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SLO-based quick notes
Chapter: 06
"FLUID DYNAMICS"

Mechanics • The branch of physics dealing with action of forces on matter.

↓

FLUID Mechanics • The study of fluids either in motion or at rest

FLUID statics
• study of fluids at rest

FLUID dynamics
• study of fluids in motion (liquids and gases)

→ **FLUID:**
The state of matter which can flow from one place to another.

1. Viscous Fluids

→ **Viscosity:** The force of friction b/w different layers of a fluid is called viscosity.

• **examples:** Honey has high viscosity
Freely Flowing Gasoline has Low viscosity.

• **Intermolecular forces:** The stronger the intermolecular forces, the more the viscosity.

• **Depends upon:** **1)** Nature of fluid **2)** Cohesive forces **3)** Temperature of fluid

→ **Coefficient of viscosity:** The numeric value of resistance to flow of a fluid (viscosity) is called coefficient of viscosity. • **represented by:** η

• **SI Unit:** Pascal second (Pa s)

• **Other units:** $Kg\,m^{-1}s^{-1}$ **or** $Nm^{-2}s$ **or** dyne second/cm^2

• **Dimension:** $[\eta] = [ML^{-1}T^{-1}]$

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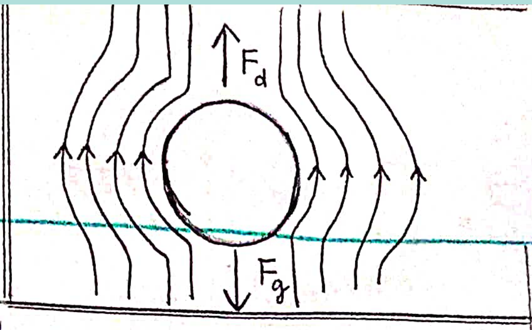
. Stokes Law



Drag Force:

→ An object moving through a fluid experiences a retarding force called drag force.

→ **Explanation:**

- When an object moves through a fluid, the fluid exerts a retarding force that reduces the speed of the object.
- The moving body exerts a force on the fluid to push it out of the way
- By Newton's 3rd law of motion, the fluid pushes back on the body with equal and opposite force

→ **Example:**

Putting our hand out the window of a fast moving car.

→ **Factors drag force depends on:**

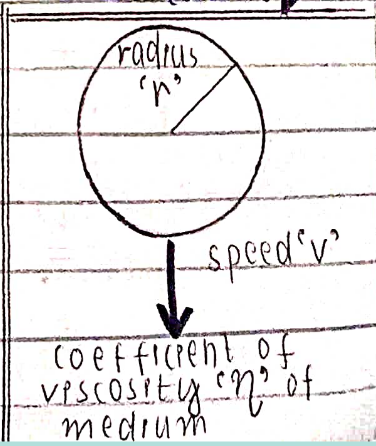
1. Size, shape and orientation
2. Properties of the fluid (viscosity & density)
3. Speed of the object relative to fluid

Stokes law:

The viscous drag force on a spherical object is expressed by a formula, termed as stoke's law.

→ **Consideration:** according to stoke's law F_D

- depends upon '**r**' radius of spherical object
- '**v**' velocity of spherical object
- '**η**' coefficient of viscosity of medium



$$F_D \propto \eta r v$$

$$F_D = A \eta r v$$

$\therefore A = 6\pi$

$$\boxed{F_D = 6\pi \eta r v}$$

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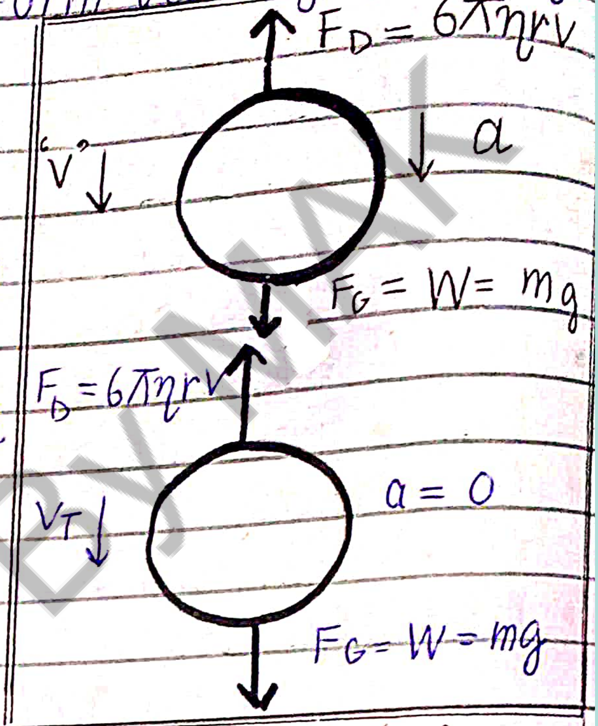
3. Terminal Velocity

definition:

- It is the maximum uniform velocity of a body facing fluid friction



explanation:

- When net force = 0, then acceleration terminates. When this happens, we say that the object has reached its terminal speed
- **terminal velocity** (V_T) ⇒ **for falling objects** in downward direction

Consideration:

- ~~Considered~~ Consider a spherical body of radius '**r**' moving with '**v**' speed through medium of viscosity '**η**'

The eq. for net can be written as,

Net force = weight − drag force

$$F = W - F_d$$
$$F_{net} = F_G - F_D$$
$$ma = mg - 6\pi\eta r v$$
$$m(0) = mg - 6\pi\eta r V_T$$
$$6\pi\eta r V_T = mg$$
$$\boxed{V_T = \frac{mg}{6\pi\eta r}} \rightarrow (a)$$

For sphere of uniform density,

$$m = \rho V$$

$\because V = \frac{4}{3}\pi r^3$

$$\boxed{m = \frac{4}{3}\pi r^3 \rho}$$

Putting value of mass in (a)

$$V_T = \frac{4/3\,\pi r^3 \rho g}{6\pi\eta r}$$
$$V_T = \frac{4\pi r^3 \rho g}{18\pi\eta r}$$
$$\boxed{V_T = \frac{2\rho g r^2}{9\eta}} \rightarrow (b)$$
$$V_T = \text{constant } r^2$$
$$\boxed{V_T \propto r^2}$$

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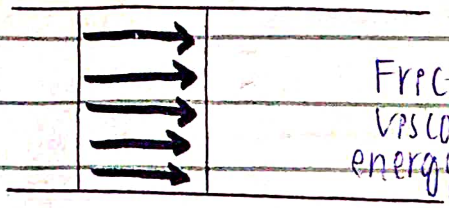
4. Fluid flow

→ Ideal Fluid Flow:

1. **Non-viscous** – No friction b/w layers of fluid
2. **Steady (Laminar) flow** – velocity of fluid at each point remains constant
3. **Incompressible** – No change in density
4. **Irrotational** – No angular momentum at any point {$\omega \to 0$}
5. **Temperature doesn't vary**



Friction = 0
viscosity (η) = 0
energy loss = 0

Laminar Flow	Turbulent flow
definition	
• The flow of a fluid in which every particle moves along a smooth path.	The irregular / unsteady flow of a fluid is called turbulent flow.
Characteristics	
• Regular, steady or smooth flow of a fluid	Irregular, unsteady or random flow of a fluid.
Effect of velocity	
• It flows with low velocity	It flows with high velocity
Effect of viscosity	
• It has high viscosity	It has low viscosity
crossing of fluid layers	
• Fluid layers do not cross each other	Fluid layers cross eachother
examples	
i) smooth flow of deep water ii) flow of gentle breeze	i) windstorm (turbulent flow of gas particles) ii) random motion of smoke particles

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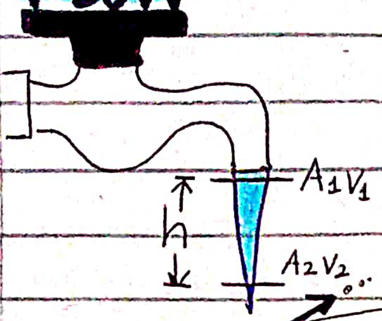
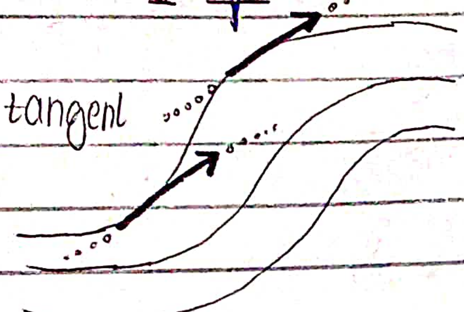
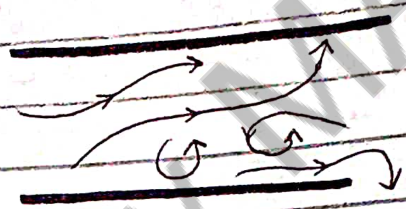
Laminar Flow



Turbulent Flow


tornado

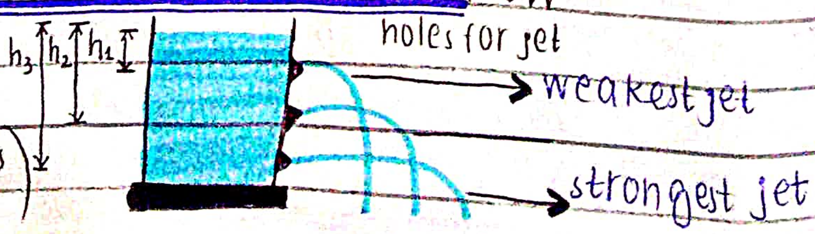




- all points follow the path of others.

Ideal Fluid		Real Fluid
	Density	
constant and hence called as incompressible		compressible, as density varies with applied pressure.
	Viscosity	
zero		Non-zero
	Irrotationality	
zero		Turbulence in flow exist.
	Surface Tension	
zero		Non-zero
	Bulk Modulus	
Infinite		Finite
→ Laminar flow		→ Turbulent flow.

→ Spouting can (e.g of torcelli's theorem)



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5. Equation of Continuity

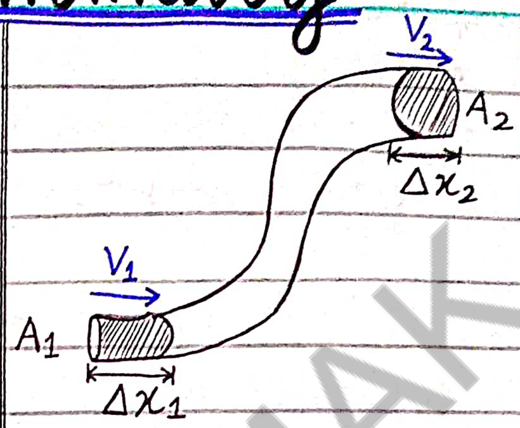
- Valid only for ideal fluids
- Based on conservation of mass

→ **Statement:**

The product of cross sectional area and speed of fluid at any point along the pipe is constant

$$A_1 v_1 = A_2 v_2$$

→ $$\boxed{Av = \text{constant}}$$



∵ rate of flown = volume flown in 1 second

⇒ $A_1 v_1 = A_2 v_2$ ∵ v = velocity ∵ A = area

⇒ Av = constant

⇒ $v \propto \frac{1}{\text{area}}$

→ **Proof:**

- **consideration:**

Consider a pipe of non-uniform size through which an ideal fluid is flowing. Let Δx_1, A_1 and v_1 are the distance, area and speed of ideal fluid at lower end of pipe as shown above

- **derivation:**

- Distance Δx_1 covered by a fluid in time Δt is given by:

$$\Delta x_1 = v_1 \Delta t$$

- Volume contained by a fluid at lower end of pipe is;

$$V = A_1 \Delta x_1$$

$$V = A_1 v_1 \Delta t \quad (\text{value of } \Delta x_1)$$

- Mass contained by ideal fluid at lower end is;

$$\Delta m_1 = V \rho_1$$

$$\Delta m_1 = A_1 v_1 \Delta t \rho_1$$

- Similarly, mass Δm_2 at upper-end of pipe

$$\Delta m_2 = A_2 v_2 \Delta t \rho_2$$

- From law of conservation of mass, $\Delta m_1 = \Delta m_2$

$$A_1 v_1 \Delta t \rho_1 = A_2 v_2 \Delta t \rho_2$$

cutting,

$$A_1 v_1 = A_2 v_2$$

In general,

$$\boxed{Av = \text{constant}}$$

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6. Bernoulli's equation

- valid for ideal fluids
- law of conservation of energy
- involves Pressure, Height and Speed

→ **Statement:**

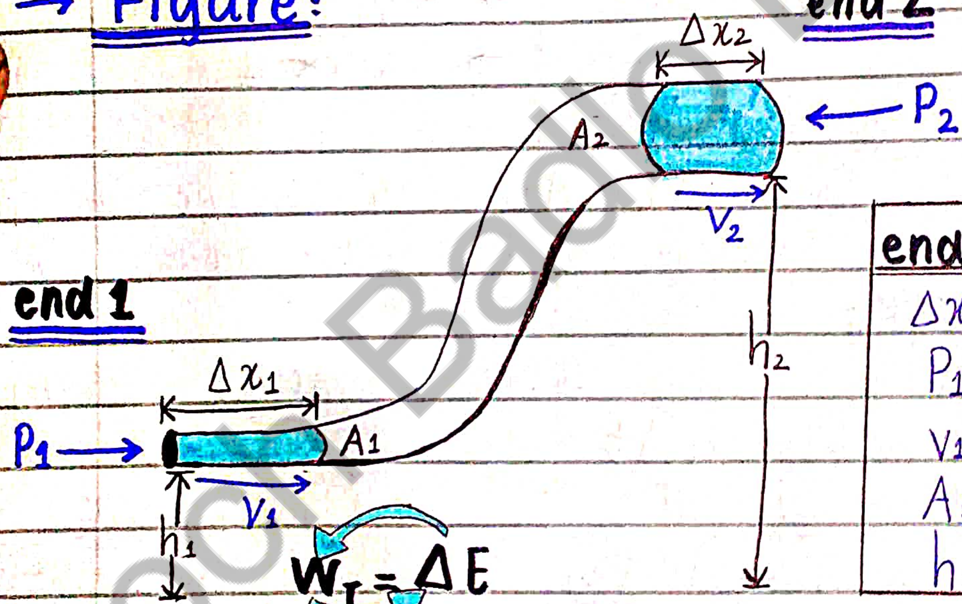
Bernoulli's equation that relates the pressure, flow speed and height of an ideal fluid

Mathematically:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

$$\boxed{P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}}$$

→ **Figure:**

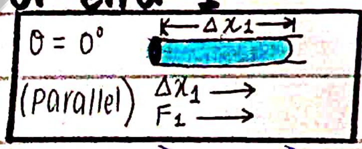


end 1	end 2
Δx_1	Δx_2
P_1	P_2
V_1	V_2
A_1	A_2
h_1	h_2

$$W_T = \Delta E$$

$$W_1 + W_2 = \Delta K.E + \Delta P.E \quad \text{(finding out)}$$

→ **For end-1**



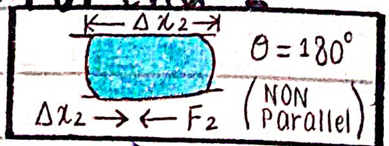
$W_1 = \vec{F_1} \cdot \vec{\Delta x_1}$

$W_1 = F_1 \Delta x_1 \cos\theta$ $\quad \because \cos(0°) = 1$

$W_1 = F_1 \Delta x_1 \cos(0°)$

$\boxed{W_1 = F_1 \Delta x_1}$

→ **For end-2**



$W_2 = \vec{F_2} \cdot \vec{\Delta x_2}$

$W_2 = F_2 \Delta x_2 \cos\theta$ $\quad \because \cos(180°) = -1$

$W_2 = F_2 \Delta x_2 \cos(180°)$

$\boxed{W_2 = -F_2 \Delta x_2}$

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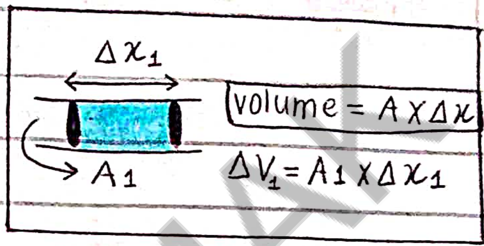
1. Pressure

As, $F = PA$

$F_1 = P_1 A_1$ and $F_2 = P_2 A_2$

$\Rightarrow W_1 = F_1 \Delta x_1$ | $\Rightarrow W_2 = -F_2 \Delta x_2$

$W_1 = P_1 A_1 \Delta x_1$ | $W_2 = -P_2 A_2 \Delta x_2$



2. Volume (remains same)

As, $\Delta V_1 = A_1 \Delta x_1$ so, $W_1 = P_1 \Delta V_1$

As, $\Delta V_2 = A_2 \Delta x_2$ so, $W_2 = -P_2 \Delta V_2$

3. Density (mass and density remains same)

$$\rho = \frac{\Delta m}{V} \Rightarrow \Delta V = \frac{\Delta m}{\rho}$$

As, $\Delta V_1 = \Delta V_2 = \Delta V$; then $\Delta V_1 = \frac{\Delta m}{\rho}$ and $\Delta V_2 = \frac{\Delta m}{\rho}$

As, $W_1 = P_1 \Delta V_1$ As, $W_2 = -P_2 \Delta V_2$

$$\boxed{W_1 = \frac{P_1 \Delta m}{\rho}} \qquad \boxed{W_2 = -\frac{P_2 \Delta m}{\rho}}$$

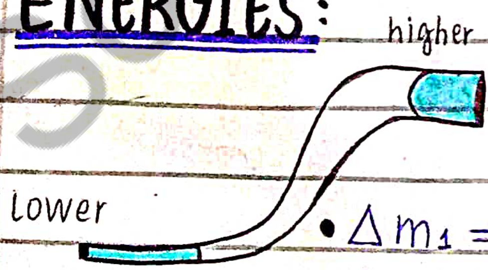
As, $W_T = W_1 + W_2$

$W_1 + W_2 = \Delta K.E + \Delta P.E$

$$\frac{P_1 \Delta m}{\rho} + \left(-\frac{P_2 \Delta m}{\rho}\right) = \frac{P_1 \Delta m}{\rho} - \frac{P_2 \Delta m}{\rho}$$

$$\boxed{W_T = \frac{P_1 \Delta m}{\rho} - \frac{P_2 \Delta m}{\rho}}$$

→ ENERGIES:



- $\Delta K.E = \frac{1}{2} \Delta m_2 V_2^2 - \frac{1}{2} \Delta m_1 V_1^2$
- $\Delta U = \Delta m_2 g h_2 - \Delta m_1 g h_1$
- $\Delta m_1 = \Delta m_2 = \Delta m$

$$W = \Delta K.E + \Delta P.E$$

$$\frac{P_1 \Delta m}{\rho} - \frac{P_2 \Delta m}{\rho} = \frac{1}{2} \Delta m_2 V_2^2 - \frac{1}{2} \Delta m_1 V_1^2 + \Delta m_2 g h_2 - \Delta m_1 g h_1$$

as mass is constant $\Delta m_1 = \Delta m_2 = \Delta m$

$$\frac{P_1 \Delta m}{\rho} - \frac{P_2 \Delta m}{\rho} = \frac{1}{2} \Delta m V_2^2 - \frac{1}{2} \Delta m V_1^2 + \Delta m g h_2 - \Delta m g h_1$$

(Δm and ρ are common)

$$\frac{\Delta m}{\rho}(P_1 - P_2) = \Delta m\left(\frac{1}{2}v_2^2 - \frac{1}{2}v_1^2 + gh_2 - gh_1\right)$$

$$\frac{1}{\rho}(P_1 - P_2) = \left(\frac{1}{2}v_2^2 - \frac{1}{2}v_1^2 + gh_2 - gh_1\right)$$

$$P_1 - P_2 = \rho\left(\frac{1}{2}v_2^2 - \frac{1}{2}v_1^2 + gh_2 - gh_1\right)$$

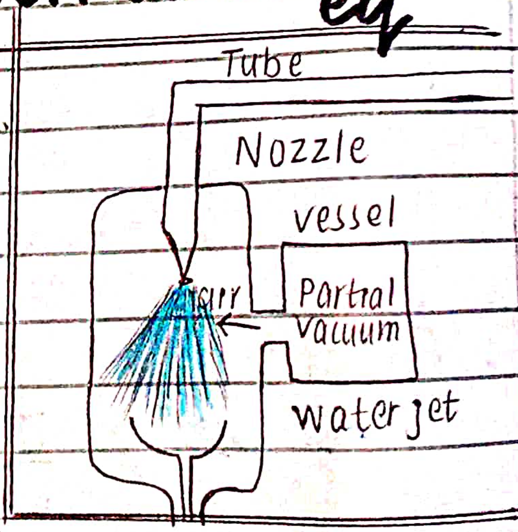
$$P_1 - P_2 = \frac{1}{2}\rho v_2^2 - \frac{1}{2}\rho v_1^2 + \rho g h_2 - \rho g h_1$$

$$\boxed{P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2}$$

generally,

$$\boxed{P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}}$$

Applications of Bernoulli's eq



1. Filter Pumps:

① Definition:

→ A device used to produce partial vacuum in vessel attached to it.

② Components:

1) Tube
2) Nozzle
3) Water jet
4) Vessel

③ Working:

1) Water flows from tube towards jet.
2) Near jet-section, water's speed increases, pressure drops
3) Air flows from the side tube
4) Air and water are forced at bottom of filter pump

④ Usage:

Pumps are used to transfer liquids from low pressure zones ⟶ high pressure zones.

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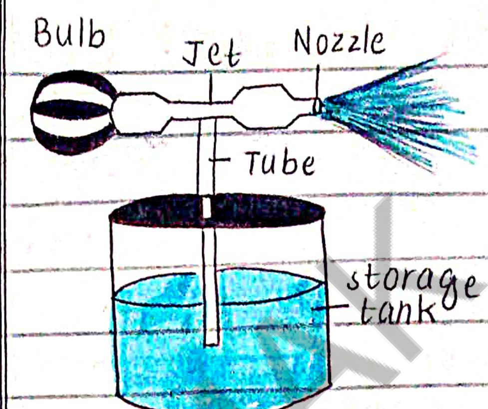
2. Atomizers

→ **definition:**
A device for emitting water, perfume, or other liquids as a fine spray.



→ **components:**
1) Jet
2) Nozzle
3) Tube
4) storage Tank
5) Bulb

→ **working:**
1) a stream of air passing over one end of open tube
2) The other end is immersed in a liquid, reducing pressure.
3) This reduction in pressure, causes the liquid to rise into air stream, ready for dispersion. like fine spray.

→ **examples:** perfume bottles, engine carburetor, water filter pumps and paint sprayers.

3. Torcelli's theorem

→ **valid for:** flowing fluids with negligible viscosity.

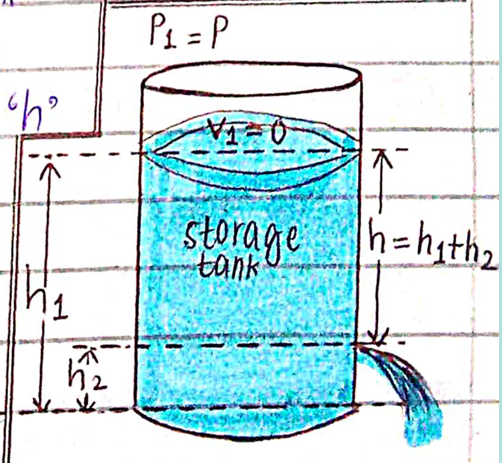
→ **Statement:** The speed of efflux is equal to the speed gained by fluid while falling through height 'h' under action of gravity

→ **formula:** $\boxed{v = \sqrt{2gh}}$

→ **Independent of:** ρ (density)

→ **Importance:** The law explains the relation b/w fluid leaving a hole and liquids 'h' at container

→ **Example:** Spouting can



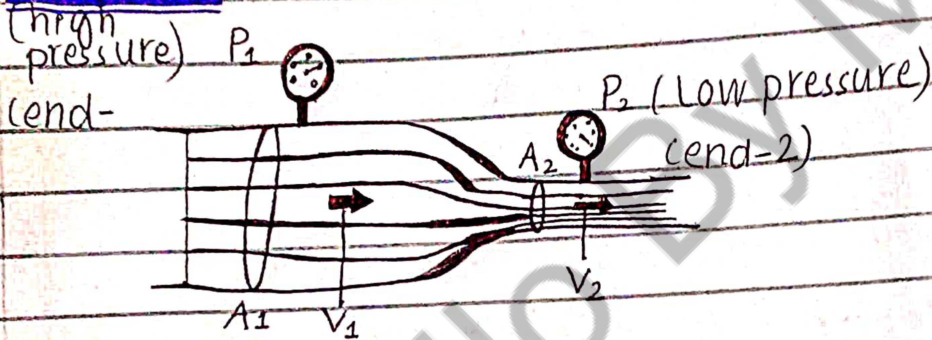
▶ a leak at bottom of a large storage tank

4. Venturi Metre (Flow metre)

→ **statement/definition:**
Venturi metre is a device used to measure the flow speed or flow rate through a piping system

→ **Principle:** Bernoulli effect.

→ **Figure:**



→ **Flow Velocity:**

mathematically;

$$V_1 = A_2 \sqrt{\frac{2(P_1 - P_2)}{\rho (A_1^2 - A_2^2)}}$$

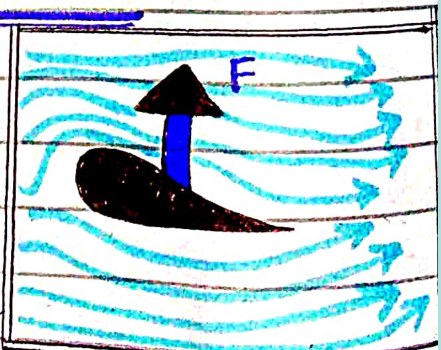
→ with barometer

$$V_1 = A_2 \sqrt{\frac{2(gh)}{(A_1^2 - A_2^2)}}$$

→ without barometer

5. Aerofoil

→ **definition:**
The devices which are shaped so that relative motion b/w it and the fluid produces a force perpendicular to the flow are called aerofoils



higher flow speed

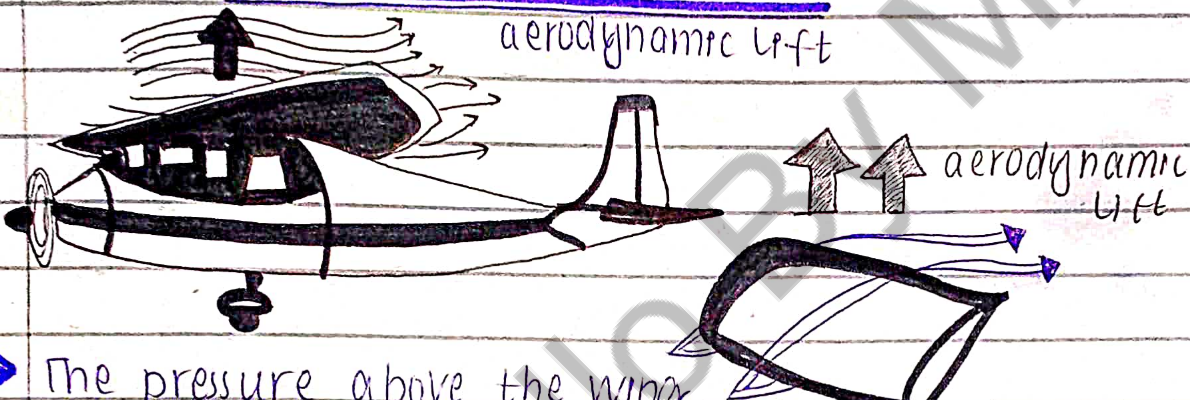
→ **Shape of aerofoils:** stream-lined

→ **Aerodynamic force:** An airfoil-shaped body moved through a fluid produces an aerodynamic for

→ Principle:
Bernoulli effect

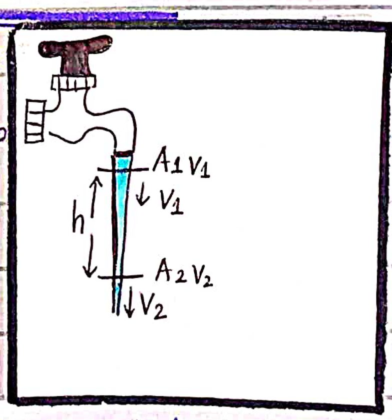
→ Components:
- perpendicular to direction of motion = **lift**
- parallel to direction of motion = **drag**

→ examples:
Aeroplane wings, helicopters, sail boats, propellers fans, compressors etc.

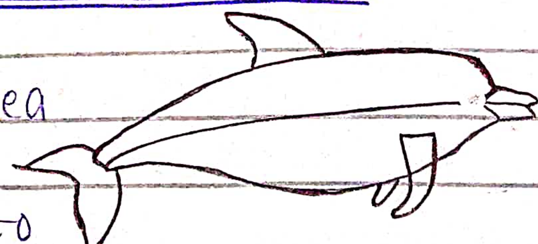


→ The pressure above the wing is reduced relative to the pressure under the wing, as a result is lifted upward.

→ equation of continuity:



- When water falls from a tap, the speed increases under the action of gravity as it falls
- When the speed increases, the cross sectional area decreases to keep the equation of continuity valid.



→ Dolphins and other sea-creatures have stream-lined bodies to assisst their movement in water.

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6. Blood Flow

→ **Introduction:**

- The flow of blood in the arteries is a very good example of Bernoulli's ~~eq~~ principle.

→ **Principle:** Bernoulli's effect

→ **Dependence:**

- The blood flowing in the body depends upon the radius of its arteries

→ **Blood velocity and pressure relationship:**

- Pressure decreases ; blood velocity increases
- Pressure increases ; blood velocity decreases
- P↑V↓ ; P↓V↑

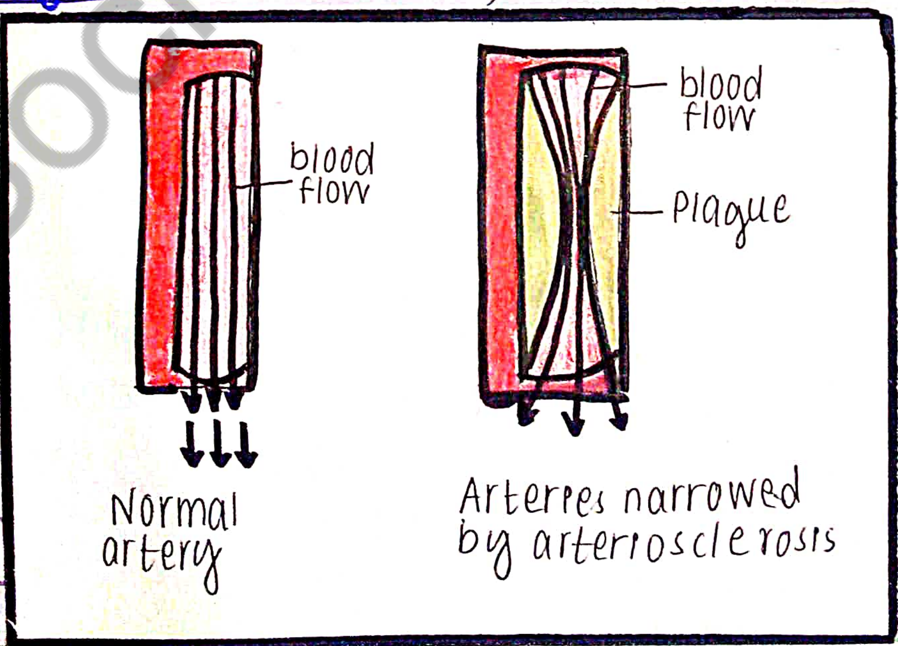
→ **Reduction of radius of arteries :**

- **arteriosclerosis** results in the thickening or hardening of artery walls, thus reducing the radius of arteries

→ **Danger of reduction of radius :**

It can even result in heart attacks.

→ **Figure:** (Master art)



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