TOPIC: MECHANICS AND PROPERTIES OF MATTER

General Objective: The learner should be able to use knowledge of Up thrust, viscosity and streamlines to explain conditions for moving with steady speed or not and to float or sink.

SUB-TOPIC: FLOATING AND SINKING (commonly known as Archimedes' principle).
SPECIFIC OBJECTIVES
The learner should be able to;
- State Archimedes Principle.
- Verify Archimedes principle.
- Solve numerical problems involving Archimedes principle.
- State the law of floatation and verify it experimentally.
- Solve numerical problems involving the law of flotation.
- Explain the principle of operation of a hydrometer.

UPTHRUST
When an object is partially or wholly immersed in water it;
(i) experiences an upward force (Upthrust) when and
(ii) displaces some water.

Note: When a different liquid like kerosene which has a lower density than that of water, the upward force exerted on the metal cylinder is less than that exerted due to water.

Definition
Upthrust is an upward force exerted by the fluid on an object immersed in it**.**

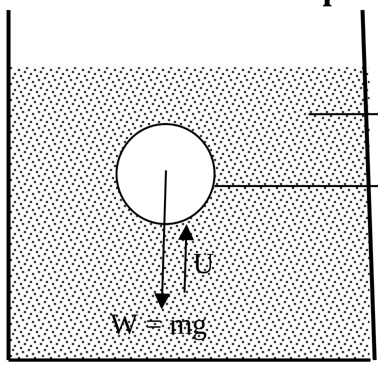
ARCHIMEDES PRINCIPLE AND FLOTATION

ARCHIMEDES' PRINCIPLE

- An object feels lighter when immersed in a liquid than its real weight in air.
- The difference in the weight of the object in air (W_a) and its weight in the liquid (W_l) is referred to as the apparent loss in weight.
- The apparent loss in the weight of the object is caused by upward force exerted by the liquid on the object.
- The upward force exerted by the liquid on the object immersed in it is called ***up thrust***.

Statement of Archimedes' principle:
When a body is wholly or partially immersed in a fluid, it experiences an up thrust equal to the weight of the fluid it displaces.
NOTE: A ***fluid*** can be either a liquid or a gas.

Illustration of Archimedes' Principle:



- **W = mg** is the weight of the object in air.
- **U =** the up thrust (upward force) exerted on the body by the fluid in which it is immersed.

Apparent weight of an object immersed in a fluid:
This is the weight of the body when it is wholly or partially immersed in a fluid.

$Apparent\ weight\ of\ an\ object\ in\ the\ fluid = weight\ of\ the\ object\ in\ air - upthrust.$

$$W_l = W_a - U$$

Also

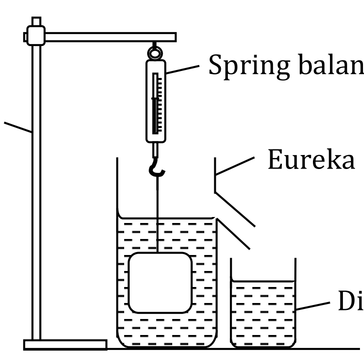
The apparent loss in the weight of the object = weight of the body in air – apparent weight of the body in the liquid.

$The\ apparent\ loss\ in\ the\ weight\ of\ the\ object\ = W_a - W_l$

Therefore

The apparent loss in the weight of the object = up thrust.

Experiment to verify Archimedes' principle.



- An object is weighed in air using a spring balance and its weight, W_a is recorded.
- A displacement can (eureka can) is completely filled with water up to its spout.
- An empty beaker of known weight, W_b is placed under the spout of the displacement can.
- The object is then immersed in the water in the displacement can.

- The new weight of the object, W_l when it is immersed in the water is also recorded.
- The object displaces some water when it is immersed in the water which is collected in the beaker below the spout.
- The weight of the beaker with the displaced water is also measured and recorded, W_c. The weight of the displaced water is calculated as $W_w = W_c - W_b$.

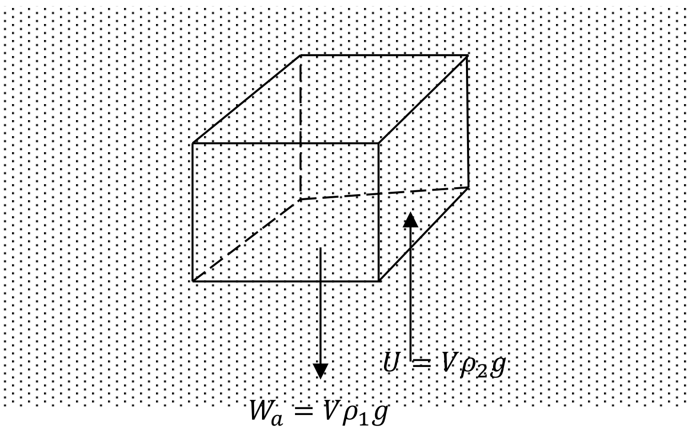
Observations show that: $W_a - W_l = W_w$

$$W_w = W_c - W_b$$

$$\therefore upthrust = weight\ of\ displaced\ water.$$

CALCULATING UPTHRUST

(a) A body that is fully immersed in a fluid.

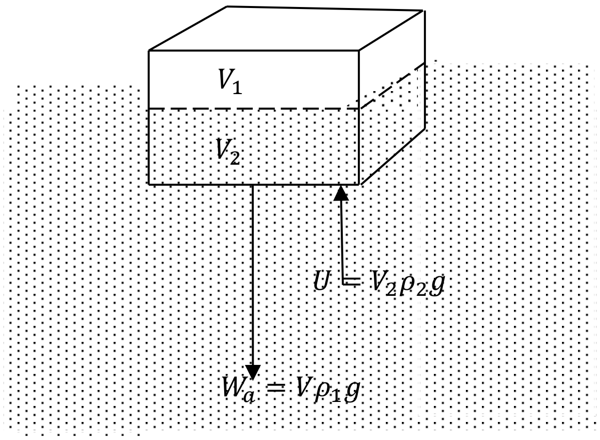


$W_a = weight\ of\ body\ in\ air$
$\rho_1 = density\ of\ the\ body$
$\rho_2 = density\ of\ the\ liquid$
$V = volume\ of\ the\ body$
$U = up\ thrust$

When a body is wholly immersed in a fluid, it displaces its own volume.

Therefore: $Volume\ of\ the\ displaced\ fluid = volume\ of\ the\ body = V$
From Archimedes' principle;
$Upthrust = weight\ of\ displaced\ fluid.$
$Upthrust = mass\ (of\ displaced\ fluid) \times acceleration\ due\ to\ gravity.$
$Upthrust = Volume\ \times density\ of\ the\ fluid \times acceleration\ due\ to\ gravity.$
$U = V\rho_2 g$
The apparent weight of the object in a fluid, $W_f = W_a - U$

(b) A body that is partially immersed in a fluid.



$W_a = weight\ of\ body\ in\ air$

$\rho_1 = density\ of\ the\ body$

$\rho_2 = density\ of\ the\ liquid$

$V = V_1 + V_2 = volume\ of\ the\ body$

$V_1 = volume\ of\ body\ above\ fluid\ surface$
$V_2 = volume\ of\ body\ immersed\ in\ the\ fluid.$
$U = up\ thrust$

When a body is partially immersed in a fluid, it displaces a volume of the fluid equal to the fraction of its volume that is submerged in the fluid.
Therefore:

$Volume\ of\ the\ displaced\ fluid$
$= fraction\ of\ volume\ of\ the\ body\ submerged\ in\ the\ fluid = V_2$

From Archimedes' principle;

$Upthrust = weight\ of\ displaced\ fluid.$
$Upthrust = mass\ (of\ displaced\ fluid) \times acceleration\ due\ to\ gravity.$
$Upthrust = Volume\ \times density\ of\ the\ fluid \times acceleration\ due\ to\ gravity.$
$U = V_2\rho_2 g$

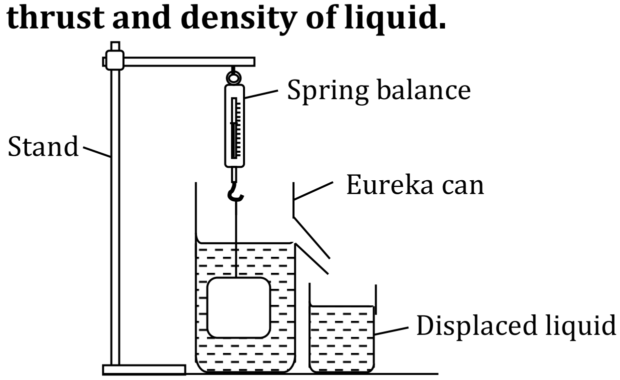
FACTORS THAT AFFECT THE MAGNITUDE OF UPTHRUST

The factors that affect up thrust are:

1. Density of the fluid in which the body is immersed.
2. The volume of the body immersed in the fluid.

Experiments to investigate factors that affect up thrust.

(a) Up thrust and density of liquid.



- The weight of a solid mass is measured first in air and when it is completely immersed in water.
- The experiment is repeated using other liquids. In each case, the solid mass is wiped dry before immersing it into the next liquid.
- The results are tabulated as below.

Name of liquid	Density (gcm^{-3})	Upthrust =$W_{ar} - W_{liquid}(N)$
Water	1.00	
Kerosene	0.84	
Cooking oil	0.89	
Brine	1.06	

Observations will show that the up thrust increases with increase in density of the liquid in which the solid is immersed.

(b) Upthrust and volume of the object.

- A glass block of known dimensions is first weighed in air.
- Its apparent weight is then determined when it is partially immersed in water and when fully immersed in the water.

Observations will show that the glass block experiences a greater apparent loss in weight (upthrust) when fully immersed than when partially immersed.

This is so because when fully immersed it displaces a bigger volume of water than when partially immersed.

It can be deduced that up thrust increases with the volume of displaced fluid.

EXAMPLES:

1. A glass block weighs 25N in air. When wholly immersed in water, the block appears to weigh 15 N calculate the up thrust on the block.

Up thrust = weight in air – weight in a fluid (apparent weight)
= W_a – W_f
= 25 – 15
= 10N.

2. A body weighs 1N in air and 0.8 N when wholly immersed in water. Calculate the weight of displaced water.

Up thrust = weight of displaced water $= \boldsymbol{W_a - W_l}$
$= \mathbf{1 - 0.8}$
$= \mathbf{0.2N}.$

3. A metal weights 20 N in air and 15 N when fully immersed in water. Calculate
   (a) Up thrust.
   (b) Weight of displaced water

(c) Volume of displaced water (density = $1000kgm^{-3}$)

(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*

Up thrust = weight of displaced water

$$W = p \times V \times g$$

$$5 = 1000 \times V \times 10$$

$$V = \frac{5}{10000}$$

$$V = 0.0005\, m^3$$

(d) *Volume of metal = volume of displaced water*

= 0.0005 m³

(e) *Density of metal* $= \frac{mass}{volume}$

$= \frac{2}{.0005}$

$= 4000kgm^{-3}$

Application of Archimedes' principle.

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

Measurement of relative density of a solid

$$\boldsymbol{Relative\ density\ of\ solid} = \frac{\boldsymbol{weight\ of\ object\ in\ air}}{\boldsymbol{upthrust\ in\ water}}$$

$$\boldsymbol{RD} = \frac{\boldsymbol{W_a}}{\boldsymbol{W_a - W_w}}$$

EXAMPLE

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

$$\boldsymbol{RD} = \frac{\boldsymbol{W_a}}{\boldsymbol{W_a - W_w}}$$

$$= \frac{5.6}{5.6-4.8} = \frac{5.6}{0.8} = \frac{56}{8}$$

$$= \mathbf{7}$$

2. An object has a relative density 7 and weighs 70 N in air. Find its weight when it is fully immersed in water.

$$RD = \frac{W_a}{W_a - W_w}$$

$$7 = \frac{70}{70 - W_w}$$

$$490 - 7\mathrm{W_w} = 70$$

$$\mathrm{W_w} = \frac{490-70}{7} = 60 \text{ N is the apparent weight in water.}$$

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

$$RD = \frac{W_a}{W_a - W_w}$$

$$\mathbf{9} = \frac{W_a}{W_a - 40}$$

$$9W_a - 360 = W_a$$

$$8W_a = 360$$

$$W_a = 45\ N$$

Determination of Relative density of a liquid

The relative density of the liquid $= \frac{upthrust\ in\ liquid}{upthrust\ in\ water}$

The up thrust in liquid $= W_a - W_l$.
The up thrust in water $= W_a - W_w$.

The relative density of the liquid $= = \dfrac{W_a - W_l}{W_a - W_w}$

Examples

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

$$\boldsymbol{RD = \frac{Wa-Wl}{Wa-Ww}} = \frac{5.6-4.6}{5.6-4.8} = \frac{1}{0.8} = \frac{10}{8} = \mathbf{1.25}$$

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

$$\boldsymbol{RD = \frac{Wa-Wl}{Wa-Ww}}$$

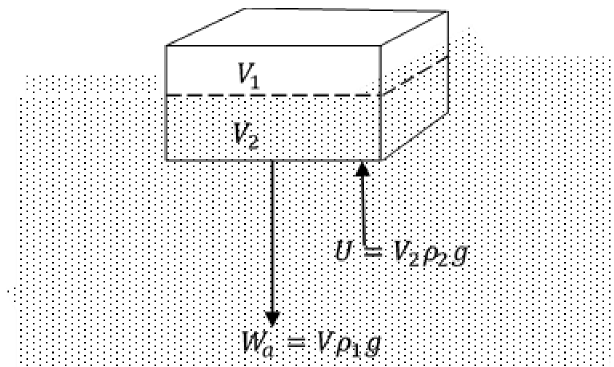
$$0.8 = \frac{100-20}{100-Ww}$$

$$80 - 0.8W_w = 80N.$$

$$W_w = 0\ N$$

FLOATING OBJECTS

There are two vertical a forces which act on an object when immersed in water namely, its weight, W_a and up thrust, U



- If W_a is less than U, the object rises to the surface of the liquid where it will then float.
- If W_a is equal to upthrust U objects floats.
- If W_a is greater than upthrust U object sinks.

Therefore, an object will float in a fluid when its weight is equal to the up thrust it experiences in the fluid. However, from Archimedes' principle, up thrust is equal to weight of a fluid displaced. **Therefore, for floating objects, the weight of the object should be equal to weight of the displaced fluid.**

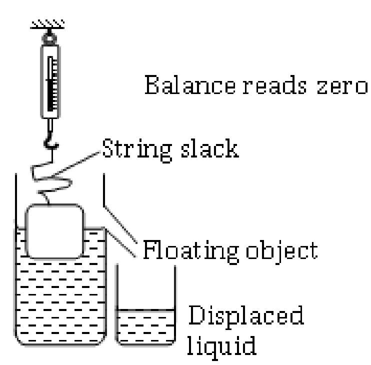
Law of flotation

States that: ***A floating object displaces its own weight of the fluid in which it floats.***

Interpretation: The up thrust is equal to the weight of the floating body.

This law means that the apparent weight of a floating body is zero.

Experiment to verify law of floatation



The displacement can is filled with water up to its spout and some time is allowed for the water to stop dripping.
The piece of wood is weighed in air and its weight, W_a is noted.
The wood is floated on the water in the displacement can; it's weight.
The displaced water is collected in a pre-weighed beaker placed below the spout of the displacement can.
The weight of the displaced water is determined using the equation

$$weight\ of\ displaced\ water = weight\ of\ beaker\ with\ water - water\ of\ empty\ beaker.$$

It is found out that

Weight of water displaced water = weight of object, W_a

Relation between the Fraction submerged and the Relative Density

Imagine an object of density ρ_1 having uniform cross-sectional area A and height h, floating in a liquid of density ρ_2 with height d of it submerged.

Then mass of liquid displaced = Mass of floating object

$\therefore$ Volume of displaced liquid x ρ_2 = volume of object x ρ_1

$$\therefore Ad\rho_2 = Ah\rho_1$$

$$\therefore \frac{d}{h} = \frac{\rho_1}{\rho_2}$$

But $\frac{d}{h}$ is the fraction of the object submerged

$$\therefore \textbf{Fraction submerged} = \frac{\textbf{Density of object}}{\textbf{Density of liquid}}$$

Examples

1. An object of R.D 0.8 floats in water. Find:

   (i) the fraction of it exposed.

   (ii) the fraction submerged if it floats in a liquid of density 1200kgm^{-3}.

   (i) Fraction submerged $= \frac{\text{Density of object}}{\text{Density of liquid}} = \frac{0.8}{1} = \frac{4}{5}$

   $\therefore$ Fraction exposed $= \frac{1}{5}$

   (ii) Fraction submerged $= \frac{\text{Density of object}}{\text{Density of liquid}} = \frac{800}{1200} = \frac{2}{3}$

2. A cube made of oak and of side 15cm floats in water with 10.5cm of its depth below the surface and with its side vertical. What is the density of oak?

$$\frac{\text{Density of oak}}{\text{Density of water}} = \frac{10.5}{15}$$

$$\therefore \quad \text{Density of oak} = \frac{10.5 \text{ x } 1000}{15} = 700 \text{ kg m}^{-3}$$

MOER WORKED OUT EXAMPLES

1. The mass of a piece of cork (0.25 gcm^{-3}) is 20g. What fraction of the cork is immersed when it floats in water?

Solution

Mass of cork = mass of water displaced

$$= \rho \, v$$

$$20 = 1 \times v$$

$$\therefore volume\ of\ displaced\ water, v = 20\ cm^2$$

$$But\ volume\ of\ cork = \frac{mass}{density} = \frac{20}{0.25} = 80\ cm^3$$

$$Fraction\ of\ cork\ immersed = \frac{volume\ of\ displaced\ water}{volume\ of\ object} = \frac{20\ cm3}{80\ cm3} = \frac{1}{4}$$

2. A solid of volume $1 \times 10\ m^3$ floats on water of density $1 \times 10\ kgm^{-3}$ with $\frac{3}{5}$ 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

$$mass\ of\ solid = volume\ of\ displaced\ water \times densiyof\ water$$

$$mass\ of\ solid = \frac{3}{5} \times volume\ of\ solid \times density\ of\ water$$

$$mass\ of\ solid = \frac{3}{5} \times 1 \times 10\ m^3 \times 1000$$

$$mass\ of\ solid = 600{,}000\ kg$$

(ii) Mass of the solid = mass of liquid displaced

$$volume \times density = 600{,}000$$

$$1 \times 10\ m^3 \times density = 600{,}000$$

$$dinsity\ of\ solid = 600\ kgm^{-3}$$

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 $5 \times 10^{-3} m^3$, calculate the tension in the string .(density of hydrogen = 0.08 kg/m^3, density of air = 1.15kg/m^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 $W = 0.05 + 0.004$

$= 0.054\, N$

$Tension\ T = U - W$

$= 0.0575 - 0.054$

= 0.0035N

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

$weight\ in\ air, W_a = mg$

$= 2 \times 10$
$= 20\, N$

$Upthrust = weight\ of\ fluid\ displaced$

$= weight\ in\ air - weight\ in\ water$

$Upthrust = 20 - 17 = 3\, N$

(ii) $upthrust = weight\ of\ displaced\ water$

$upthrust = mass\ of\ displaced\ water \times gravitational\ acceleration$

$3\ N = m \times 10$

$m = 0.3\ kg$

$3 = m\ x10$ hence M = $\frac{3}{10}$ = 0.3 kg

Up thrust = weight of fluid displaced

$U = \rho\ v\ g$

$3 = 1000 \times v \times 10$

$V = \frac{3}{10000}$

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

Density =$\frac{mass}{volume}$

= $\frac{2}{3.0\ x\ 10m3}$

= 6.7 x10^3 kgm^{-3}

5. When a metal is completely immersed in liquid A its apparent weight is 20 N. When immersed in another liquid B the apparent weight is 16 N if the density of B is $\frac{9}{8}$ times that of A, calculate the mass of the metal.

Solution

(i) Up thrust in A Up thrust in B

$U_A = W_a - W_A$ $U_B = W_a - W_B$

$U_A = (W_a - 20)$ $U_B = W_a - 16$

$Relative\ density\ of\ liquid\ B\ to\ liquid\ A = \frac{\rho_B}{\rho_A} = \frac{U_B}{U_A} = \frac{W_a - 16}{W_a - 20}$

$but\ \rho_B = \frac{9}{8}\rho_A \quad \therefore \frac{\rho_B}{\rho_A} = \frac{9}{8}$

$\therefore \frac{9}{8} = \frac{W_a - 16}{W_a - 20}$

$\therefore 9(W_a - 20) = 8(W_a - 16)$

$\therefore 9W_a - 180 = 8W_a - 128$

$\therefore W_a = 180 - 128 = 52$

$\therefore mg = 10\,m = 52\,N$

$mass, m = 5.2\,kg$

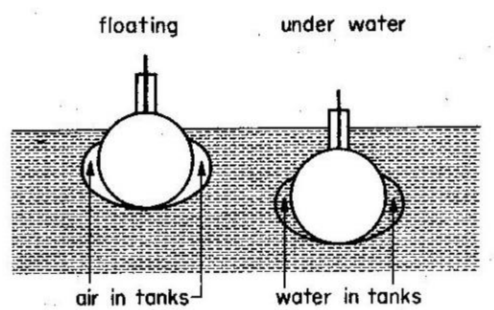
Applications of law of floatation

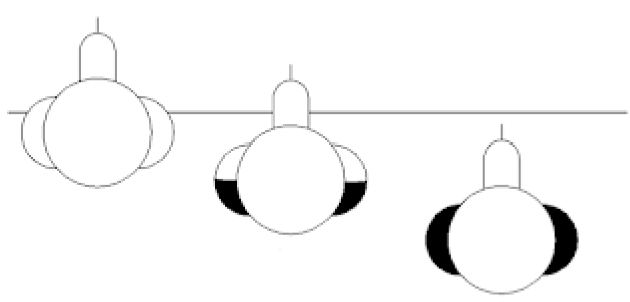
1. Ships.

A ship floats when the up thrust of the water it displaces equals its weight.
i.e. the weight of floating ship = the weight of water displaced
When a ship is being loaded, it sinks lower and displaces more water to balance the extra load.
Though ships are made of steel, a material that would normally sink in water, they float because they are made hollow. The hollow space is filled with air and therefore the average density of the ship is less than the density of water.
If a hole develops on the side of the ship, mainly due to accidents, the ship will take in water and may sink.

2. Submarines

A submarine has ballast tanks which can be filled with water or air. When full of water, the average density 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.

3. Balloons and air ships

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.

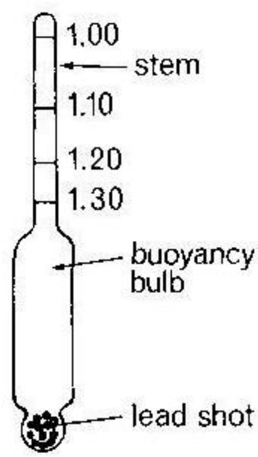
$$\text{The lifting power} = \text{up thrust} - \text{total weight}$$

$$= \text{weight of air displaced} - \text{weight of } (\text{bag} + \text{gas})$$

Balloons that carry passengers control their weight by blowing in hot light gases into the gas bag to make them rise and by letting gas out of the gas bag to make them descend. 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 liquid.



It consists of a longer glass tube with a bulb at the bottom filled with mercury or lead 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.

Uses of a hydrometer

It is used for measuring the densities of milk (lactometer) , beer, wines, acids in cars batteries(the acid in a fully charged accumulator should have a density of $1.25gcm^{-3}$, if it falls below 1.18, the accumulator needs recharging).

SUB-TOPIC: FLUID FLOW
SPECIFIC OBJECTIVES
The learner should be able to;
- Carryout experiment to demonstrate streamline flow and turbulence.
- State the relationship between pressure, velocity and closeness of streamlines.
- Mention and explain practical applications of the relationship between pressure and velocity.
- Identify and draw forces on an object falling in a fluid
- Explain the factors that led to terminal velocity.
- Explain the factors that lead to terminal velocity.
- Displacement-time graphs to illustrate terminal velocity.

Fluids in motion:

A fluid is any substance that can flow freely.
Fluids are usually either liquids or gases.
Examples of fluids in motion include:
- Sea water breaking against the seashore.
- Flow of water in a river.
- Columns of smoke swirling up from chimneys, e.t.c.

Streamline and Turbulent Flow

Streamline flow (steady flow) or laminar

Streamline flow in fluids is defined as the flow in which the fluids flow in parallel layers such that there is no disruption or intermixing of the layers and at a given point, the velocity of each fluid particle passing by remains constant with time

When a water tap is opened slightly, the water oozes out slowly in form of a thin smooth orderly stream. As the tap is opened further, eventually the water flows fast and the order disappears. Thus, by increasing the velocity, the flow changes from being steady and orderly to being unsteady and disorderly.

The orderly flow of a fluid is termed as *streamline flow.*

In streamline flow, the liquid molecules move in layers and do not cross from one layer to another *i.e. each and every molecule of the fluid travels in the same direction and with the same speed*.

Streamline flow occurs when the fluid is moving at low speeds.

NOTE:
A *streamline* is a line indicating the path of the particles having a streamline flow.

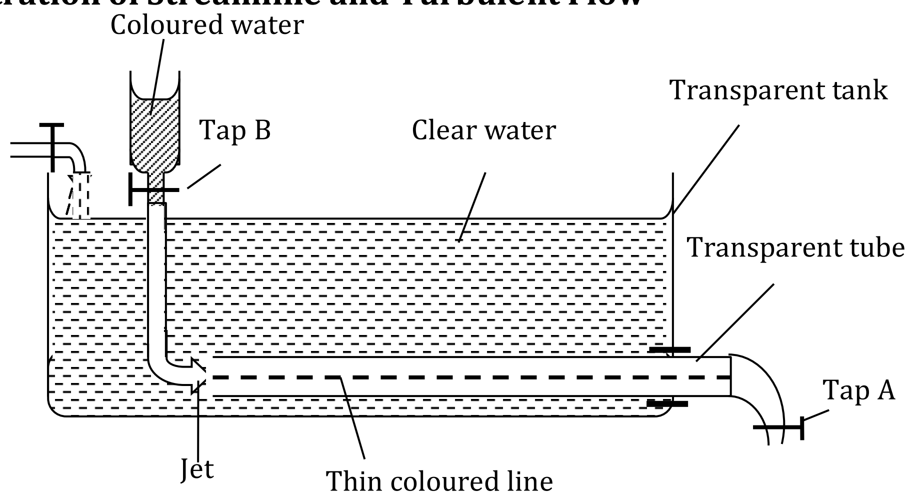
Conditions for streamline flow:

1. The fluid must be non-viscous such that there is no friction between the layers of the fluid.
2. there should be no friction between the liquid and the walls of the pipe.
   Usually the above conditions are impossible to fulfill and fluids rarely flow at the same velocity at all points throughout the fluid.

Turbulent flow

This is a fluid (gas or liquid) **flow** characterized by irregular movement of the particles of the fluid.
In **turbulent flow** the speed of the fluid at a point is continuously undergoing changes in both magnitude and direction.
Here the liquid no longer flows in layers and the movement of the molecules occurs in all directions.

Demonstration of Streamline and Turbulent Flow



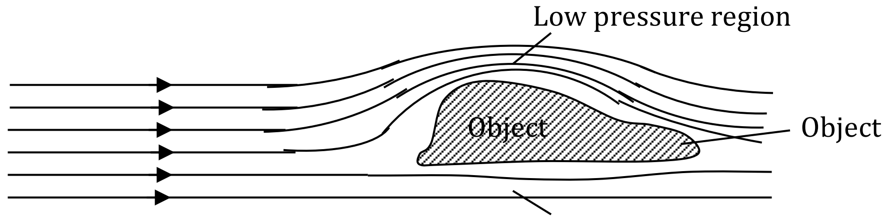
A transparent tank, fitted with a horizontal transparent tube is filled with water from a tap.
Tap A controls the rate of flow through the horizontal tube while tap B opens for the coloured liquid.
Tap A is opened, first slightly and then B is opened to release some coloured liquid.
Tap A is progressively opened further.

Observation

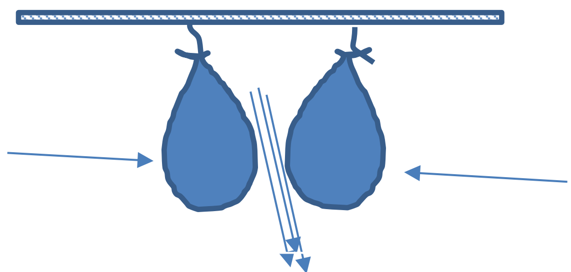
At first a thin coloured line is seen in the horizontal tube. This is streamline flow. However, as A is opened further, the coloured line disappears and instead the colour fills the whole tube. The flow has now become turbulent.

Relationship between Pressure, Velocity and Closeness of streamlines.

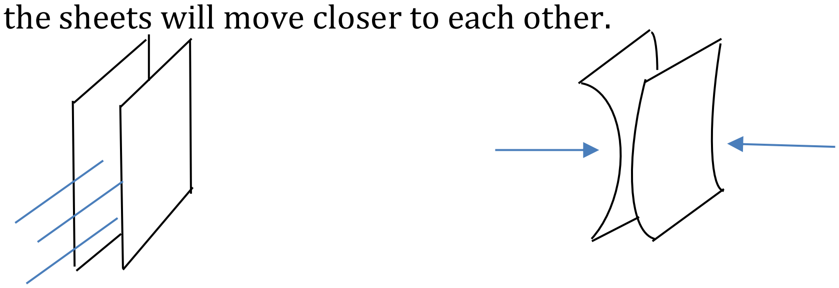
A streamline is a path where molecules have steady speed and each molecule retraces the path of the one directly ahead of it. Where the streamlines are close, the velocity of the fluid is high but the pressure is low, and vice versa. This was discovered by a scientist known as Bernoulli.
The diagram below shows air flowing past an object. The shape of the object makes the air above it to flow faster and at reduced pressure than that passing below. So the streamlines above are closer.



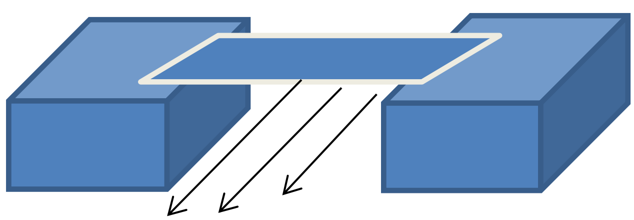
The following experiments demonstrate Bernoulli's effect:
When a stream of fast moving air is blown between two freely suspended balloons, the balloons will move closer to each other.



When a stream of fast moving air is blown between two thin sheets of paper held vertically close to each other, the sheets will move closer to each other.



When a stream of fast moving air is blown below a thin sheet of paper held horizontally on pieces of wooden blocks, the paper will move downwards. If the air is blown above the same paper, it will move upwards.



Explanation:
The above demonstrations, the pressure is reduced in the regions where the air is moving at high velocity compared to the pressure where the air velocity was lower. This causes the greater pressure to push the objects towards the regions were the pressure has reduced.

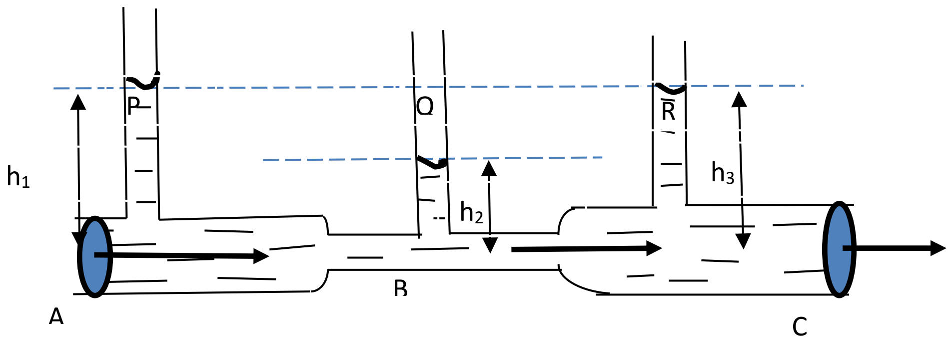
Explaining Bernoulli's effect:
By considering a liquid that is flowing steadily along a horizontal pipe which has a constriction in the middle with narrow vertical tubes, P, Q and R that act as manometers.

If the liquid has streamline flow, then the rate of flow of liquid at any section of the pipe is the same.

$$rate\ of\ flow = \frac{volume}{time} = \frac{Area \times distance}{time} = Area \times velocity$$

It follows that the liquid is faster in the narrow section of the tube, B than in the wider sections of A and C.

This means that the pressure of the liquid is lower at B in the narrow tube, and its greater in the wider sections of the tube at A and C.



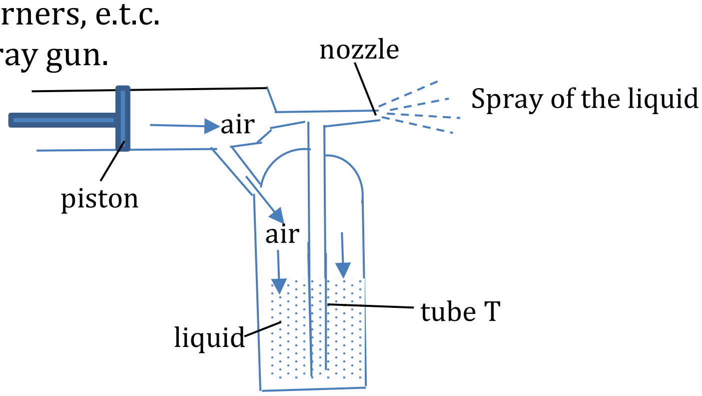
Since liquid pressure is given by the equation $h\rho g$, then the liquid columns at A and C are such that $h_1 = h_3$. Therefore, the liquid pressure is equal at A and C. But $h_1 > h_2$, where h_2 is the height of the liquid column at B. This means that the liquid pressure at A and C is greater than that at B.
This proves that *pressure is maximum when the velocity is a minimum*.
The above relationship is known as Bernoulli's principle or Bernoulli's effect.

Bernoulli's principle is an idea of fluid dynamics. It says that as speed of the fluid increases, pressure decreases.

Note: In the sections where the velocity is greatest, the streamlines are closest together and vice-versa.

Applications of Bernoulli's principle:
This principle is applied:
- Aerofoils (useful in steering an aeroplane).
- in carburetors
- in sprayers
- Bunsen burners, e.t.c.

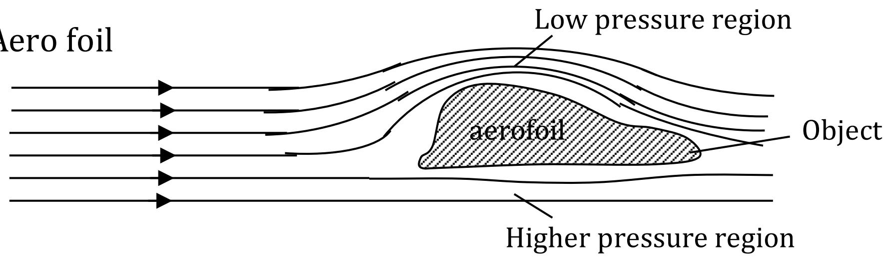
1. The spray gun.



When the piston is pushed in, it forces the air in the cylinder to move with a high velocity over the tip of the tube, T. This causes the air inside the cylinder to fall below that in the liquid reservoir. The pressure acting on the liquid surface forces the liquid to rise up the

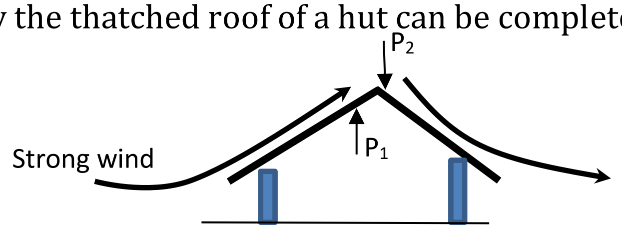
tube, T. The liquid breaks into a fine spray due to the impact of the high velocity molecules of air.
A paint sprayer, perfume or deodorant sprayer also works on the same principle.
Bunsen burner
In a Bunsen burner, the gas is made to escape with a high velocity through a fine nozzle.
The pressure in the area near the nozzle is reduced and as a result, the air from the outside atmosphere is drawn in and mixes with the gas.

2. Aero foil



The wing of an aircraft has a curved upper surface and a flat under surface. This compels the air passing over the top of the wing to travel a longer distance resulting in a higher air velocity than that below the bottom surface.
Since the velocity of the air is higher on the top surface, the pressure is lower than that at the bottom surface.
The pressure difference above and below the wing produces a large lifting force causing the aircraft to rise.

Question
Explain how the thatched roof of a hut can be completely lifted off the hut by a strong wind.
Answer:



A strong wind blowing over the roof top with a high velocity creates a low pressure above the roof top compared to the atmospheric pressure below the roof. The pressure difference, ($P_1 - P_2$) causes an upward force and the roof is lifted up and may be blown off by the wind.

Probe questions:
'It is dangerous to stand near the edge of a platform in a railway station, when a fast moving train passes without stopping'. Explain the statement using Bernoulli's principle.
"Air flow over the wings of an aircraft causes a lift". Explain this statement with the aid of a diagram.

Viscosity

Viscosity is a measure of a fluid's resistance to flow. It describes the internal friction of a moving fluid.

Viscosity in Liquids

When a liquid is flowing, the different layers of its molecules do not move at the same velocity. This means that the adjacent planes of molecules are sliding (rubbing) over each other. The molecules adjacent to the walls of the container are held stationary because of adhesion. The further away from the walls the molecules are, the higher is their velocity. The intermolecular attraction creates a force that opposes sliding of the planes of liquid molecules. This is known as the *viscous force.*
The viscous force resists flow of a fluid and the movement of an object through a fluid.

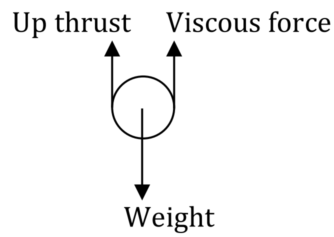
<u>Viscosity increases with velocity</u>. To prove this, stir a liquid in a beaker, first slowly and then increase the speed. At higher speeds the force opposing the motion of the stirrer is greater. A liquid with high viscosity flows very slowly. You may compare water with oil. Which one has higher viscosity? High viscosity liquids are used as lubricants.

<u>Viscosity decreases as the temperature of the liquid rises.</u>

Viscosity in gases

In a gas, the intermolecular attraction is negligible but the molecules collide frequently with each other and with any object that is moving through the gas. The momentum transfers involved bring about viscosity in a gas.

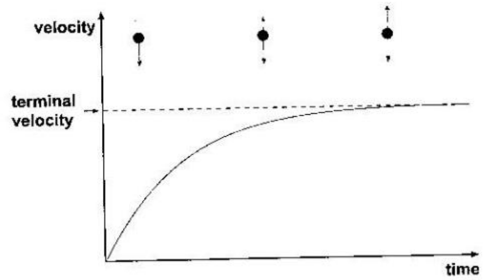
Fall of Objects through the Atmosphere



When an object is released to fall through air, in addition to its weight and upthrust due to air, it experiences a viscous force due to the air. The weight (gravity) acts downwards while the up thrust and the viscous force act upwards on such a body (See diagram below)

So, at first the body accelerates downwards, but since the viscous force goes on increasing with velocity, eventually the body can no longer accelerate. It reaches a maximum constant velocity known as the *terminal velocity*.

Below is a velocity-time graph for the motion of such a body.



Factors Affecting Terminal Velocity:

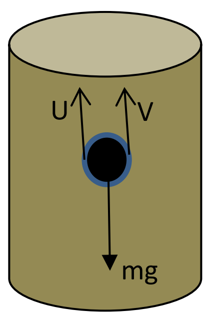
- density of the medium (the fluid)
- density of the falling body
- viscosity of the fluid

Motion of a body through fluids

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

- Weight of the body
- Viscous force
- Up thrust

The weight of the body acts downwards towards the earth. Upthrust acts upwards and viscous force acts in the direction opposite to the motion.



EXPLANATION OF THE PARTS OF THE GRAPH

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

$F = W - (U + V)$

As the body continues to fall, it attains a uniform velocity called **terminal velocity**. When the weight of the body $W = U + V$

At this stage the resultant force or net force of the body is zero.

DEFINITION OF 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.

In case of a balloon or a rain drop falling, the resisting force or retarding force on the body is called air resistance.

THE END