MECHANICAL PROPERTIES OF MATTER

This deals with materials used in construction of structures like bridges, dams, tanks, motor vehicles, screw drivers etc.

Materials used in common are;

- Timber
- Metals
- Glass
- Plastics
- Rubber
- Concrete
- Bricks

Before materials are put to use, it is necessary to determine whether they will withstand the condition of finished structure and tools which they will be subjected to

These conditions are known as by tests called ***Mechanical properties***

Some mechanical properties include:

- Strength
- Stiffness
- Ductility
- Brittleness
- Elasticity
- Plasticity
- Hardness

Strength;

It is the property of material that makes it require a large force to break. The material which has this property is said to strong e.g concrete, metals etc.

Stiffness;

It is the property of material that makes it resist being bent. Materials with this property are said to be stiff e.g steel, iron and concrete.

Ductility;

It is a property of materials that makes it possible to be molded in different shapes and sizes or rolled into sheets, wires or useful shapes without breaking. Materials which have this property are called ***ductile materials e.g.*** Copper wire, Soft iron wire etc.

Brittleness;

This is the ability of a material to break suddenly when force is applied on it. Materials which have this property are called brittle materials e.g. bricks, chalks, glass, charcoal etc.

Elasticity;

This is property that makes material stretch when force is applied on it and regains original size and shape when the force is removed. Materials with this property are called elastic materials e.g rubber, copper spring etc.

Plasticity;

This is the property which makes materials stretched (deformed) permanently even when the applied force is removed materials which have this property are called plastic materials e.g. plasticine, clay, putty or tar etc.

Hardness;

This is a measure of how difficult it is to scratch a surface of a material. Hard materials include; metals, stones etc.

Timber as a building material;

It is used for making furniture, walls, bodies of vehicles, bridges, making ceilings etc.

Advantages	**Disadvantages**
It is cheap	Can get rotten
It is durable when seasoned and treated	Not fire resistant
They are easier to work with	Needs treating and seasoning

Mechanical properties;

It is strong, stiff and somehow hard.

Bricks and blocks as building materials.

These are stony materials.

Uses; For construction of bridges, walls, floors etc.

Mechanical properties;

- It is hard
- It is strong under compression
- It is stiff.

Advantages;-They are cheap, durable, and easy to work with.

Disadvantages;-They are brittle

- They need firing, and it turn out to be expensive.
- Not suitable under wet conditions i.e can soften and weaken.

Glass as a building material;

Glass is used as a building material because it has a number of desirable properties which include;

- It is transparent
- Few chemicals react with it
- It can be melted and formed into various shapes
- Its surface is hard and difficult to scratch
- It can be re-enforced (strengthened)

Construction materials;

These include concrete, bricks, glass, timber, iron bars, iron sheets etc.

Concrete;

A concrete is a mixture of cement, sand and gravels (small stones) and water.

Concrete is strong under compression but weak under tension. It can with stand tensional forces when it is *re-in forced*.

Re- in forced concrete;

- Pour wet concrete on steel rods when it dries; it gets stuck on the rods which is strong under tension. This forms a re-in forced concrete.
- It can also be re-in forced by putting fibre in concrete when it is wet and leave it to harden.

Other re-in forcing materials include;

- Bamboo stripes
- Wood stands
- Metal rods and wire mesh.

Advantages of re-in forcing concrete;

- It is weather resistant
- It does not need firing and it is fire safety.
- It is ductile when still wet
- It is durable
- It has a high tensile strength
- It is stiff or tough

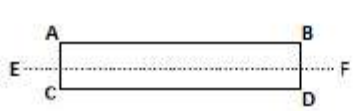
Advantages of concrete over bricks;

- Concrete can be molded in various shapes
- Concrete does not need firing
- Concrete is weather resistant
- Concrete can have a range of properties depending on the proportion of the mixture.
- Concrete can used to fill holes of different shapes.

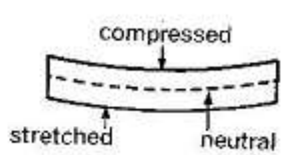
BEAMS:

A beam is along piece of materials e.g. wood, metal, concrete etc. It is usually horizontal and supported at both ends. It carries the weight of the part of the building or other structures.

When a force is applied on a beam it bends on one side of the beam in compressed (under compression), the other side is stretched (under tension) and its centre is unstretched (neutral).



Beam before bending:



Beam after bending

AB – Under compression

DC – Under tension

EF – Unstretched i.e. it neither under tension nor compression.

The neutral axis of beam does not resist any forces and can therefore be removed without weakening the stretch of the beam.

GIRDERS

A girder is a beam in which the material's neutral axis can be removed.

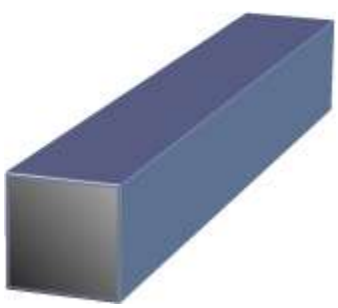
Examples of Girders;

(i) I – Shape girders

This I – shaped girder is used in construction of large structures like bridges.

(ii) Hollow tube/girder (hollow cylinder)

(iii) Square beam/girder



(iv) Triangular beam/girder

(v) L – Shaped girder.

Advantages of hollow beams

- It is light
- Economically cheap
- It is strong than solid beam.

Disadvantages of solid beams

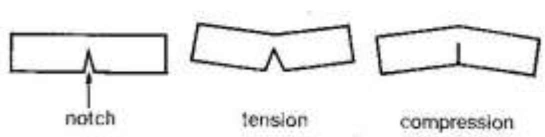
- They are heavier
- They are economically expensive
- They are weak

Disadvantages of a material used in the neutral axis:

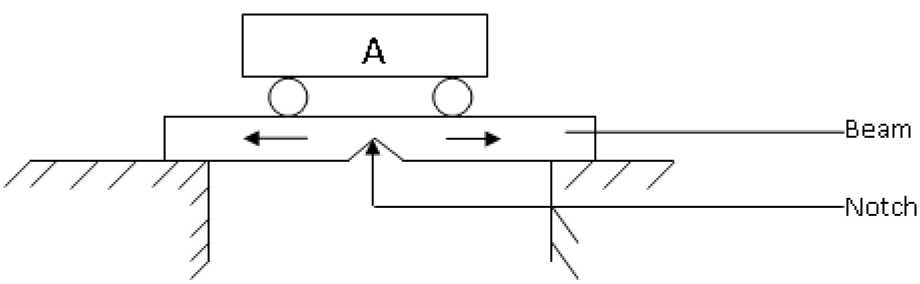
- It is a wastage and un necessary

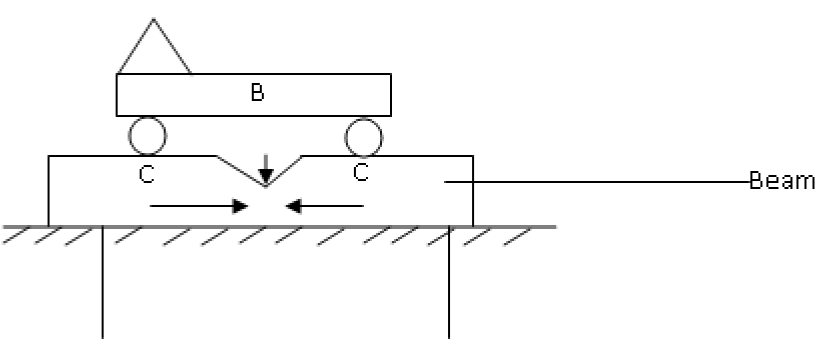
NOTCH AND NOTCH EFFECTS

A notch is a cut on a weak point on a material. It is either a crack or scratch on the surface of the material.



A notch weakens the strength of a material when it is the region of tension than when it is under compression





In ‘A’ the beam breaks easily when the car crosses the bridge because the notch is in the region of tension and therefore weakens the beam.

In ‘B’ the beam does not break easily when the car crosses.

Notch effect: This is the effect that the notch has on the strength of the material i.e. the notch weakens the strength of the material.

WAYS OF REDUCING NOTCH EFFECTS

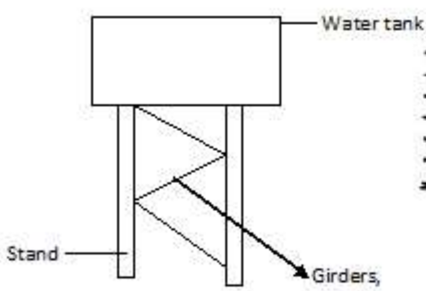
- Designing the structures in such way that all its parts are under compression.
- Making the surface of the construction material smooth.
- Use of laminated rather solid materials in construction.
- Making the notch blunt.

Structures;

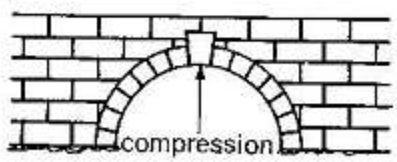
A structure consists of pieces of materials joined together in a particular way. The pieces of materials used to strengthen structures are called girders.

Examples of structures;

(i) Stands of water tank.

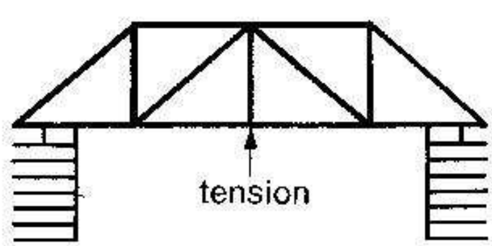


(ii) Arched bridge



-Both the upper and lower parts of the bridge are under compression. The bridge is weak under tension

(iii) Girder Bridge;

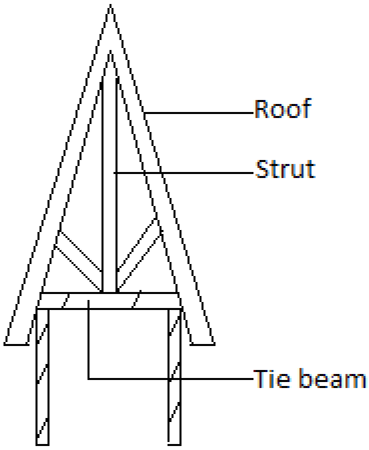


STRUTS AND TIES:

Tie: A tie is a girder under tension and can be replaced by a string.

Strut:

A strut is a girder under compression

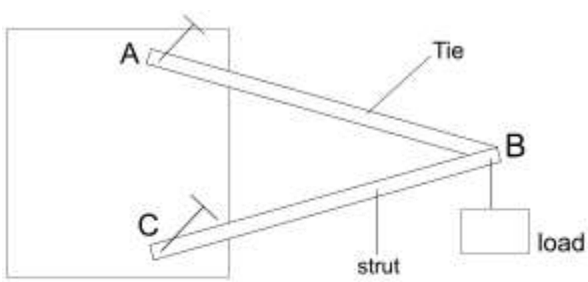


HOW TO IDENTIFY SHUTS AND TIES IN A STRUCTURE

- Remove each of the girder one at a time from the structure of the frame work and the effect it causes on the frame work is noted.
- If the frame work moves further apart the girder is a tie otherwise the girder is a strut

Experiment to distinguish between a tie and a strut

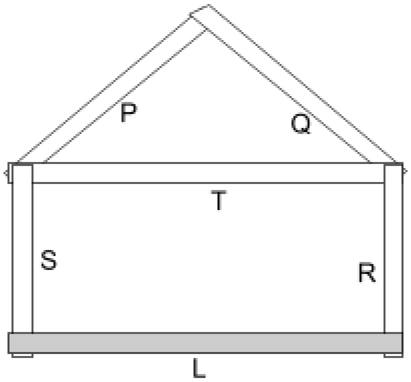
- Two straws are fixed on the side of a piece of soft board.
- A small load is added at the end B. The structure supports the load.
- The straw AB is now replaced by the string of the same length.
- If the structure still supports the load, then AB is under tension hence it is a tie.
- Similarly straw AB is then replaced with the string of the same length. If the structure does not support the load and it collapses then AB was under compression and it is a strut.



<u>Example;</u>

In the frame work below, identify the struts and ties.

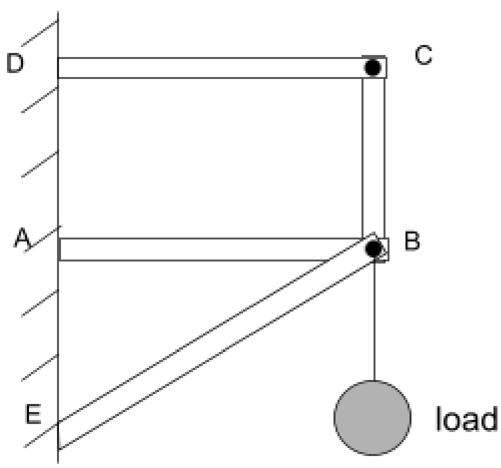
(a)



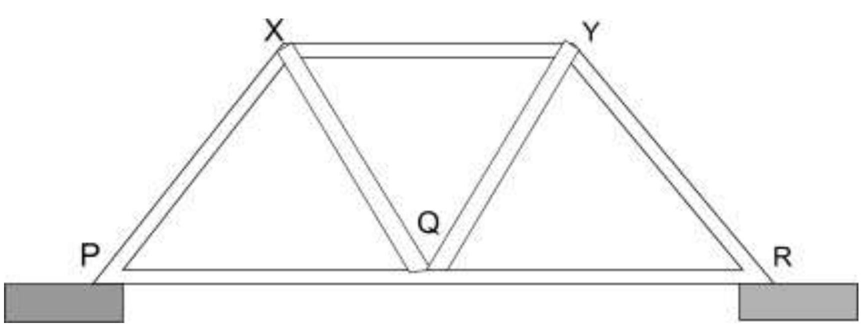
T – Tie P – Strut S- Strut

Q – Strut L – Tie R- Strut

(b)



(C)



HOOKE'S LAW OF ELASTICITY

It states that the extension of an elastic material is directly proportional to the applied force provided the elastic limit is not exceeded

I.e. applied force F α e where e-extension or

$F = k e$ k- Elastic constant of material and F- Applied force.

Example

1. An elastic wire of length 10cm has force applied on it of 3N. If its

   a) Extension e.
   b) Elastic constant k.

   Extension $e = l - l_0$ =12 -10 = 2cm = 0.02m
   Using $F = K e$
   $3 = k \times 0.02$
   $K = 150Nm^{-1}$

2. A spring extends by 0.5 cm when a load of 0.4N hangs on it.
   a) Find the load required to cause an extension of 1.5cm.
   b) What additional load causes the extension of 1.5cm?

Method 1

Using $F = K e$
$0.4 = k \times 0.5$
K = =0.8N/cm
$F_2 = ke_2$ = 0.8 x 1.5 = 1.2N.

Method 2

= = =

F_2 = = 1.2N

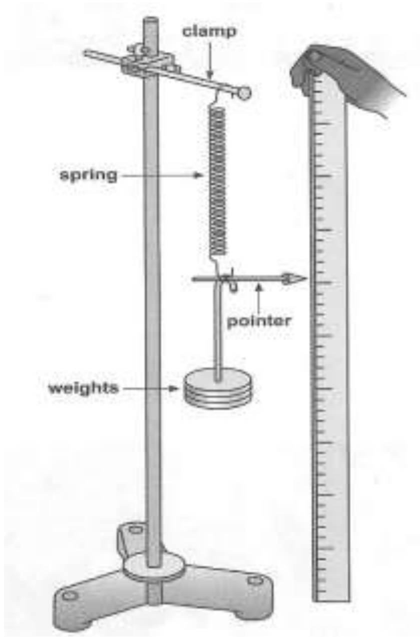
Additional load required = (1.2 – 0.4) = 0.8N

Exercise;

1. A spring has an un stretched length of 12 cm. When a force of 8N is attached to its length becomes 6cm.
   a. Extension produced
   b. The constant of the spring
   c. Extension which will be produced by a force of 12N

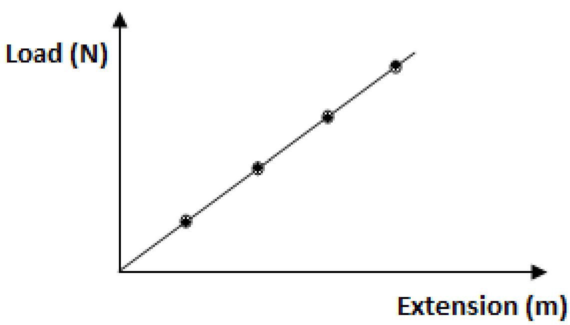
Experiment to verify (prove) Hooke's law

A spring is suspended next to the metre rule with a pointer at the bottom end used to obtain a reading on a scale as shown below



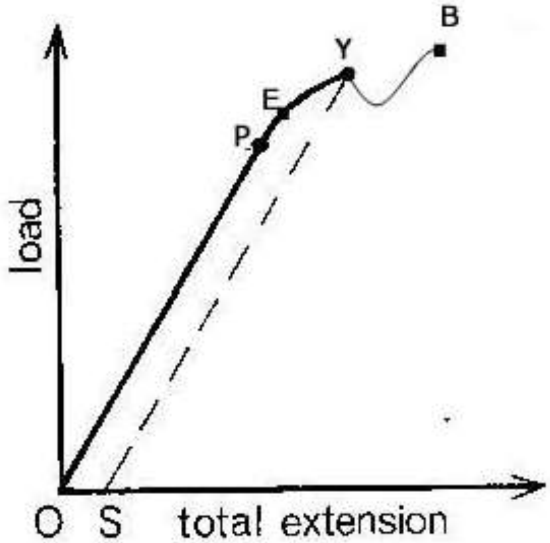
- The initial position X_0 on the pointer is read and recorded
- Uniformly load the spring by adding standard masses on the mass hanger
- The new position X of the pointer whenever the spring is loaded is recorded
- The extension for each load added is recorded from

  $e = X - X_0$.
- A graph of load against extension is plotted as shown



A straight line passing through the origin verified hook's law.

A graph load against extension for a ductile wire



Points;

P- Proportional limit

E- Elastic limit

Y- Yield point

B- Breaking point.

Lines/ regions

OP – Region where hook's law is obeyed or region of proportionality, the materials under goes elastic deformation.

OS – materials undergoes permanent extension.

SY – Material undergoes plastic deformation.

Definitions;

Elastic deformation;

This is the deformation which occurs before the elastic limit. The wire regains its shape and size after deformation. Energy is stored as potential energy.

Plastic deformation;

This occurs after the elastic limit. The wire fails to recover its original shape and size fully. Permanent extension is made and part of the energy is stored as elastic potential energy and the rest is converted into heat in the wire as it stretches. The wire recovers along YS and not OE.

STRESS, STRAIN AND YOUNG'S MODULUS

Consider a force F acting on a material e.g. a wire of length l and cross section area A so that it extends by length e.

Stress for the wire is defined as the ratio of applied force on a material to its cross section area

i.e. Stress =

SI unit: N/m^2

Strain is a ratio of extension of a material to its original length

i.e. Strain or Strain =

Strain has no units.

Young's modulus is defined as the ratio of stress to strain

Y =

SI unit = N/m^2

Young's modulus is determined when the elastic limit is not exceeded and its value is constant

Example;

1. A force of 20N acting on a wire of cross sectional area $10cm^2$ = makes its length to increase from 3m to 5m. Find stress?

   a) Stress = = = $2Nm^{-2}$

   b)

2. A copper wire of length 10cm is subjected to a force of 2N if the cross section area is $5cm^2$ and a force causes an extension of 0.2cm

   Calculate;

(i) Tensile stress

(ii)

(iii) Young's modulus

<u>Questions</u>

1. A mass of 200kg is placed at the end of the wire 15cm long and cross sectional $0.2cm^2$ if the mass causes an extension of 1.5cm

   Calculate.

   i. Tensile stress

ii. Tensile stress.

2. A mass of 200g is placed at the end of a wire 15cm long are cross sectional area 0.2m .if the mass causes an extension of 1.5 calculate
   (i) Tensile stress
   (ii) Tensile strain
   (iii) Young modulus

PRESSURE

Pressure is defined as force acting normally per unit area

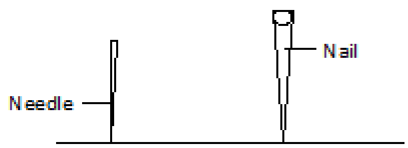
SI unit is Nm^{-2} or Newton per square metre or Pascal

Note:

Other units: Kilo Pascal (kpa) or Kilo Newton per metre squared

Note:

The pressure increases when the surface area is decreased. This can be demonstrated using a needle and a nail as shown



When the same force is applied at the top of the needle and nail, one tends to feel more pain from the needle than the nail.

This is because surface area of the bottom of the needle is smaller therefore the pressure is high

The increase in pressure when the surface area is decreased explains why a tractor can easily move in a muddy area than the bicycle.

Example;

1. A car piston exerts a force of 200N on a cross sectional area of $40cm^2$. Find the pressure exerted by the piston

2. The pressure exerted on foot pedal of cross sectional area $5cm^2$ is $200Nm^{-2}$.Calculate the force.

=

= =

<u>Minimum and maximum pressure</u>;

Pressure is minimum when area is maximum and on the other hand, pressure is maximum when area is minimum

i.e

Example;

1. A box measures 5m by 1m by 2m and has weight of 60N while resting on the surface. What is the minimum pressure?

2. A box of dimensions of 6m x 2m x 4m exerts its weight of 400N on the floor. Determine its
   a) Maximum pressure
   b) Minimum pressure
   c) Density

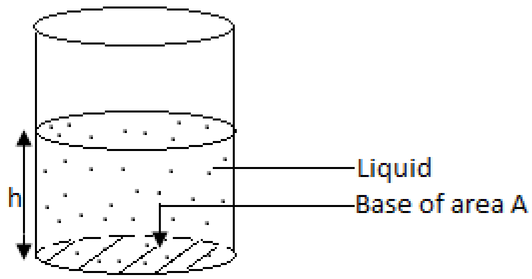
a) Maximum pressure;

b) Minimum pressure;

c) ***Density;***

PRESSURE IN LIQUIDS

Consider a column of liquid to a height h above the base in a cylinder as shown below;



The pressure on the surface of the base of cross sectional area A is due to weight W of the liquid above it

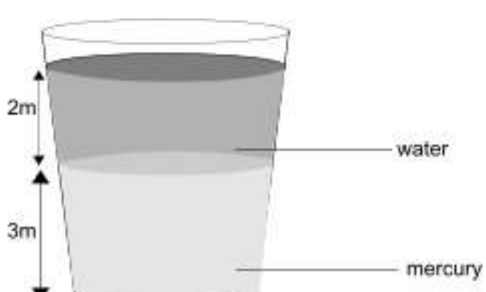
It follows that pressure is the same in all directions and depends on;

(i) Depth (h) of the liquid
(ii) Density (ρ) of the liquid

Examples

1. The density of liquid X is 800kgm^{-3}. It was poured in a container to a depth of 400cm. Calculate the pressure it exerts at the bottom of the container

2.



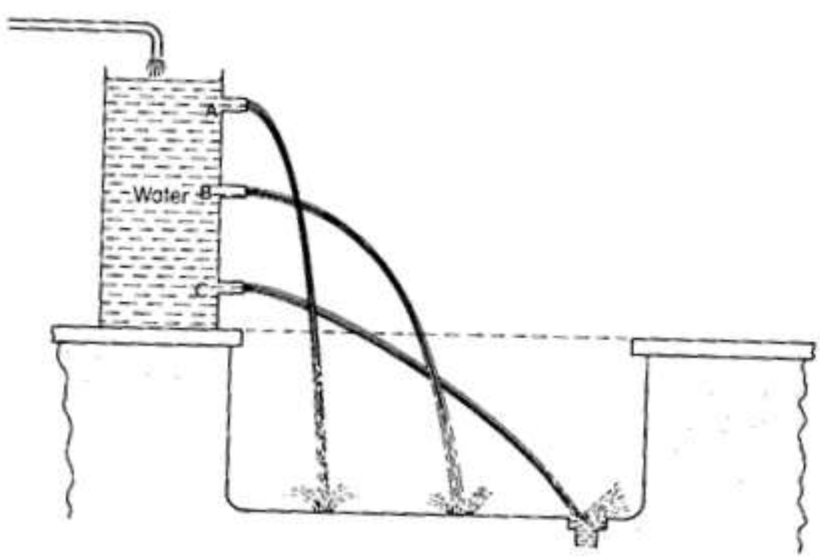
The tank contains mercury and water. The density of mercury is $13600kgm^{-3}$ and that of water is $1000kgm^{-3}$. Find the total pressure exerted at the bottom.

3. A cylindrical vessel of cross section area $50cm^2$ contains mercury to a depth of 2 cm. calculate

   i) The pressure that mercury exerts on the vessel

   ii) The weight of water in the vessel (density of mercury $=13600kgm^{-3}$)

Experiment to show that pressure in liquids increases with increase in depth (h)



Three equally sized holes A, B and C are made on a tall can at different depths h_1, h_2 and h_3 as shown in the figure above

The holes are blocked with cork and the can is filled with water

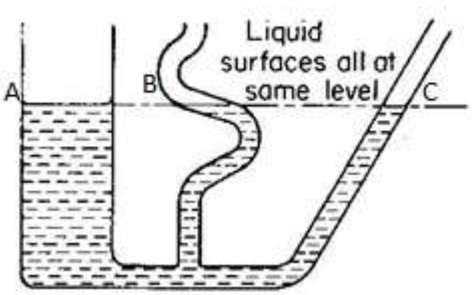
The holes are unblocked and the sizes of water jets noted

Observation;

The speed with which water spurts out is greatest for the lowest jet, showing that pressure increases with depth.

NB: pressure does not depend on shape and cross sectional area of the container. This can be illustrated using communication tube.

Experiment to show that pressure is independent of cross section area and shape of container



The liquid is allowed into the tubes A, B and C as shown above

The liquid reaches the same height h in all the tubes.

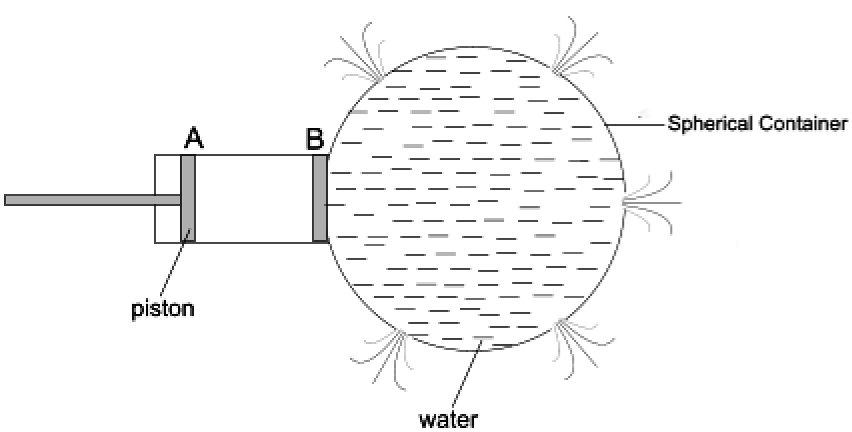
Since the tubes are of different cross sectional area and shape. It follow that pressure does not depend on shape and cross sectional area

PRINCIPAL OF TRANSMISSION OF PRESSURE IN LIQUIDS

(*Pascal's principal or Law of liquid pressure)*

The principal states that "pressure at a point in a liquid is equally transmitted throughout the liquid. The principal assumes that the liquid is incompressible

Experiment to verify the principal of transmission of pressure in liquids



A spherical container is pinched at different points around it

The piston is moved in such way that it pushes "B" to compress the liquid

The pressure caused is transmitted equally throughout the liquid. This can be observed by having all holes pouring out the liquid at the same rate when the piston is pushed in, hence pressure in liquid is equally transmitted.

Summary;

Experiment above show that pressure in liquids;

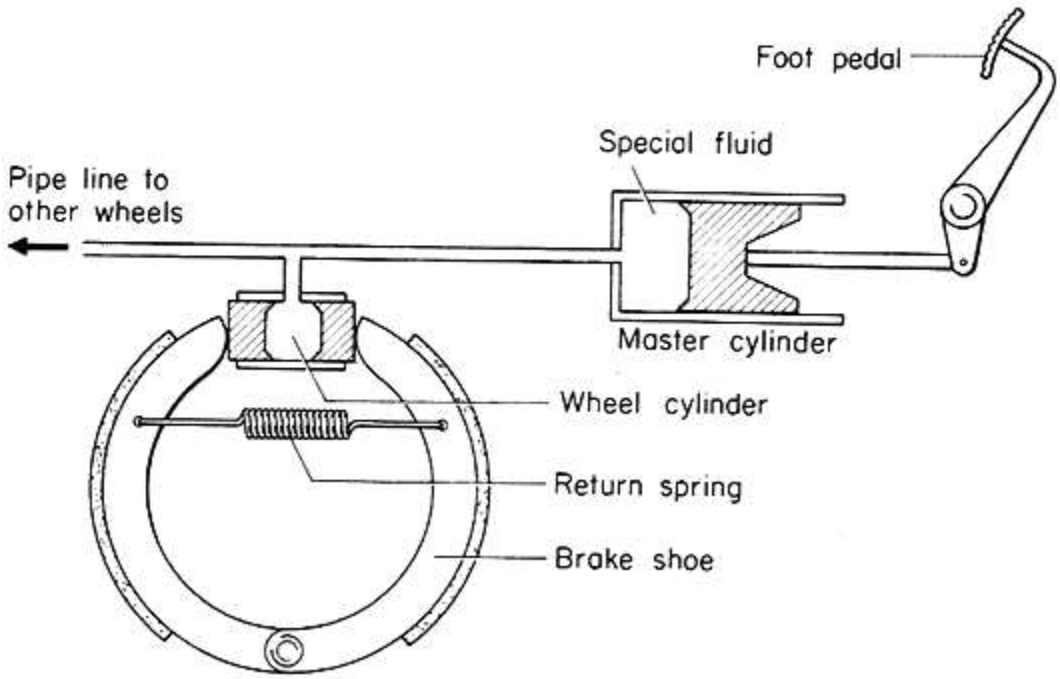
1. Depends on depth and density
2. Equally transmitted throughout the liquids
3. Is independent of shape or cross sectional area of the container in which the liquid is placed.

<u>Application of the Pascal's principle:</u>

Some machines where the Pascal's principle is used include;

1. Hydraulic car brakes
2. Hydraulic press
3. Hydraulic lifts.

THE HYDRAULIC CAR BRAKE SYSTEM

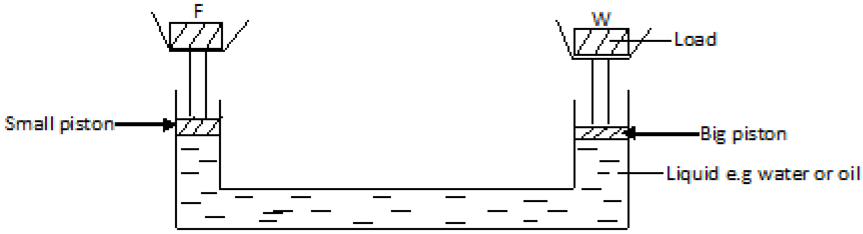


Mode of action:

- When a foot is applied on a foot pedal, the piston in the master cylinder exerts a force on the brake fluid (special fluid)
- The resulting pressure is transmitted to the wheel cylinder of each wheel
- The force caused then moves the wheel piston which push against the break pad, making them squeezed against the car wheel, hence the wheel stops rotating and the car stops.

HYDRAULIC PRESS;

A hydraulic press consists of two connected cylinders of different bores, filled with water or any other incompressible liquid and fitted with piston shown in the figure below

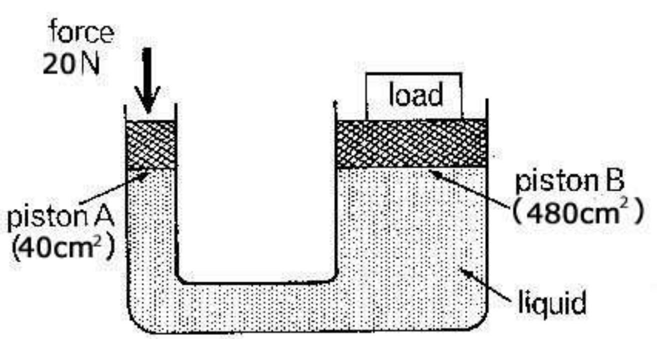


- When the force F is exerted on the liquid via piston A, the pressure produced is transmitted equally through out to piston B, which supports a load W
- The force created at B raises the load squeezing a hard substance

Example;

1. The cross sectional area of the piston A = $2m^2$ and the force applied at piston A is 10N. Calculate the force on B, given the cross section area as $150m^2$

2. Calculate the weight B, lifted by the piston of area $48cm^2$ with a force of 20N whose piston area is $400cm^2$ as shown below;



Pressure at B = pressure at A

=

= 5000 Nm^{-2}

Weight W =pressure at B x piston area B

=5000 x0.048

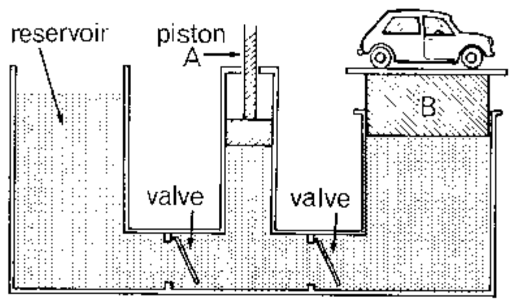
= 240N

Questions

1. Calculate the weight W raised by a force of 56N applied on a small piston area of $14m^2$. Take the area of the large piston to be $42m^2$

2. A force of 32N applied on a piston of area 8cm^2 is used to lift a load W acting on large area of 640cm^2. Determine the value of W

Hydraulic lift



This is commonly used in garages; it lifts cars so that repairs and service on them can be done easily underneath the car

A force applied to the small piston, raises the large piston, which lifts the car. One valve allows the liquid to pass from the small cylinder to the wider one. A second valve allows more liquid (usually oil) to pass from oil reservoir on the left to the small cylinder. When one valve is open, the other must be shut

ATMOSPHERIC PRESSURE:

The earth is surrounded by a sea of air called atmosphere. Air has weight therefore it exerts pressure at the surface of the earth. The pressure this air exerts on the earth's surface is called atmospheric pressure.

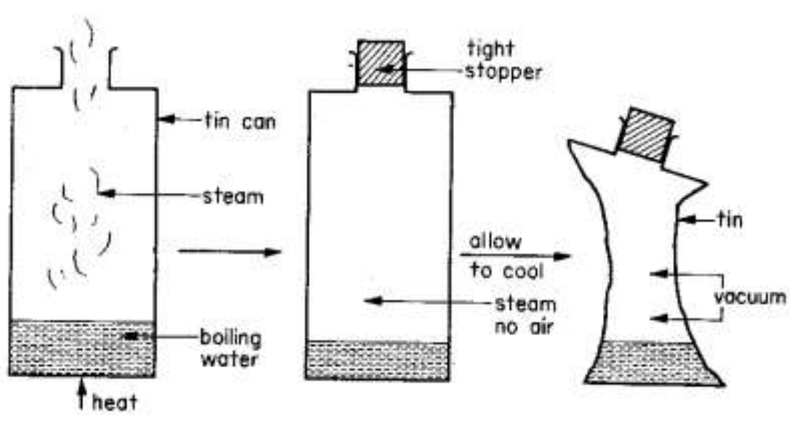
Atmospheric pressure is the pressure exerted by the weight of air on all objects on earth's surface

The higher you go the less dense the atmosphere and therefore atmospheric pressure decrease at high altitude and increase at low altitude

The value of atmospheric pressure is about 101325N/m.

Experiment to demonstrate the existence of atmospheric pressure;

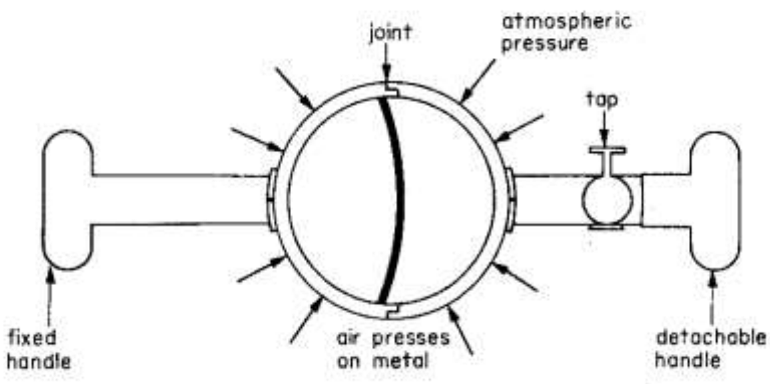
a. Crushing can experiment or collapsing can experiment;



- A metal can with its tight stopper removed, is heated until the small quantity of water in boils.

- When the steam has driven out all the air, the cork is tightly replaced and the heat removed at the same time.
- Cold water is poured over the can. This causes the steam inside to condense reducing air pressure inside the can
- The can collapses in wards. This is because the excess atmospheric pressure outweighs the reduced pressure inside the can.

b. <u>The Magdeburg's hemisphere</u>



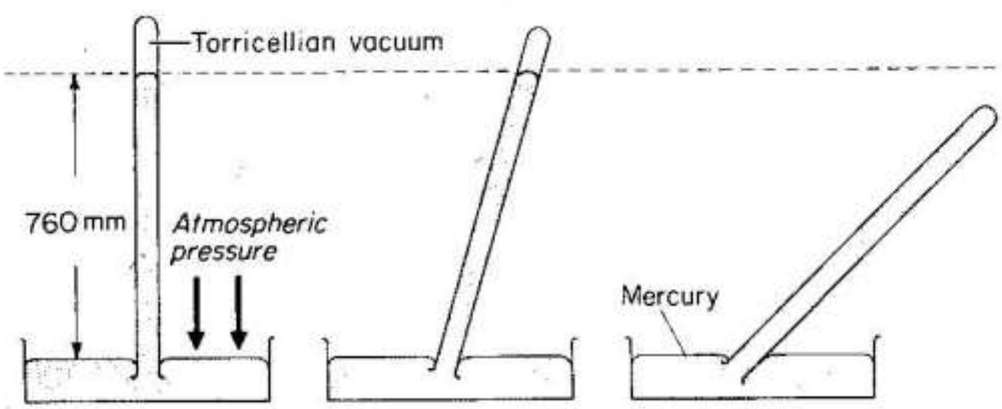
The hemisphere is made of two hollow bronze with a stop cork on one side. The rims are placed together with grease tightening between them to form an air tight joint. The air is pumped out and the stop cork closed. It becomes impossible for even eight horses to separate them. When air is re admitted in the sphere they are easily separable. This indicates the existence of atmospheric pressure.

MEASUREMENT OF ATMOSPHERIC PRESSURE:

Atmospheric pressure is measured using an instrument called Barometer.

Types of barometers	Units of pressure
1. Simple barometer	Nm^{-2}
2. Fortin barometer	Pa
3. Aneroid barometer	atmospheres

Simple barometer



A simple barometer is made by completely filling a thick walled glass tube of uniform bore about 1m long with mercury

The tube is tapped from the open side and inverted several times to expel any air bubbles trapped in mercury

It is inverted over a dish containing mercury as shown in the diagram.

The mercury level falls leaving a column "h" of about 76 cm

The height "h" gives the atmospheric pressure 76cmHg.The empty space created above the mercury in the tube vacuum called Torricellian vacuum

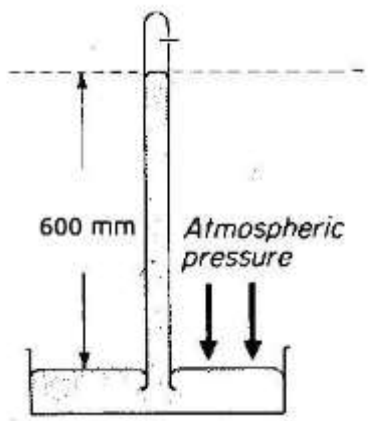
NB; The vertical height of the mercury will remain constant if the tube is lifted as in (2) provided the top of the tube is not less than 76cm above the level of mercury in the dish.

If it is lifted so that "h" is less than 76cm.The mercury completely fills the tube. This shows that vacuum was a trice vacuum and a column of mercury is supported by atmospheric pressure

Generally, Atmospheric pressure = Barometer height x Density of liquid x gravity

Example; 1. Determine the atmospheric pressure (i) in cmHg and in (ii) Pascal's (Nm^{-2}) using the following barometer.

(a)



(i) Height = 600mm p = 60cmHg

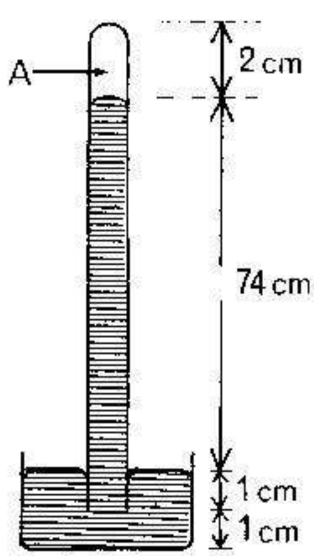
(ii) P = hpg

= 600mm x 13600 x 10

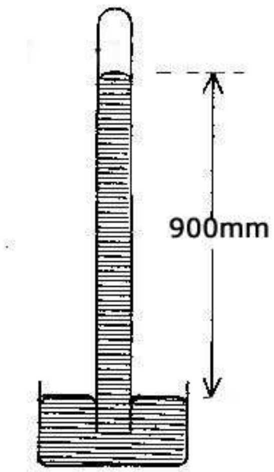
= x 13600 x 10

= 81600pa or 81600Nm^{-2}

(b)



(c)



2. Express (i) 76cm Hg in Nm^{-2} (density = $13600kgm^{-2}$)

$P = h\rho g$

$= \times 13600 \times 10 \quad = 103360$ Pascals

(ii) 540mmHg in pa

$P = h\rho g \quad = \times 13600 \times 10 \quad = 73440N/m^2$

3. The column of mercury supported by the atmospheric pressure is 76cm. Find column of water that the atmospheric pressure will support in the same place. Comment on your answer.

$P = h\rho g \quad = \quad \times 13600 \times 10$

$= 103360\ Nm^{-2}$

In the same place atmosphere pressure is the same as using water;

$P = h\rho g$

$103360 \quad = h \times 1000 \times 10$

$h = 103360/ 1000 X 10$

$h = 1034m$

The answer to the question above, explains why water is not used in a barometer because the column will be too long.

Applications of Atmospheric pressure

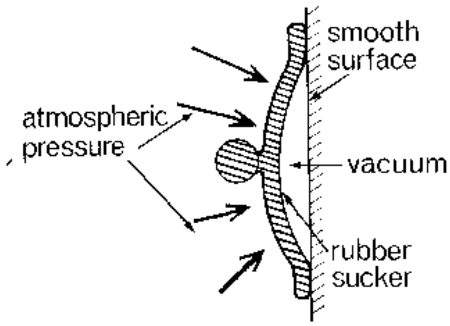
Atmospheric pressure may be made useful in

a. Rubber suckers
b. Bicycle pump
c. Lift pump
d. Force pump

e. Siphon
f. Water supply system
g. Drinking straw

Rubber Sucker

This is circular hollow rubber cap before it is put to use it is moisturized to get a good air seal and firmly pressed against a small flat surface so that air inside in pushed out then atmospheric pressure will hold it firmly against surface as shown below

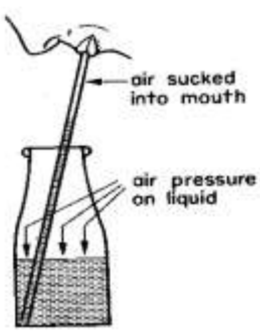


<u>Uses of rubber sucker;</u>

-Fitting sheets against walls

-It is used printing machines for lifting papers to be fed into the printer

Drinking straw;

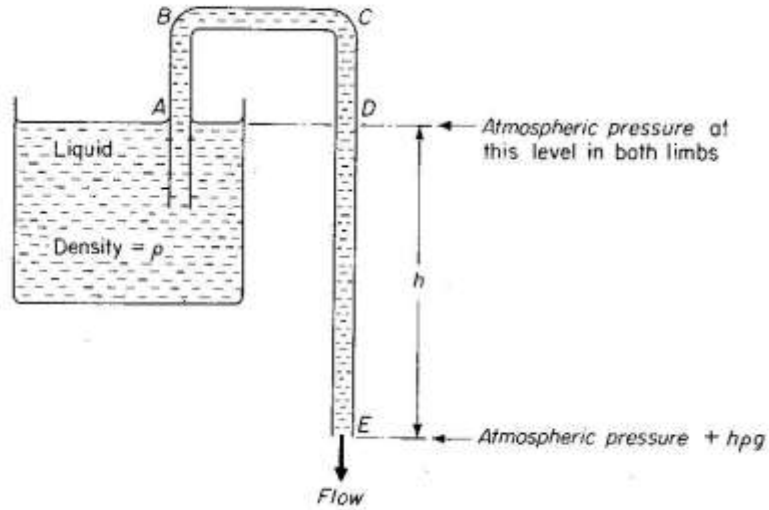


-When drinking using a straw some of the air in the straw goes into the lungs once sucked.

-This leaves space in the straw partially evacuated and atmospheric pressure pushing down the liquid becomes greater than the pressure of the air in the straw

The siphon;

This is used to take the liquid out of vessels (eg. Aquarium, petrol tank)



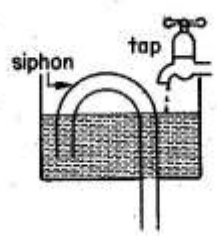
How a siphon works

The pressure at A and D is atmospheric, therefore the pressure at E is atmospheric pressure plus pressure due to the column of water DE. Hence, the water at E can push its way out against atmospheric pressure

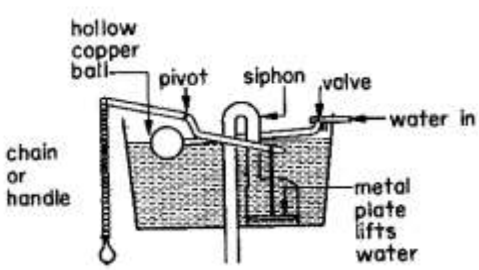
NB: To start the siphon it must be full of liquid and end A must be below the liquid level in the tank.

Applications of siphon principle

1. **Automatic flushing tank:** This uses siphon principle.
   Water drips slowly from a tap into the tank. The water therefore rises up the tube until it reaches and fills the bend
   In the pipe, the siphon action starts and the tank empties (the water level falls to the end of the tube).The action is then repeated again and again.



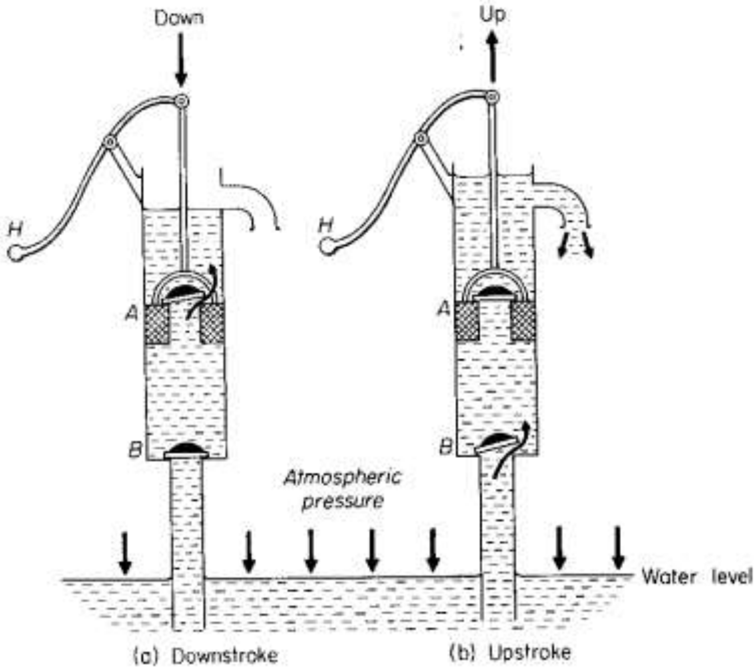
2. **Flushing tank of water closet:** This also uses the siphon principle.
   When the chain or handle is pulled, water is raised to fill the bend in the tube as shown below:



The siphon action at once starts and the tank empties.

Lift pump or common pump;

Pumps are used to raise water from walls. They consist of cylindrical metal barrel with side tubes near the top to act as spouts.



Down stroke;

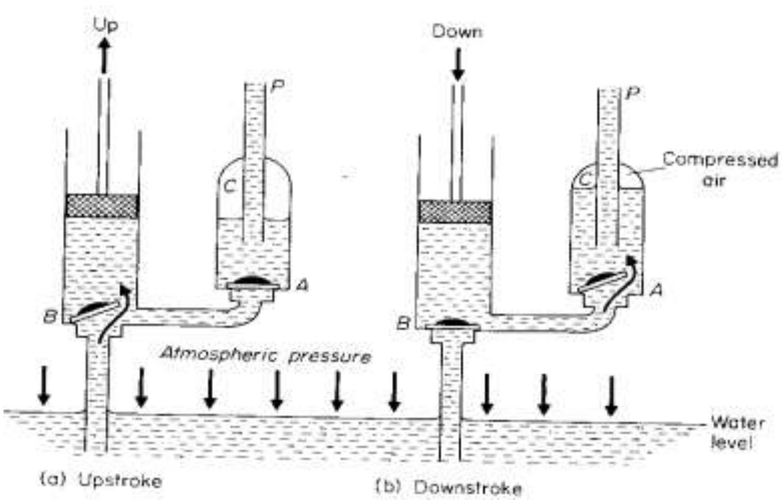
When the plunger moves down wards valve B closes due to force of gravity on it and weight of water above it.

At the same time water inside the barrel passes upwards through A into the space above the plunger.

The upstroke;

- Valve A closes due to the force of gravity on it and weight of water above it.
- As the plunger rises water is pushed up the pipe through valve B by atmospheric pressure on the surface of the water in the well.
- At the same time, the water above it is raised and flows out at the spout.

Force pump;



A force pump is used to raise water from a deep well or reservoir to a storage tank.

It is first pumped to make it air tight.

On the upstroke, valve A closes and atmospheric pressure forces the water up the barrel through valve B.

On the down stroke valve B closes, water is forced into the reservoir through valve A and also out of the spout D.

The air in the spout is compressed and on the next up stroke, it expands so keeping the supply of water at B.

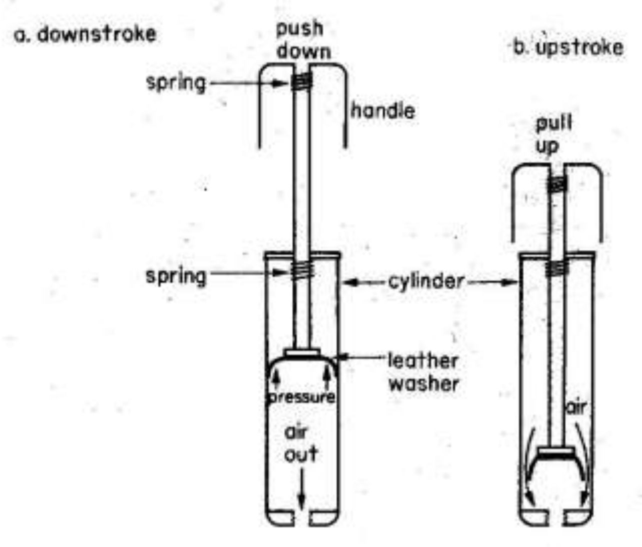
BICYCLE PUMP;

Principle and action of a pump

-The air in the pump barrel is compressed.

-The high pressure of the air in barrel presses the leather washer against the inside of the barrel closing the pump valve.

-When the pressure of compressed air becomes greater than that of air already in the tyre, air is forced past the tyre valve into the tyre.



When the handle is pulled out, the pressure of the air in the barrel is reduced.

The high pressure of air in the tyre closes the tyre valve preventing the air escaping.

The atmospheric pressure being greater than the reduced pressure in the barrel, forces the air past the leather washer opening the valve refilling the barrel with air.

<u>**Water supply system**</u>:

Water supply in towns often comes from a reservoir on a high groundwater flows from it through a pipe to any tap or storage tank that is below the water reservoir.

In very tall building it may be necessary to first pump water to a large tank on a roof. Reservoirs of water supply in hydro electric power stations are often made in mountainous areas.

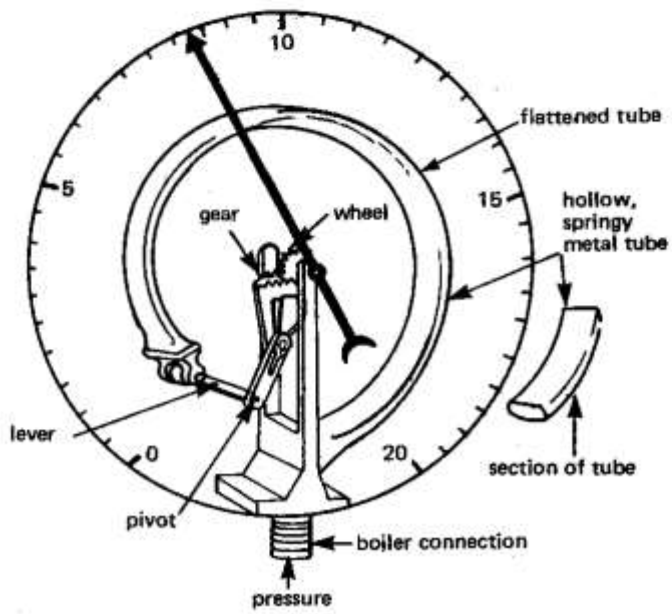
The dam must be thicker at the bottom than at the top to with stand large water pressure at the bottom.

Atmospheric pressure is 760mmHg.When you move on the top of the mountain, the pressure reduces to about 600mmHg.***This shows that pressure reduces with increase in altitude.***

Measurement of fluid pressure:

a. **Bourdon gauge**

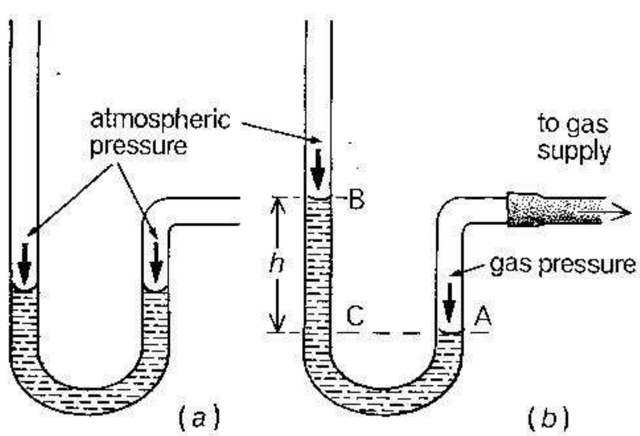
This gauge measures the very high pressures of liquids or gases, e.g. the pressure of steam in boilers. It is a hollow curved tube of springy metal closed at one end. The tube straightens slightly when pressure acts on the inside. The closed end of the tube is joined to a series of levers and gear wheels which magnify the slight movement. A pointer moving over a scale (usually graduated in 10^5 Pa, which is about 1 atmosphere pressure) records the pressure. The recorded pressure is the excess pressure of liquid or gas over atmospheric pressure, but some gauges can record the actual pressure.



Bourdon gauges are commonly used at fueling stations.

b. Manometer;

It is a U – shaped tube containing mercury



Action;

One limb is connected to the gas or air cylinder whose pressure P is required.

Second limb is left open to the atmosphere

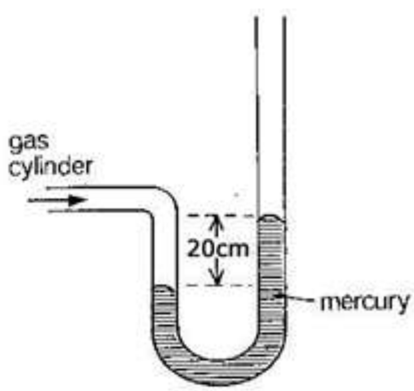
Using a metre rule, pressure P of the gas is calculated as

Pressure at B = Pressure at C

= H + h (when B is above A)

= H – h (when B is below A)

Example;



1 .Find the gas pressure given atmospheric pressure H = 76cmHg

(i) In cmHg
(ii) In Nm^{-2}

Solution

1. (i) Gas pressure P = H + h = 76 + 20 = 96 cmHg

   (ii) P = hpg = x 13600 x 10 = 130560 Nm^{-2}

2. Express a pressure of 75cmHg into Nm^{-2}

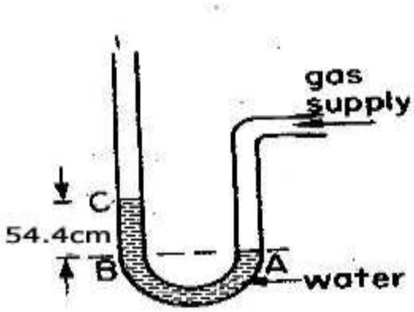
   P = hpg = x 13600 x 10 = 102000Nm^{-2}

3. A man blows in one end of a water U – tube manometer until the level differ by 40.0cm.If the atmospheric pressure is 1.0x 10^5 N/m^2 and density of water is 1000kgm^{-3}.calculate his lung pressure.

   Pressure of air = H + hpg

   = 1.01 x 10^5 + x 1000 x 10 = 105,000Nm^{-2}

   Therefore lung pressure = 105,000Nm^{-2}



4. The manometer contains water, when the tap is opened; the difference in the level of water is 54.4cm. The height of mercury column in the barometer was recorded at 76cm.What is the pressure in cmHg at points A, B, and C.

Pressure at A = pressure B

$= H + h$

Pressure using mercury = pressure of water

$h_1 \, p_1 \, g_1 = h_2 \, p_2 \, g_2$

$h \times 13600 \times 10 = 54.4 \times 1000 \times 10$

=

$h = 4$ cm

Therefore at B, $P = H + 4$

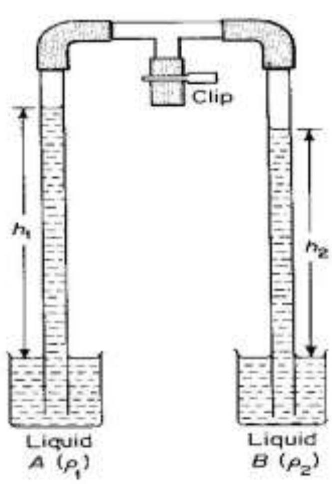
$P = 4 + 76 = 80$cmHg

5. The difference in pressure at the peak of the mountain and the foot of the mountain is Given that the density of air is 1.3kgm^{-3}, calculate the height of the mountain.

Difference of P = hpg → $5.0 \times 10^4 = h \times 1.3 \times 10$

h = 3846.15m or 3.85km

Comparison of densities of liquids using Hare's apparatus



Liquids of different densities are placed in glass pots as shown above.

When the gas tap is opened each liquid rises to different height h_1 and h_2.Since they are subjected to the same gas supply,

Pressure on liquid 1 = pressure on liquid 2

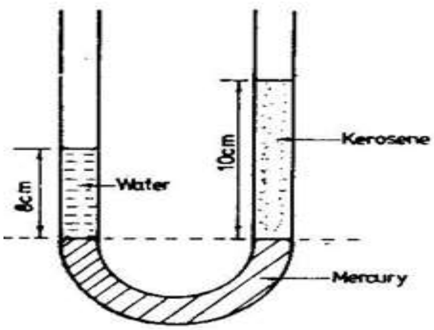
$$h_1 \ p_1 \ g = h_2 \ p_2 \ g$$

$$h_1 \ p_1 = h_2 \ p_2$$

$$=$$

Example;

1.



Water and kerosene are placed in U-tube containing mercury as shown above.

Determine the density of kerosene

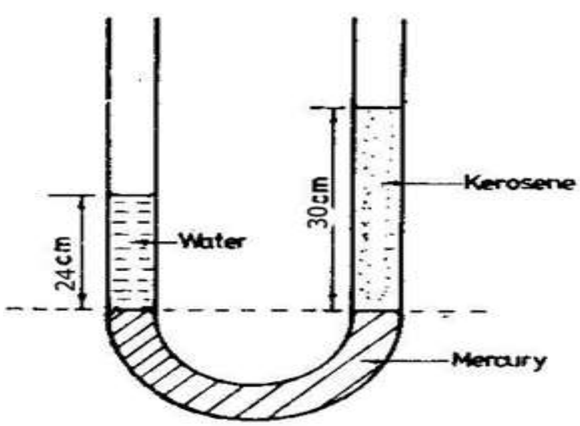
Pressure of kerosene = Pressure of water (since both tube are open to the atmosphere)

$$h_x \ \rho_x \ g = h_w \ \rho_w \ g$$

$$h_x \rho_x = h_w \ p_w \qquad \rho_x = \quad =$$

2. The level of the mercury in arms of the manometer shown below is equal. Determine

(i) Density kerosene
(ii) Relative density of kerosene



$h_1 \rho_1 g = h_2 \rho_2 g$

$24 \times 1000 = 30 \times \rho_2$

=

Density $\rho = 800 kgm^{-3}$

Relative density of kerosene

R.d =

=

= 0.8

MOMENTS AND EQUILIBRIUM

The turning of a force is the moment of force.

Moment of a force about a point depends on

i) The size of force
ii) perpendicular distance from a line of action of force from the pivot.

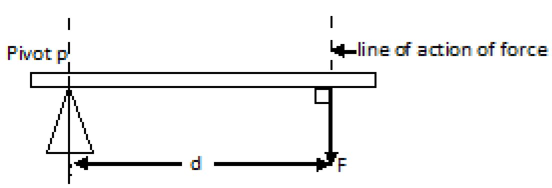
Moment of a force is = force x perpendicular distance

m = f x d where m is moment of force f is the force and d is the perpendicular distance.

Definition

Moment of a force about a point is the product of the force and the perpendicular distance of its line of action from the pivot. S.I unit is Nm

ILLUSTRATION



Moment of force about p

m = F x d

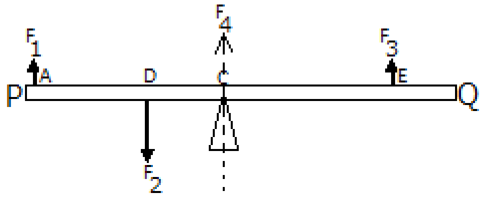
Types of moments

i) Clock wise moment
These are moments which produce clockwise turning effects

ii) Anti - clock wise moments
These are moments that produce anti - clockwise turning effects

Static equilibrium

A body acted upon by several forces is in static equilibrium when sum of clockwise moments about any point = sum of anti - clock wise about the same point.



If PQ is in equilibrium then:-

1. Sum of upward forces = sum of downward forces

$$F_1 + F_3 + F_4 = F_2$$

2. Sum of clockwise = sum of anti clock wise moment

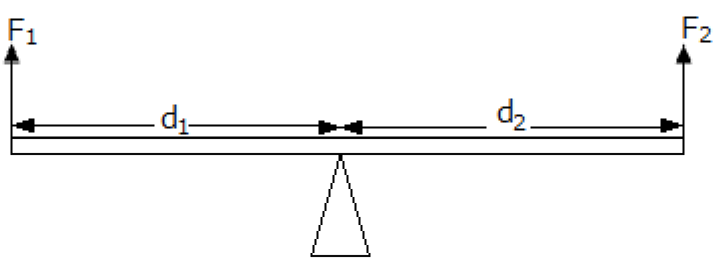
$$F_1AC = F_2DC + F_3EC$$

Conditions for a body to be in a mechanical equilibrium

1. The resultant force on body must be zero
2. The sum of clockwise moments about a turning point must be equal to the sum of anti - clockwise moments.

PRINCIPAL OF MOMENTS

It states that for a body in equilibrium, under the action of several forces, the sum of clockwise moments about a point is equal to the sum of anti - clockwise moments about the same point.

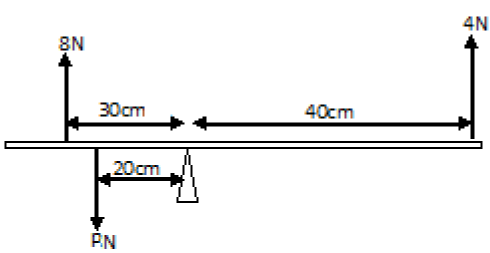


Sum of clockwise moments = sum of anti-clockwise moments

$$F_2 \times d_2 = F_1 \times d_1$$

Example 1

Forces of 8N, pN and 4N act on a body as shown;



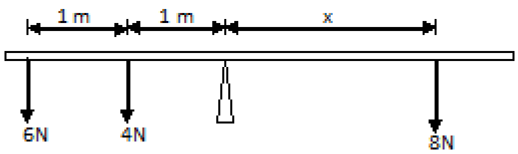
Find the value of P if the system is in equilibrium.

Sum of Anti-clockwise moments = Sum of clockwise moments

$4 \times 40 + p \times 20 = 8 \times 30$

$P = 4N$

3. Forces below act on the plank as shown



If the body is in equilibrium find the distance x

Anti clockwise = clockwise moments

$6 \times 2 + 4 \times 1 = 8x$

$X = 2m$

Centre of gravity

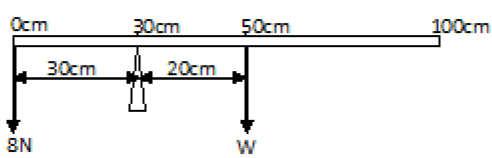
Centre of gravity is a point on the body through which the weight of the body acts.

Object	**Centre of gravity**
Cube or Cuboid	It is the intersection of diagonals
Uniform rectangular square sheet	At the intersectional of the diagonal
Uniform cylinder	At the centre of its axis
Uniform sphere	At the centre
Uniform rod or bar	At the centre

Example: 1

(a) What is meant by centre of gravity?
(b) i) Define moment of a force

ii) A uniform metre rule is balanced at 30cm mark. When a load of 8N is hang at zero mark. Find the weight of the metre ruler



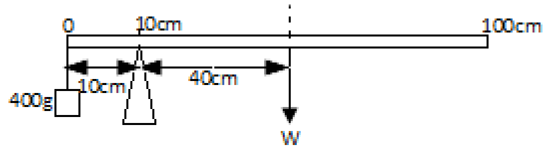
Sum of clockwise moments = Sum of anticlockwise moments

$W \times 20 = 8 \times 30$

$W = 12N$ (W is the weight of metre rule)

Example: 2

A uniform metre rule pivoted at 10cm mark balances when a mass of 400g is suspended at 0cm mark as shown below.



Calculate the weight of the metre rule.

Sum of clockwise moments = Sum of anticlockwise moments

W x 40 = 400 x 10

W = 100g

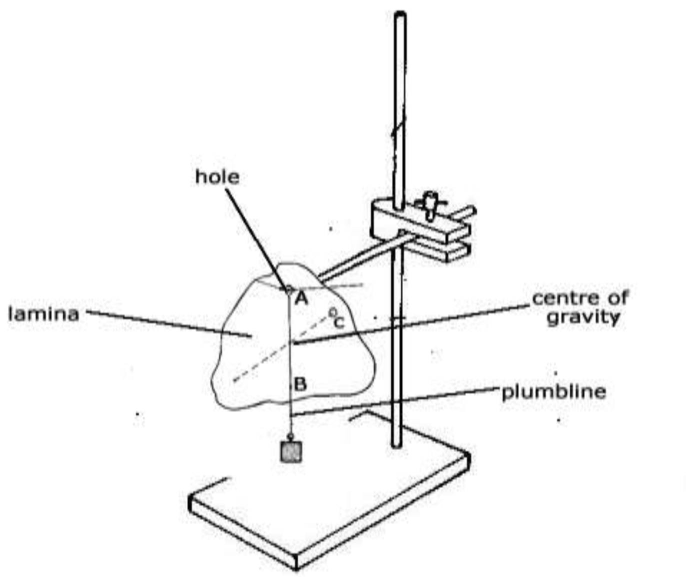
Weight = Mg

= x 10

= 1N

Determination of centre of gravity of an irregular object e.g cardboard

Plumb line method;



Make 3 holes A, B, C at different points near the edge of the lamina.

Suspend the lamina in hole A and the plumb line on a nail on a retort stand.

Mark the path of the thread of the plumb line on the lamina.

Repeat the procedure on holes B and C

The intersection of the three lines gives the centre of gravity (C.G)

STABILITY:

The stability of a body depends entirely on two factors namely:-

i) Position of the centre of gravity
ii) Size of base area

To increase the stability of a body, the following should be done.

- Increase the base area
- Lower the centre of gravity by making the base heavier

Types of stability equilibria

- Stable equilibrium
- Unstable equilibrium
- Neutral equilibrium

Stable equilibrium

This occurs when the center of gravity is in the lowest possible position

The body doesn't over turn when slightly displaced but returns to its original position after the displacement.

When slightly displaced, the center of gravity is raised and the line of action of the weight acts with in the base

Moment decreases when a body is slightly displaced

Unstable equilibrium

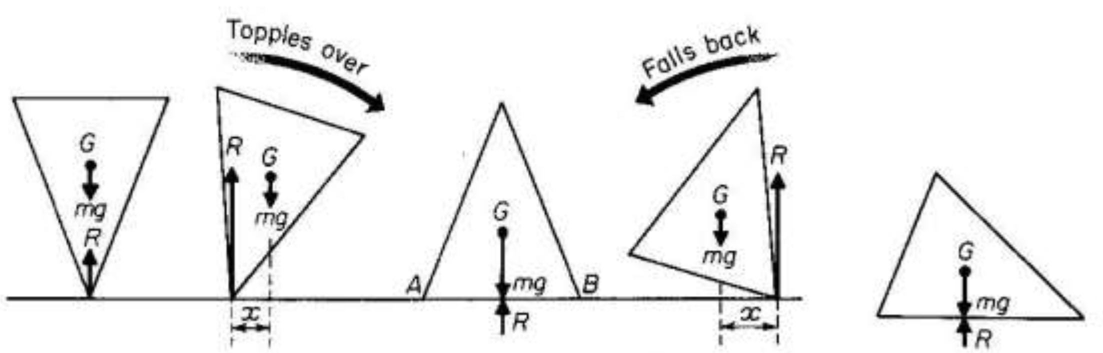
This occurs when the centre of gravity is in the highest position. The body overturns when slightly displaced.

When the center of gravity is lowered and the line of action of the weight acts outside the base

Neutral equilibrium

This is when a body is slightly displaced but the position of its center of gravity remains at the same height

Illustration



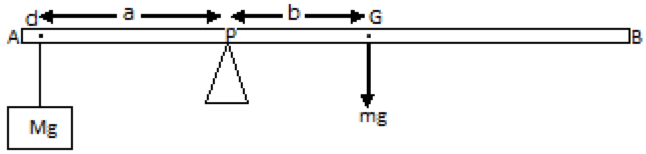
(a) Unstable equilibrium (b) Stable equilibrium (c) Neutral equilibrium

Application of principal of moments

- Action of a beam balance / weighing scale.
- Action of a sea saw.
- Determination of centre of gravity of a beam

- Determination of mass or the weight of a beam.
- Determination of relative density of a solid.

Determination of mass of a beam or rod or any straight material



Procedure

- Locate the centre of gravity of the beam AB by balancing it horizontally on a knife edge
- Note the position of the center of gravity
- Again balance AB horizontally on a knife edge using a mass M at a point d as shown in the diagram
- Measure distance dP = a and PG = b
- Calculate the mass m from;

Sum of clockwise moments = sum of anticlockwise moments

mg x b = Mg x a

m = =

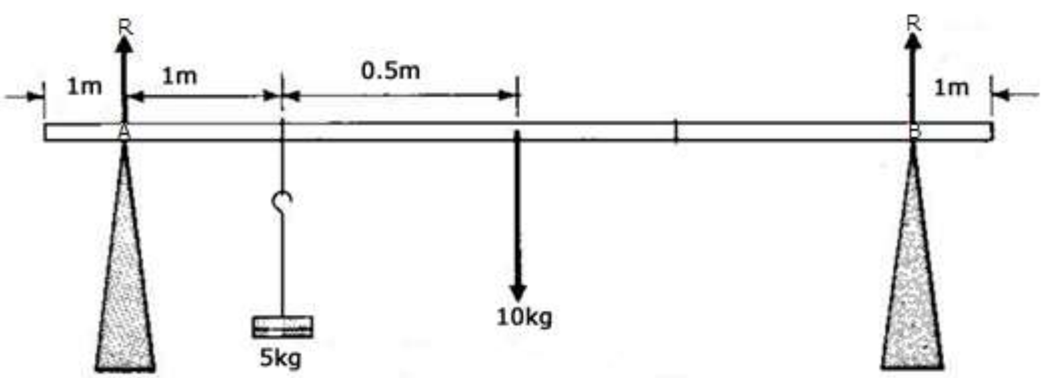
m =

Weight of beam, W = mg

Example

A uniform beam 5m long weighing 10kg is carried by 2 men each 1m from either ends of the beam if the mass of 5 kg rests 2m away from one end

i) Draw a diagram showing all forces acting on the bar
ii) Calculate the reaction due to the men acting on the bar



Taking moments about A

Sum of clockwise moments = sum of anticlockwise moments

50 x 1 + 100 x 1.5 = RB x 3
200 = 3RB

RB =

RB = 66.67N

Sum of upward forces = sum of downward forces
RA + RB = 50 + 100
RA + 66.67 = 150
RA = 83.33N.

Reaction at A= 83.33N
Reaction at B = 66.67N.

MOTION

Terms used

Speed

This is the rate of change of distance with time

Speed =

S.I unit is m/s

Distance

This is the length between two points

S.I units is metres

Displacement

This is the distance moved in the specified direction

S.I unit is meters

Velocity

This is the rate of change of displacement

OR

This is the rate of change of distance moved in a specified direction

S.I unit is m/s

Acceleration

This is the rate of change of velocity

A body travelling with increasing velocity is said to be accelerating

Acceleration a =

But change in velocity = final velocity – initial velocity
= v –u

Acceleration in velocity a =

S.I unit is m/s^2

Example 1

A car increases its speed steadily from 30 km/hr to 60km/hr in one minute

a) Determine its average speed during this time in

i) km/hr

ii) km/min

iii) m/s

b) How far does it travel whilst increasing its speed?

i) average speed = where v is final velocity / speed

=

= 45km/ hr

ii) average speed =

= 0.75km/min

iii) Average speed =

= 12.5m/s

b) Distance = speed x time

=12.5 x 60

=750m

2. A motor car is uniformly retarded and brought to rest from a speed of 108km/hr in 15seconds. Find its acceleration

Initial velocity u =

=

= 30m/s

Final velocity = 0 m/s

Acceleration =

= $-2m/s^2$

The minus (-) sign means the car is accelerating in opposite direction to its initial velocity i.e. the body is decelerating.

Uniform speed

A body is said to move with uniform speed if its rate of change of distance moved with time is constant.

Uniform velocity

This is the constant rate of change of displacement

A body is said to move with uniform velocity if its rate of change of displacement is constant.

When a body moves with uniform velocity, it travels equal distances in equal time intervals. A graph of distance against time is a straight line.

Its initial velocity must be equal to its final velocity.

Non uniform velocity

This is when the rate of change of displacement is changing. The body covers different distances in equal time intervals.

Uniform acceleration

This is when the rate of change of velocity is constant. When a body moves with uniform acceleration, the final velocity is not equal to the initial velocity

Equations of motion (Newton's equations of motion)

1st equation

Consider a body moving at initial velocity u accelerates with uniform acceleration a to the final velocity v in time t

Then acceleration a =

a =

$V = u + at$ 1st equation

2nd equation

A body moving with uniform acceleration has an average velocity equal to half of the sum of its initial velocity u and final velocity v.

Average velocity = substituting for v in equation 2

Total distance s = average velocity x time

$S = (\ )\ t$ but from equation 1, $V = u + at$

$S = (\ t = ()t$

$S = u\,t + at^2$ 2nd equation

3rd equation

This is obtained by eliminating time t from equation 1 and 2.

S =

$S = (\ )$

$(v + u)(v - u) = 2aS$

$V^2 = u^2 + 2aS$ 3rd equation.

The three equations of motion are

i) $V = u + at$

ii) $S = u\,t + ½at^2$

iii) $V^2 = u^2 + 2as$

Example

1. A car starts from rest and is accelerated uniformly at a rate of $1\ m/s^2$ in 20 seconds. Find;

a) Its final velocity.

b) The distance covered.

a) $V = u + at$

$= 0+1 \times 20$
$= 20 m/s$

b) $S = u t + \frac{1}{2} at^2$
$= 0 \times 20 + \frac{1}{2} \times 1 \times 20^2$
$= 200 m$

2. A car accelerates uniformly at a speed of 20m/s for 4 seconds. Find

a) Final velocity if acceleration is 2 m/s^2

b) Distance traveled.

a) $V = u + at$
$V = 20 + 2 \times 4$
$V = 28 m/s$

b) $S = u t + \frac{1}{2}at^2$
$S = 20 \times 4 + \frac{1}{2} \times 2 \times 4^2$
$S = 96 m.$

3. A body moving with velocity of 20 m/s accelerates to a velocity of 40m/s in 5 seconds. Find
   a) Acceleration to 40m/s
   b) Distance traveled in 5s.

a =

=
$= 4 m/s^2$

$S = u t + \frac{1}{2}at^2$
$S = 20 \times 5 + \frac{1}{2} \times 4 \times 5^2$
$S = 150 m$

4. A body at rest at height of 20m falls freely to the ground. Calculate
   i) The velocity with which it hits the ground
   ii) The time before striking the ground.

Solution

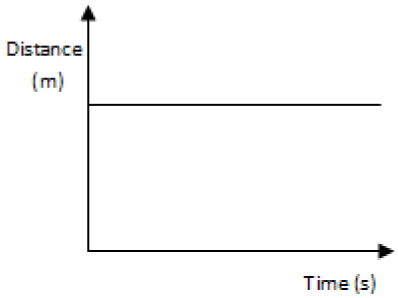
i) $a = g = 10$
$V^2 = u^2 + 2as$
$V^2 = 0^2 + 2 \times 10 \times 20$
$V = 20 m/s$

ii) $V = u + at$
$20 = 0 + 10 \times t$
$t = 2 s$

Graphs of motion

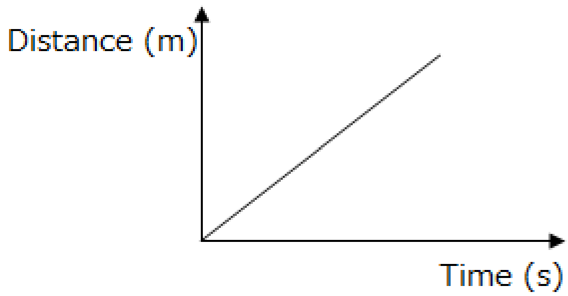
Distance – time graphs

i) For a body at rest



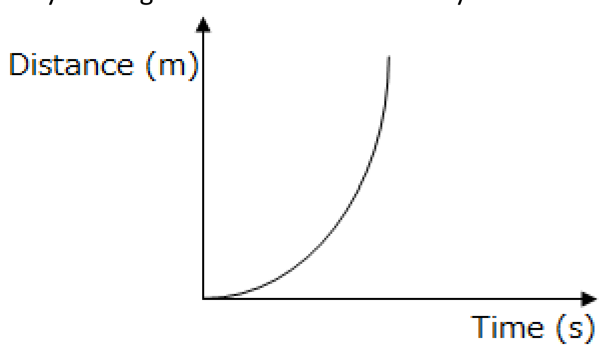
If a body is at rest its distance from a certain point does not change as time passes

ii) For a body moving with uniform velocity



If a body is moving with the same velocity it travels equal distance in equal intervals of time i.e. the object distance increases by equal increase in time.

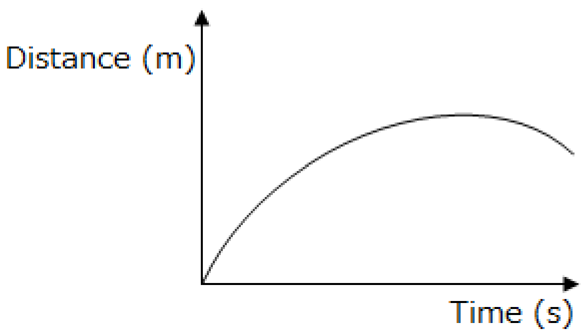
iii) Body moving with non uniform velocity



Varying distances are moved in equal intervals of time

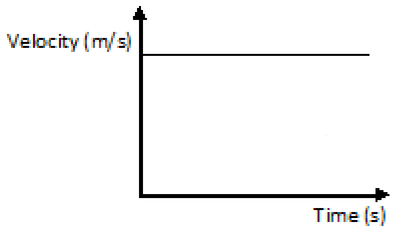
iv) Body moving with decreasing acceleration (retardation)

For a body whose velocity is decreasing the graph bends towards the horizontal. Velocity decreasing (retardation)

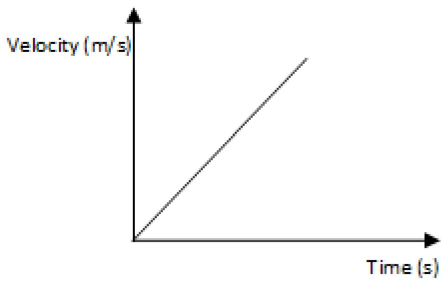


Velocity time graphs

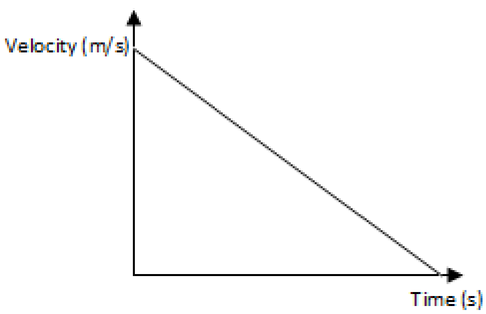
i) Body moving with uniform velocity



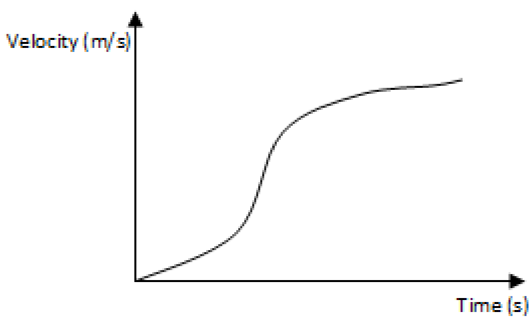
ii) Body moving with uniform acceleration



iii) Body moving with uniform deceleration.



iv) Body moving with non uniform acceleration.



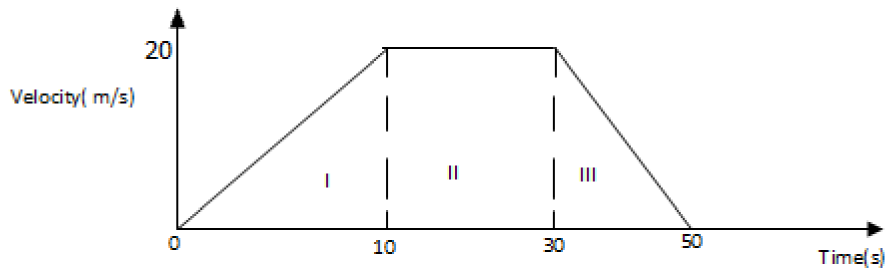
Note

i) The area under a velocity time graph gives the distance covered by the body.

ii) The slope of a uniform velocity time graph gives the uniform acceleration.

Examples

1. A car starts from rest and steadily accelerates for 10s to a velocity of 20m/s. It continues with this velocity for a further 20s before it is brought to rest in 20s
   a) Draw a velocity time graph to represent this motion.
   b) Calculate
   i) Acceleration
   ii) Deceleration
   iii) Distance travelled
   iv) Average speed



b (i) acceleration

a = = = = $2m/s^2$

ii) Deceleration

a = = = =$-1m/s^2$

Deceleration = -a = $1m/s^2$

iii) Distance

Distance traveled = area under a velocity time graph

S = ½bh+ L x w + ½bh

= ½ x10 x20 + 20 x 20 + ½ x 20 x 20

= 700m

Iv) Average speed =

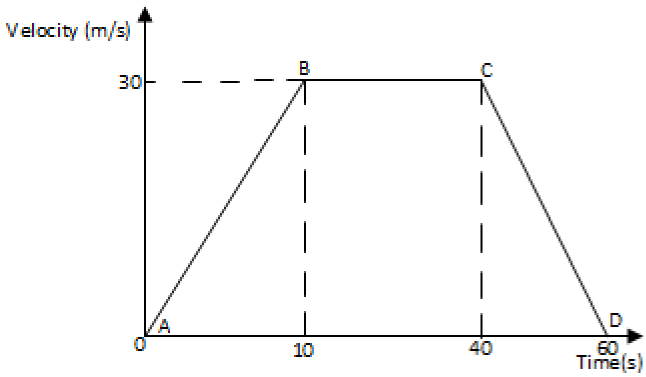
=

= 14m/s

2. A car from rest accelerates to velocity 30m/s in 10s. It continues at uniform velocity for 30s and then decelerate so that it stops in 20s
   a) Draw a velocity time graph to represent its motion
   b) Calculate
      i) Acceleration
      ii) Deceleration
      iii) Distance travelled

iv) Average speed

a)



i. Acceleration a = = = $3m/s^2$

ii. Deceleration

a == = $-1.5m/s^2$

Deceleration = $1.5m/s^2$

iii. Distance travelled

Total distance Covered = total area under a v –t graph

= ½bh + L x w +½bh

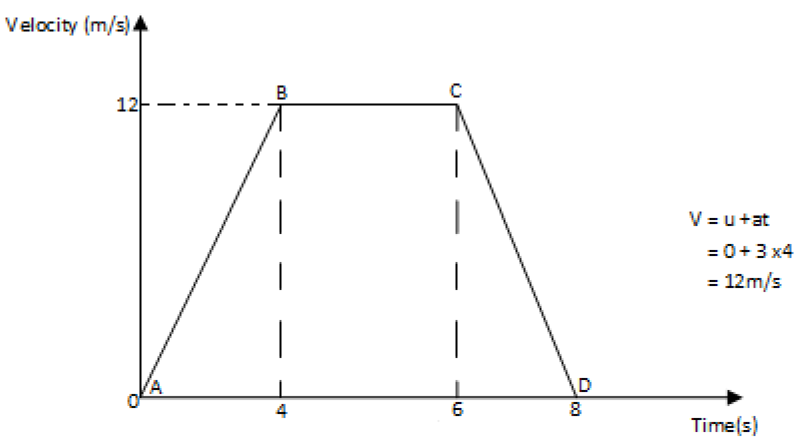
= ½ x10 x30 + 30 x30 +½x20 x30

= 1350m

iv. Average speed

Average speed = = 22.5m/s

3. A racing car starts from rest and moves with uniform acceleration of $3m/s^2$ for 4 seconds. Then moves with uniform velocity for 2 seconds. It is brought to rest after a further 2 seconds
   a) Draw a velocity time graph for motion of the car
   b) Find total distance travelled
   c) Average speed
   a)



b) Total distance covered

Total distance = total area under a velocity time graph

=½bh +Lx w + ½bh

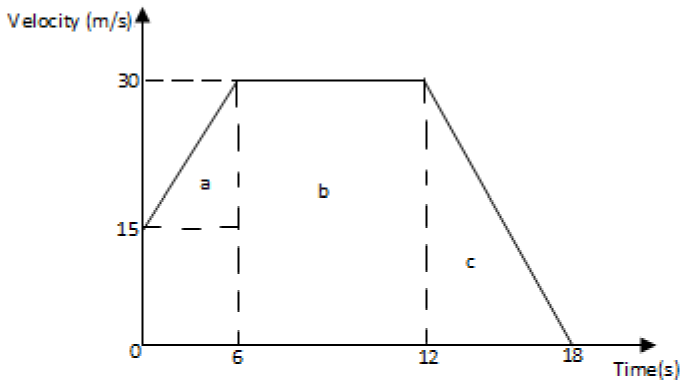
= ½ x4 x12 + 2 x12+ ½ x2x12

= 60m

c) Average speed = ==7.5m/s

Question

1) The graph below represents a velocity time graph of a body in motion.



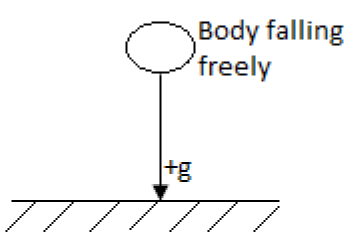
a. Describe the motion of the body.
b. Calculate the total distance travelled
c. Total distance travelled = total area under a v- t graph
d. Determine the average speed.

2) A body of mass 60 kg starts moving with an initial velocity of 15 m/s and accelerates at a rate of $4m/s^2$ in 5s, then maintains a constant velocity for another 5s and brought to rest in 7s.
   a. Draw a velocity –time graph to represent this motion.
   b. Calculate the total distance travelled
   c. Calculate the retarding force

MOTION UNDER GRAVITY

For a body falling under gravity, acceleration due to gravity is positive but for a body thrown vertically upwards, acceleration due to gravity is negative. At maximum height, the body is momentarily at rest therefore final velocity is 0m/s

Equations of motion for a body falling freely under gravity, g



V = u+gt

$S = ut + ½gt^2$

$V^2 = u^2 + 2gs$

Equations of motion for a body thrown vertically up wards

$V = u - gt$

$S = ut - ½gt^2$

$V^2 = u^2 - 2gs$

Examples

1) A stone is raised from rest at point 20m above the ground so as to fall freely vertically down wards. Find
   I. Time to land on the ground.
   II. Velocity with which the body lands

I. Using $s = u t + gt^2$
$20 = 0 + ½ \times 10 t^2$
$t = 2s$

II. Using
$V = u + g t$
$= 0 + 10 \times 2$
$= 20m/s$

2) A ball is thrown vertically upwards with an initial velocity of 30m/s. Find
   a. The maximum height reached
   $u = 30m/s$

   $V^2 = u^2 - 2gs$
   $0 = 900 - 2 \times 10 \times s$
   $= 900 - 20s$

   $S = 45m$

   b. Time taken to reach the maximum height
   $S = u t + ½gt^2$
   $45 = 0 + ½ \times 10t^2$
   $t = 3s$
   c. Time taken to return to the starting point.
   $V = u + gt$
   $30 = 0 + 10t$
   $t = 3$ seconds.
3) A stone thrown vertically upwards with an initial velocity of 14m/s neglecting air resistance, find
   i. The maximum height reached
   $v^2 = u^2 - 2gs$
   $0 = 196 - 2 \times 10s$
   $0 = 196 - 20s$
   $S = 9.8m$
   ii. The time taken before it reached the ground

$v = u + g\,t$

$14 = 0 + 10t$

$t = 1.4$ s

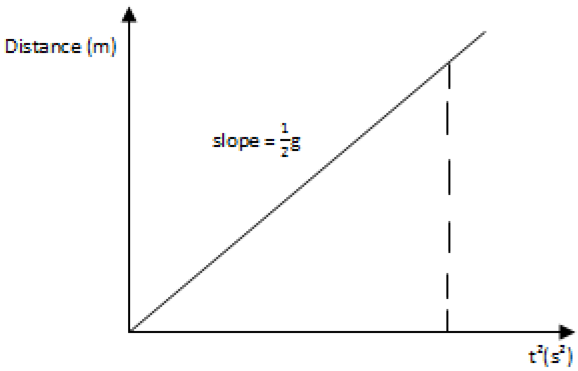
Acceleration of free fall is constant for a body falling from rest

$S = u\,t + ½gt^2$

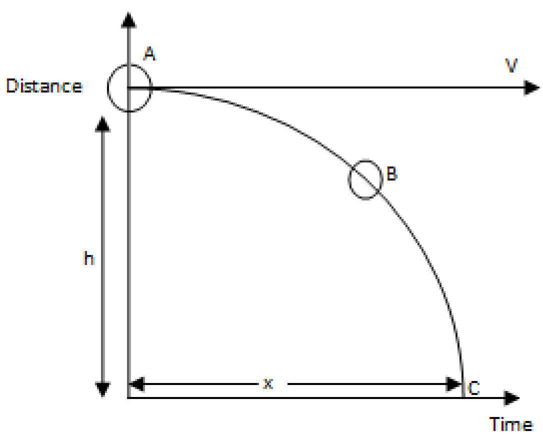
$S = ½gt^2$

$S = (\text{constant})t^2$

$S\ t^2$



Projectile motion



In projectiles, the horizontal velocity of the body in motion remains the same throughout whole journey (trajectory). Acceleration due to gravity continues to act on the body vertically downwards and it doesn't affect the horizontal motion of the body.

Horizontal motion, distance is x

$x = v_x t$

Vertical motion, distance is s =h

$h = gt^2$

i.e. $S = ut +^2$

$S = h$ and $u = 0$

$S = \frac{1}{2}gt^2$

Where v_x is horizontal velocity of a given body and t is the time of flight.

Example

1. An object is dropped from a helicopter. if the object hits the ground after 2 seconds, calculate the height from which object was dropped

   $t = 2s$, $g = 10mls$

   $h = \frac{1}{2}gt^2$

   $= \frac{1}{2} \times 10 \times 4 = 20m$

2. An object is dropped from helicopter at a height of 45m above the ground.
   a) If the helicopter is at rest, how long does the object take to reach the ground and what is its velocity on arrival.
   b) If the helicopter falls with a velocity of 1m/s when the object is released, what would be the final velocity of the object?

a) $h = gt^2$

$45 = \frac{1}{2} \times 10t^2$

$t = 3$ seconds

b) Velocity on arrival

$v = u + g\,t$

$= 0 + 10 \times 3$

$= 30m/s$

Question

An object is released from an air craft travelling horizontally with a constant velocity of 200m/s at a height of 500m. Ignoring air resistance;

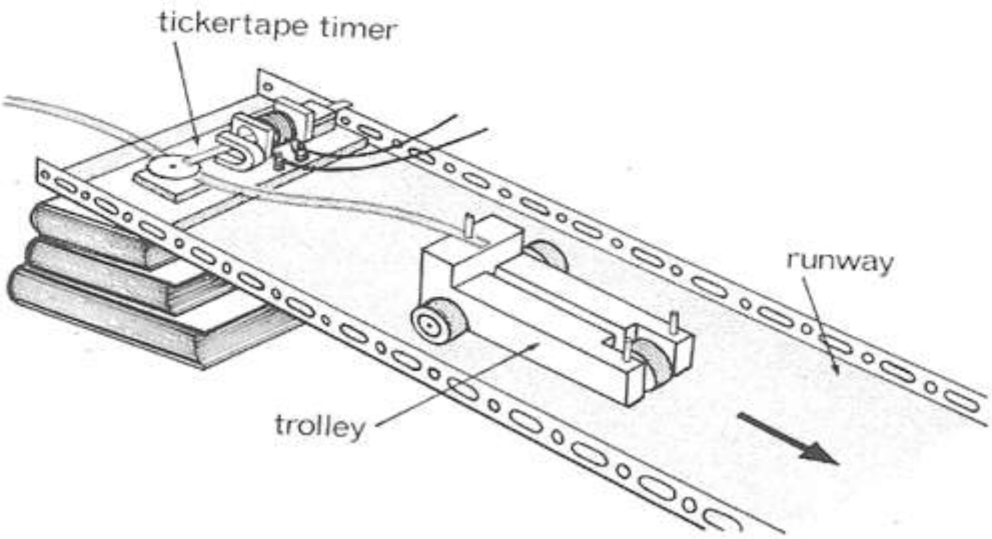
a) How long does it take the object to reach the ground?
b) Find the horizontal distance covered by the object leaving the air craft and reaching the ground.

TICKER – TAPE TIMER

A ticker timer is a steel strip which vibrates rapidly and print dots on a length of a paper tape pulled through it. It prints 50 dots on a tape every second (frequency, f = 50Hz)

A ticker timer is used to measure speed or velocity and acceleration of bodies in motion.

Experiment with a ticker – timer

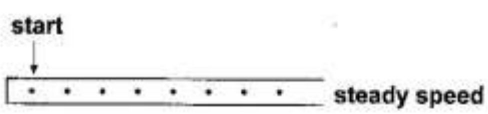


The paper tape is pulled by a trolley moving down an inclined plane as shown above.

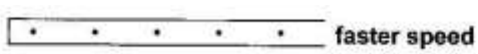
Different results are obtained on the speed of the trolley.

Typical results

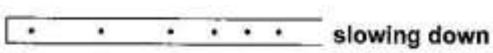
- Trolley moving with uniform speed, spacing between successive dots is the same throughout.



- The trolley is accelerating, the spacing between dots gets bigger and bigger.

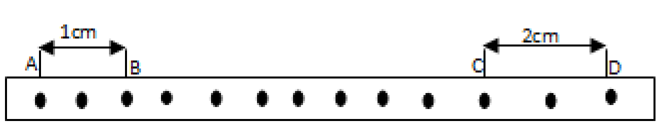


- Trolley decelerating, the spacing between successive dots gets smaller and smaller.



Example

1. The paper tape shown below was made by a trolley moving with uniform acceleration. if the ticker timer operated with a frequency of 100Hz, determine
   i) Initial velocity
   ii) Final velocity
   iii) Acceleration.



i) t = = time taken to print successive dots, where n is the number of spaces between dots.

Number of spaces between AB = 2

Time taken a long AB = = 0.02s

Initial velocity or speed u = = = 0.5m/s

Number of spaces between CD = 2

Time taken a long CD = =0.02

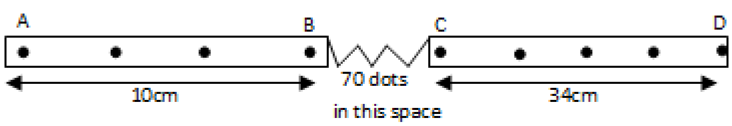
Final velocity / speed = = = v =1m/s

ii) Acceleration a = where t is time taken from B to D, Hence

=

= $5m/s^2$

2. Below is a tape by a ticker – timer of frequency 50Hz



Calculate

i) Initial velocity

ii) Final velocity

iii) The acceleration of the trolley

Solution

i) Initial velocity

Time taken along AB = = 0.06s

Initial velocity or speed u = = = 1.67m/s

ii) Time taken long CD= = 0.08s

Final velocity/ speed = = =4.25m/s

iii) Acceleration a = where t is time taken from B to D

= t= =1 .46s

= $1.77m/s^2$

Note

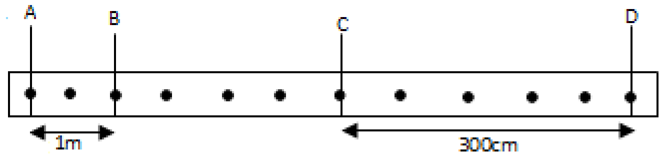
Usually, the first and last sections of the tape are ignored in experiments because the motion of the trolley is unsteady and the dots are near each other.

3. The ticker timer below printed dots. Assuming it vibrates at frequency of 20Hz, calculate

i) Initial velocity

ii) Final velocity.

iii) Acceleration



Solution

i) Time taken along AB = = 0.1s

Initial velocity or speed = = =10m/s

ii) Time taken a long CD = =0.25s

Final velocity or speed = = = 12m/s

iii) Acceleration a = where t is time taken from B to D i.e. t = = 0.45m/s

a = = 4.5m/s

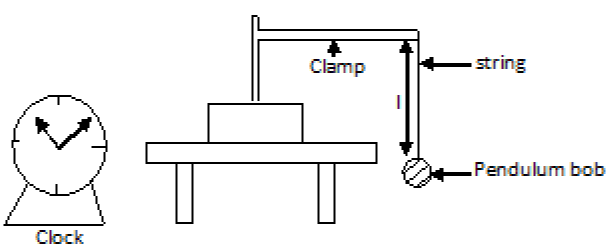
ACCELERATION DUE TO GRAVITY

Acceleration due to gravity is the rate of change of velocity with time of a freely falling object.

Experiment to determine acceleration due to gravity

Using a simple pendulum

The apparatus is arranged as below.



Measure and record the length, l of the pendulum

Displace the bob slightly and let it oscillate freely

Determine the time for 20 oscillations and calculate the period T

Repeat the procedure for various values of l

Record your results in a suitable table including T^2

Plot a graph of l against T^2

Obtain acceleration due to gravity from:

$g = -4\pi^2 S$ where S is the slope of the graph.

NEWTON'S LAWS OF MOTION

1^{ST} law of motion (law of inertia)

It states that a body continues in its state of rest oruniform motion in a straight line, unless acted upon by an external force.

This law suggests that everybody has inertia.

INERTIA

Inertia is the tendency of the body to remain at rest or if moving, to continue in its motion in a straight line with uniform velocity

The larger the mass of the body, the greater is its inertia, therefore the mass of the body is a measure of its inertia.

2^{nd} law of motion

It states that the rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction of the force.

Momentum of a body is the product of its mass and velocity i.e momentum = mass x velocity

S .I unit is kg m/s or kg ms^{-1}

Change in momentum = = where – final momentum and

– initial momentum

Applied force F

Where k is constant of proportionality.

From the definition of a Newton which is a force which gives a mass of 1kg an acceleration of $1m/s^2$.

If F = 1N, m = 1kg, a = $1m/s^2$

Example;

1. A 20 kg mass travelling at 5m/s is accelerating to 8m/s in 10s. calculate

i) The change in momentum.
ii) The rate of change in momentum
iii) The applied force

Change in momentum =
=
=

i) Rate of change of momentum =
ii) Applied force = rate of change of momentum
= 6N

2. A body of mass 600g moving at 10m/s is accelerated uniformly at 2m/s for 4s. Calculate the;
i) Change in momentum
ii) Rate of change in momentum
iii) The force acting on a body.

i)

Change in momentum

Change in momentum =

=

i) Rate of change in momentum.
=
=
= 1.2N

ii) The force acting on a body = rate of change of momentum
= 1.2N

3rd law of motion

It states that action and reaction are equal but opposite.

This means that whenever force acts on a body, an equal and opposite force act on the same body. Examples include:

i) A person walking exerts his weight (action) on the ground and the ground exerts an equal upward force (reaction) on him or her
ii) Two cars which collide both get damaged because each car exerts equal but opposite force

Example

1. A one turn car travelling at 20 m/s is accelerated at 2ms^{-2} for 5 seconds. Calculate the
   i) Change in momentum
   ii) The rate of change of momentum
   iii) Accelerating force acting on a body

i) Change in momentum =

=

ii) The rate of change of momentum =

=

= 2000N

iii) Accelerating force acting on the body = rate of change of momentum

= 2000N

Question

1. A block of mass 500g is pulled from rest on a horizontal frictionless bench by a steady force (F) and travels 8m in 2 seconds

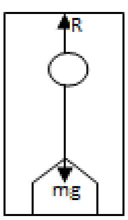
Find

(a) Acceleration

(b) Value of F

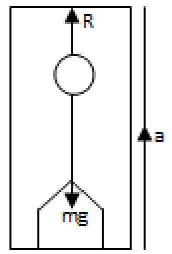
MOTION OF A BODY IN A LIFT

a) Lift at rest



R – Reaction of a body
Mg – person's weight
When the lift is at rest, a person feels his / her normal weight using

b) Lift ascending (moving upwards)



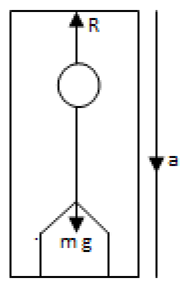
$R - mg = ma$

$R = mg + ma$

$R = m (g + a)$

The person feels heavier than his normal weight.

c) Lift descending (moving down wards)



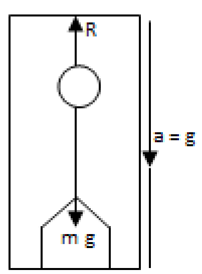
$mg - R = ma$

$R = mg - ma$

$R = m(g - a)$

The person feels loss in weight

d) Lift descending with acceleration a = g



$mg - R = ma$

$R = mg - mg$

$R = m(g - g)$

$R = 0N$

Some one feels weightless.

1. Find the reaction on a woman of mass 70 kg standing in a lift if the lift is
   (a) at rest
   (b) ascending upwards with uniform acceleration of $4m/s^2$
   (c) moving down wards with uniform acceleration of $4m/s^2$

Solution

a) $R = mg$

$= 70 \times 10$

$= 700N$

b) $R - mg = ma$

$R = ma + mg$

$= m(a + g)$

$= 70(4 + 10)$

$= 980N$

c) $mg - R = mg$

$R = mg - mg$

$R = m(g - g)$

$= 70(10 - 10)$

$= 0N$

d) $R = m(g - a)$

$= 70(10 - 4)$

$= 420N$

COLLISION AND LINEAR MOMENTUM

Linear momentum is the product of mass and velocity for bodies moving in a straight line. S.I unit is kgm/s

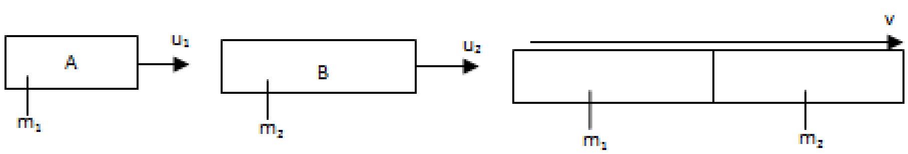
Collision

There are two types of collision

i) Inelastic collision
ii) Elastic collision

INELASTIC COLLISION

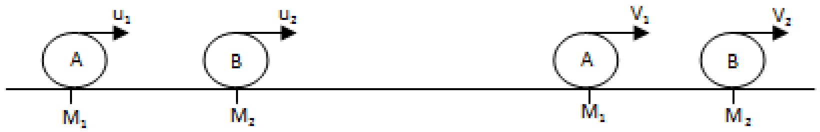
This is a type of collision where colliding bodies stick together and move with the same velocity after collision e.g. a bullet shot at a thief



$m_1 u_1 + m_2 u_2 = (m_1 + m_2) v$

ELASTIC COLLISION

This is a type of collision where colliding bodies separate after collision and move with independent velocities



$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ where u_1 and u_2 are initial velocities v_1 and v_2 are final velocities

PRINCIPLE OF CONSERVATION OF LINEAR MOMENTUM

It states that when two or more bodies collide, the total momentum of the bodies remains constant provided no external forces act i.e.
Total momentum before collision = total momentum after collision

Example

1. A body of mass 2kg travelling at 8m/s collides with a body of mass 3kg travelling at 5m/s in the same direction. If after collision the two bodies move together. Calculate the velocity with which the two bodies move.

By principal of conservation of linear momentum

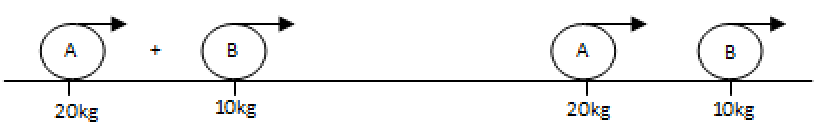
Total momentum before collision= total momentum after collision

$M_1u_1 + m_2u_2 = (m_1+m_2)v$

$2 \times 8 + 3 \times 5 = (2 + 3)v$

$v = 6.2m/s$

2. A body of mass 20 kg travelling at 5m/s collides with another stationary body with a mass of 10kg and they move separately in the same direction. If the velocity of the 20 kg mass after collision was 3m/s, calculate the velocity with which 10kg mass will move.



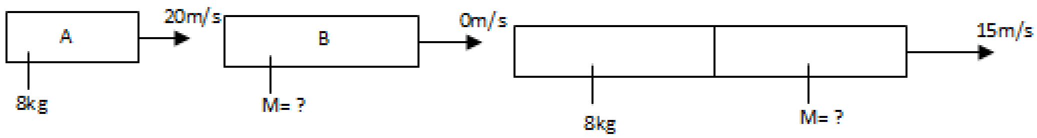
Total momentum before collision = Total momentum after collision

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

$20 \times 5 + 10 \times 0 = 20 \times 3 + 10v_2$

$v_2 = 4m/s$

3. A body of mass 8kg travelling at 20m/s collides with a stationary object and they move together with a velocity of 15m/s. Calculate the mass of the stationary body.



$m_1u_1+m_2u_2 = (m_1+m_2)v$

$8 \times 20 + 0 = (8 + M)v$

$M = 2.7kg$

EXPLOSION

Momentum is conserved in explosions such as that which occurs when a rifle is fired. Before firing, the total momentum is zero since both rifle and bullet are at rest.

During firing, the riffle and the bullet receive equal but opposite momentum, so the total momentum after firing is zero

$M_f V_f + M_b V_b = 0$

$M_b V_b = -M_f V_f$ where M_b –mass of bullet

M_f – mass of riffle

V_b- velocity of bullet

V_f – recoil velocity of the riffle

Recoil velocity

When the bullet leaves the barrel, the total momentum must be conserved. Therefore the bullet moves forward, the gun jacks backwards (recoils) with a velocity called recoil velocity.

Example

1. A bullet of mass 50g is fired with a velocity of 400m/s from a gun of 5kg. Calculate the recoil velocity of a gun.

   $M_g v_g + m_b v_b = 0$

   $V_g = -4m/s$ (negative means opposite direction)

2. A 50kg girl jumps out of a rowing boat of mass 300kg to the bank with a horizontal velocity of 3m/s. With what velocity does the boat begin to move backwards

   $M_g v_g + m_b v_b = 0$
   $300 \times v_g + 50 \times 3 = 0$
   $V_g = -0.5m/s$

Question

1. (a) Outline the similarities and the differences between elastic and inelastic collisions

b) Fatimah of mass 60kg running at 64 km/hr jumps on a stationary trolley of mass 20kg. If the collision is perfectly inelastic, Find

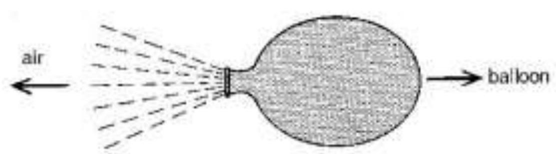
i) Loss in kinetic energy

ii) Final kinetic energy

APPLICATION OF NEWTON'S 3RD LAW OF MOTION AND CONSERVATION OF MOMENTUM

i) Inflated balloon

When a balloon filled with air is released in space so that the air can escape from the balloon. The balloon darts forward in space until all the air has escaped.



Explanation

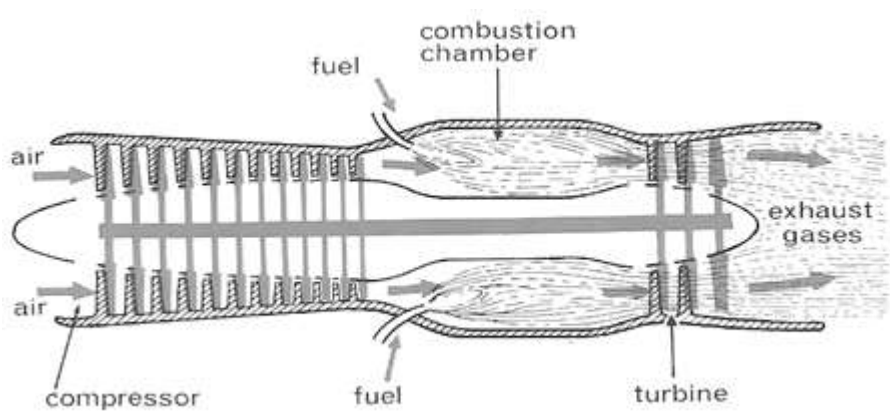
As air escapes from the balloon at a high speed backwards, it does so with a big force. According to Newton's law of motion, the air exerts a reaction on the balloon causing it to move forward with the same force.
From the principle of conservation of momentum, a backward momentum due to the air escaping sets up equal but opposite forward momentum, on the balloon causing it to move forward.

ii) Rocket and jet engines.

Jet engine

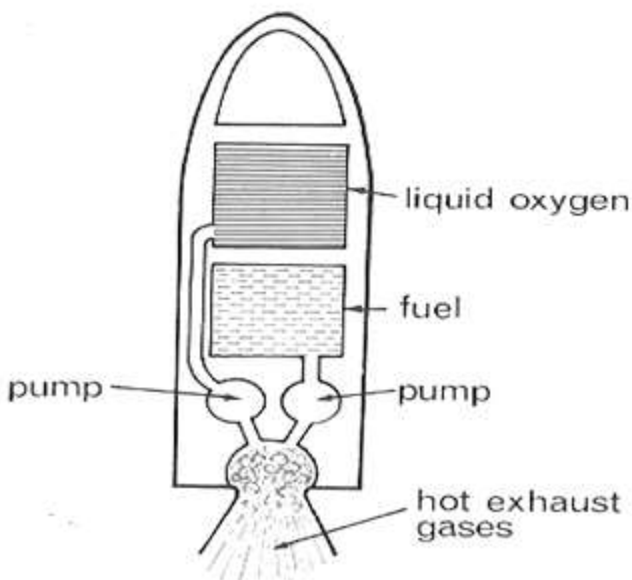
To start the engine, an electric motor sets the compressor to rotate. The compressor is like a fan; its blades draw in and compress air at the front of the engine. Compression raises the temperature of the air before it reaches the combustion chamber.

Fuel (kerosene) is injected and burns to produce a high speed stream of hot gas which escapes from the rear of the engine, as a result, the gaseous product set a reaction of equal but opposite momentum to the plane making it propel forward.



Rocket engine

Rockets, like jet engines, obtain their thrust from the hot gases they inject by a fuel. They can however, where there is no air since they can carry the oxygen needed for burning instead of taking it from the atmosphere as does the jet engine. Space rockets use liquid oxygen (at -183^oC). Common fuels are kerosene and liquid hydrogen (at -253^oC), but solid fuels are also used.



Differences between a rocket and jet engine

A jet engine doesn't go outside atmosphere because it uses atmospheric oxygen to burn its fuel while, a rocket engine goes out of atmosphere since it burns fuel when it is in space because it can be loaded with liquid oxygen cylinders.

ARCHIMEDES AND FLOATATION

ARCHIMEDE'S PRINCIPAL

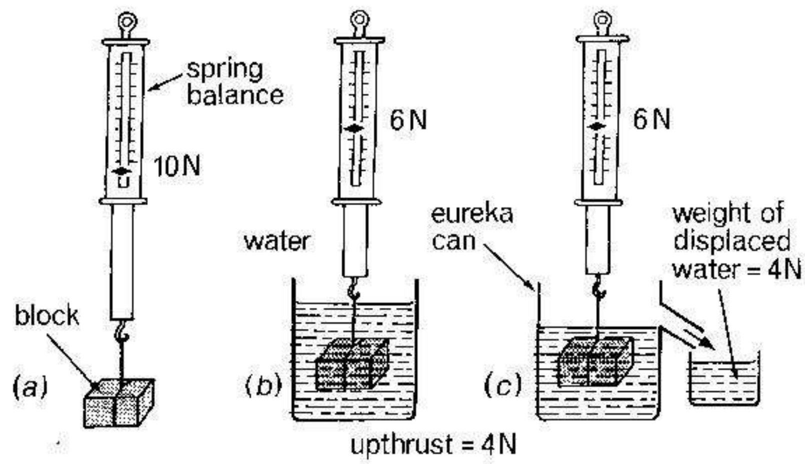
Up thrust

It is an upward force due to the fluid resisting being compressed. When any object is immersed or submerged into a fluid, its weight appears to have been reduced because it experiences an up thrust from the fluid.

Statement of Archimedes's principal

It states that when a body is wholly or partially immersed in a fluid, it experiences an up thrust equal to the weight of the fluid displaced
i.e up thrust = weight of fluid displaced

Experiment to verify Archimedes's principal



An object is weighed in air using a spring balance to obtain its weight w_1

The eureka can is completely filled with the liquid and a beaker is put under its spout

The body is then immersed in the liquid

The new weight w_2 is also read from the spring balance

The liquid collected in the small beaker is weighed to determine its weight w_3.

It is found that $w_3 = w_1 - w_2$

The weight of the body when completely immersed or submerged is called the apparent weight. The apparent weight is less than the weight of the body because when the body is immersed it experiences an up thrust

Example

1. A glass block weighs 25N. When wholly immersed in water, the block appears to weigh 15N, calculate the up thrust.
   Upthrust = weight in air – weight in a fluid (apparent weight)
   $= W_a - W_f$
   $= 25 - 15$
   $= 10N$
2. A body weighs 1N in air and 0.3N when wholly immersed in water. Calculate the weight of water displaced

   Up thrust $= W_b - W_f$

   $= 1 - 2.8$
   $= 0.2N.$

For a body completely immersed

Volume of the body immersed = volume of displaced fluid

$M = \rho \times v$

where ρ – density of displaced fluid

Volume of body, V = volume of displaced fluid

But

Up thrust = weight of fluid displaced

= mg

U = ρvg

Example

A metal weights 20N in air and 15N when fully immersed in water. Calculate

a) Up thrust.
b) Weight of displaced water
c) Volume of displaced water (density = 1000kg/m^2)
d) Volume of metal
e) Density of metal.

a) Up thrust = weight in air – weight in water
   = 20N – 15N
   = 5N
b) Weight of displaced water = up thrust
   = 5N
c) Volume of displaced water
   Upthrust = weight of displaced water
   5 = ρ v g
   S = 1000 × V × 10
   V =

   V = 0.0005 m^3

d) Volume of metal = volume of displaced water
   = 0.0005m^3

e) Density of metal =
   =
   = 4000kgm^{-3}

Application of Archimedes's principal

1. Measurement of relative density of solids
2. Measurement of relative density of a liquid

Measurement of relative density of a solid

- Weigh the object in air and note it to be W_a
- Weigh the object in water and note it to be W_w
- Determine the upthrust U = $W_a - W_w$

- Relative density of solid

EXAMPLE

1. An object weighs 5.6 N in air and 4.8N in water, find its relative density

=

= 7

2. An object of relative density 7 and weight 70N in air. What is its weight in water?

W_w = 60N

3. An object of relative density 9 weighs 40N in water find its weight in air.

W_a = 45N

Determination of RD of a liquid

- Weigh the object to find its weight in air W_a using a spring balance
- Weigh the object in the liquid whose RD is to be determined, label it W_l
- Weigh the object in water, call it W_w
- Find the up thrust in liquid = $W_a - W_l$
- Find the up thrust in water = $W_a - W_w$
- Obtain RD of a liquid from RD =

RD =

Example

1. An object weighs 5.6N in air, 4.8N in water and 4.6N when immersed in a liquid. Find the R.D of the liquid

=

=

2. An object weighs 100N in air and 20N in a liquid of RD 0.8. Find its weight in water.

$W_w = 0N$

FLOATING OBJECTS

There are two vertical forces which act on an object when immersed in water, Weight W and up thrust U

If W is less than U, the object rises

If W is equal to up thrust U object floats

If W is greater than up thrust U object sinks

Therefore floating objects weigh equal to up thrust. From Archimedes principal, up thrust is equal to weight of a fluid displaced. Therefore for floating objects, weight of objects should be equal to weight of fluid displaced.

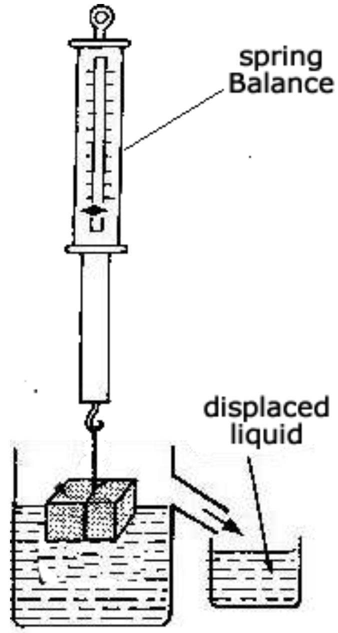
Law of floatation

It states that a floating object displaces its own weight of the fluid in which it floats

Experiment to verify law of floatation

Method

- Weigh the object in air and note its weight W_a
- Fill the overflow can until water just overflows from the spout
- Place an empty measuring cylinder under the spout after dripping of water has stopped
- Gently lower the object into the overflow can and collect the displaced water
- Weigh the displaced water



- It is found out that weight of water displaced = weight of object W_a

Application of law of floatation

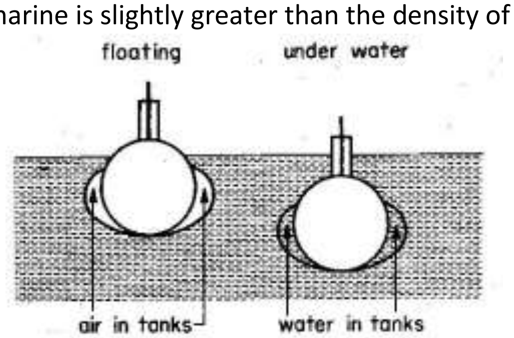
1. Ship

A ship floats when the up thrust of the water it displaces equals its weight

i.e. Weight of floating ship =weight of water displaced

While a ship is being loaded, it sinks lower and displaces more water to balance the extra load
While steel does not float, steel ship floats. This is because steel ship is hollow and most of its parts contain air, hence its average density is less than the density of water. Therefore hollow steel displaces many times its volume of water

2. Submarines
A submarine has ballast tanks which can be filled with water or air. When full of water, the average density of the submarine is slightly greater than the density of sea water and it sinks



When air is pumped into the tanks, the average density of the submarine falls until it's the same or slightly less than that of water around it. The submarine therefore stays at one depth or rises to the surface

Balloons and airships
A balloon is an airtight, light bag with hydrogen or helium. These gases are less dense than air. An airship is a large balloon with a motor to move it and fins to steer it.

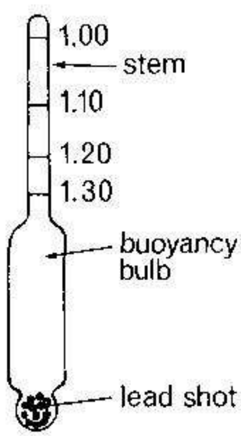
The down ward force on the balloon equals to the weight of the bag plus the weight of gas in it.
The balloon rises if the up thrust is greater than the downward force
The lifting force= up thrust –total weight

= weight of air displaced –weight of bag + weight of gas

Balloons that carry passengers control their weight by dropping ballast to make them rise and by letting gas out of the gas bag to make them fall. As the balloon rises, the atmospheric pressure on it becomes less. The gas in the balloon tends to expand. Therefore the gas bag must not be filled completely when the balloon is on the ground.

4. Hydrometers

A hydrometer is a floating object used to find the density of liquids by noting how far it sinks in them.



No weighing is necessary. It consists of a longer glass tube with a bulb at the bottom. Mercury or lead is in the bulb so that the hydrometer floats up right. The stem is long and thin and is graduated. The thin stem means that the hydrometer is sensitive i.e. it sinks to different levels even in two liquids whose densities are almost the same.

Uses of a hydrometer

It is used for measuring the densities of milk (lactometer), beer, wines, acids in car batteries(the acid in a fully charged accumulator should have a density of 1.25g/cm^3, if it falls below 1.18, the accumulator needs recharging).

Experiment to measure density of a liquid using the hydrometer

Mark a simple hydrometer in cm beginning at the end that sinks

Place it in a tall jar of water

Mark the level to which it sinks

Measure the length that was in the water

Remove the hydrometer, dry it and place it in a jar of another liquid. A gain measure the depth to which it sinks

Obtain density of liquid =

Worked out examples

1. The mass of a piece of cork ($0.25 g/cm^3$) is 20g. What fraction of the cork is immersed when it floats in water?

Solution

Mass of cork = Mass of water displaced

$= \rho v$

$20 = 1 \times v$ volume of water displaced $=20 cm^3$ =volume of cork immersed

But volume of cork = = = $80 cm^3$

Fraction of cork immersed = = ¼

2. A solid of volume $1 \times 10^{-4} m^3$ floats on water of density $1 \times 10^3 kgm^{-3}$ with of its volume submerged. Find
   i) The mass of solid
   ii) The density of solid

   Solution

i) Mass of the solid = mass of liquid displaced

$= v \times \rho$

$= \times 10^{-4} \times 1 \times 10^3$

$= 0.06 kg$

ii) Fraction of the body immersed=

=

Density of the body =

$= 600 kgm^3$

3. A rubber balloon of mass $5 \times 10^{-3} kg$ is inflated with hydrogen and held stationary by means of a string. If the volume of the inflated balloon is 5×10^{-3}, calculate the tension in the string (density of hydrogen = $0.8 m^3$) (density of air=$1.15 kgm^3$)

Solution

Up thrust U = weight of fluid displaced

$= \rho_a vg$

$=1.15 \times 5 \times 10^{-3} \times 10$

$= 0.0575 N$

Weight of balloon fabric = mg

$= 5 \times 10^{-3} \times 10$

$= 0.05 N$

Weight of hydrogen = $\rho_h v g = 0.08 \times 5 \times 10^{-3} \times 10 = 0.004 N$

Total weight of balloon W =0.05 + 0.004

= 0.54N

Tension T = U – W

= 0.0575 – 0.054

= 0.0035N

4. A body of mass 2kg is suspended from a spring which reads 17N when is completely submerged in water;
   i) What is the up thrust of the water in the body
   ii) What is the mass of water displaced by the body
   iii) If the density of water is $1000kg/m^3$, what is the volume of water displaced?
   iv) Calculate the density of the material of which the body is made.

$W_a = mg$

$= 2 \times 10$ and $U = W_a - W_w = 20 - 17$

$= 20N$ $= 3N$

i) Up thrust = weight of fluid displaced

= 3N

W = mg

3 = m x10 hence m = = 0.3 kg

ii) Up thrust = weight of fluid displaced

$U = \rho\, v\, g$

3 = 1000 x v x 10

V =

$= 3.0 \times 10^{-4} m^3$

iii) Density =

=

$= 6.7 \times 10^3\ kg/m^3$

5. When a metal is completely immersed in liquid A its apparent weight is 5N. When immersed in another liquid B the apparent weight is 16N. If the density of B is times that of A calculate the mass of the metal.

Solution

(i) Up thrust in A

$U_1 = W_a - W_A$

$U_1 = (W_a - 20)$

Up thrust in B

$U_2 = W_a - W_B$

$= (W_a - 16)$

Up thrust = weight of fluid displaced

U = weight of fluid displaced

$W_a - 20 = \rho_A Vg$ …….. (i) $W_a - 16 = \rho_A Vg$………..(ii)

Divide (i) by (ii)

=

$8(w_a - 16) = 9(w_a - 20)$

$w_a = 52N$

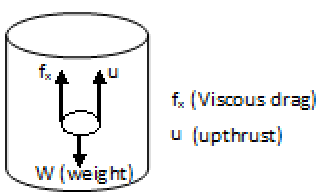
Mass of solid = =

= 5.2kg

Motion of a body through fluids

When a body falls through a fluid, it is acted on by forces namely

a) Weight of the body
b) Viscous force
c) Up thrust



The weight of the body acts downwards towards the earth. Up thrust acts upwards and viscous force acts in the direction opposite to body's motion

As the body falls, it accelerates first with net resultant force

$F = w - (f_x + u)$

As the body continues to fall, it attains a uniform velocity called terminal velocity, when the weight of the body $w = f_x + u$

At this stage, the resultant force or net force on the body is zero

Terminal velocity

This is a constant or uniform velocity with which a body falling through a fluid moves such that the upward forces acting on it are equal to its weight

OR

Is the uniform velocity attained by a body falling through a fluid when the net force on the body is zero.
Incase of a balloon or a rain drop falling, the resisting force or retarding force on the body is called air resistance