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

A streamline flow is one where, at a given point, each and every molecule of the fluid travels in the same direction and with same velocity.

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.

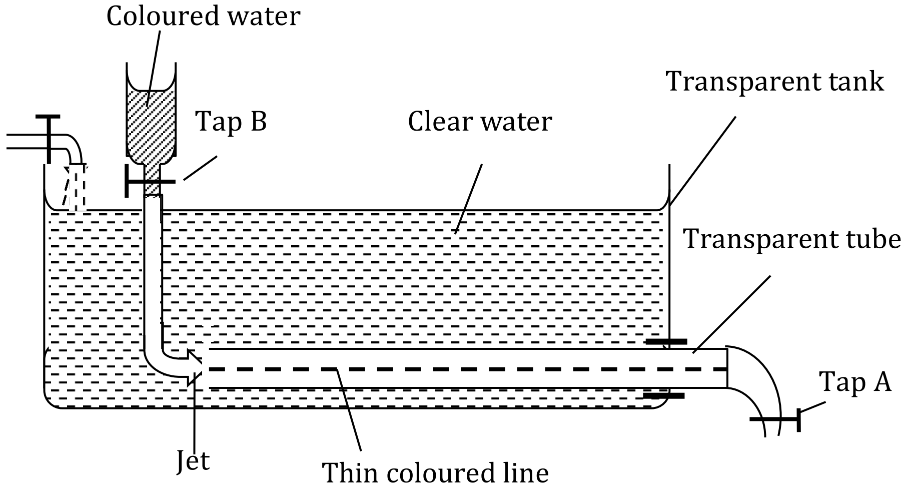
Turbulent flow

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.
In a turbulent flow, the molecules in a fluid move in many different directions and at many different speeds.

CONDITIONS FOR TURBULENT FLOW

- The pipe should be non-uniform
- There should be friction in the fluid.
- The liquid should be compressible
- The pipe should have bends/curves

Demonstration of Streamline and Turbulent Flow



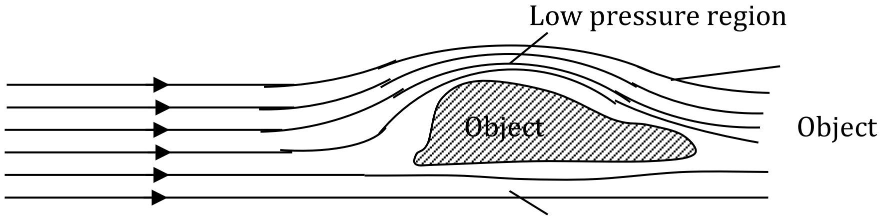
A transparent tank, fitted with a horizontal transparent tube is filled with water from a tap. Tap A controls the rate of flow through the horizontal tube while tap B opens for the coloured liquid.
Tap A is opened, first slightly and then B is opened to release some coloured liquid.
Tap A is progressively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

Observation

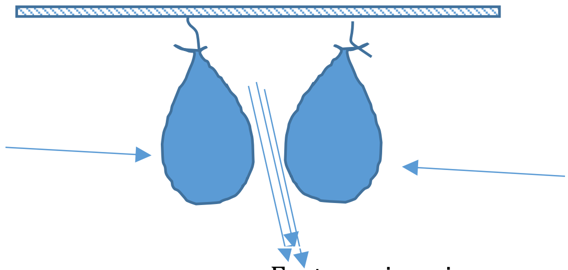
At first a thin coloured line is seen in the horizontal tube. This is streamline flow. However, as A is opened further, the coloured line disappears and instead the colour fills the whole tube. The flow has now become turbulent.

Relationship between Pressure, Velocity and Closeness of streamlines.

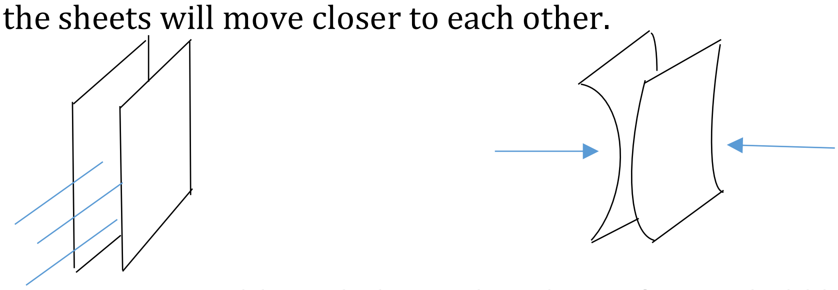
A streamline is a path where molecules have steady speed and each molecule retraces the path of the one directly ahead of it. Where the streamlines are close, the velocity of the fluid is high but the pressure is low, and vice versa. This was discovered by a scientist known as Bernoulli.
The diagram 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.



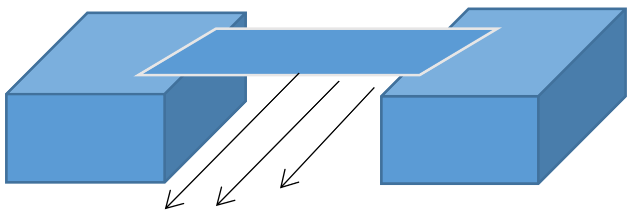
The following experiments demonstrate Bernoulli's effect:
When a stream of fast moving air is blown between two freely suspended balloons, the balloons will move closer to each other.



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.

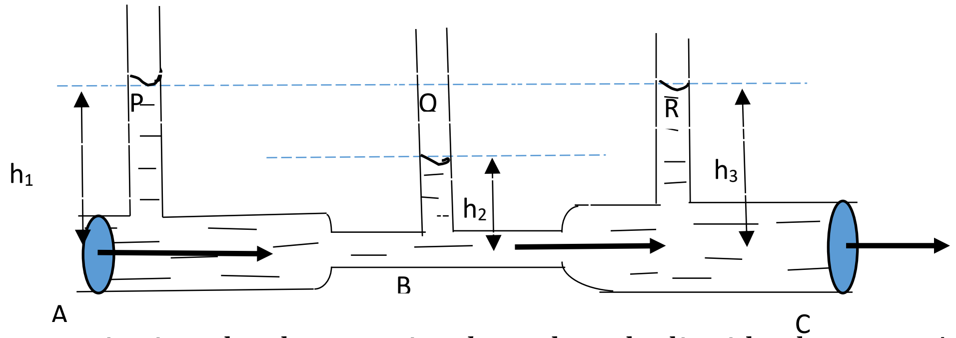
Explaining Bernoulli's effect:
By considering a liquid that is flowing steadily along a horizontal pipe which has a constriction in the middle with narrow vertical tubes, P, Q and R that act as manometers.

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.

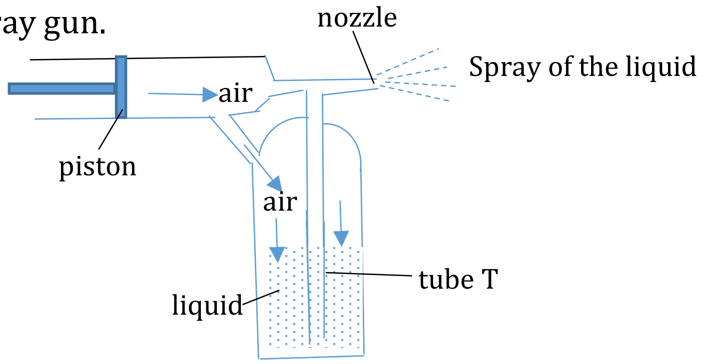
Note: In the sections where the velocity is greatest, the streamlines are closest together and vice-versa.

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.

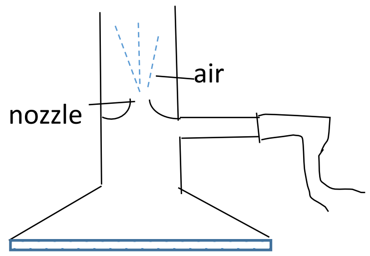


When the piston is pushed in, it forces the air in the cylinder to move with a high velocity over the tip of the tube, T. This causes the air inside the cylinder to fall below that in the liquid reservoir. The pressure acting on the liquid surface forces the liquid to rise up the tube, T. The liquid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

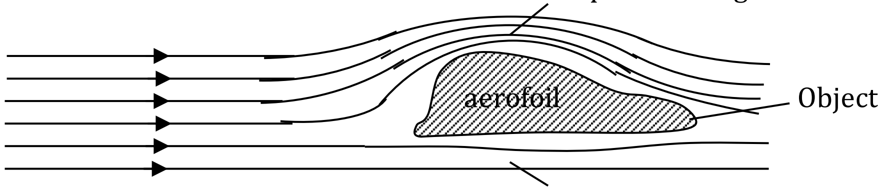
A paint sprayer, perfume or deodorant sprayer also works on the same principle.

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.

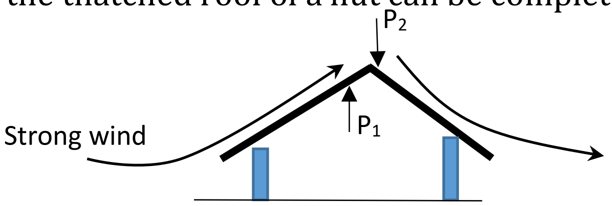


2. Aero foil



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.

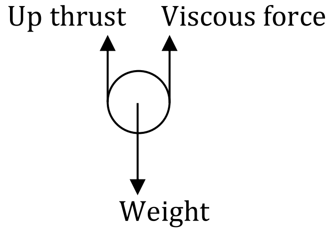
The intermolecular attraction creates a force that opposes sliding of the planes of liquid molecules. This is known as the *viscous force.*
The viscous force resists flow of a fluid and the movement of an object through a fluid.

Viscosity increases with velocity. 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.

Viscosity decreases as the temperature of the liquid rises.

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.

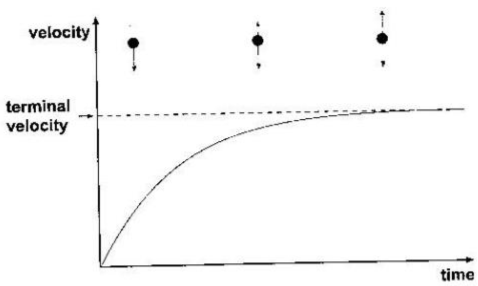
Fall of Objects through the Atmosphere



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.

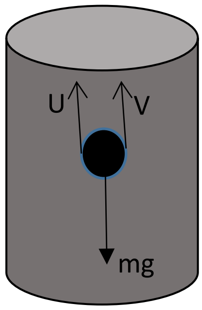


Factors Affecting Terminal Velocity:
- density of the medium (the fluid)
- density of the falling body
- viscosity of the fluid

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.

Factors Affecting Terminal Velocity
- density of the medium (the fluid)
- density of the falling body
- viscosity of the fluid
- shape of the body
- radius (size) of the body.

Applications of terminal velocity
- Sky diving: Air resistance opposes motion of the objects falling freely in air. When a skydiver opens a parachute in air, the large surface area as well as the design of the parachute increases air resistance. This in turn lowers the terminal velocity which helps the sky diver land safely on the ground.
- Rain drops. : The small size of raindrops lowers the terminal velocity hence little or no damage is caused to plants when it rains.

THE END