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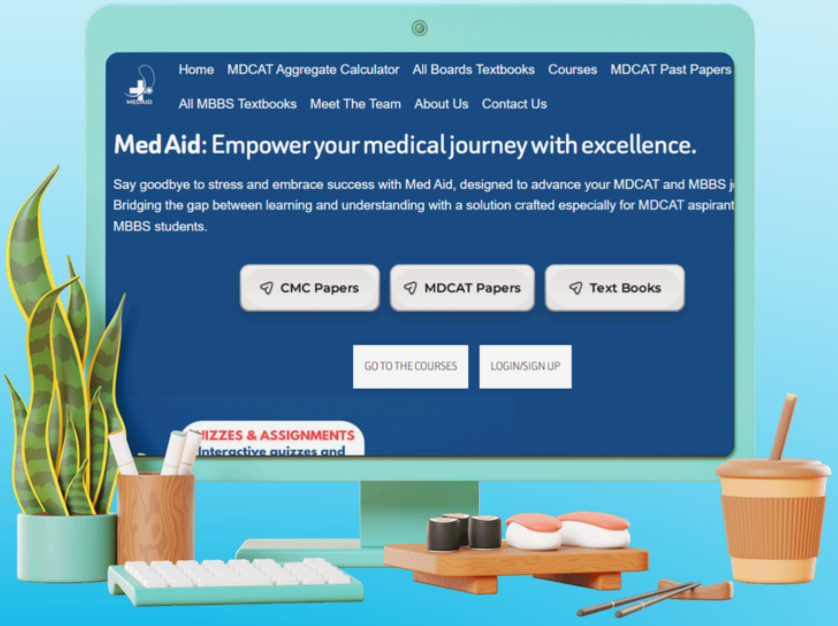

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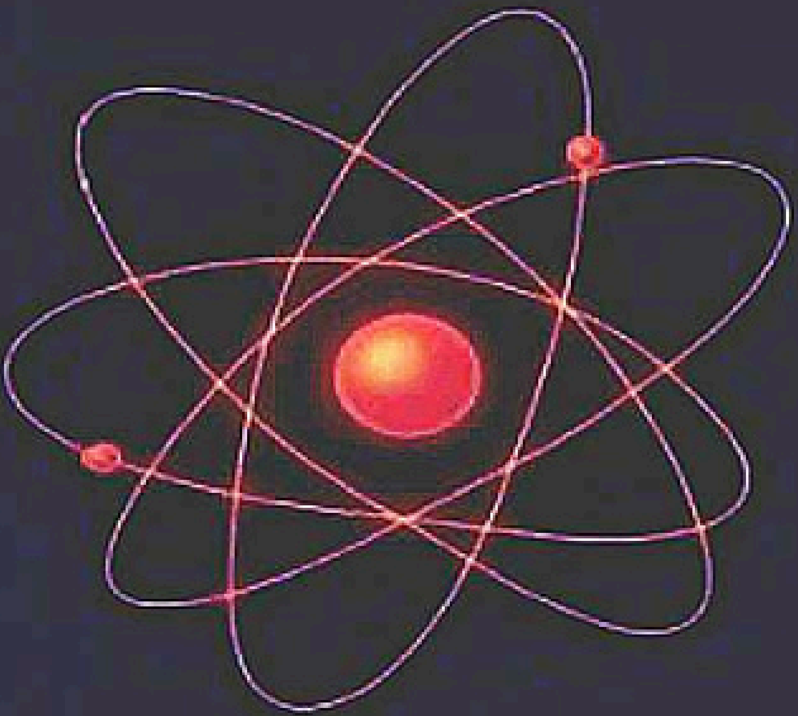

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FAISAL NADEEM

VECTORS AND EQUILIBRIUM

SCALARS:

A scalar is a physical quantity that has **only magnitude**, no direction.

EXAMPLES:

- Length
- Mass
- Time
- Temperature
- Speed
- Energy
- Work
- Heat
- Entropy
- Pressure
- Luminous intensity
- Amount of substance

NOTE:

Electric current has direction but is a scalar because it **does not obey vector algebra**.

VECTORS:

A vector is a physical quantity that has **both magnitude and direction** and follows the **laws of vector algebra**.

EXAMPLES:

- Displacement
- Velocity
- Acceleration
- Force
- Weight
- Thrust
- Momentum
- Impulse
- Torque
- Angular momentum
- Angular velocity

VECTOR NOTATION:

- In books: **Boldface** letters (e.g., **A**, **F**, **v**)
- In handwriting: **Arrowed letters** (e.g., $\vec{A}, \vec{F}, \vec{v}$)
- Magnitude written as: $A = |\vec{A}|$

VECTOR REPRESENTATION:

- Graphically: Straight line with an arrowhead
- Length ∝ magnitude
- Arrowhead shows direction

TYPES OF VECTORS:

- **Null/Zero Vector**: Magnitude is zero, direction is arbitrary
- **Unit Vector**: Magnitude = 1, indicates direction only
- **Equal Vectors**: Same magnitude and direction
- **Parallel Vectors**: Same direction
- **Anti-parallel Vectors**: Opposite direction
- **Perpendicular Vectors**: Angle = 90°, dot product = 0
- **Position Vector**: Vector from origin to a point
- **Resultant Vector**: Vector sum of two or more vectors

ADDITION OF VECTORS:

Vectors are added by head to tail rule

Graphically vectors are added by head to tail rule.

"According to this rule vectors are drawn in such a way that head of first vector coincides with the tail of second vector."

PROPERTY	DESCRIPTION
Commutative Law	$\vec{A} + \vec{B} = \vec{B} + \vec{A}$
Associative Law	$\vec{A} + (\vec{B} + \vec{C}) = (\vec{A} + \vec{B}) + \vec{C}$
Only Same Type Add	Only vectors of same physical quantity can be added (e.g., force + force)

RESULTANT VECTOR:

The sum of two or more vectors is called resultant vector.

OR "A single vector that has the same effect as two or more vectors acting together."

PROPERTIES:

- Max when vectors are in same direction:
  $$R = A + B$$
- Min when vectors are opposite: $R = |A - B|$
- If three vectors form a closed polygon (cyclic order), their resultant is zero.
- Resultant of two equal vectors cannot be zero.
- Resultant two vectors having equal magnitude but opposite direction is zero.

یادرکھیں

اگر دو vectors کا magnitude اور دی گئی ہو تو اس فارمولے سے Resultant کا magnitude معلوم کریں۔

$$R = \sqrt{A^2 + B^2 + 2AB cos\theta}$$

EXAMPLE:

The resultant of two direction perpendicular vectors having magnitude 5 and 12 is

$$R = \sqrt{(5)^2 + (12)^2 + 2(5)(12)cos90}$$
$$= \sqrt{25 + 144} = \sqrt{169} = 13$$

اگر دو برابر magnitude والے ویکٹرز کے درمیان اینگل 60° ہو تو ان کے resultant کا magnitude بھی ان کے برابر ہی ہو گا۔

SUBTRACTION OF VECTORS:

The subtraction of a vector is equivalent to the addition of same vector with its direction is reversed.

جس vector کو subtract کرنا ہو پہلے اس کی direction کو reverse کریں پھر
“head to tail rule” سے دوسرے vector میں add کر دیں۔

COMPONENTS OF A VECTOR:

Component of a vector in any direction is its effective value in that direction.

Components of a vector which are perpendicular to each other are called rectangular components.

Let a vector $\vec{A}$ make an angle θ with the **positive x-axis**.
Then it can be resolved into:

$$\vec{A}_x = A\cos\theta \quad \text{(X-component)}$$
$$\vec{A}_y = A\sin\theta \quad \text{(Y-component)}$$

So, the vector can be written as:

$$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath}$$

If components are given:

$$A_x = A\cos\theta, \quad A_y = A\sin\theta$$

Then,

- **Magnitude** of $\vec{A}$:
$$A = \sqrt{A_x^2 + A_y^2}$$
- **Direction (angle with x-axis)**:
$$\theta = \tan^{-1}\left(\frac{A_y}{A_x}\right)$$

VECTOR ADDITION BY RECTANGULAR COMPONENTS

- Resolve each vector into x and y components.
- Add all x-components: $R_x = \sum A_x$
- Add all y-components: $R_y = \sum A_y$
- Resultant: $R = \sqrt{R_x^2 + R_y^2}$
- Direction: $\theta = \tan^{-1}(R_y/R_x)$

SCALAR MULTIPLICATION OF A VECTOR

Scalar multiplication means multiplying a **vector** by a **real number (scalar)**. The result is a **new vector** whose **magnitude changes**, but the **direction may or may not change**, depending on the sign of the scalar.

If $\vec{A}$ is a vector and n is a scalar:

$$\vec{B} = n\vec{A}$$

- If $n > 0$: Direction of $\vec{B}$ is **same** as $\vec{A}$
- If $n < 0$: Direction of $\vec{B}$ is **opposite** to $\vec{A}$
- If $n = 0$: $\vec{B}$ becomes the **null vector** (zero vector)

SCALAR PRODUCT (DOT PRODUCT)

DEFINITION:

The **scalar product** (also called **dot product**) of two vectors is a number (scalar) obtained by multiplying their magnitudes with the **cosine of the angle** between them.

Mathematical Formula

If $\vec{A}$ and $\vec{B}$ are two vectors making an angle θ between them:

$$\vec{A}\cdot\vec{B} = AB\cos\theta$$

Where:

- $A = |\vec{A}|$ = magnitude of vector $\vec{A}$
- $B = |\vec{B}|$ = magnitude of vector $\vec{B}$
- θ = angle between $\vec{A}$ and $\vec{B}$
- Result is a **scalar (number)**

Dot product gives the **product of one vector's magnitude** with the **component of the other vector in its direction**.

COMPONENT FORM:

If:

$$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}, \quad \vec{B} = B_x\hat{\imath} + B_y\hat{\jmath} + B_z\hat{k}$$

Then:

$$\vec{A}\cdot\vec{B} = A_xB_x + A_yB_y + A_zB_z$$

EXAMPLES:

PHYSICAL QUANTITY	FORMULA
Work	$W = \vec{F}\cdot\vec{d} = Fd\cos\theta$
Power	$P = \vec{F}\cdot\vec{v}$
Electric Flux	$\Phi_E = \vec{E}\cdot\vec{A}$
Magnetic Flux	$\Phi_B = \vec{B}\cdot\vec{A}$

CHARACTERISTICS:

PROPERTY	RULE
Commutative	$\vec{A}\cdot\vec{B} = \vec{B}\cdot\vec{A}$
Distributive	$\vec{A}\cdot(\vec{B}+\vec{C}) = \vec{A}\cdot\vec{B} + \vec{A}\cdot\vec{C}$
Scalar Output	Always gives a **number**, not a vector
Perpendicular Vectors	If $\theta = 90°$, then $\cos 90° = 0 \rightarrow \vec{A}\cdot\vec{B} = 0$
Parallel Vectors	Dot product is **maximum**, $\theta = 0° \rightarrow \vec{A}\cdot\vec{B} = AB$
Self Dot Product	$\vec{A}\cdot\vec{A} = A^2$

ANGLE BETWEEN TWO VECTORS:

If:

$$\vec{A}\cdot\vec{B} = AB\cos\theta \Rightarrow \cos\theta = \frac{\vec{A}\cdot\vec{B}}{AB} \Rightarrow \theta = \cos^{-1}\left(\frac{\vec{A}\cdot\vec{B}}{AB}\right)$$

Use this formula to **find angle between two vectors**.

NOTE:

- Dot product = scalar
- Only **parallel components** multiply
- Zero result means **perpendicular vectors**
- Used in **work**, **flux**, and **angle calculations**

VECTOR PRODUCT (CROSS PRODUCT)

Definition

The **vector product** (also called **cross product**) of two vectors is a **vector** obtained by multiplying their magnitudes and the **sine of the angle** between them. The result is a vector **perpendicular** to the plane of the two original vectors.

Mathematical Formula

If $\vec{A}$ and $\vec{B}$ are two vectors making angle θ:

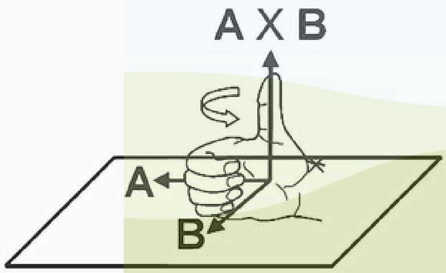
$$\vec{A} \times \vec{B} = AB\sin\theta\,\hat{n}$$

Where:

- $A = |\vec{A}|$, $B = |\vec{B}|$ are magnitudes
- θ is the angle between $\vec{A}$ and $\vec{B}$
- $\hat{n}$ is a **unit vector perpendicular** to the plane of $\vec{A}$ and $\vec{B}$
- The result is a **vector**

RIGHT HAND RULE:

- Point fingers in direction of $\vec{A}$
- Curl fingers toward $\vec{B}$ (through **smaller angle**)
- Thumb points in the **direction of resultant vector**



Magnitude:

$$|\vec{A} \times \vec{B}| = AB\sin\theta$$

- Maximum when $\theta = 90^\circ$
- Zero when $\theta = 0^\circ$ or 180°

Vector Product in Determinant Form

$$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}, \quad \vec{B} = B_x\hat{\imath} + B_y\hat{\jmath} + B_z\hat{k}$$

Then:

$$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

EXAMPLES:

QUANTITY	FORMULA
Torque	$\vec{\tau} = \vec{r} \times \vec{F}$
Angular Momentum	$\vec{L} = \vec{r} \times \vec{p}$
Magnetic Force	$\vec{F} = q\vec{v} \times \vec{B}$
Tangential Velocity	$\vec{v} = \vec{\omega} \times \vec{r}$

CHARACTERISTICS:

PROPERTY	RULE
Not Commutative	$\vec{A} \times \vec{B} = -(\vec{B} \times \vec{A})$
Distributive	$\vec{A} \times (\vec{B} + \vec{C}) = \vec{A} \times \vec{B} + \vec{A} \times \vec{C}$
Zero Result	If vectors are **parallel** or **antiparallel**
Max Result	If vectors are **perpendicular**
Self Cross Product	$\vec{A} \times \vec{A} = \vec{0}$
Unit Vectors	$\hat{\imath} \times \hat{\jmath} = \hat{k}, \quad \hat{\jmath} \times \hat{k} = \hat{\imath}, \quad \hat{k} \times \hat{\imath} = \hat{\jmath}$

EXAMPLE:

Let:

$$\vec{A} = \hat{\imath} + \hat{\jmath}, \quad \vec{B} = \hat{\imath} - \hat{\jmath}$$

Then:

$$\vec{A} \times \vec{B} = (\hat{\imath} + \hat{\jmath}) \times (\hat{\imath} - \hat{\jmath}) = \hat{\imath} \times \hat{\imath} - \hat{\imath} \times \hat{\jmath} + \hat{\jmath} \times \hat{\imath} - \hat{\jmath} \times \hat{\jmath}$$

Use:

- $\hat{\imath} \times \hat{\imath} = 0$
- $\hat{\imath} \times \hat{\jmath} = \hat{k}$
- $\hat{\jmath} \times \hat{\imath} = -\hat{k}$
- $\hat{\jmath} \times \hat{\jmath} = 0$

So:

$$\vec{A} \times \vec{B} = -\hat{k} - \hat{k} = -2\hat{k}$$

NOTE:

- Cross product = **vector**
- Direction = **perpendicular to both**
- Use **right-hand rule**
- Common in **torque, magnetism, angular motion**

REMEMBER:

- Scalar ÷ Vector = ✕ (Not valid)
- Vector + Vector = Vector
- Vector − Vector = Vector
- Unit vector: magnitude = 1
- Dot product → scalar
- Cross product → vector

FLUID DYNAMICS

FLUID DYNAMICS: The **study of the motion of fluids** is called **fluid dynamics**.

FLUID: **A fluid is a substance that can flow and take the shape of its container.**

TYPES OF FLUIDS:

- **Liquids** (water, oil etc.)
- **Gases** (Air, steam etc.)

Fundamental Equations of Fluid Dynamics

1. **Equation of Continuity** (conservation of mass)
2. **Bernoulli's Equation** (conservation of energy)

VISCOSITY:

The frictional effect between different layers of a flowing fluid is called viscosity.

COEFFICIENT OF VISCOSITY:

- Denoted by the Greek letter η **(eta)**
- **SI Units**:

$$\text{Kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1},\quad \text{N}\cdot\text{s}\cdot\text{m}^{-2},\quad \text{or Pa}\cdot\text{s}$$

TYPES OF VISCOSITY:

VISCOSITY TYPE	BEHAVIOR	EXAMPLES
High Viscosity	Fluid does **not flow easily**	Glue, Honey, Thick tar, Glycerine
Low Viscosity	Fluid **flows easily**	Air, Water, Alcohol

Viscosities of Liquids and Gases at 30°C

Material	Viscosity 10^{-3} (N s m^{-2})
Air	0.019
Acetone	0.295
Methanol	0.510
Benzene	0.564
Water	0.801
Ethanol	1.000
Plasma	1.6
Glycerin	6.29

Effect of Temperature on Viscosity:

- **FOR LIQUIDS:** Viscosity **decreases** as **temperature increases**
- **FOR GASES:**

DRAG FORCE:

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

- This force is always **opposite to the direction of motion or velocity**.
- The work done by drag force is always negative.

DEPENDENCE:

Drag force depends upon:

- **Speed of object** $(F \propto v)$
  ↑ velocity ⇒ ↑ drag force (F)
- **Size of object** $(F \propto r)$
  ↑ size ⇒ ↑ F
- **Shape of object**
  Streamlined shape ⇒ ↓ F
- **Viscosity of the fluid** $(F \propto \eta)$
  ↑ viscosity ⇒ ↑ F

STOKES' LAW:

Drag force F on a sphere of radius r, moving slowly with speed v through a fluid of viscosity η is given by:

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

LIMITATIONS OF STOKES' LAW:

- Object must be **spherical**
- Motion should be **slow** (low speed)
- Flow around object must be **streamlined**

TERMINAL VELOCITY:

The maximum constant velocity of an object when the drag force becomes equal to its weight is called terminal velocity.

BEFORE TERMINAL VELOCITY:

When object falls in a fluid under gravity

- Acceleration decreases
- Speed increases
- Drag force increases with speed

- Net force = $mg - F_d$ (decreases)

EVENTUALLY:

- Speed becomes maximum (terminal velocity)
- $F_d = mg$
- $F_{\text{net}} = 0, a = 0$
- **Drag force is maximum** (equal to weight)

FORMULA:

$$\boxed{v_t = \frac{mg}{6\pi\eta r}} \quad \text{or} \quad \boxed{v_t = \frac{2r^2\rho g}{9\eta}}$$

Where:

- ρ = density of object
- g = acceleration due to gravity
- r = radius of object
- η = viscosity of the fluid

DEPENDENCE:

Terminal velocity depends upon:

1. Density of the Object

$$v_t \propto \rho \quad \text{or} \quad \frac{v_1}{v_2} = \frac{\rho_1}{\rho_2}$$

2. Size or Radius of the Object

$$v_t \propto r^2 \quad \text{or} \quad \frac{v_{t1}}{v_{t2}} = \left(\frac{r_1}{r_2}\right)^2$$

3. Viscosity of the Medium

$$v_t \propto \frac{1}{\eta} \quad \text{or} \quad \frac{v_{t1}}{v_{t2}} = \frac{\eta_2}{\eta_1}$$

NOTE:

- **If two objects have same mass**, then

$$v_t \propto \frac{1}{r}$$

- **If two objects have same density**, then

$$v_t \propto r^2 \text{ OR } v_t \propto d^2$$

EXAMPLE: Two raindrops A and B have radii r and $2r$, respectively. They fall through air. What is the ratio of their terminal velocities?

(a) 1:2 (b) 2:1

(c) 4:1 (d) 1:4

SOLUTION: As both raindrops have the **same density**,

$$v_t \propto r^2 \text{ OR } v_t \propto d^2$$

$$r_A : r_B = 1:2 \Rightarrow v_A : v_B = 1^2 : 2^2 = 1:4$$

Correct answer: (d) 1:4

Time Taken to Attain Terminal Velocity

- Time taken to attain terminal velocity:

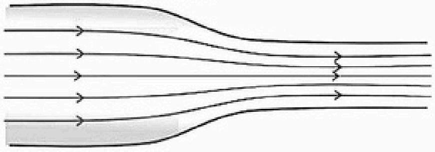
$$t \propto v_t$$

- An object with **greater terminal velocity** takes **more time** to attain it.
- In the above example: Since $v_{tB} > v_{tA}$, object **A** will attain terminal velocity **earlier**.

FLUID FLOW

LAMINAR FLOW:

A type of fluid flow in which **every particle follows the same path** as the particles before it.



- Fluid particles move in **parallel layers** without mixing.
- **Each particle follows the path** of the one before it.
- **Velocity is low and steady.**
- **No sound is produced.**
- **Streamlines do not cross.**
- Flow is smooth and **predictable**.

STREAMLINES:

- **Imaginary lines** that show the path of a fluid particle.
- **Density of streamlines ∝ Speed** of flow
  - **Closer streamlines ⇋ higher speed**
  - **Wider streamlines ⇋lower speed**

STEADY FLOW:

- Flow where **velocity at each point remains constant over time**.
- Used in ideal fluid models.
- Opposite of **unsteady flow**, where velocity changes with time.

COMPRESSIBLE FLOW:

Density changes with pressure (e.g. gases)

INCOMPRESSIBLE FLOW:

Density remains constant (e.g. liquids)

VISCOSITY IN FLOW:

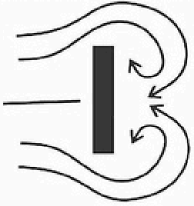
- **Viscosity opposes flow** and causes **energy loss**.
- Higher viscosity = more **resistance to flow**
- Determines whether flow is **laminar or turbulent**

CRITICAL VELOCITY

- The **maximum velocity** of a fluid for which the flow remains **laminar**.
- Above this, flow becomes **turbulent**.

TURBULENT FLOW

- Fluid particles move **randomly and chaotically**.
- Occurs at **high velocities** or with **obstructions**.
- **Streamlines cross each other.**
- Produces **eddies**, **whirlpools**, and **noise**.
- Flow is **irregular and unpredictable**.



IDEAL FLUID

An **ideal fluid** has the following characteristics:

1. **Non-viscous** ($\eta = 0$)
2. **Incompressible** (density ρ = constant)
3. **Steady flow**

SUPERFLUID

Fluids having **no viscosity** are called superfluids.

- Can **flow without energy loss**
- Occurs at extremely low temperatures (e.g., liquid helium)

EQUATION OF CONTINUITY

1. For an **ideal fluid**, the product of **cross-sectional area** and **speed of the fluid** always remains constant.

$$A \cdot v = \text{constant} \quad \text{or} \quad v \propto \frac{1}{A}$$

- **If area increases**, speed **decreases**
- **If area decreases**, speed **increases**

2. For an **ideal fluid**, **Flow rate always remain constant**.

$$\frac{Volume}{time} = constant$$

FLOW RATE:

Volume of fluid **flowing per unit time** is called flow rate or rate of flow.

$$\text{Flow rate} = \frac{\text{Volume}}{\text{time}} = \frac{\text{V}}{\text{t}} = \text{Av}$$

- SI unit: $m^3 s^{-1}$

BASED ON CONSERVATION OF MASS:

- Mass cannot be created or destroyed.
- For an **incompressible fluid**, the **mass flow rate** must remain **constant** throughout the flow.

CONDITIONS:

The fluid is assumed to be:

- ○ **Incompressible** (ρ = constant)
- ○ **Non-viscous**
- ○ **Steady (streamline) flow**

LIMITATIONS:

- Does **not account for energy losses** (like friction or turbulence)
- Applicable only when flow is **steady** and fluid is **incompressible**

DIFFERENT MATHEMATICAL FORMS:

1. Standard Form (Volume Flow Conservation):

$$Av = constant \Rightarrow v \propto {}^{1}/_{A}$$

$$A_1 v_1 = A_2 v_2$$

Where:

- A = Cross-sectional area (m²)
- v = Fluid velocity (m/s)
- Assumes incompressible fluid (ρ = constant)

2. In Terms of Radius:

Since $A = \pi r^2$, the equation becomes:

$$\pi r_1^2 v_1 = \pi r_2^2 v_2 \quad \Rightarrow \quad r_1^2 v_1 = r_2^2 v_2$$

$$\Rightarrow v \propto {}^{1}/_{r^2}$$

3. In Terms of Diameter:

Since $A = \frac{\pi d^2}{4}$, then:

$$\frac{\pi d_1^2}{4} v_1 = \frac{\pi d_2^2}{4} v_2 \quad \Rightarrow \quad d_1^2 v_1 = d_2^2 v_2$$

$$\Rightarrow v \propto {}^{1}/_{d^2}$$

4. In Terms of Mass Flow Rate:

For compressible flow:

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

5. In Terms of Volume (V) and Time (t):

$$V = Avt \quad \Rightarrow \quad V_1 = V_2 \text{ (for same time interval)}$$

APPLICATION IN DAILY-LIFE:

- Blood flow in arteries and veins
- Air flow in wind tunnels
- Water flow through pipes and nozzles
- Jet engines and carburetors
- Spraying devices (atomizers)

BERNOULLI'S EQUATION

STATEMENT:

Bernoulli's equation relates pressure, kinetic energy, and potential energy per unit volume of an incompressible, non-viscous fluid flowing in a streamline.

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

Where:
P = Pressure energy
$\frac{1}{2}\rho v^2$ = Kinetic energy per unit volume
$\rho g h$ = Potential energy per unit volume
ρ = Density of the fluid
v = Fluid speed
h = Height above a reference level

NOTE: Each term in Bernoulli's equation represents energy per unit volume:

- P → **Pressure Energy** → unit: J m^{-3}
- $\frac{1}{2}\rho v^2$ → **Kinetic Energy** → unit: J m^{-3}
- $\rho g h$ → **Potential Energy** → unit: J m^{-3}

ASSUMPTIONS / CONDITIONS:

- Fluid is **incompressible**.
- Fluid is **non-viscous** (no internal friction).
- Flow is **steady** (velocity at each point does not change with time).
- Flow occurs **along a streamline**.
- No energy is added (no pump) or removed (no friction losses).

LIMITATIONS

- Cannot be applied to **turbulent** or **viscous** flows.
- Not valid for **compressible** fluids (e.g., high-speed gases).
- Fails when energy is added or dissipated (e.g., pumps, friction losses).

DIFFERENT CASES:

1. Basic Form:

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

2. Between two points:

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

3. In horizontal flow ($h_1 = h_2$):

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

$$P + \frac{1}{2}\rho v^2 = constant$$

- No change in gravitational potential energy.
- Pressure difference is caused **only** by change in velocity.
- Where speed is high → pressure is low
- Where speed is low → pressure is high

4. Open flow:

$$P_1 = P_2 = \text{atmospheric pressure}$$
$$\frac{1}{2}\rho v_1^2 + \rho g h_1 = \frac{1}{2}\rho v_2^2 + \rho g h_2$$
$$\frac{1}{2}\rho v^2 + \rho g h = constant$$

- Useful in **tank draining** or **fountain** problems.
- Fluid speed increases when height decreases (and vice versa).

5. Flow in Pipe of Uniform Area:

Fluid flows through a pipe of **same cross-sectional area** ($A_1 = A_2$) but located at **different vertical heights.**

$$v_1 = v_2 \quad \text{(since A is constant and flow rate is same)}$$

$$P_1 + \rho g h_1 = P_2 + \rho g h_2$$

$$P + \rho g h = constant$$

- Velocity is **constant** throughout (no kinetic energy change).
- Pressure difference is due to **height difference**.
- At higher point pressure is low.
- At lower point pressure is high.
- Explains why **pressure decreases with elevation** in vertical pipes.

TORRICELLI'S THEOREM

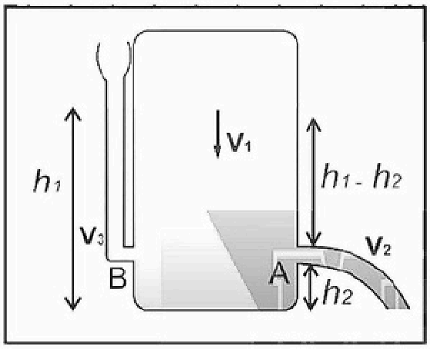
STATEMENT:

Speed of efflux is equal to velocity gained by the fluid in falling through distance $(h_1 - h_2)$ under the action of gravity.

$$v = \sqrt{2g(h_1 - h_2)}$$

Where:

v = speed of efflux
h_1 = height of water level
h_2 = height of orifice
$h_1 - h_2$ = vertical depth of the orifice below the fluid surface



DEPENDECE:

- Efflux speed only depends **upon the vertical depth** $(h_1 - h_2)$ between the surface and the orifice
- Efflux speed is independent of area of the orifice.

Time to reach ground:

$$t = \sqrt{\frac{2h_2}{g}}$$

Horizontal range:

$$x = v \times t = \sqrt{2g(h_1 - h_2)} \times \sqrt{\frac{2h_2}{g}} = 2\sqrt{h_2(h_1 - h_2)}$$

If orifice is at the bottom $(h_2 = 0)$

$$v = \sqrt{2gh_1} \; (max.)$$

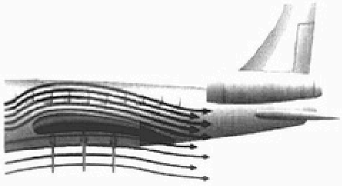
If orifice is at middle point $(h_2 = {}^{h_1}/_{2})$

1. **Basic Efflux Speed**:
$$v = \sqrt{gh_1}$$
2. **Time to hit ground**:
$$t = \sqrt{\frac{h_1}{g}}$$
3. **Horizontal Range:**
$$x = h_1$$

APPLICATIONS OF BENOULLI'S EQUATION

1. AEROPLANE WINGS

The wing of an aero-plane is designed to deflect the air so that **streamlines are closer together above the wing** than below it as illustrated in Figure.

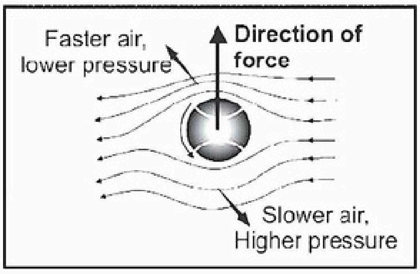


We have seen that where the streamlines are forced closer together, the speed is faster. Thus, **air is travelling faster on the upper side of the wing than on the lower.** The **pressure will be lower at the top of the wing,** and the wing will be forced upward and the lift of an aero-plane is due to this effect.

2. SWING OF A BALL

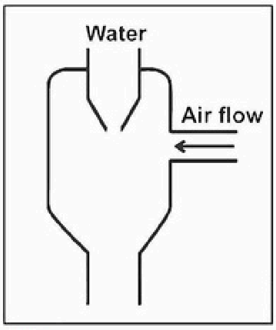
When a ball is thrown or kicked with spin, the ball is made smoother on one side by the bowler.

As the ball spins through the air, the airflow behaves differently on each side. **Air moves faster over the smoother side and slower over the rougher side.** According to Bernoulli's principle, faster-moving air results in lower pressure, while slower-moving air results in higher pressure. This pressure difference generates a sideways force known as the **Magnus effect**, which causes the ball to curve in the air.



3. FILTER PUMP

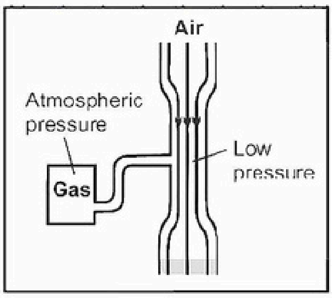
A **filter pump has a constriction in the center**, where a jet of water from the tap flows faster. According to Bernoulli's principle, **this increase in water speed causes a drop in pressure at the constriction.** As a result, air is drawn in through a side tube. The mixture of air and water is then expelled through the lower part of the pump.



4. CARBURETOR

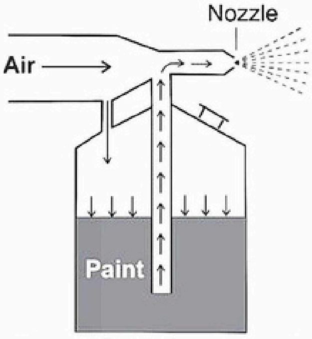
The carburetor of a car engine **uses a Venturi duct** to feed the correct mixture of air and petrol to the cylinders. Air is drawn through the duct and along a pipe to the cylinders. A tiny inlet at the side of duct is fed with petrol.

The air through the duct moves very fast, creating low pressure in the duct, which draws petrol vapours into the air stream.



5. PAINT SPRAYER

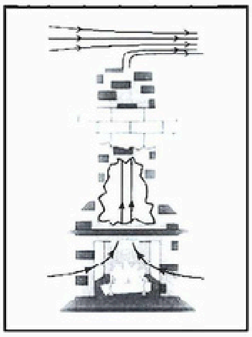
A stream of air passing over a tube dipped in a liquid will cause the liquid to rise in the tube as shown in Figure.



This idea is used in **perfume bottles** and **paint sprayers**. When you squeeze the rubber bulb, air rushes out through a small opening. This **fast air lowers the pressure** at the top of the tube and the atmospheric pressure pushes the perfume up leading to the narrow aperture.

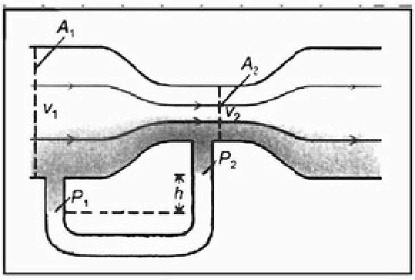
Do You Know?

A chimney works best when it is tall and exposed to air currents, which reduces the pressure at the top and forces the upward flow of smoke.



6. VENTURI RELATION

Consider a pipe within which a fluid of density ρ is flowing through different areas of cross-section as shown in the Figure.



$$\boxed{P_1 - P_2 = \frac{1}{2}\rho(v_2^2 - v_1^2)}$$

OR

$$\boxed{P_1 - P_2 = \frac{1}{2}\rho v_2^2}$$

This is known as Venturi relation, which is used in **venturi meter, a device used to measure speed of liquid flow.**

Blood Flow

- Blood is an **incompressible fluid**, similar in density to water.
- High red blood cell (RBC) concentration increases viscosity by 3–5 times.

BLOOD PRESSURE:

- Blood vessels are elastic and stretchable.
- Tension exists in vessel walls due to internal pressure being greater than atmospheric pressure.

PRESSURE OF ONE HEART BEAT:

- **Systolic pressure:** 120 torr
- **Diastolic pressure:** 75–80 torr

PRESSURE UNITS:

- 1 Torr = 133.3 $\mathrm{Nm^{-2}}$

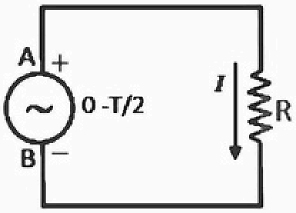
SPHYGMOMANOMETER:

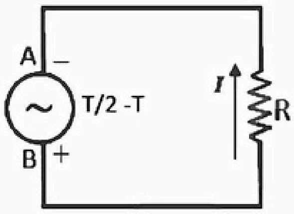
- Used to measure **blood pressure.**

ALTERNATING CURRENT

ALTERNATING CURRENT

An electric current that reverses its direction periodically with time is called alternating current.





- **During the interval O to T/2,** the terminal A of the source is positive with respect to terminal B. Current flows in one direction.
- After time T/2, the terminals change their polarity and thus current reverses its direction.
- **During the interval T/2 to T,** A is negative with respect to B. Current flows in opposite direction.

ALTERNATING VOLTAGE:

- A voltage that changes its polarity periodically with time is known as alternating voltage.
- The time taken for one complete cycle of AC is called the time period.
- The number of cycles completed in one second is called frequency.

$$f = \frac{1}{T} \quad \text{unit: Hz}$$

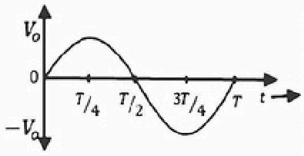
- Frequency of A.C used **in Pakistan is 50Hz.**

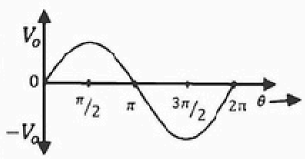
APPLICATIONS OF AC:

- Used in domestic power supply **(220 V, 50 Hz in Pakistan)**
- Easy to step up/down using transformers
- More economical for long-distance transmission
- Powers appliances like fans, lights, refrigerators

WAVEFORM:

This graph between voltage and time is known as waveform of alternating voltage.





Time	0	$T/4$	$T/2$	$3T/4$	T
θ	0	$\pi/2$	π	$3\pi/2$	2π
Voltage	0	V_o	0	$-V_o$	0
Current	0	I_o	0	$-I_o$	0

1.INSTANTANEOUS VALUE:

The value of voltage or current that exists in a circuit at any instant of time is called instantaneous value.

Mathematically, it is given by

$$\boxed{V = V_o sin\theta = V_o sin\omega t}$$

$$\boxed{I = I_o sin\theta = I_o sin\omega t}$$

- The **instantaneous value** can be **positive, negative, or zero**, depending on the time.
- It **varies sinusoidally** with time.
- The instantaneous value is **zero or minimum** when

$$t = n\frac{T}{2} \quad OR\ \theta = even\ \pi$$

- The instantaneous value is **maximum** when

$$t = odd\ \frac{T}{4} \quad OR\ \theta = odd\ \frac{\pi}{2}$$

2. PEAK VALUE:

The **peak value** (also called **maximum value** or **amplitude**) is the highest value that an alternating current or voltage reaches in one half of the cycle.

- I_0: peak value of current
- V_0: peak value of voltage
- Peak value is **not the average** or **effective value**, but the **extreme value** reached momentarily.

3. PEAK TO PEAK VALUE:

The sum of the positive and negative peak value is known as peak-to-peak value.

- The **peak-to-peak value** is the total vertical distance between the **positive peak** and the **negative peak** of an alternating current or voltage waveform.
- $I_{P-P} = 2I_0$ and $V_{P-P} = 2V_0$

4. ROOT MEAN SQUARE VALUE:

The **RMS (Root Mean Square) value** of alternating current or voltage is the value of **DC current or voltage** that would produce the **same amount of heat** in a resistor as the given A.C. does over one complete cycle.

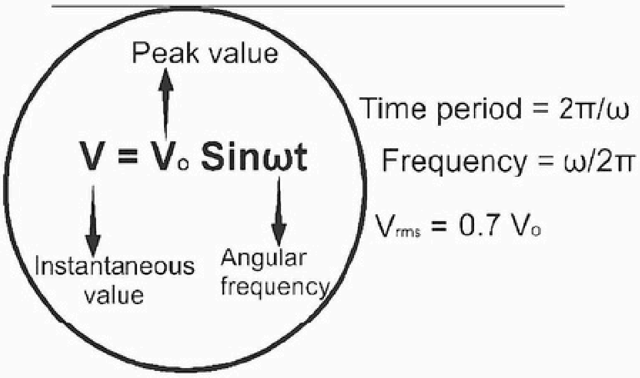
- **For voltage:** $V_{rms} = \frac{V_o}{\sqrt{2}} = 0.7V_o$
- **For current**: $I_{rms} = \frac{I_o}{\sqrt{2}} = 0.7I_o$
- RMS value is the **effective value** of A.C. used in **power calculations** just like DC.
- Domestic appliances and power ratings are based on **RMS values**
  (e.g., Pakistan mains supply: 220 V RMS)
- Lies between **zero and peak value** on the waveform
- It is about 71% of peak value.
- Most of the alternating current and voltage meters are calibrated to read rms values.
- **When we speak of A.C. meter reading, we usually mean rms values unless stated otherwise.**

NOTE:

- Both magnitude and direction of alternating current varies with time.
- Alternating current reaches maximum value twice in a cycle.
- Alternating current reaches to zero twice in a cycle.
- Alternating current reverses its direction once in a cycle.
- Average value of alternating current is zero in a cycle.

Comparison Between AC and DC:

PROPERTY	A.C	D.C
Definition	Current that reverses direction periodically	Current flows in one constant direction
Graph Representation	Sine wave (or cosine wave)	Straight horizontal line
Direction of Flow	Changes periodically	Unidirectional (constant)
Frequency	Has a specific frequency	Frequency is zero
Source Examples	Power plants, generators	Batteries, solar cells
Voltage Level	Can be easily stepped up/down using a transformer	Cannot be easily stepped up/down using a transformer
Transmission	Efficient for long distances	Not suitable for long-distance transmission
Energy Loss	Less due to low current at high voltage	More due to high current in transmission
Applications	Home appliances, factories, power grids	Electronic devices, mobile phones, cars



PHASE OF A.C:

The instantaneous value of the alternating voltage is given by

$$V = V_o sin\theta$$

This angle θ which specifies the instantaneous value of the alternating voltage or current is known as its phase.

PHASE DIFFERENCE:

Phase difference refers to the angular displacement between two sinusoidal waveforms of the **same frequency**.

- In A.C. circuits, this often occurs between **voltage** and **current**.

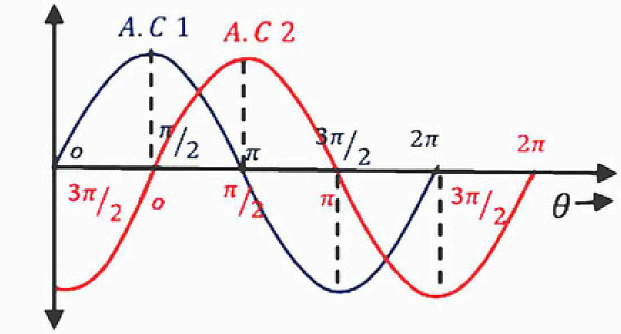
PHASE LEAD:

A waveform is said to **lead if it reaches its maximum value before** another waveform.

PHASE LAG:

A waveform is said to **lag if it reaches its maximum value after** another waveform.

EXAMPLE:



It can be seen that at each point the phase of waveform 2 is less than the phase of waveform 1 by an angle of π/2.

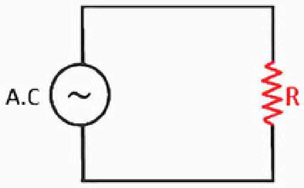
- **Hence, we will say that A.C 2 lags behind the A.C 1 by phase angle π/2.**

OR

- **A.C 1 leads A.C 2 by phase angle π/2.**

A.C. THROUGH RESISTOR

When an alternating voltage is applied across **a pure resistor**, the **current follows the same waveform** as the voltage.



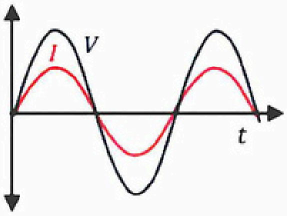
Voltage across resistor:

$$V(t) = V_0 \sin(\omega t)$$

Current through resistor:

$$I(t) = I_0 \sin(\omega t)$$

WAVEFORM:

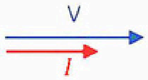


This means voltage and current are in phase.

- When voltage decreases, Current **decreases** along with the voltage.
- When voltage increases, Current **also increases** in the **same direction**.
- Both reach their **maximum (peak)** at the same time.
- When voltage is zero, Current is **also zero** at that exact moment.

VECTOR REPRESENTATION:

The **vectors for voltage and current are drawn parallel** because there is no phase difference between them.



Resistor Obeys Ohm's law:

$$V = I \times R$$

RESISTANCE:

Resistance is the opposition offered by a material (conductor) to the flow of electric current.

$$R = \frac{V}{I} = \frac{V_0}{I_0} = \frac{V_{rms}}{I_{rms}}$$

- Resistance has same effect for both A.C. and D.C.
- It is measured in **ohms (Ω)**
- Resistance does **not change** with frequency.
- It only **controls the amplitude** of the current.

POWER:

- Instantaneous power:

$$P(t) = V_0 I_0 \sin^2(\omega t)$$

- **Average power:**

$$P_{av} = V_{rms} I_{rms} = \frac{V_0 I_0}{2}$$

- **Power factor:**

$$\cos(\varphi) = 1 \text{ (because } \varphi = 0°)$$

IMPORTANT POINTS:

- No phase difference
- Power is always positive (current and voltage rise and fall together)
- Energy is **continuously dissipated** as heat in the resistor
- No energy is stored

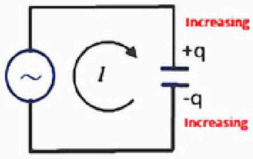
A.C. THROUGH CAPACITOR

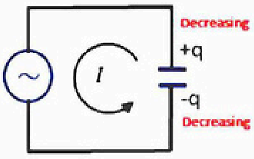
D.C cannot pass through capacitor. OR capacitor blocks the D.C.

- D.C. means constant voltage.
- When a D.C. voltage is applied to a capacitor:
  - The capacitor **charges up**.
  - Once fully charged, **no more current flows**.
- The capacitor then **acts like an open circuit** for D.C.
- **Only a brief current** flows at the beginning (during charging), then it **stops**.

A.C can pass through the capacitor

- A.C. voltage **changes direction continuously**.
- This **prevents the capacitor from fully charging**.
- As the voltage alternates, the **capacitor charges and discharges** constantly.
- This **allows current to keep flowing** back and forth through the circuit.





When an alternating voltage is applied across a **pure capacitor**, the current does **not follow** the voltage.

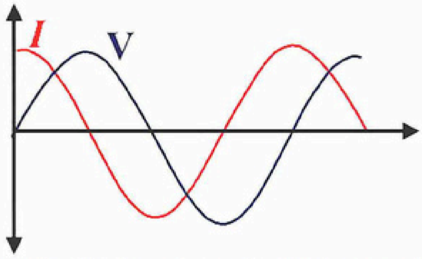
Voltage across capacitor:

$$V(t) = V_0 \sin(\omega t)$$

Current through capacitor:

$$I(t) = I_0 \sin(\omega t + 90^\circ)$$

WAVEFORM:



The **current leads the voltage by 90 degrees** (Current reaches its peak **before** voltage.)

Voltage Condition	Capacitor Behavior	Current Behavior
Increasing voltage	Capacitor charges	Current flows into capacitor
Decreasing voltage	Capacitor discharges	Current flows out (opposite direction)
Voltage is zero	Fast charging/discharging starts	Current is at maximum
Voltage is maximum	No charging or discharging	Current is zero.

VECTOR REPRESENTATION:

The vectors for voltage and current are **drawn perpendicular** because the current is leading the applied voltage by 90^o or $\pi/2$.

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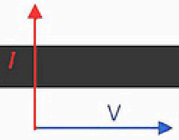


REACTANCE OF CAPACITOR:

The measure of the opposition offered by the capacitor to the flow of A. C. is known as Reactance of a capacitor. It is usually represented by X_c, Its value is given by

$$\boxed{X_C = \frac{V_{rms}}{I_{rms}}}$$

. The unit of reactance is ohm.

DEPENDENCE:

In terms of frequency the reactance of capacitor is given as

$$X_c = \frac{1}{2\pi f C} = \frac{1}{\omega C}$$

It depends upon

i. Capacitance of capacitor
ii. Frequency of alternating current

At low frequency, the reactance of capacitor is large. So, current through the capacitor will be small and vice versa.

- **In case of D.C. frequency is zero.**

$$X_C = \infty$$

POWER:

- In a pure capacitor, **no net power** is consumed.
- Energy is **stored and returned** to the source each cycle.
- Average power over a full cycle is **zero**.

A.C. THROUGH INDUCTOR

D.C. can pass through an inductor. An inductor allows D.C. to pass freely.

- D.C. means constant current.
- When D.C. is applied to an inductor:
    - The inductor **initially opposes** the change in current (due to self-induced emf).
    - Once current becomes steady, the **inductor behaves like a conductor**.
    - So, an inductor **does not block D.C.** after the current stabilizes.

A.C. does not pass easily through an inductor.

- A.C. current **changes continuously**.
- This causes the inductor to **continuously oppose the change in current**.
- The inductor **opposes** the change in current (due to self-induced emf).

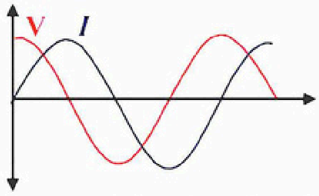
Voltage across inductor:

$$V(t) = V_0 \sin(\omega t)$$

Current through inductor:

$$I(t) = I_0 \sin(\omega t - 90°)$$

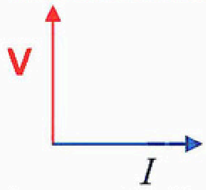
WAVEFORM:



- The **current lags the voltage by 90 degrees**.
- That means current reaches its peak **after** the voltage does.

Voltage Condition	Inductor Behavior	Current Behavior
Increasing voltage	Magnetic field builds up	Current increases slowly
Decreasing voltage	Magnetic field collapses	Current continues in same direction
Voltage is zero	Field is changing rapidly	Current is maximum
Voltage is maximum	Field is steady	Current is zero

VECTOR REPRESENTATION:



- The vector for **current is drawn 90° behind** the voltage vector.

- This shows that **current lags voltage by 90 degrees** (or π/2 radians).

REACTANCE OF INDUCTOR:

- The **opposition** offered by an inductor to the flow of A.C. is called **inductive reactance**.
- It is represented by **X_L**.

Formula:

$$X_L = 2\pi f L \text{ or } X_L = \omega L$$

Where:

- f = frequency
- L = inductance
- ω = 2πf (angular frequency)

Unit: Ohm (Ω)

DEPENDENCE:

It depends upon

i. Inductance
ii. Frequency of alternating current

- Inductive reactance **increases with frequency**.
- At **high frequency**, X_L is large ⇒ **less current flows**.
- At **low frequency**, X_L is small ⇒ **more current flows**.
- In case of D.C. (frequency = 0), $X_L = 0$ ⇒ Inductor behaves like a normal wire for steady current.

POWER:

- In a pure inductor, **no net power is consumed**.
- Energy is **stored temporarily in the magnetic field** during one half of the cycle and **returned** in the next half.
- Therefore, the **average power over one complete cycle is zero**.

SUMMARY TABLE: A.C. THROUGH RESISTOR, CAPACITOR, AND INDUCTOR

ASPECT	RESISTOR	CAPACITOR	INDUCTOR
D.C. Behavior	D.C. passes normally	D.C. gets blocked after charging	D.C. passes after initial opposition
A.C. Behavior	A.C. passes easily	A.C. passes as capacitor keeps charging/discharging	A.C. faces opposition due to changing magnetic field
Voltage Equation	$V(t) = V_0 \sin(\omega t)$	$V(t) = V_0 \sin(\omega t)$	$V(t) = V_0 \sin(\omega t)$
Current Equation	$I(t) = I_0 \sin(\omega t)$	$I(t) = I_0 \sin(\omega t + 90°)$ → **leads voltage**	$I(t) = I_0 \sin(\omega t - 90°)$ → **lags voltage**
Phase Difference	0° (in phase)	Current **leads** voltage by 90°	Current **lags** voltage by 90°
Vector Diagram	Voltage and current vectors are parallel	Current vector is **ahead by 90°**	Current vector is **behind by 90°**

ASPECT	RESISTOR	CAPACITOR	INDUCTOR
Waveform Relation	Voltage and current rise/fall together	Current reaches peak **before** voltage	Current reaches peak **after** voltage
Voltage Increasing	Current increases in same direction	Capacitor charges → current flows into capacitor	Magnetic field builds → current increases slowly
Voltage Decreasing	Current decreases in same direction	Capacitor discharges → current flows in opposite direction	Magnetic field collapses → current continues in same direction
Voltage = 0	Current is also zero	Rapid charge/discharge → current is **maximum**	Field changing rapidly → current is **maximum**
Voltage Maximum	Current is also maximum	No charge flow → current is **zero**	Field steady → current is **zero**
Opposition (Reactance)	Not frequency-dependent: $R = V/I$	Capacitive Reactance: $Xc = 1/(2\pi fC)$	Inductive Reactance: $X_L = 2\pi fL$
Dependence	Depends on resistance only	Depends on capacitance and frequency ($Xc \propto 1/f$)	Depends on inductance and frequency ($Xl \propto f$)
Unit of Reactance	Ohm (Ω)	Ohm (Ω)	Ohm (Ω)
Effect of Frequency	No effect	Higher f → smaller Xc → more current	Higher f → larger Xl → less current
Power Consumed	Real power consumed: P(avg) = V(rms) × I(rms)	**No net power consumed** Energy stored and returned	**No net power consumed** Energy stored and returned
Power Factor	cos(ϕ) = 1 (ϕ = 0°)	cos(ϕ) = 0 (ϕ = 90°) → power = 0	cos(ϕ) = 0 (ϕ = 90°) → power = 0
Energy Behavior	Energy is **dissipated** as heat continuously	Energy is **stored in electric field** and then returned	Energy is **stored in magnetic field** and then returned
Ohm's Law	Obeys Ohm's Law: V = IR	Does not obey Ohm's Law directly	Does not obey Ohm's Law directly

ELECTROMAGNETIC WAVES

DEFINITION:

Electromagnetic (EM) waves are **waves of energy** that consist of **oscillating electric and magnetic fields** which are **perpendicular to each other** and to the **direction of wave propagation**.

- They are **transverse waves**.
- **Do not need a medium** to travel; can move through vacuum.
- Produced by **accelerating or oscillating electric charges**.
- Travel at the **speed of light in vacuum: $c = 3 \times 10^8$ m/s**

COMPONENTS:

- Two fields:
    - **Electric field (E)**
    - **Magnetic field (B)**
- E and B are:
    - **Perpendicular to each other**
    - **Perpendicular to the direction of wave motion**

- In vacuum: **$c = E_0 / B_0$** where E_0 = max electric field, B_0 = max magnetic field
- Also: **$c = \lambda \times f$** where λ = wavelength, f = frequency
- **Wavelength (λ):** Distance between two consecutive peaks
- **Frequency (f):** Number of oscillations per second
- **Amplitude:** Maximum value of E or B field
- **Speed:** In vacuum, same for all EM waves ($c = 3 \times 10^8$ m/s)

SOURCES:

- Oscillating electric charges
- Accelerating electrons in antennas
- Energy transitions in atoms (e.g., emission of light)

POLARIZATION:

- EM waves can be polarized because they are transverse.
- Only the electric field gets polarized.

ENERGY AND MOMENTUM:

- EM waves carry **energy and momentum**.

- Energy is stored in **both electric and magnetic fields**.
- **Intensity ∝ amplitude²**

PROPERTIES OF EM WAVES:

- Travel at same speed in vacuum
- Can be **reflected, refracted, diffracted, and interfere**
- Can be **polarized**
- Do **not require a medium**
- **Carry energy and momentum**
- Follow inverse square law in free space

Electromagnetic Spectrum – Summary Table

Region	Wavelength Range	Frequency Range (Hz)	Source
Radio Waves	> 1 meter	$< 3 \times 10^8$	Oscillating charges (antennas)
Microwaves	1 m to 1 mm	3×10^8 to 3×10^{11}	Klystrons, magnetrons
Infrared (IR)	1 mm to 700 nm	3×10^{11} to 4×10^{14}	Warm bodies, hot objects
Visible Light	700 nm to 400 nm	4×10^{14} to 7.5×10^{14}	Electron transitions in atoms
Ultraviolet (UV)	400 nm to 10 nm	7.5×10^{14} to 3×10^{16}	Sun, mercury lamps
X-Rays	10 nm to 0.01 nm	3×10^{16} to 3×10^{19}	Inner electron transitions, X-ray tubes
Gamma Rays	< 0.01 nm	$> 3 \times 10^{19}$	Radioactive nuclei, nuclear reactions

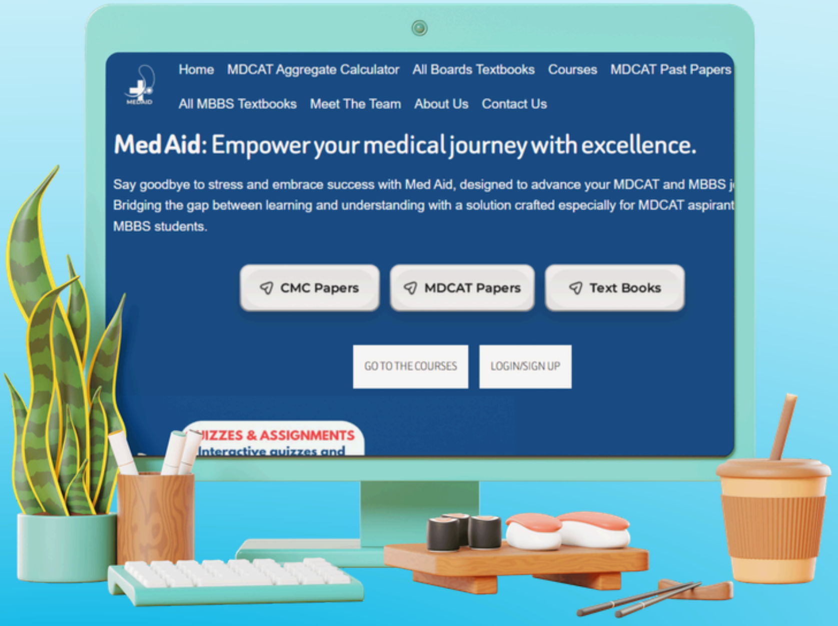
TRENDS IN EM SPECTRUM:

- **From radio to gamma rays:**
  - **Wavelength ↓** (decreases)
  - **Frequency ↑** (increases)
  - **Energy ↑** (increases)
- **Visible light** is the **only part** of the spectrum detectable by the **human eye**.

Color	Wavelength (approx.)
Red	700 nm
Orange	620 nm
Yellow	580 nm
Green	550 nm
Blue	470 nm
Indigo	440 nm
Violet	400 nm

APPLICATIONS:

- **Radio waves:** Communication, radio, TV
- **Microwaves:** Cooking, mobile phones, radar
- **Infrared:** Remote controls, thermal imaging
- **Visible light:** Vision, photography
- **Ultraviolet:** Sterilization, vitamin D production
- **X-rays:** Medical imaging
- **Gamma rays:** Cancer treatment, nuclear reactions



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