PRESSURE (UCE)

Pressure is defined as force acting normally per unit area.

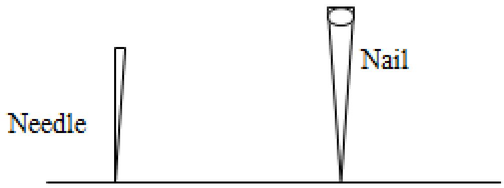
SI unit is Nm^{-2} or Newton per square metre or Pascal.

$P = \frac{Force}{Area}$ Note: $1Nm^{-2} = 1pa$

Other units: Kilo Pascal (Kpa) or Kilo Newton per metre squared (KNm^{-2})

Note: 1Kpa =1000pa and $1KNm^{-2} = 1000Nm^{-2}$

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 end of the needle and nail

One tends to feel more pain from the needle than the nail.

This is because surface area of contact of the top of the needle is smaller therefore the pressure is high.

The increase in pressure when the surface area of contact is decreased explains why the 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

P = $\frac{Force}{Area}$ and Area = $\frac{40}{10,000}$ = 0.004 m^2

$= \frac{200}{0.004}$ = 50,000N/m^2

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

Force = pressure xarea

= 200 x 0.0005 = 0.1N m^{-2}

3. A block of metal produces an average pressure of 1000 NM^{-2} when resting on a flat surface of area $0.5m^2$. calculate the force exerted on the surface.

Solution

Given P = 1000 NM^{-2} , and area (A) = $0.5\,m^2$

Using $P=\frac{F}{A} \gg> F=PA=1000\,x\,0.5=500\,N$

Minimum and maximum pressure;

Pressure is always minimum (smallest) the area largest

Pressure is always maximum (largest) when the area is smallest.

Therefore minimum pressure = $\frac{Force}{maximum\,area}$

Pressure (maximum) = $\frac{Force}{minimum\,area}$

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.

Maximum area = 5 x 2 = 10 m^2

Minimum pressure. = $\frac{Force}{maximum\,area}$ = $\frac{60}{10}$ = 60N/m^2

Minimum.Area = 2 x 1 = 2m^2

Maximum pressure = $\frac{Force}{minimum\,area}$ = $\frac{60}{2}$ = 30N/m^2

2. A box of dimension of 6m x 2m x 4m is exerted on the floor by a force of 400N.Determine its density.

Maximum pressure;

Minimumarea = 4 x 2 = 8m^2

Maximum pressure = $\frac{Force}{min}$ = $\frac{400}{6}$ 400/8 = 50N/m^2

2m

Maximum area = 6 x 4 = 24m^2

.minimum pressure = $\frac{Force}{Area}$ =400/24 = 16.67Nm^{-2}

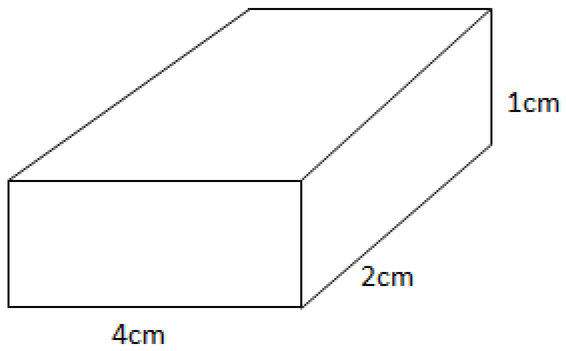
6m

Density

4m

V = L x W x H = 6 x 2 x 4 = 48m^3 ρ ¿ $\frac{m}{v}$ =40/48 = 0.833kg/m^3

2. Find the greatest and minimum pressure in the cuboids below given that it has a mass of 48kg.

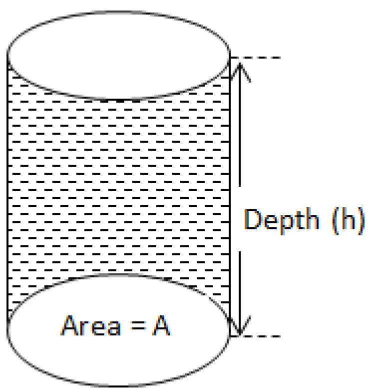


Trial problems

1. A cuboids has dimensions of 0.2m x 0.4m x 6cm and a force of 12N is exerted. Determine the maximum and minimum pressure it exerts on its support. $\left(ans\ P_{max}=1500\ pa\ , P_{min}=50\ pa\right)$
2. A rectangular solid measures 5cm x 4cm x 3cm. if the mass of the solid is 250kg, Dwtwrmine the minimum and maximum pressure it exerts on its supports. $\left(ans\ P_{max}=2.083\,x\,10^{6}\ pa\ , P_{min}=1.25\,x\,10^{4}\ pa\right)$

PRESSURE IN LIQUIDS

Consider a column of liquid of density $\rho \in kgm^{-3}$ contained in a cylinder of area A in m^2 at a depth h in metres as shown below;



The volume occupied by the surface of a liquid is $V=Ah\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(i)$

From $\rho=\frac{m}{V} \gg > m=\rho V=\rho Ah \ldots\ldots\ldots\ldots\ldots (ii)$

But pressure $, P=\frac{F}{A}=\frac{mg}{A}=\frac{\rho Ahg}{A}=\rho hg$

If follows that pressure is the same in all directions are depends on.

(i) Depth (h) of the liquid

(ii) Density (ρ) of the liquid

(iii) Pull of gravity, g

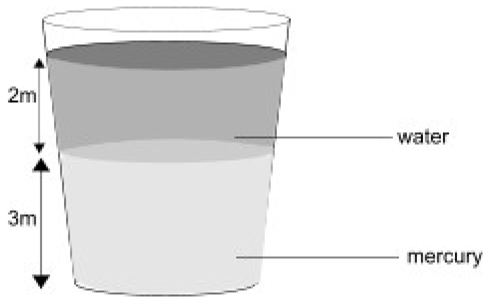
Example I

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.

Pressure p = hpg

$= \frac{400}{100}$ x 800 x 10 = 32,000Nm^{-2}

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.

Pressure due to water

P = h ρ g = 2m x 1000 x 10 = 20000Nm^{-2}

Pressure due to mercury = h ρ g = 3 x 13600 x 10 = 408000Nm^{-2}

Total Pressure = 408000 + 20000 = 428000Nm^{-2}

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

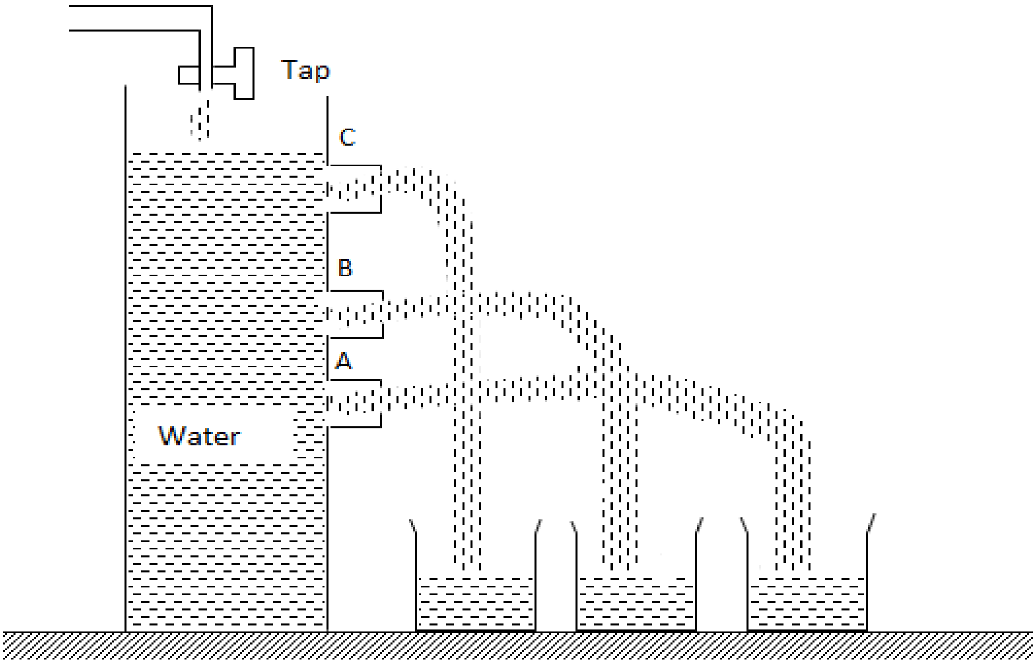
i) The pressure that mercury exerts on the vessel
P = hpg
= 2 x 13600 x 10 = 2720Nm-^{2}

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

$w = P \times A$ and $A = 50/10000\ m^2$

$$= 2720 \times \frac{5}{10000} = 1.36N$$

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



Use a long can with three equally sized holes A, B, C blocked by the corks at different depths h_1, h_2 and h_3 respectively as shown above. Where $h_1 > h_2 > h_3$

Water is filled in the can so that it just remains full and the three holes opened at once.The speed at which the water jets out of the holes is noted.

Observation;

The speed with which water spurts out is greatest for the lowest jet (A) than the rest (B and C). This is because the weight of the liquid above the last hole (A) is greater than that of the fist hole (B and C).

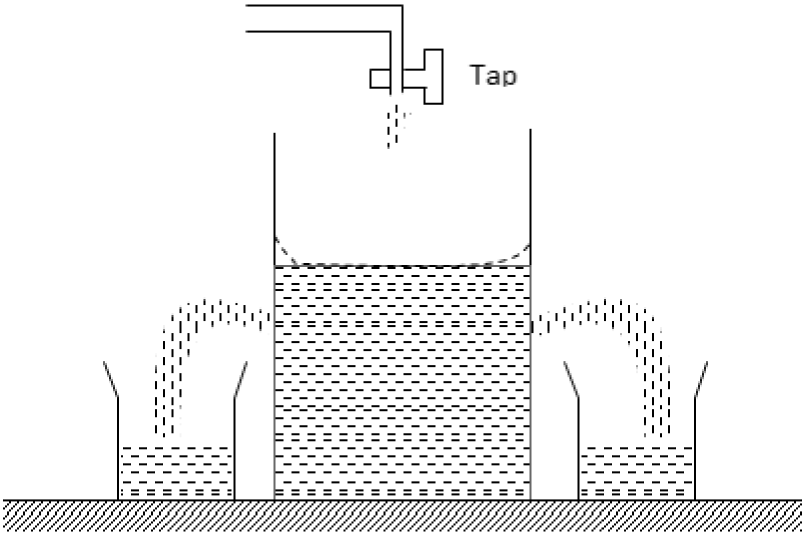
This shows that pressure increases with depth.

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 the same at the same depth, h

Method

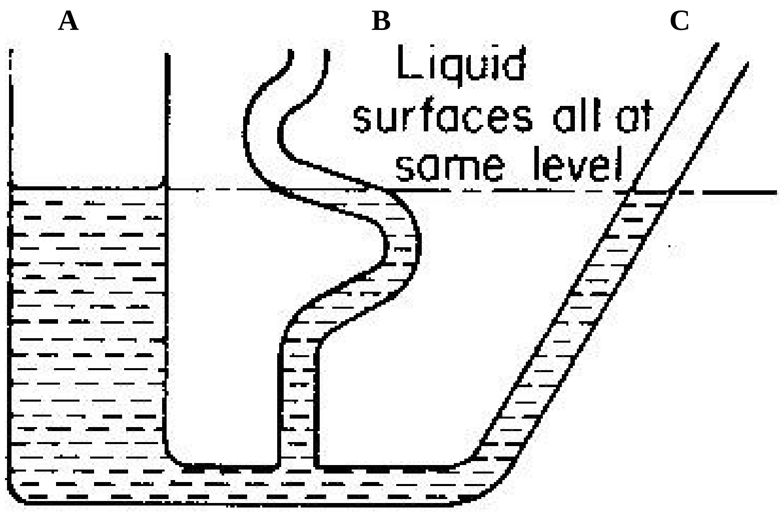
Pour water in the container and there after drill 2 holes in the can at the same level as shown below.



Observation

Water from the two holes travel the same distance implying that pressure is the same at the same depth, h.

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



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

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

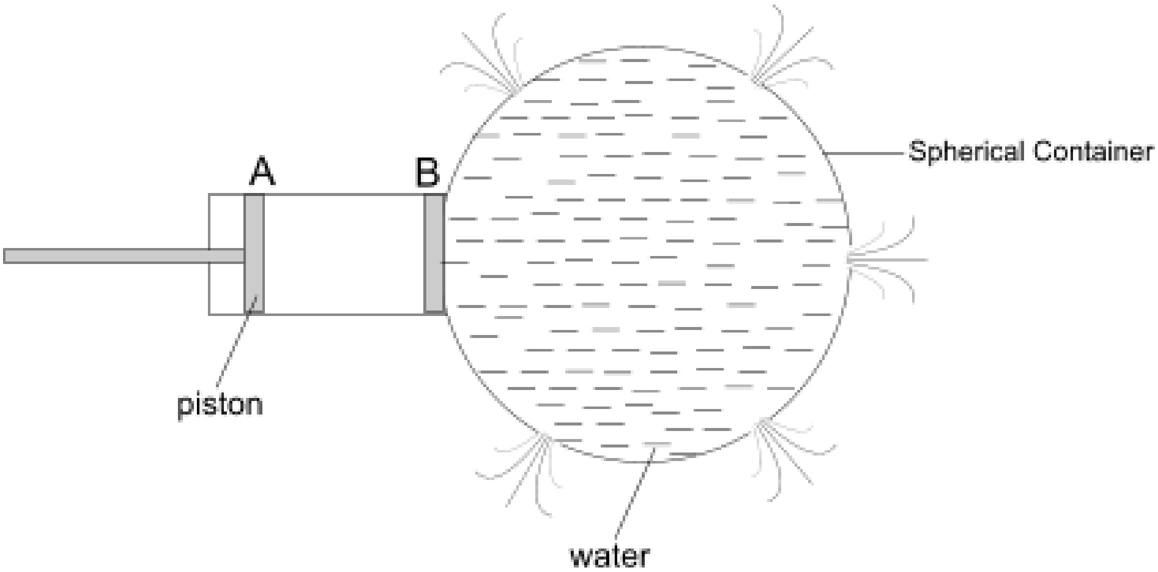
Since the tubes are of different cross sectional area and shape. It follow that pressure does not depend on shape and cross sectional area.

PRINCIPAL OF TRANSMISSION OF PRESSURE IN LIQUIDS

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

The principal states that "pressure at a point of an incompressible liquid is equally transmitted throughout the liquid in all directions. The principl 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. When 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 in all directions.

Summary;

Experiment above show that pressure in liquids;

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

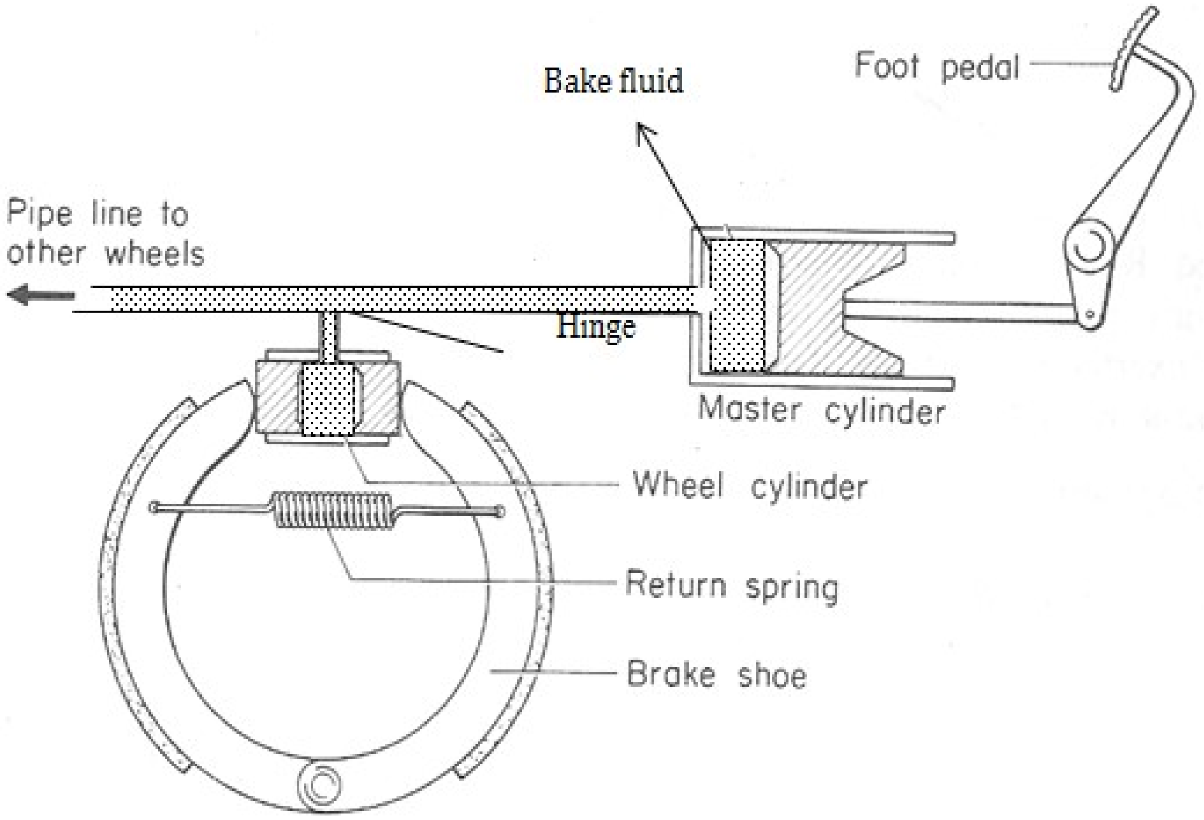
Application of the Pascal's principle:

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

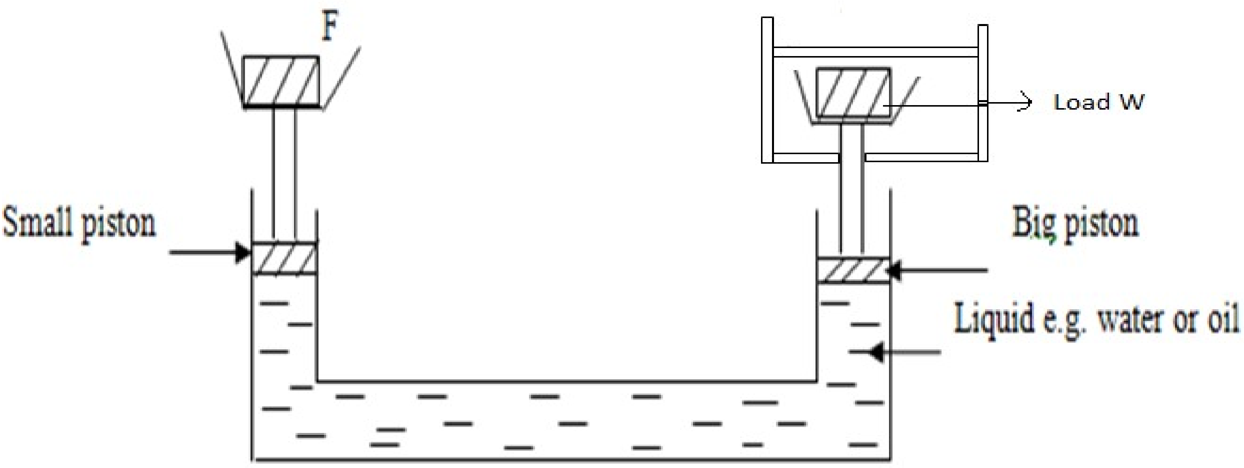


Mode of action:

- When a foot is applied on a foot pedal, the piston in the master cylinder exerts a force on the brake fluid.
- 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.

Note: pressure exerted on piston A (P_1) = pressure exerted on piston B (P_2)

>>> $P_1 = P_2$

>>> $$\boxed{\frac{F_1}{A_1} = \frac{F_2}{A_2}}$$

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.

Pressure at A, P = $\frac{Force}{Area}$ = $\frac{10}{2}$ = 5N/m^2

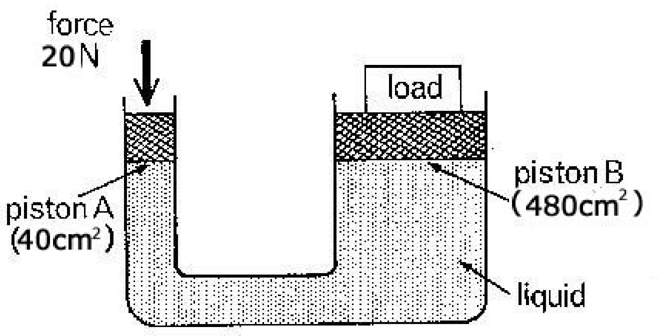
Pressure at A, = Pressure at B

$$5 = \frac{W}{150} \qquad \text{Therefore, Force W } = 5 \times 150 = 750\text{N}$$

Hence a small force of 10N applied on a big of 750N.

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

below:



Pressure at B, = pressure at A

=20/0.004

= 5000 Nm^{-2}

Weight W =pressure at B xpiston area B

=5000 x0.048

= 240N

Questions

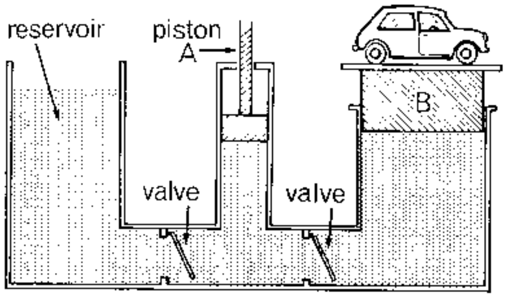
1. Calculate the weight W raised by a force of 56N applied on a small piston area of 14m^2.take the area of the large piston to be 42m^2.

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.

Applications / uses of the hydraulic press

1. It is used to compress materials such as waste paper and cotton into compact bales.
2. It is used to shape motor car bodies.
3. It is also used in the forging of steel armour plate and light alloys.

Hydraulic lift



This is commonly used in garages; it lifts cars so that repairs and service on them can be done easily under neath 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.

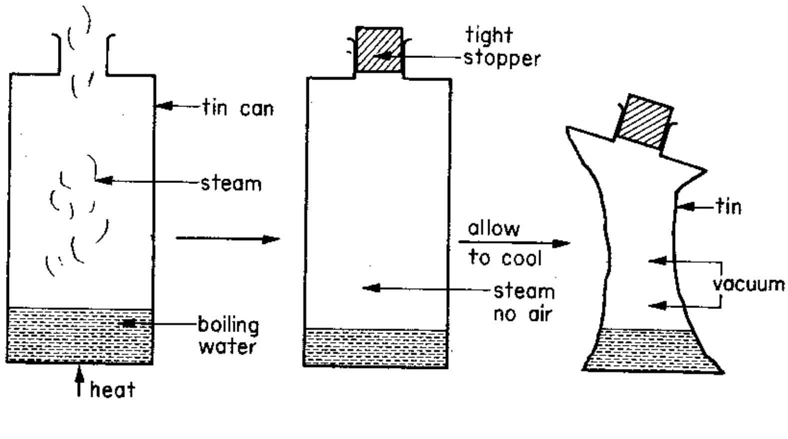
Atmospheric pressure is the pressure exerted by the weight of air on all objects on earth's surface.

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.

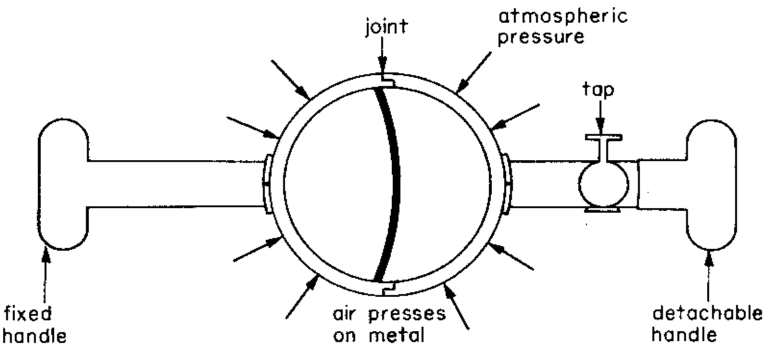
Experiment to demonstrate the existence of pressure;

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

b**. The Magdeburg’s hemisphere**



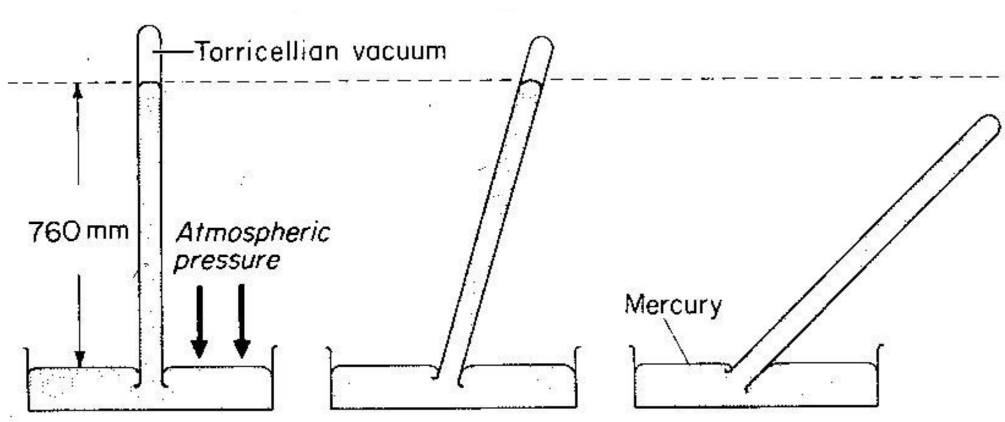
The hemisphere is made of two hollow bronze with a stop cork on onside. The rims are placed together with grease tightening between them to form an air tight joint. The air is pumped out and the stop cork closed. It becomes impossible for even eight horses to separate them. When air is re admitted in the sphere they are easily separable. This indicates the existence of atmosphere 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 filling completely a thick walled glass tube of about 1m long with mercury.

The tube should have uniform bore, the tube is tapped from time to time 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 cmHg.

The height “h” gives the atmospheric pressure 76cm Hg.The empty space created above the mercury in the tube vacuum called Torricellian vacuum.

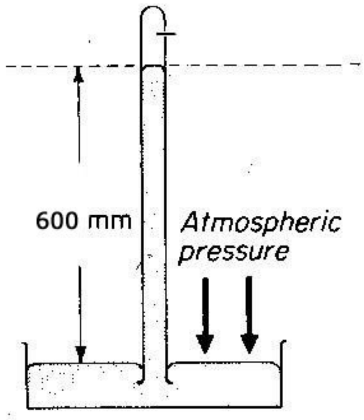
NB;The vertical height of the mercury will remain constant if the tube is lifted as in (2) provided the top of the tube is not less than 76cm above the level of mercury in the dish.

If it is fitted 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 = 600mmHg p = 60cmHg

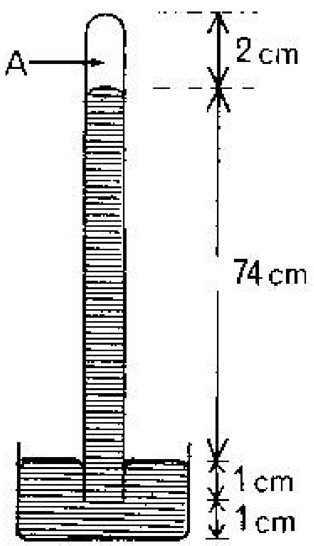
(ii) P = h ρ g

= 600mm x 13600 x 10

= $\frac{600}{100}$ x 13600 x 10

¿ 81600pa or 81600Nm^{-2}

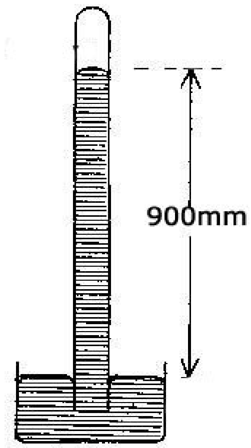
(b)



(i) h = 78– 4 = 76cmHg (ii) p = h ρ g = 0.76 x 13600 x10

=105, 53Nm^{-2}

(c)



(i) P=h=900mmhg= 90cmHg

ii) P= h ρ g = 0.9 x13600 x10

= 122400 Nm^{-2}

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

P= h ρ g

$= \frac{76}{100}$ x 13600 x 10 = 103360 Pascals

(ii) 540mmHg in pa

P = h ρ g $= \frac{540}{1000}$ x 13600 x 10 = 73440N/m^2

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

P = h ρ g $= \frac{76}{100}$ x 13600 x 10

= 103360 Nm^{-2}

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

P = h ρ g

103360 = h x 1000 x 10

h = 103360/ 1000 X 10

h = 1034m

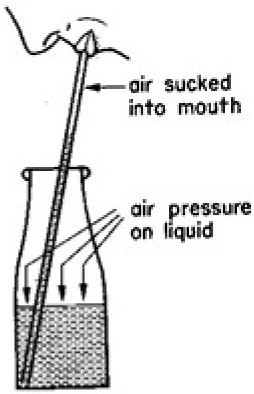
The answer to the question a above, explains why water is not used in a barometer because the column will be too long.

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

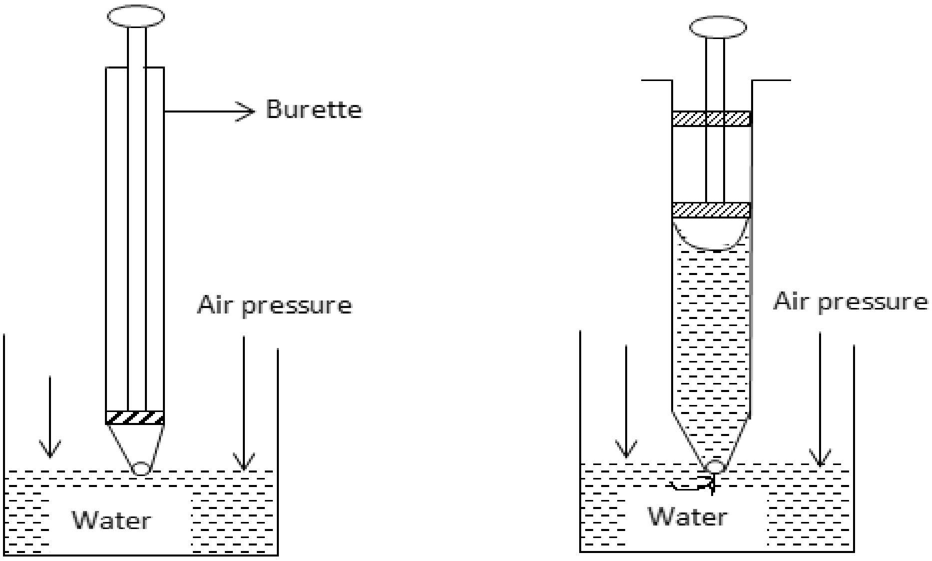
Drinking straw;



When using these, the air inside is sucked into the mouth, therefore the atmospheric pressure outside is greater than that inside and the liquid is pushed up by the atmosphere.

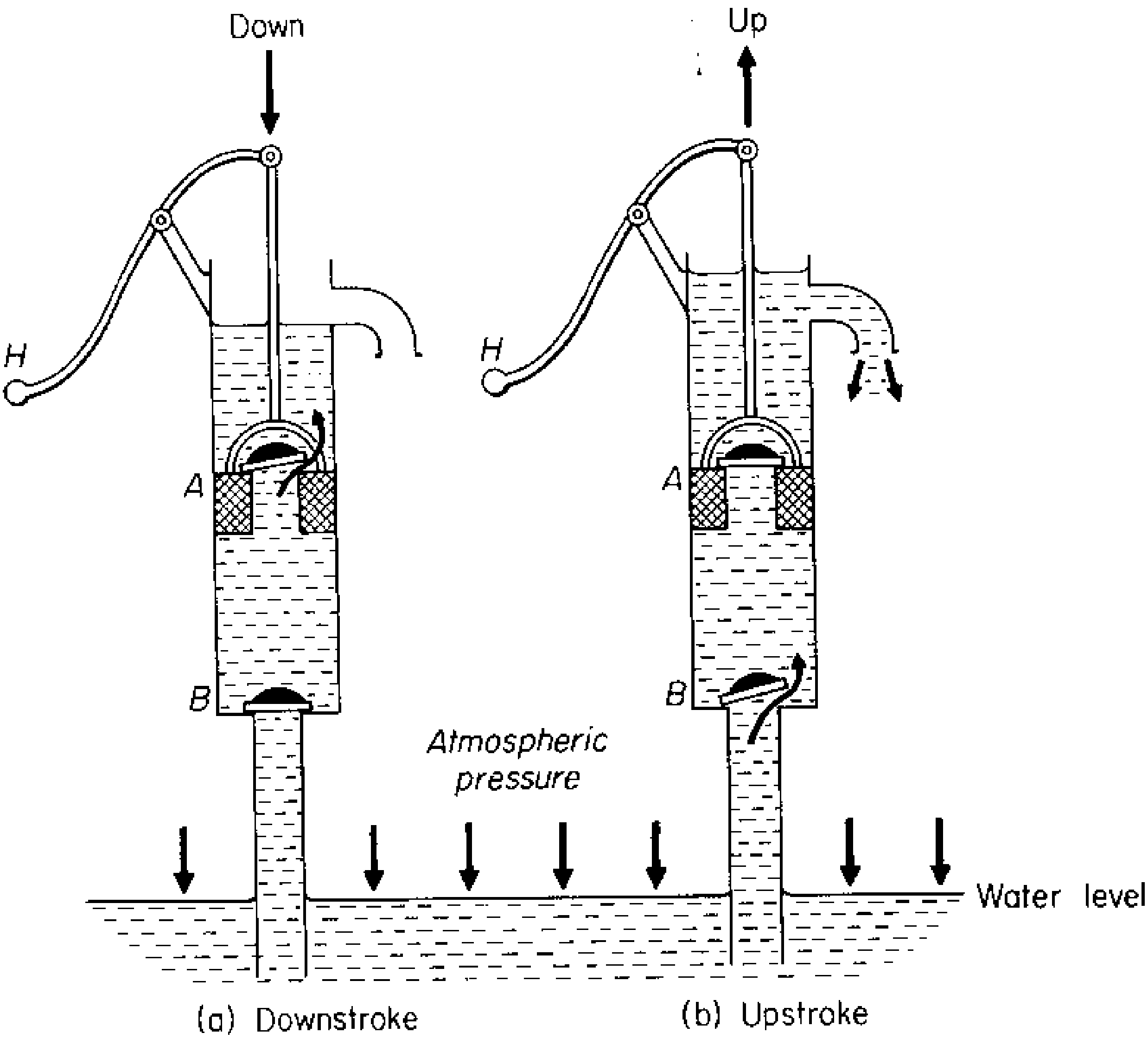
Syringe

This is a tube with a piston inside it. The piston is pushed right down to remove the air and place the end of the tube under a liquid, raise the piston, there is a partial vacuum under it and atmospheric pressure on the liquid forces some liquid into the syringe as shown below.



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;

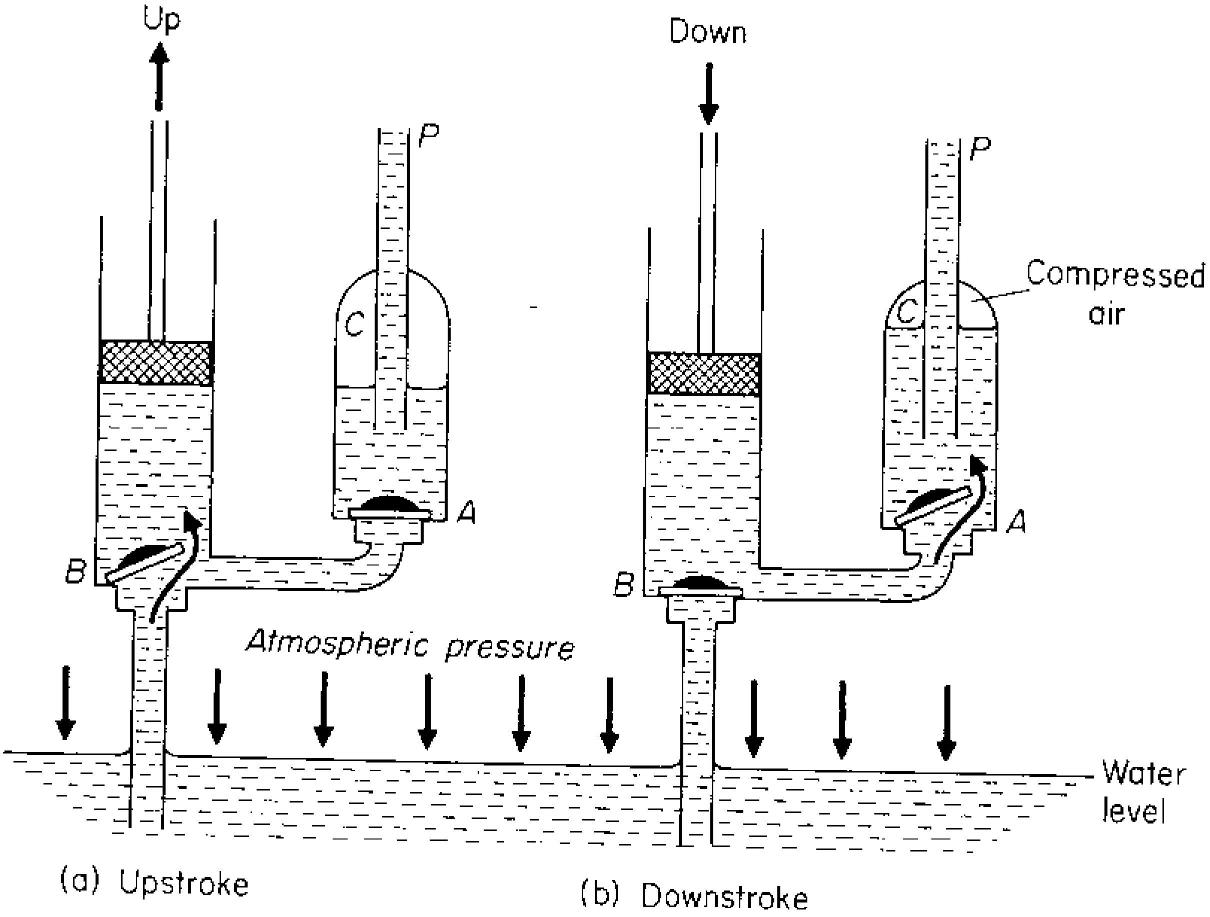
When the plunger moves down wards valve B closes due to force of gravity on it and weight of water above it.

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 acting on the surface of the water in the well.
- At the same time, the water above it is raised and fall out at the spout.

A force pump



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

It is first primed 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.

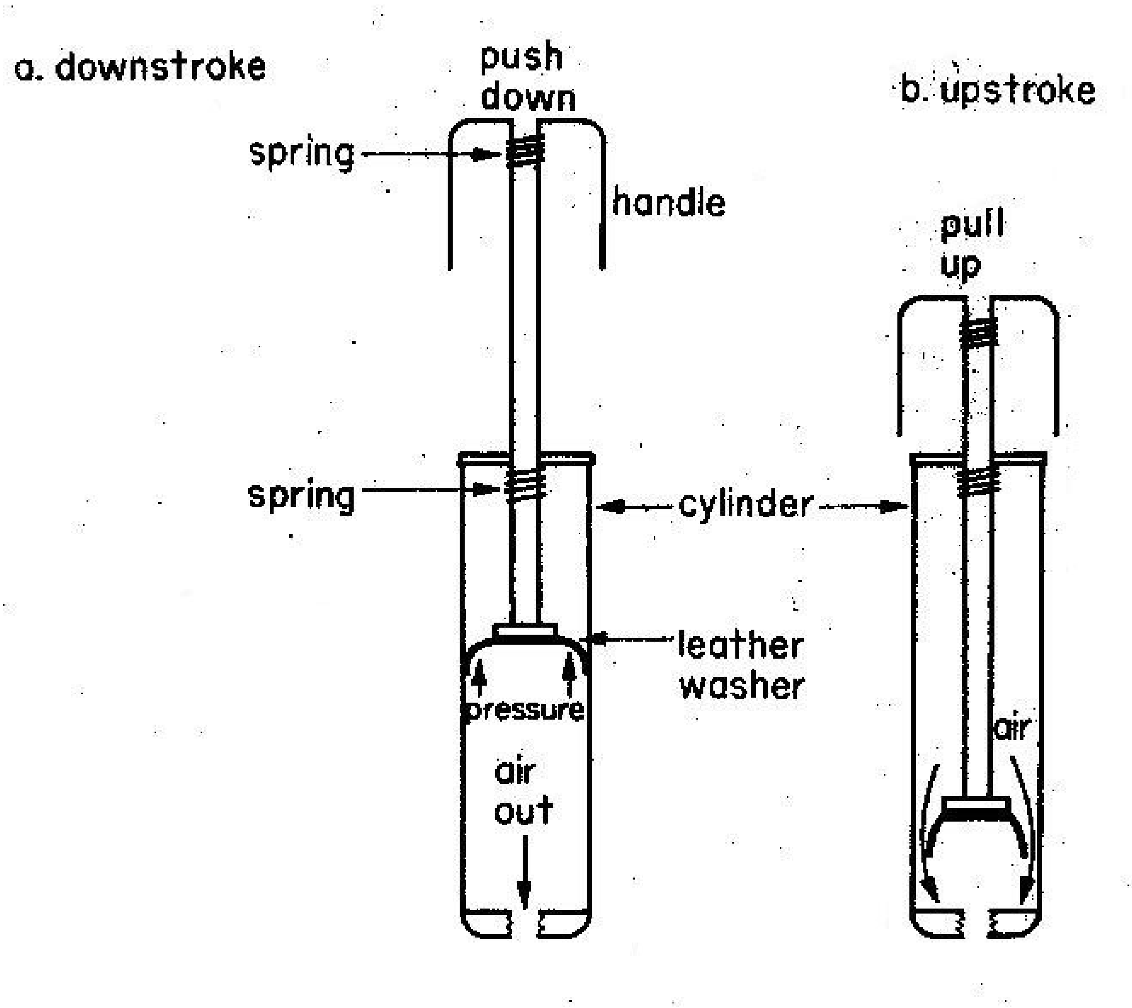
BICYCLE PUMP:

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 passed the tyre valve into the tyre.



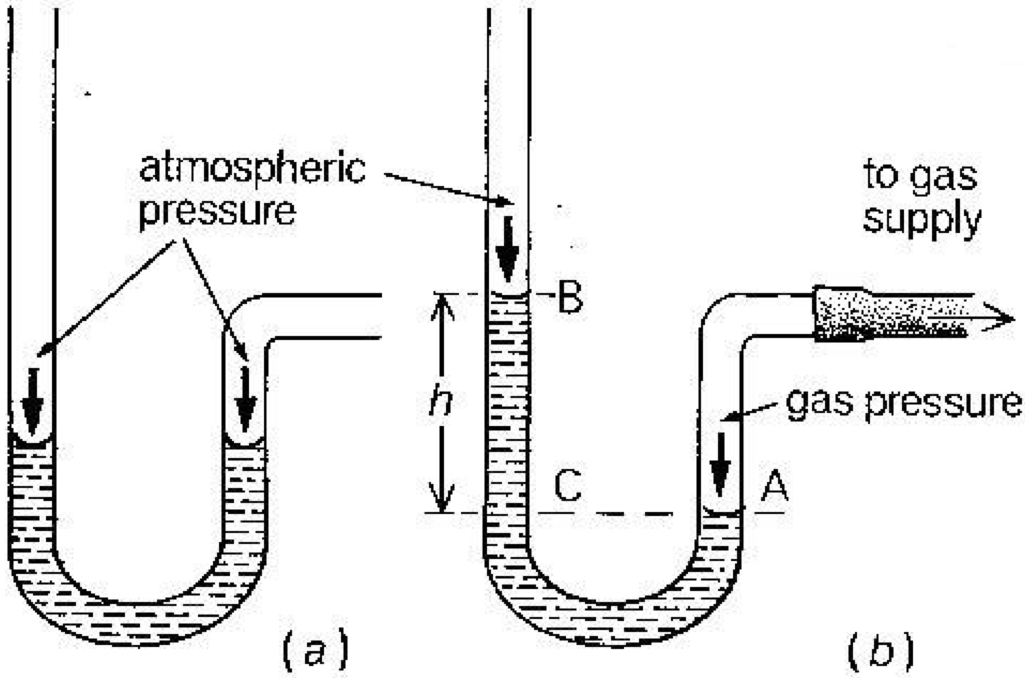
When the handle is pulled out, the pressure of the air in the barrel is reduced.

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.

a. **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.

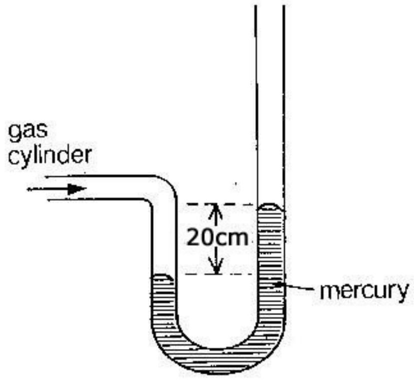
Pressure P, of the gas is calculated as

Pressure at A = H + h (when B is above A)

Or,

Pressure at 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) $P = h\rho g = \frac{96}{100} \times 13600 \times 10 = 130560\ Nm^{-2}$

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

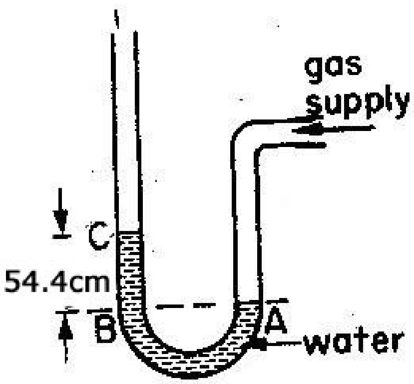
$P = h\rho g = \frac{75}{100} \times 13600 \times 10 = 102000Nm^{-2}$

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 $1.0 \times 10^5\ N/m^2$ and density of water is $1000kgm^{-3}$.calculate his lung pressure.

Pressure of air = $H + h\rho g$

$= 1.01 \times 10^5 + \frac{40}{100} \times 1000 \times 10 = 105,000Nm^{-2}$

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 cm Hg at points A, B, and C.

Pressure at A = pressure C

= H + h

Pressure using mercury = pressure of water

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

= h x 13600 x 10 = 54.4 x 1000 x 10

$$= \frac{h1\,x\,136000}{13600} = \frac{54.4\,x\,1000}{13600}$$

h = 4 cm

Therefore at B, P = h + 4

P = 4 +76 = 80cm Hg

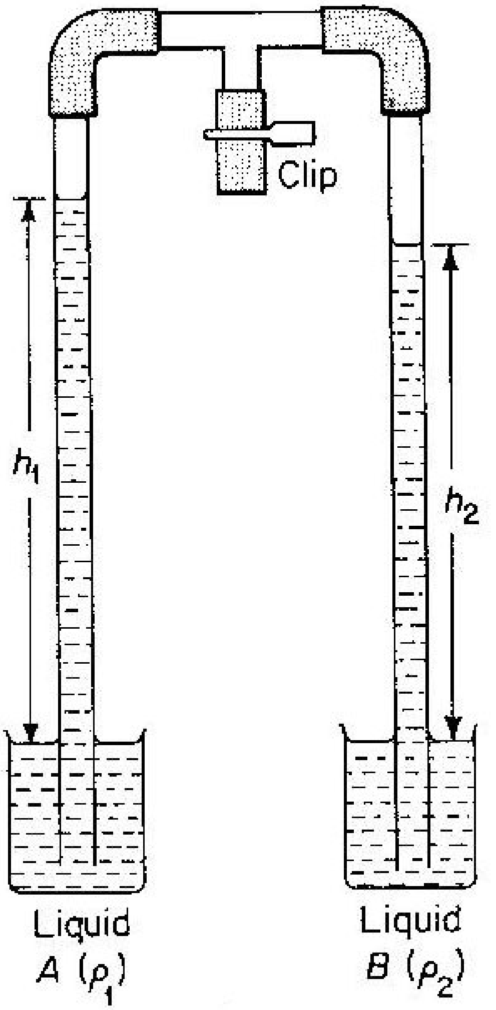
5. The difference in pressure at the peak of the mountain and the foot of the mountain is

5.0 x 10Nm^{-2}.Given that the density of air is 1.3kgm^{-3},Calculate the height of the mountain.

Difference of P = hpg → 5.0 x 10^4 = h x 1.3 x 1.0

h = 7846.15m or 7.85km

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,

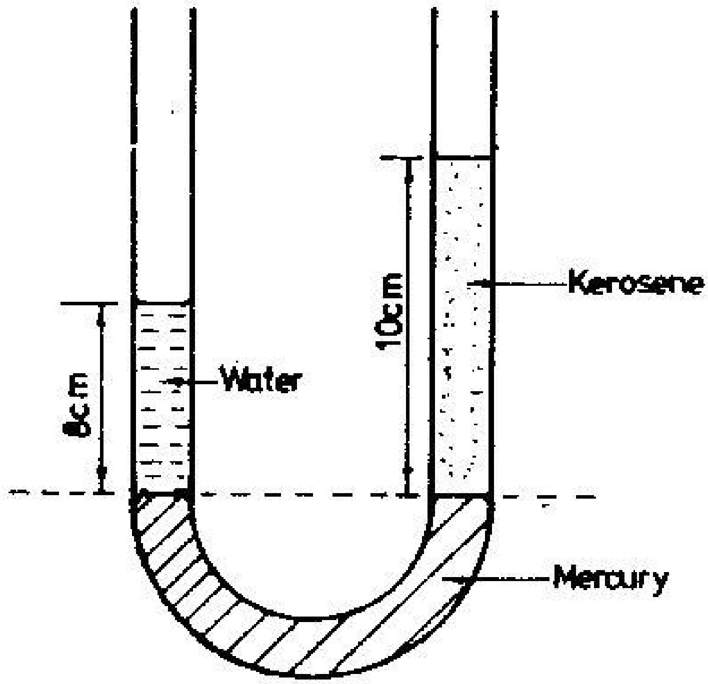
Pressure on liquid 1 = pressure on liquid 2

$$\rho_1 \rho_1 g = h_2 \rho_2 g$$

$$\rho_1 \rho_1 = h_2 \rho_2$$

$$\frac{\rho_1}{\rho_2} = \frac{h2}{h1}$$

Example;



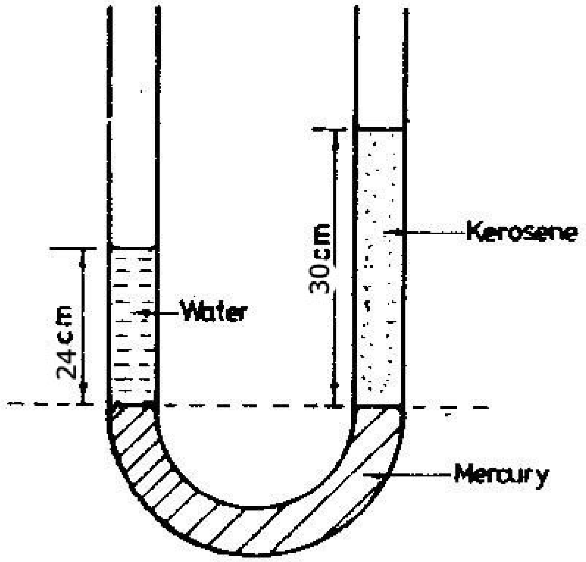
1. Water and kerosene are placed in U-tube containing mercury as shown above.

Determine the density of kerosene?

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

$h_x \rho_x g = h_w \rho_w g$

$h_x \rho_x = h_w \rho_w$ $\rho_x = \frac{hw\,pw}{hX} = \frac{18 X 1000}{20}$



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

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

$h_1 p_1 g = h_2 p_2 g$

$24 \times 1000 = 30 \times p_2$

$$\frac{24000}{30} = \frac{30P2}{30}$$

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

Relative density of kerosene

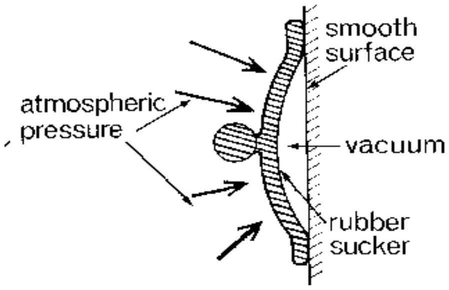
$$R.d = \frac{P\,of\,alcohol}{P\,of\,water}$$

$$= \frac{800}{1000}$$

$$= 0.8$$

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

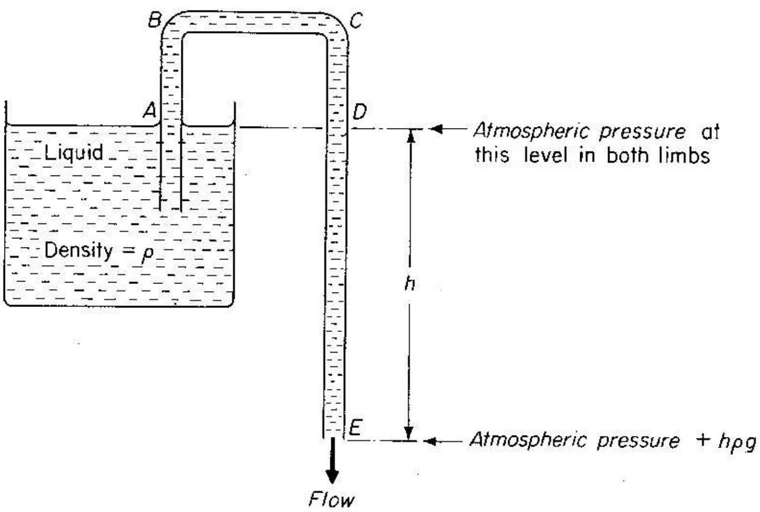


Uses of rubber sucker;

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

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..

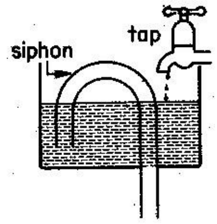
NB: To start the siphon it must be full of liquid and end A must be below the liquid level in the tank.

Applications of siphon principle

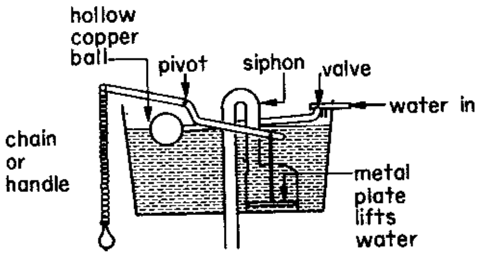
1. Automatic flushing tank: This uses siphon principle.

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.

Water supply system:

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.

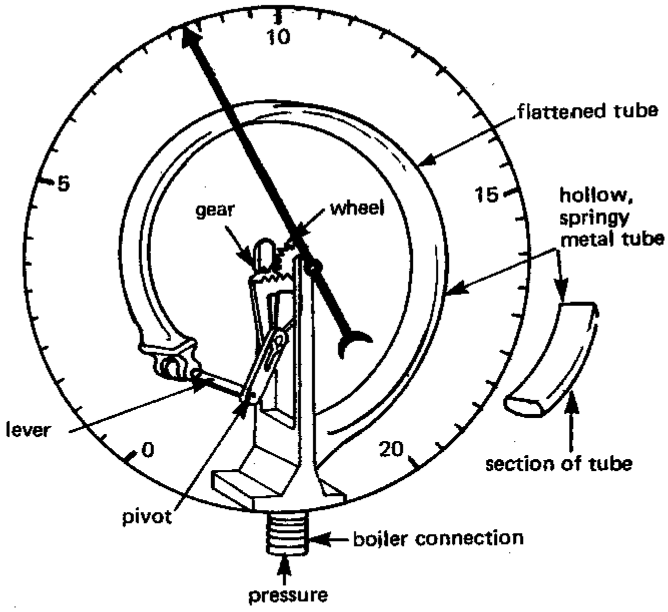
In very tall building it may be necessary to first pump water to a large tank on a roof. Reservoirs of water supply in hydro electric power stations are often made in mountainous.

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

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:

b. **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 reorded 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 filling stations.

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