2]

5. (a) Fig. 5.1 shows the same vertical force of 200 N exerted by a cyclist on the pedal of a bicycle in three different positions **A**, **B** and **C**.

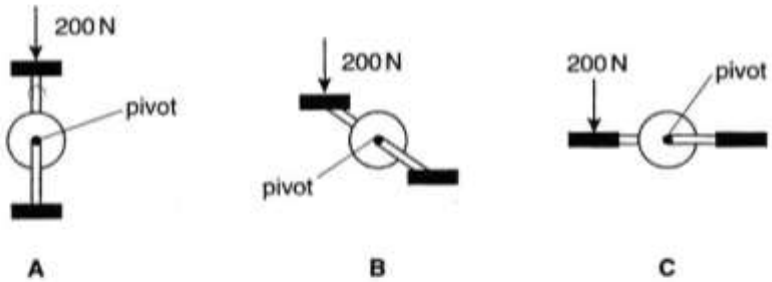


Fig. 5.1

State the position, **A**, **B** or **C**, in which the force exerts the largest moment about the pivot. Give a reason for your answer. [2]

(b) Fig. 5.2 shows a support for a leg in plaster and Fig. 5.3 shows a simplified diagram of the forces acting on the leg.

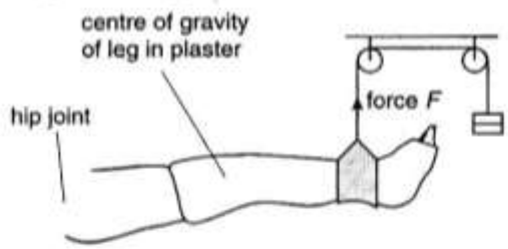


Fig. 5.2

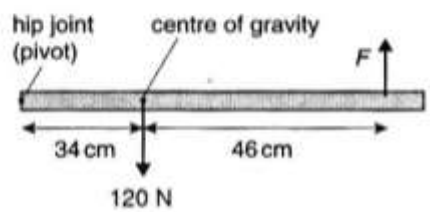


Fig. 5.3

Calculate the force F needed to keep the leg in a horizontal position. [3]

SOLUTIONS

1. (a) Taking moment about pivot P,

anticlockwise moment = clockwise moment

$$F \times 1.5 = 60 \times 10 \times 0.3$$
$$F = 120\text{ N}$$

(b) Force needed to lift the mass = weight = $60 \times 10 = 600$ N

Work done = force × distance
$= 600 \times 0.12$
$= 72$ J

(c) Power = work done / time
$= 72 / 4$
$= 18$ W

Power developed by the operator must be greater than the calculated value because there is some energy lost due to friction in the machine.

(d) (i) If PH is 0.3 m, the force required to lift the mass is equal to the weight. The 60 kg mass may not be lifted because a greater force is needed.

(ii) If PH is 5.0 m, it will be easier to lift the weight as a smaller force is required. However the device will be too bulky.

2. (a) Moment of a force is the turning effect produced by the force about a given point. It is determined by the product of the force and the perpendicular distance between the point and the line of action of the force.

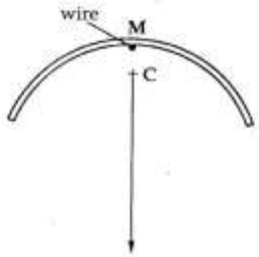
The unit for moment is Nm.

(b) Taking moment about pivot P,

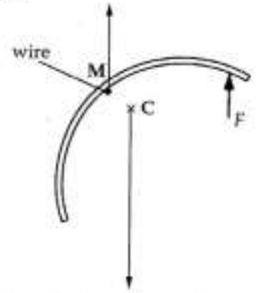
anticlockwise moment = clockwise moment

$$W \times 0.4 = 200 \times 2.4$$
$$W = 1200\text{ N}$$

3. (a) (i)



(ii)



(b) The pole will start to rotate in clockwise direction because there is a net clockwise moment produced by the remaining two forces.

4. The prism should be placed on side PQ for maximum stability.

Reasons: (1) The centre of mass of the prism is the lowest from the table.

(2) The base contact area is the largest.

Candidates should realise that the stability increases with a lower centre of mass and a larger base area.

5. (a) Position C.

The perpendicular distance between the line of action of the force from the pivot is the greatest in position C.

(b) When the leg is kept in a horizontal position, it is in equilibrium.

Taking moment about the hip joint (pivot),

$$F \times (34 + 36) = 120 \times 34$$
$$F = 51 \text{ N}$$

(a) Moment = force x perpendicular distance

Position C has the greatest moment as the perpendicular distance is the longest.

Position A has zero moment as the perpendicular distance is zero.

Position B has a moment produced but less than that in position C.

(b) The leg is not turning so the principle of moment can be applied.

ENERGY, WORK AND POWER

WORK

Work is said to be done on a body whenever a force produces a displacement on the body. This displacement must be in the direction of the applied force.

Therefore,

$Work\ Done = Force \times Distance$

$W = F \times d$

- SI Unit is **joule (j)**
- 1 Joule = 1 Nm
- Nm can be used for both work and moment of force.
- Joule cannot be used for moment of force.

Work Done by Frictional Force

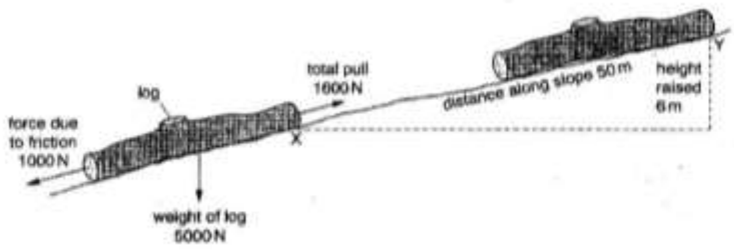
- When a force is applied on a body resting on a surface, frictional force is developed, opposing the motion of the body.
- Hence, work has to be done to overcome friction.

$Useful\ Work\ Done = Work\ Done\ by\ the\ Applied\ Force - Work\ Done\ Against\ Friction$

$Useful\ Work\ Done = Fd - fd$

Example

[Q] The diagram shows a log being pulled up an earth slope from X to Y. How much work is done against friction?



A 6000 J B 9600 J C 50000 J D 80000 J

[Ans] C Work done against friction = friction × distance moved
= 1000 × 50
= 50000 J

more examples…

A force of 40 N is applied on a body. The body moves a horizontal distance of 7 m. Calculate the work done on the body.

Work done $= F \times d$

$= 40\text{ N} \times 7\text{ m} = 280\text{ J}$

A box of mass 30 kg is pushed with a force of 130 N up an inclined track of length 14 m onto a platform (Fig. 13.4).

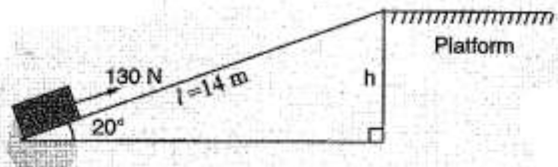


Fig. 13.4

If the track is inclined at an angle of 20°, calculate the:

(a) height of the platform.

(b) work done by the force of 130 N.

(c) work done, if the box was lifted vertically upwards. Comment on the answer in part (b) and (c).

(d) frictional force between the box and the track.

Solution

(a) $\sin 20° = \frac{h}{l}$ (Fig. 13.4)

$h = \sin 20° \times 14\text{ m}$

$= 4.79\text{ m}.$

(b) Work done by the force of 130 N

$W = F \times x$

$= (130 \times 14)\text{ Nm}$

$= 1\,820\text{ J}$

(c) Work done in lifting the box vertically upwards

$W =$ weight of box $\times h$

$= 30\text{ kg} \times 10\text{ N/kg} \times 4.79\text{ m}$

$= 1\,437\text{ J}$

The two are different. Some work is used to overcome friction

(d) Total work = work done by the force + work done against friction.

work done against friction

$= 1\,820 - 1\,437 = 383\text{ J}$

$383\text{ J} = f_s \times x = f_s \times 14\text{ m}$

$f_s = \frac{383\text{ J}}{14\text{ m}} = 27.4\text{ N}$

(f_s is force of friction)

PRACTICAL 10 – WORK DONE IN STRETCHING A SPRING

Apparatus

- A spiral spring
- A metre rule
- Five-20 g masses

Procedure

- Measure the original length of a spring when no mass is hung from the free end (l_0). Hang a mass from the spring and measure the length, l_1, as shown in Fig. 13.11. The difference between l_1 and l_0 gives the extension of the spring, *e*.
- Repeat the experiment with other masses and record the results in a table (Table 13.1). Plot a graph of force (*F*) against extension, *e*.

Table 13.1

Mass (g)	Weight (N)	Extension (cm)

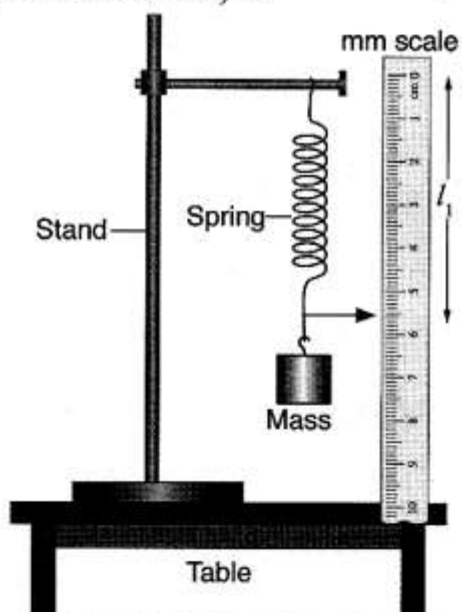


Fig. 13.11: Loaded spring

Discussion

The area under the graph (Fig. 13.12) represents the work done in stretching the spring. This work done is stored in the spring as elastic potential energy.

work done = average force applied × extension

$$= \frac{0 \times F}{2} \times e = \frac{1}{2} Fe$$

= area under the graph

Therefore

work done = area under the graph

$$= \frac{1}{2} AB \times OB$$

$$= \frac{1}{2} Fe$$

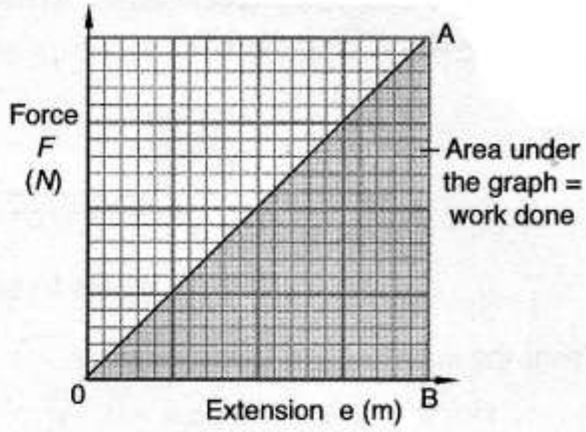


Fig. 13.12: Graph of force against extension

Work done on a spring = $\frac{1}{2} Fe$ = *Energy stored in the spring.*

By Hooke's law, the force applied on a spring is F = ke, where k is the spring constant. The energy stored in a spring can also be written as:

work done = $\frac{1}{2}$ (ke).e. Therefore

work done = $\frac{1}{2} ke^2$.

ENERGY

- **Energy** is the capacity to do work.
- Energy can change from one form to another
- It has no direction (scalar)
- SI Unit is **Joule (j)**
- Everything around us has energy in different forms

Forms of Energy

	COMMON EXAMPLE
Chemical Energy	Fuels(oil, coal, petrol), electric cells, food, explosives
Electrical Energy	The energy associated with the current in electric motors, heaters, electrical appliances etc.
Mechanical Energy 1. Kinetic Energy 2. Potential Energy i. Gravitational Potential Energy **ii.** Elastic Potential Energy	All objects in motion have Kinetic Energy. Raised bodies have Gravitational Potential Energy. Compressed or Stretched material has Elastic Potential Energy.
Nuclear Energy	The energy released from nuclear reactions like fission and fusion.

[Q] Which example best illustrates the conversion of electrical energy to chemical energy?

A melting a fuse

B charging an accumulator

C starting a car

D generating hydro-electric power

[Ans] B Charging an accumulator is to convert the electrical energy from the power source to the chemical energy stored inside the accumulator.

KINETIC ENERGY

- All moving objects have **kinetic energy.**
- When an object is at rest, there is **no kinetic energy**.
- Kinetic energy depends on an objects mass and speed.
  A running elephant has more kinetic energy than a running man.
- To measure kinetic energy, we apply the following equation;

$K.E = \frac{1}{2}mv^2 \quad where\ K.E = Kinetic\ Energy;\ m = Mass; v = Speed$

Example

A body of mass 12 kg is pulled from rest with a constant force of 25 N. The force is applied for 6.0 s. Calculate (a) the distance travelled, (b) work done on the body, (c) the final kinetic energy and (d) the final velocity of the body.

Solution

(a) $s = ut + \frac{1}{2}at^2$ but $u = 0$. Therefore $s = \frac{1}{2}at^2$

From F = ma ; $a = \frac{25}{12} = 2.1\ m/s^2$

$s = \frac{1}{2} \times 2.1 \times 6^2 = 37.8\ m$

(b) Work done = F × d

= 25 × 37.8

= 945 J

(c) Kinetic energy = work done

= 945 J

(d) $\frac{1}{2}mv^2 = 945$

$v = \sqrt{\frac{945 \times 2}{12}}$

= 12.6 m/s.

GRAVITATIONAL POTENTIAL ENERGY

- The energy of position is called **potential energy.**
- When an object is lifted to a higher position, it gains **gravitational** potential energy.
- This is stored energy which can be converted to kinetic energy when the object falls down.
- **e.g Water stored behind a dam.**
- Potential Energy depends on an object's **mass** and **height.**
- To measure potential energy, apply the following equation:

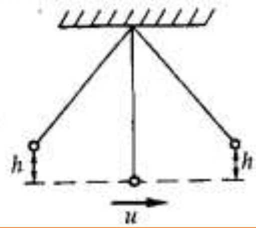
$$P.E = mgh$$

$where\ P.E = potential\ energy\ (j); m = mass\ (kg);\ g = gravity\ \left(\frac{N}{Kg}\right)\ and\ h = Height\ (m)$

Example

[Q] A pendulum bob of mass m, attached to a light string, is released from rest at a height h above its lowest point. The speed of the bob at its lowest point is u.

What will be the kinetic energy of the bob when it reaches a height h on the other side?



A zero C $\frac{1}{2} mu^2$

B mgh D mu^2

[Ans] A At the highest point, the bob is momentarily at rest and so the kinetic energy is zero.

Kinetic energy is the energy of motion. There is no kinetic energy if the object is at rest. It is potential energy at h.

more examples…

A stone of mass 10 g is projected vertically upwards with a velocity of 40 m/s. Find

(a) the maximum height reached.

(b) the P.E at the height in (a). (Take $g = 10 m/s^2$)

Solution

(a) $v^2 = u^2 + 2as$

$0 = u^2 - 2gs$

$2gs = u^2$

$s = \frac{u^2}{2g} = \frac{40 \times 40}{2 \times 10} = 80$ m

(b) P.E $= mgh;\ s = h$

$= \frac{10}{1\ 000} \times 10 \times 80$

$= 8$ J

Example 13.4

A crane is used to lift a body of mass 30 kg through a vertical distance of 6.0 m.

(a) How much work is done on the body?

(b) What is the P.E stored in the body?

(c) Comment on the two answers.

Solution

(a) Work done $= F \times d = mg \times d = 30 \times 10 \times 6 = 300 \times 6 = 1\ 800$ J

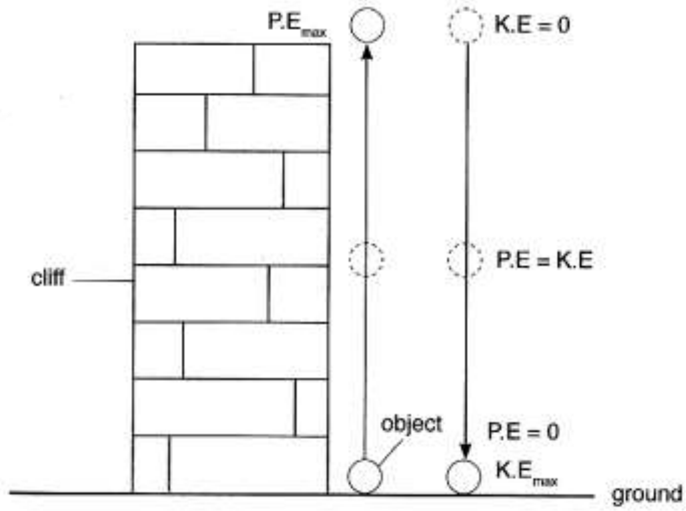
(b) P.E $= mgh = 300 \times 6 = 1\ 800$ J

(c) The work done against gravity is stored as P.E in the body.

ELASTIC POTENTIAL ENERGY

- A compressed or stretched spring goes back to its original shape when released. The work done on stretching or compressing the spring is called **elastic potential energy.**

LAW OF CONSERVATION OF ENERGY



- **STATES: Energy can be changed from one form to another, but it can neither be destroyed nor created.**
- When energy changes from one form to another, the total amount of energy stays the same.

Example

Q] A car accelerates up a hill. What happens to its kinetic energy and to its potential energy?

	kinetic energy	potential energy
A	decreases	increases
B	increases	decreases
C	increases	increases
D	unchanged	decreases

[Ans] C The speed of the car increases and so the kinetic energy is increasing. Accelerating up a hill implies an increase in vertical height and so the potential energy increases.

Example

What is the velocity of an object dropped from a cliff of height 20 m immediately before it strikes the ground? $g = 10\ m/s^2$.

Solution

$$v = \sqrt{2gh}$$
$$v = \sqrt{2 \times 10 \times 20}$$
$$v = \sqrt{400}$$
$$= 20\ m/s$$

Note that the total sum of P.E and K.E at each point is equal to mechanical energy M.E given as: M.E = P.E + K.E

INTERNAL ENERGY

Bodies at rest possess **Internal Energy** due to their mass.

The mass of the body at rest is known as its **rest mass (m)** and its internal energy as **rest energy.**

Example

Example 13.10

Coal of mass 2 kg was used as a fuel in the bakery. If all the coal was burned, calculate the total output energy that was made available. Take $c = 3 \times 10^8$ m/s

Solution

$$E = mc^2$$
$$= 2 \times (3 \times 10^8)^2$$
$$= 1.8 \times 10^{17} \text{ J}$$

Example 13.11

In a chemical reaction, it was found that 2.7×10^{19} J of energy was dissipated. Calculate the mass of the substance that was used in the reaction.

Solution

From $E = mc^2$, $E = 2.7 \times 10^{19}$ J, $c = 3.0 \times 10^8$

$$\text{Therefore } m = \frac{E}{c^2} = \frac{2.7 \times 10^{19} \text{ J}}{(3.0 \times 10^8)^2}$$
$$= 300 \text{ kg}$$

EFFICIENCY

This is **the ratio of useful output to total energy input.**

$$Efficiency = \frac{Useful\ energy\ output}{Total\ energy\ input}$$

POWER

This is **the rate at which work is done.**

$$Power = \frac{Work\ Done\ (in\ j)}{time\ taken\ (in\ s)}$$

$$or\ \ Power = \frac{Energy\ converted\ (in\ j)}{time\ taken\ (in\ s)}$$

$$P = \frac{W}{t}$$

$$or \qquad P = \frac{E}{t}$$

The SI Unit of power is **j/s** or **watt (W).** 1 watt is equal to 1 j/s.

[Q] A windmill is used to raise water from a well. The depth of the well is 5 m. The windmill raises 200 kg of water every day. What is the useful power extracted from the wind? ($g = 10\,N/kg$)

A $\frac{200 \times 10 \times 4}{5}$ W

B $\frac{200 \times 10 \times 5}{24 \times 60 \times 60}$ W

C $\frac{200 \times 10}{5 \times 24}$ W

D $\frac{200 \times 5}{24 \times 60}$ W

[Ans] B Power $P = \frac{E}{t}$

$$P = \frac{F \times s}{t}$$

$$= \frac{200 \times 10 \times 5}{24 \times 60 \times 60}$$

SIMPLE MACHINES

What is a Simple Machine?

- A machine is **any mechanical device that facilitates a force applied at one point to overcome another force at a different point in the system.**
- **A simple machine** is a machine that is **made up of only one type of machine. E.g The screw, lever, inclined plane, pulley, wheel and axel, gears.**
- A machine made up of many simple machines is called a **compound machine**.
- The force applied is called **EFFORT** and the force that the machine must overcome is called the **LOAD.**

Mechanical Advantage

This is the number of times a machine magnifies the effort.

$$Mechanical\ advantage = \frac{load\ (N)}{effort\ (N)}$$

Mechanical advantage has **no units** because it is a ratio.

Velocity Ratio

This is the ratio of the velocity of the effort to the velocity of the load.

$$Velocity\ ratio = \frac{displacement\ of\ effort}{displacement\ of\ load}$$

Velocity ratio has **no units** because it is a ratio.

Velocity ratio is the number of times the effort moves further than the load.

Efficiency of Machines

The following formula can be used;

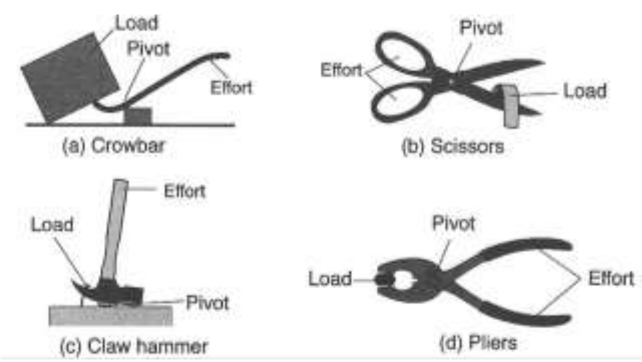
$$efficiency = \frac{useful\ energy\ output}{energy\ input} \times 100\% \quad OR \quad efficiency = \frac{M.A}{V.R} \times 100\%$$

Types of Simple Machines

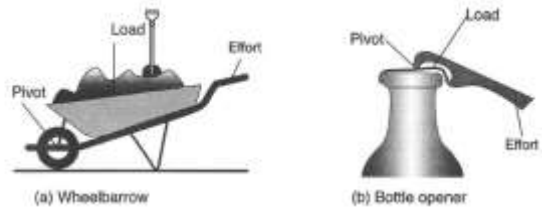
1. LEVERS:

They are simple machines that apply the principle of moments. A lever is a bar capable of rotating about a fixed point called a **PIVOT**. Examples;

Levers have a **mechanical advantage greater than 1** as well as a **velocity ratio greater than 1.**

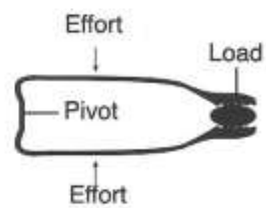


(a) Crowbar (b) Scissors (c) Claw hammer (d) Pliers



(a) Wheelbarrow (b) Bottle opener

(b) Fishing rod



(c) Tweezers

Example

A worker uses a crow bar 2.0 m long to lift a rock weighing 750 N (Fig. 14.7).

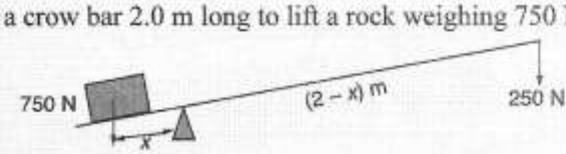


Fig. 14.7

(a) Calculate the position of the pivot in order to apply an effort of 250 N.

(b) Find the (i) velocity ratio (ii) mechanical advantage and (iii) efficiency of the lever.

(c) Comment on your answer. (Assuming no energy loss)

Solution

(a) applying the principle of moments

$750x = 250(2 - x)$

$750x = 500 - 250x$

$1\,000x = 500$

$x = 0.5$ m from the end with 750 N.

(b) (i) velocity ratio $= \dfrac{\text{effort distance}}{\text{load distance}}$

$= \dfrac{1.5}{0.5}$

$= 3$

(ii) mechanical advantage $= \dfrac{750}{250}$

$= 3$

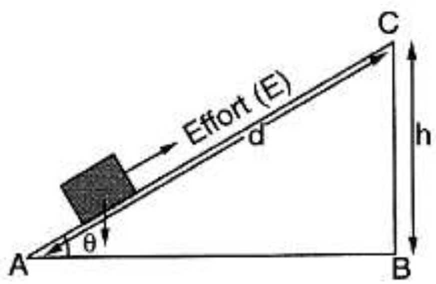
(iii) efficiency $= \dfrac{M.A}{V.R} \times 100\% = \dfrac{3}{3} \times 100\%$

$= 100\%$

(c) We have assumed that there is no friction and that the crowbar is weightless

2. INCLINED PLANE:

This is a slope that enables a load to be raised more gradually by using a smaller effort than when it is raised vertically upwards.



It is easier to move a heavy load from **A to C than from B to C**.

PRACTICAL 11 – LENGTH AND MECHANICAL ADVANTAGE OF THE INCLINED PLANE

Apparatus

- A trolley
- Masses
- Inclined plane

Procedure

- Measure the mass of a trolley. Place it on an inclined plane of length *l*, (Fig. 14.9). Add slotted masses until the trolley just begins to move up the plane.
- Record the values of the load, effort and the length *l* of the inclined plane.
- Repeat the experiment with inclined planes of different lengths. Make sure the height, *h*, and the load are kept constant.

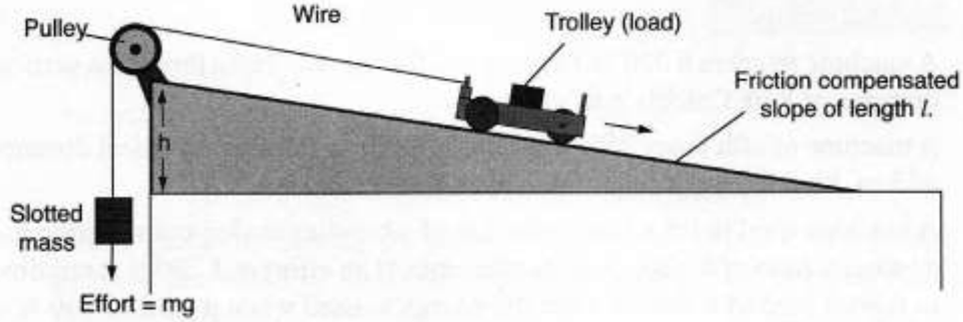


Fig. 14.9: How the length of inclined plane affects the mechanical advantage.

- Record your results in Table 14.1. What happens to the applied effort when the length of the incline plane is increased.

Table 14.1

Effort E (N)	Length l	Mechanical advantage = $\frac{L}{E}$

Discussion

We observe from the experiment that as the length l is increased the effort applied is decreased.

Work done on the load = load × distance moved by the load

$= L \times h$

Work done on the effort = effort × distance moved by the effort

$= E \times l$

But the work done on the load is equal to the work done by the effort i.e.

$El = Lh.$

$\therefore \; E = \frac{Lh}{l} = \frac{mgh}{l}$ since $L = mg$

But mgh is a constant

$\therefore \; E \propto \frac{1}{l}$.

Therefore a small effort travels a long distance to overcome a large load.

Velocity Ratio of an Inclined Plane

$$Velocity\ Ratio = \frac{Distance\ moved\ by\ effort}{Distance\ moved\ by\ load}\quad thus;\ \ Velocity\ Ratio = \frac{1}{sin\theta}$$

Mechanical Advantage of an Inclined Plane

$$M.A = \frac{load}{effort}\quad thus;\ \ Mechanical\ Advantage = \frac{1}{sin\theta}$$

3. SCREWS AND BOLTS

Velocity Ratio of Bolt

$$Velocity\ ratio = \frac{displacement\ of\ effort}{displacement\ of\ load}$$

$$V.R = \frac{2\pi R}{p}$$

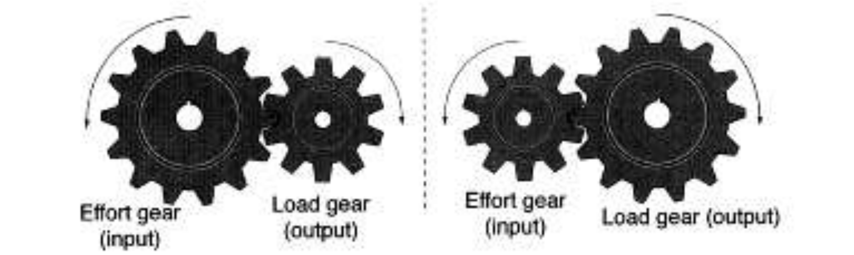
Where p = pitch and R = Radius as the load is raised or lowered

4. SCREW JACK

$$V.R = \frac{2\pi R}{p}$$

$$M.A = \frac{2\pi R}{p}$$

5. GEARS



(a) Velocity ratio is less than 1 (V.R < 1) (b) Velocity ratio is greater than 1 (V.R > 1)

Gears are toothed wheels of different diameters.

$$Velocity\ ratio = \frac{speed\ of\ rotation\ of\ driving\ wheel}{speed\ of\ rotation\ of\ driven\ wheel}$$

$$Velocity\ ratio = \frac{revolutions\ per\ second\ of\ the\ driving\ wheel}{revolutions\ per\ second\ of\ the\ driven\ wheel}$$

OR

$$Velocity\ ratio = \frac{number\ of\ teeth\ on\ the\ driven\ wheel (load)}{number\ of\ teeth\ on\ the\ driving\ wheel\ (effort)}$$

A bicycle has a driving gear wheel of radius 10 cm with 24 teeth. The driven rear wheel has a radius of 40 cm mount on a rear gear with 8 teeth determine:

(a) (i) the velocity ratio for the gear wheel system.

(ii) the mechanical advantage.

(iii) efficiency.

(b) What is the effect of increasing the

(i) number of teeth on the driving wheel.

(ii) radius of the driven wheel.

(c) Why is it unrealistic to have both wheels having the same radius and equal number of teeth?

Solution

(a) (i) velocity ratio $= \dfrac{\text{number of teeth on the driven wheel}}{\text{number of teeth on the driving wheel}}$

$$= \frac{8}{24}$$

$$= \frac{1}{3}$$

(ii) Mechanical advantage $= \dfrac{\text{Radius of the driving wheel}}{\text{Radius of the driven wheel}}$

$$= \frac{R}{r} = \frac{10}{40} = 0.25$$

(iii) efficiency $= \dfrac{\text{mechanical advantage}}{\text{velocity ratio}} = \dfrac{0.25}{\frac{1}{3}} \times 100\% = 75\%$

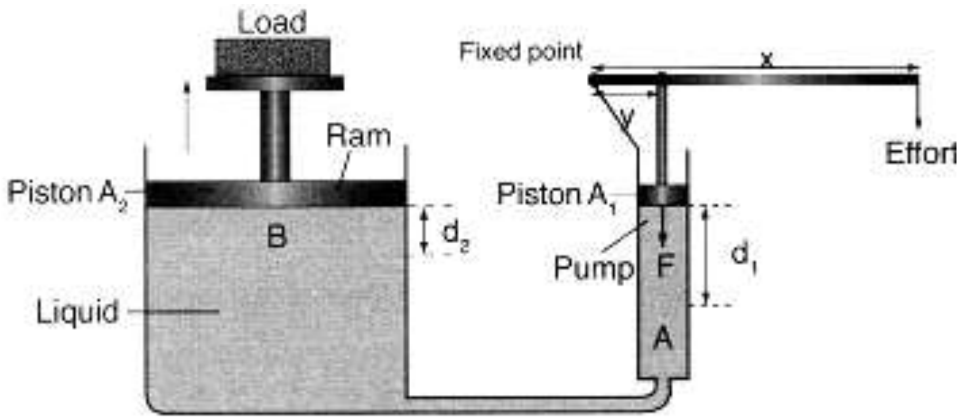
(b) (i) The velocity ratio will be decreased and the arrangement will speed up the rotation

(ii) The velocity ratio will be increased but the speed will reduce since

velocity ratio $= \dfrac{\text{speed of the driving wheel}}{\text{speed of the driven wheel}}$

(c) There will be no increase on mechanical advantage. This means that the effort applied must be very large even on a flat ground. The friction will cause the load to be less than effort.

HYDRAULIC MACHINE



- The force on the smaller piston is calculated by applying the principle of moments.
  $E \times x = y \times F$
  $F = \frac{E \times x}{y}$
- Suppose while pressing down on A_1, the piston moves a distance d_1 and the piston at A_2 moves up a distance d_2. The volume of the liquid swept from piston A_1 is equal to the volume of the liquid moved to A_2

Volume from $A_1 = A_1d_1$
Volume moved to $A_2 = A_2d_2$
Thus; $A_1d_1 = A_2d_2$

$$velocity\ ratio = \frac{d_1}{d_2} = \frac{A_2}{A_1} = \frac{\pi R^2}{\pi r^2} = \frac{R^2}{r^2}$$

Refer to hydraulic press in Fig. 14.23 on page 219. Given that x = 30 cm, y = 6 cm, effort = 60 N area A_1 = 4 cm², area A_2 = 12 cm². Calculate

(a) the force, F_A, exerted on the liquid at A.
(b) velocity ratio.
(c) maximum load that could be raised at B.

Solution

(a) By the principle of levers,

load × load arm = effort × effort arm.

$$F_A \times 6\text{ cm} = 60\text{ N} \times 30\text{ cm}$$

$$F_A = \frac{60 \times 30}{6}$$

$$= 300\text{ N}$$

(b) Velocity ratio $= \frac{A_2}{A_1}$

$$= \frac{12}{4}$$

$$= 3$$

(c) Pressure at A = pressure at B

Pressure at A $= \frac{300}{4 \times 10^{-4}}$ Pa ; Pressure at B $= \frac{\text{Load}}{12 \times 10^{-4}}$ Pa.

$$\therefore \frac{\text{Load}}{12 \times 10^{-4}} = \frac{300}{4 \times 10^{-4}}$$

$$\text{Load} = \frac{12 \times 300}{4} = 900\text{ N}$$

Alternatively;

$$\text{M.A} = \frac{F_L}{F_E}$$

assuming perfect machine;

$$\text{M.A} = \text{V.R}$$

$$\frac{L}{300} = 3$$

$$L = 900\text{ N}$$

CHALLENGING QUESTIONS- 6

[Q] A windmill is used to raise water from a well. The depth of the well is 5 m. The windmill raises 200 kg of water every day. What is the useful power extracted from the wind? (g = 10 N/kg)

A $\frac{200 \times 10 \times 4}{5}$ W

B $\frac{200 \times 10 \times 5}{24 \times 60 \times 60}$ W

C $\frac{200 \times 10}{5 \times 24}$ W

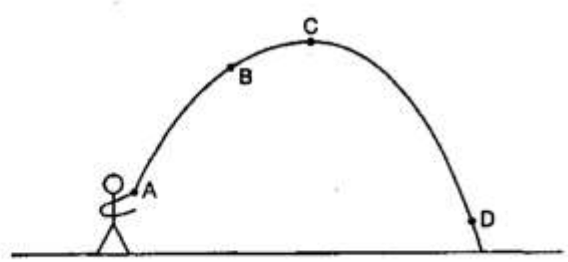
D $\frac{200 \times 5}{24 \times 60}$ W

[Ans] B Power $P = \frac{E}{t}$

$$P = \frac{F \times s}{t}$$

$$= \frac{200 \times 10 \times 5}{24 \times 60 \times 60}$$

3. The figure below shows the path of a ball thrown into the air.



(a) (i) State at which point A, B, C or D the ball travels the slowest.

(ii) Explain your choice in (i). You should write about the kinetic energy and the potential energy of the ball. [3]

(b) The mass of the ball is 0.20 kg. At point A, the ball has kinetic energy 2.5 J. Taking the gravitational force on a mass of 1.0 kg to be 10 N, calculate

(i) the weight of the ball,

(ii) the speed of the ball at point A. [4]

4. Fig. 4.1 shows a wind turbine used to produce electricity. The turbine blades are turned by the wind and are connected to an electrical generator.

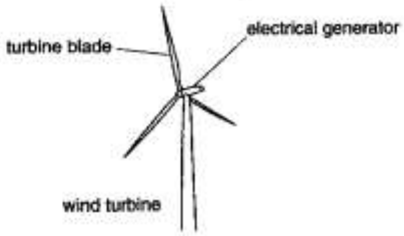


Fig. 4.1

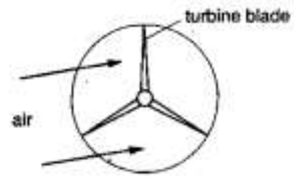


Fig. 4.2

(a) Energy can be converted from one form into another.

(i) State the useful energy transformations that occur during the operation of a wind turbine.

(ii) Describe briefly why more energy is produced per second if

1. the wind blows faster,
2. the turbine blades are longer,
3. the turbine is more efficient.

(iii) State one other energy transformation that produces electricity on a large scale and in which fuel is not burnt. [6]

(b) In one revolution the blades sweep out a circle, as shown in Fig. 4.2. In 60 s a volume of 540 000 m^3 of air travelling at a speed of 6.0 m/s is incident at right angles on that circle. The density of air is 1.2 kg/m^3.

Calculate

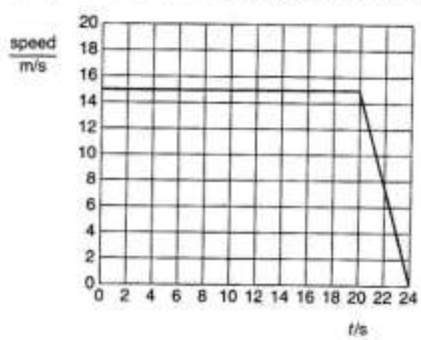
(i) the mass of air that passes through this circle in 60 s,

(ii) the initial kinetic energy of this mass of air,

(iii) the maximum input power available to the wind turbine. [9]

5. The graph shows the variation with time of the speed of a car as it travels along a level road. The car brakes when the time t = 20 s, and comes to rest when t = 24 s.

The car has a mass of 800 kg and the forward driving force on the wheels is 1200 N.



(a) For the first 20 s of the motion shown in the graph calculate

(i) the distance travelled,

(ii) the work done by the driving force,

(iii) the power supplied by the driving force. [6]

(b) (i) Calculate the kinetic energy of the car while it is travelling at the constant top speed.

(ii) When the car is travelling at a constant speed there is no change in its kinetic energy.

1. Explain why the car engine is needed to maintain this constant speed.
2. Suggest what happens to the energy that is provided by the engine. [5]

(c) During braking the speed of the car decreases uniformly. The engine no longer provides a driving force.

(i) Calculate the deceleration of the car between t = 20 s and t = 24 s.

(ii) Calculate the total braking force acting on the car during this period.

(iii) Explain why the power dissipated in the brakes to slow the car is greater at the beginning of the braking period than at the end. [4]

SOLUTIONS

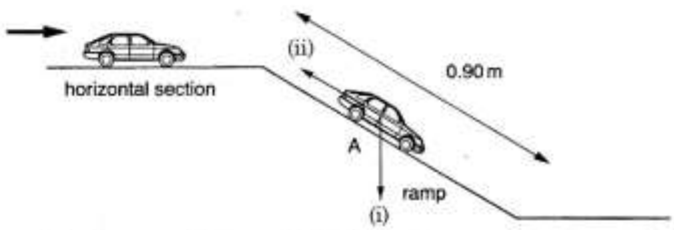
1. (a) (i) Work done by a force is the magnitude of the force multiplied by the distance moved in the direction of the force.
SI unit of work done: Joule
Symbol: J

(ii) Power is the rate at which work is done.
SI unit of power: Watt
Symbol: W

(b) (i) gain in P.E. $= mgh$
$= 60 \times 10.0 \times 4.0$
$= 2400$ J

(ii) Useful power $= \dfrac{\text{gain in P.E.}}{\text{time}}$
$= \dfrac{2400}{3.0}$
$= 800$ W

2. (a) (i) (ii)



(b) (i) The car decelerates and the speed of the car decreases.

(ii) The acceleration of the car decreases.

(c) (i) Work done against friction $=$ friction force $\times$ distance moved by the car
$= 0.11 \times 0.90$
$= 0.099$ J

(ii) By conservation of energy,
P.E. at the top + K.E. at the top = P.E. at the bottom + K.E. at the bottom + work done against friction
P.E. loss + K.E. at the top = K.E. at the bottom + work done against friction

K.E. at the bottom $=$ P.E. loss + K.E. at the top − work done against friction
$= 0.50 + 0.30 - 0.099$
$= 0.701$ J

3. (a) (i) C

(ii) As the ball moves upwards, its kinetic energy is converted to potential energy. At point C, the ball is at its highest point. Therefore its potential energy is the maximum and its kinetic energy is the minimum. The ball is slowest in speed.

(b) (i) Weight W
$$W = mg = 0.20 \times 10 = 2.0\ N$$

(ii)
$$K.E. = \frac{1}{2}mv^2$$
$$v = \sqrt{\frac{2K.E.}{m}} = \sqrt{\frac{2 \times 2.5}{0.20}} = 5.0\ m/s$$

4. (a) (i) Kinetic energy of the wind is converted to kinetic energy of the turbine which is finally converted to electrical energy.

(ii) 1. The turbine turns faster and thus more kinetic energy is converted to electrical energy per second.

2. The mass of air passing through the turbine per second increases.

3. If the turbine is more efficient, more kinetic energy of the wind is converted to electrical energy.

(iii) Nuclear energy from a nuclear reactor in the nuclear power station is converted to electrical energy.

(b) (i)
$$\text{mass} = \text{density} \times \text{volume} = 1.2 \times 540000 = 6.48 \times 10^5\ kg$$

(ii)
$$K.E. = \frac{1}{2}mv^2 = \frac{1}{2} \times 6.48 \times 10^5 \times 6^2 = 1.17 \times 10^7\ J$$

(iii)
$$\text{Power} = \frac{\text{energy}}{\text{time}} = \frac{1.17 \times 10^7}{60} = 1.95 \times 10^5\ W$$

5. (a) (i) distance travelled $= \text{area under the graph}$
$= 15 \times 20$
$= 300 \text{ m}$

(ii) work done $= \text{force} \times \text{distance travelled}$
$= 1200 \times 300$
$= 360000 \text{ J}$

(iii) power $= \dfrac{\text{work done}}{\text{time}}$
$= \dfrac{360000}{20}$
$= 18000 \text{ W}$

(b) (i) kinetic energy $= \dfrac{1}{2} mv^2$
$= \dfrac{1}{2} \times 800 \times 15^2$
$= 90000 \text{ J}$

(ii) 1. The car engine is needed to maintain the constant speed because energy is required to overcome friction and air resistance.

2. The energy provided by the engine is converted to internal energy.

(c) (i) $a = \dfrac{v-u}{t}$
$= \dfrac{0-15}{4}$
$= -3.75 \text{ m/s}^2$

deceleration of the car $= 3.75 \text{ m/s}^2$

(ii) total braking force $= ma$
$= 800 \times 3.75$
$= 3000 \text{ N}$

(iii) The loss in kinetic energy at the beginning is larger than the loss in kinetic energy towards the end of the car's journey.

PRESSURE

What is Pressure?

- Pressure is **force acting normally per unit area.**
- Larger area results in lower pressure.
- Smaller area results in higher pressure.

$$P = \frac{F}{A}$$

P = Pressure; F = Force; A = Area;

- SI unit of pressure is **N/m²** or Pascal (**Pa**).

Example

A rectangular solid glass of density 2.5 g/cm³ has dimensions 10 cm × 40 cm × 30 cm. The block rests on a horizontal flat surface. Calculate the:
(a) minimum pressure, (b) maximum pressure it can exert.

(a) For minimum pressure, the area must be maximum

Maximum area $= (40 \times 30)\ \text{cm}^2 = 1\,200\ \text{cm}^2 = 0.12\ \text{m}^2$

Density of block $= 2.5\ \text{g/cm}^3$

Volume of block $= 10 \times 40 \times 30$

$= 1\,200\ \text{cm}^3$

Mass = density × volume

$= (2.5 \times 1\,200)\text{g} = 3\,000\ \text{g}$

$= 3\ \text{kg}$

Weight = mass × pull of gravity

$= 3\ \text{kg} \times 10\ \text{N/kg}$

$= 30\ \text{N}$

$$\text{Minimum pressure} = \frac{\text{Force}}{\text{Area (maximum)}}$$

$$= \frac{30\ \text{N}}{0.12\ \text{m}^2} = 250\ \text{Pa}$$

(b) For maximum pressure, the area considered must be minimum

Minimum area $= (10 \times 30)\ \text{cm}^2 = 300\ \text{cm}^2$

$= 0.03\ \text{m}^2$

$$\text{Maximum pressure} = \frac{\text{Force}}{\text{Area (minimum}}$$

$$= \frac{30\ \text{N}}{0.03\ \text{m}^2}$$

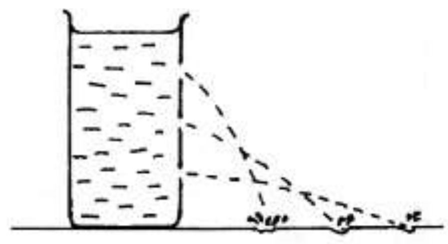
$= 1\,000\ \text{Pa}$

ATMOSPHERIC PRESSURE

1 atmosphere or 1 atm is about 1.013 x 10^5 pa (or 101 300 pa). This is the normal atmospheric pressure.

PRESSURE IN LIQUIDS

- Pressure increases in depth



- Given the volume of the liquid is **V** and its density is $\boldsymbol{\rho}$ then;

$$\mathrm{P} = \frac{F}{A}$$

$$\mathrm{P} = \frac{mg}{A}$$

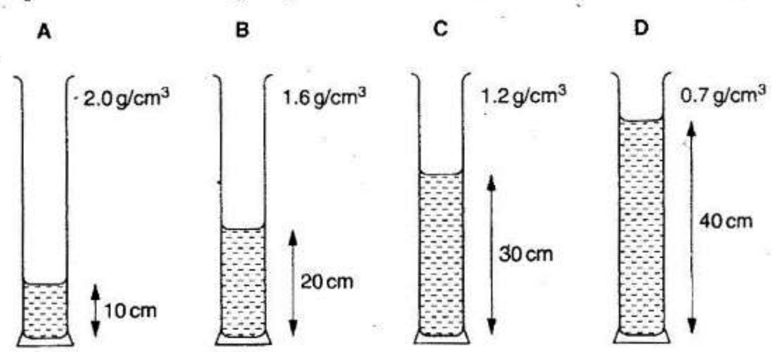
Hence;

$$\mathrm{P} = \rho g h$$

Where m = mass; g = gravity; h = height;

[Q] Four different liquids are poured into identical measuring cylinders. The diagrams show the heights of the liquids and their densities.

Which liquid causes the largest pressure on the base of its measuring cylinder?



[Ans] C Liquid pressure due to a liquid column is $\rho gh = 1.2 \times 10^3 \times 10 \times 0.3$
$= 3600$ Pa (largest)

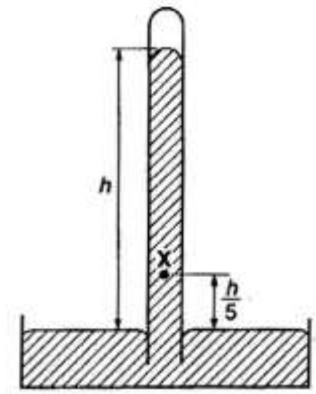
[Q] The height of a mercury barometer is h when the atmospheric pressure is 100000 Pa. What is the pressure at X?

A 20000 Pa

B 80000 Pa

C 120000 Pa

D 180000 Pa

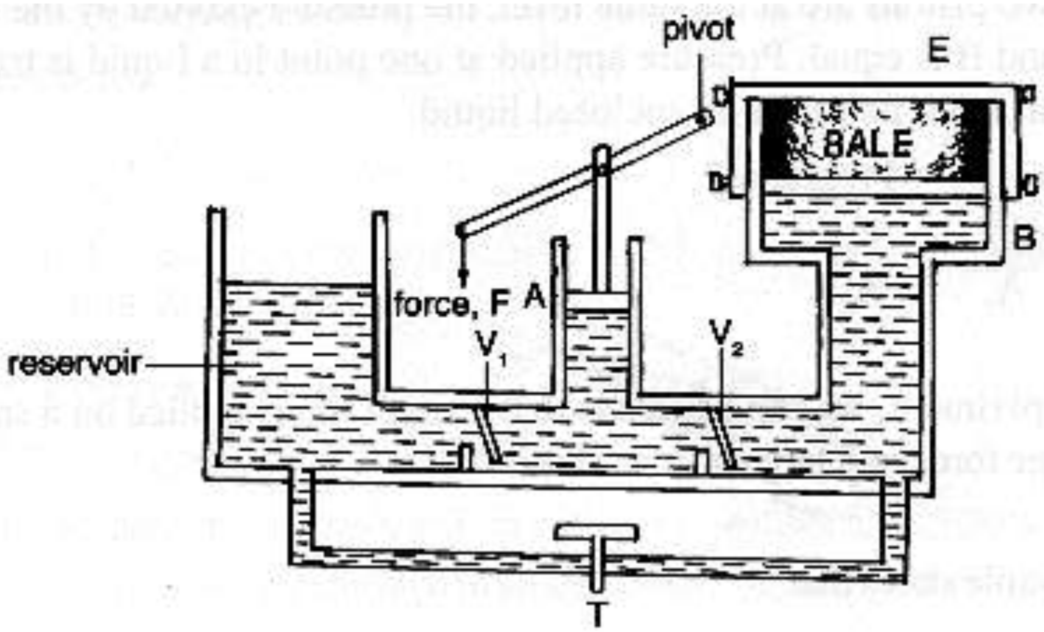


[Ans] B Pressure at X $= (h - \frac{h}{5})$ of atmospheric pressure $= \frac{4}{5}(100000) = 80000$ Pa

- Pressure acts in **all** directions.
- Pressure does **not** depend on shape of the container.

HYDRAULIC PRESS

It uses the principle of transmission of pressure.



Example

The area of the large syringe in Experiment 15.7 is 18 cm^2 and that of the smaller one is 3.0 cm^2. A force of 2 N is applied on the smaller piston. Find the force produced at the larger piston.

Solution

$$\frac{\text{Force on large piston}}{\text{Force on small piston}} = \frac{\text{Area of large piston}}{\text{Area of small piston}}$$

$$\frac{\text{Force on large piston}}{2\text{ N}} = \frac{18\text{ cm}^2}{3.0\text{ cm}^2}$$

$$\text{Force on large piston} = 2\text{ N} \times \frac{18\text{ cm}^2}{3.0\text{ cm}^2}$$

$$= 12\text{ N}.$$

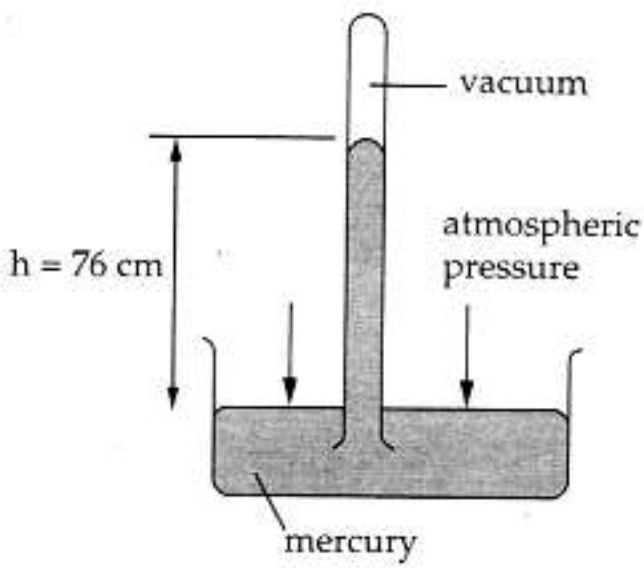
THE BAROMETER

A mercury barometer is used to measure **atmospheric pressure.**

Construction of a simple mercury barometer:

1. A thick-walled glass tube (about 1m long) is filled with mercury completely.
2. The open end of the tube is covered with a finger and inverted.
3. Place the inverted tube in a trough of mercury.

The height of the mercury column is found to be about 760mm (76cm)



- Since the height of the mercury column reflects the value of the atmospheric pressure, atmospheric pressure can be expressed in terms of the height of a column of mercury.
- **1 atm is 760 mmHg or 76 cmHg**
- Hg is Mercury.

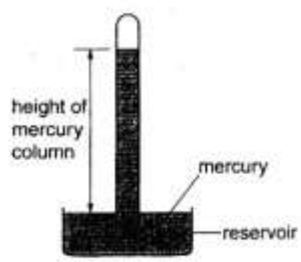
[Q] The diagram shows a simple mercury barometer. Which of the following does **not** cause the height of the mercury column to vary?

A changes in the atmospheric pressure

B changes in the value of g

C evaporation of mercury from the barometer reservoir

D leakage of air into the tube



[Ans] C Atmospheric pressure = density of mercury × g × height of mercury column. The height of the mercury column therefore would decrease if atmospheric pressure decreases or if g increases or if there is a leakage of air into the tube.

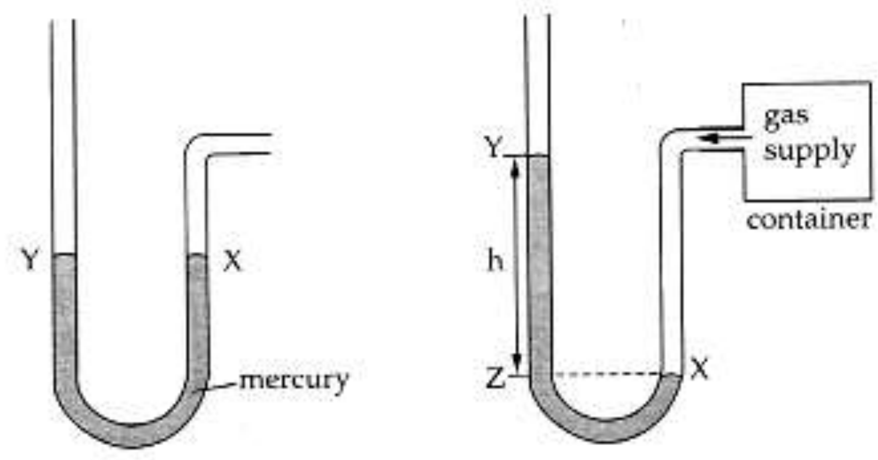
MANOMETER

Manometer is used to measure **gas pressure.**

Construction of a manometer:

1. The manometer consists of a U-tube containing a column of liquid.

2. The liquid can be mercury, water or oil.



How to measure gas pressure?

- When both arms are open, same atmospheric pressure is exerted on the liquid surfaces X and Y, and they are at the same horizontal level.
- To measure the pressure of a gas, side X is connected to a gas supply by a length of rubber tubing.
- The gas exerts pressure on the surface X. The gas pressure must be greater than atmospheric pressure to cause level Y to rise.
- The gas pressure at X is given by:

$$Pressure\ of\ gas\ at\ X = atmospheric\ pressure + pressure\ due\ to\ liquid\ column\ YZ$$

$$P_X = P_O + \rho g h$$

Where P_o = atmospheric pressure

ρ = density of liquid

g = gravitational field strength

h = length of column YZ

Example

The Fig. 15.25 is a u-tube manometer used to determine the pressure of the gas used to inflate the tyre. The density of mercury is 13 600 kg/m³ and g = 10 N/kg and atmospheric pressure P_A is 1.02×10^5 Pa.

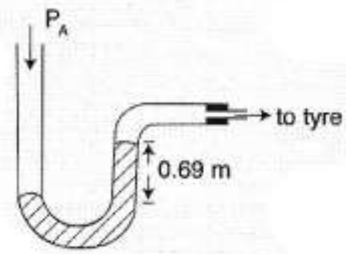


Fig. 15.25

Calculate the pressure of the gas.

Solution

From $P_A = P_g + h\rho g$

$\therefore \quad P_g = P_A - h\rho g$

$= 1.02 \times 10^5 \text{Pa} - 0.69 \text{ m} \times 13\,600 \text{ kg/m}^3 \times 10 \text{ N/kg}$

$= 1.02 \times 10^5 - 93\,840 \text{ Pa}$

$= 8\,160 \text{ Pa}$

$\therefore$ The pressure of the gas used to inflate the tyre is 8 160 Pa.

ARCHIMEDES' PRINCIPLE

When a body is wholly or partially immersed in a fluid, it experiences an upthrust which is equal to the weight of the fluid displaced.

Example

A concrete block of mass 2.7×10^3 kg and volume $0.9\ m^3$ is totally immersed in sea water of density $1.03 \times 10^3\ kg/m^3$. Find:

(a) Weight of the block in air.

(b) Weight of the block in sea water.

Solution

(a) Weight in air $= mg$

$= 2.7 \times 10^3 \times 10$

$= 2.7 \times 10^4$ N

(b) Volume of water displaced $=$ volume of the block

$= 0.9\ m^3$

Weight of water displaced $= V\rho g = 0.9 \times 1.03 \times 10^3 \times 10$

$= 9.27 \times 10^3$ N

Upthrust = weight of water displaced

$= 9.27 \times 10^3$ N

upthrust $= W_{air} - W_{liquid}$

$\therefore W_{liquid} = W_{air} -$ upthrust

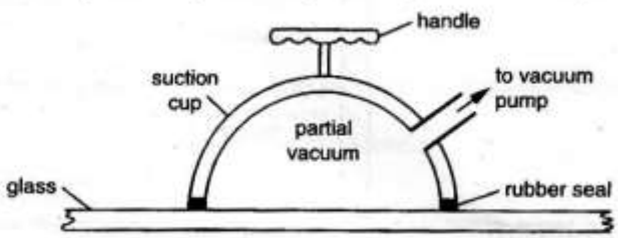
$= (27 \times 10^3) - (9.27 \times 10^3)$

$= 17.73 \times 10^3$ N

$= 1.77 \times 10^4$ N

CHALLENGING QUESTIONS – 8

1. The figure below shows a piece of glass being lifted by a suction cup.



Air is removed from the cup by a vacuum pump and a partial vacuum is created inside the cup. Atmospheric pressure outside pushes the glass on to the cup.

The area of the glass covered by the cup is $0.0025\ m^2$. The pressure inside the cup is reduced to 60000 Pa. Atmospheric pressure outside is 100000 Pa.

(a) (i) State the formula that relates pressure to force and to area.

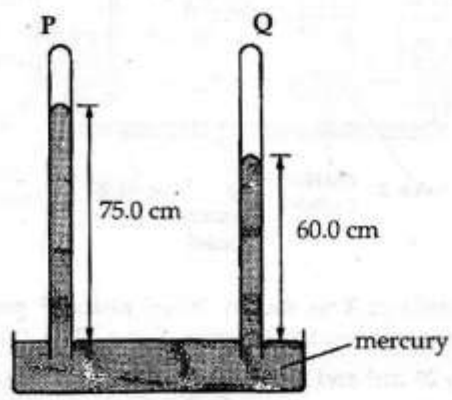
(ii) Calculate the greatest weight of glass that can be lifted with this cup. [4]

(b) State two changes that would allow a suction cup to lift a heavier piece of glass. [2]

2. The figure below shows two vertical tubes P and Q, each closed at the upper end. The pressure in the space above the mercury meniscus in tube P is negligibly small. There is a small amount of air in this space in the tube Q.

The density of mercury is $13.6 \times 10^3\ kg/m^3$.

The gravitational force on a mass of 1.00 kg is 10.0 N.

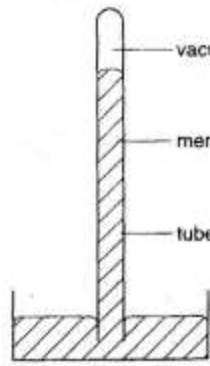


Using the data given in the figure, determine

(a) the atmospheric pressure, in Pa, at the time, [3]

(b) the pressure, in Pa, exerted by the air in the space at the top of tube Q. [3]

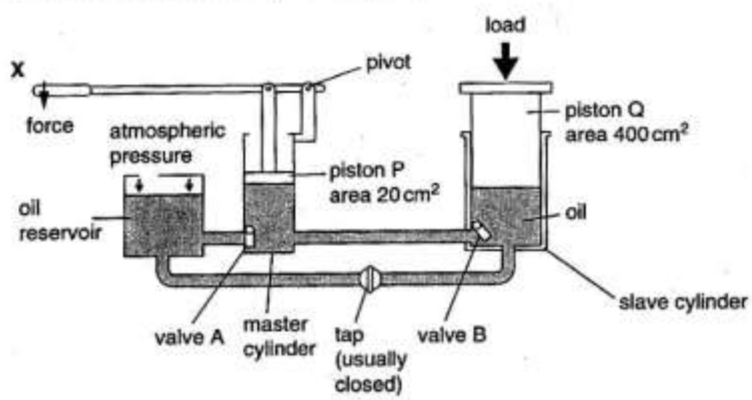
3. The figure below shows a simple mercury barometer that can be used to measure the pressure of the atmosphere.



(i) On the figure, mark a vertical distance that would provide a measurement of atmospheric pressure.

(ii) State and explain what happens to the level of the mercury in the tube when atmospheric pressure increases. [3]

4. The figure shows a hand-operated hydraulic press.



A force is applied downwards at **X** as shown. When piston **P** moves downwards, valve **A** closes, valve **B** opens and oil is forced through to raise piston **Q** in the slave cylinder.

(a) The area of piston **P** is 20 cm^2 and the area of piston **Q** is 400 cm^2. Piston **P** exerts a downward force of 300 N on the oil.

(i) Calculate the pressure, in N/cm^2, exerted by piston **P** on the oil.

(ii) State the value of the pressure in the slave cylinder.

(iii) Calculate the force exerted by the oil on piston **Q**. [5]

(b) Piston **P** moves down 5 cm.

(i) Calculate the volume of oil that moves out of the master cylinder.

(ii) Calculate the distance that piston **Q** rises. [2]

(c) After **X** is pushed down, it is lifted up again. State what happens, as **X** is lifted, to valve **A**, valve **B**, piston **Q**. [2]

(d) State why oil and not air is used in the hydraulic press. [1]

SOLUTIONS

1. (a) (i) Pressure $= \dfrac{\text{Force}}{\text{Area}}$

(ii) Greatest weight of glass = greatest force produced by the pressure difference
$= \text{pressure} \times \text{area}$
$= (100000 - 60000) \times 0.0025$
$= 100\ \text{N}$

(b) (1) Reduce further the pressure inside the cup by removing more air from it

(2) Increase the area of glass covered by the suction cup

Exam Tip

(a) (i) Candidates do not need to calculate the pressure in this part as they are asked to state the formula only.

(ii) Greatest weight of glass lifted is the force produced by the pressure difference between the two sides of the glass. The pressure inside the suction cup is lower than that of the air below the glass as it is partial vacuum. The pressure below the glass is atmospheric pressure.

(b) Force = pressure x area.

If you want to increase the force, you can either increase the pressure difference or increase the area.

2. (a) Atmospheric pressure $= \rho gh$

$$= (13.6 \times 10^3) \times 10.0 \times \left(\frac{75.0}{100}\right)$$
$$= 1.02 \times 10^5\ \text{Pa}$$

(b) Air pressure at the top of tube Q + liquid pressure due to 60.0 cm mercury = Atmospheric pressure

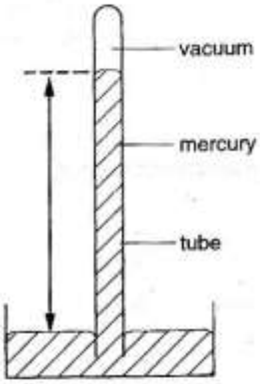
Air pressure at the top of tube Q = Atmospheric pressure – liquid pressure due to 60.0 cm mercury

$$= 1.02 \times 10^5\ \text{Pa} - (13.6 \times 10^3) \times 10.0 \times \left(\frac{60.0}{100}\right)$$
$$= 2.04 \times 10^4\ \text{Pa}$$

Exam Tip

(a) (b) The consistency of units is important for this question. The height of the mercury is usually expressed in cm. It is compulsory for the candidates to convert it to m.

3. (i)



(ii) The level of the mercury column in the tube increases because the mercury column inside the tube is supported by the force due to the atmospheric pressure. When atmospheric pressure increases, the force is greater. Therefore a higher mercury column can be supported.

Exam Tip

(i) The height of the mercury that would provide a measurement of atmospheric pressure is from the top of the meniscus of the mercury to the reservoir level.

(ii) The mercury column inside the tube is due to the atmospheric pressure. When atmospheric pressure is changed, the height of the mercury column will change accordingly.

4. (a) (i) Pressure = $\frac{F}{A} = \frac{300}{20} = 15\ \text{N}/\text{cm}^2$

(ii) 15 N/cm^2

(iii) Force = p × A = 15 × 400 = 6000 N

(b) (i) Volume of oil = 20 × 5 = 100 cm^3

(ii) Distance moved by piston Q = $\frac{100}{400}$ = 0.25 cm

(c) Valve A: open

Valve B: close

Piston Q: remain stationary

(d) Oil is incompressible whereas air is compressible.

Exam Tip

(a) (ii) Pressure is transmitted to piston Q through the oil. If the oil is incompressible, the pressure at piston Q is same as the pressure at piston P.

(b) The volume of oil moving out of the master cylinder must be equal to the volume of oil moving into the slave cylinder.

(c) In order to keep the load at the same height, valve B is closed and valve A is open to let the oil go into master cylinder when X is lifted.

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