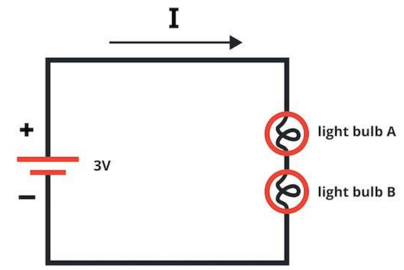
ELECTROMAGNETIC FIELDS AND WAVES

What is field ?

- Field is a function that specifies a particular quantity everywhere in a region.
- **ELECTROMAGNETIC FIELD** is produced by interaction of time varying electric and magnetic field.
- Voltage produces electric field.



- Time varying electric field produces magnetic field

What is field ?

- Magnetic field may be stationary or time varying it depends on time varying current.
- When the current is varying with respect to time then the magnetic field will also vary with respect to time.
- Time varying magnetic field produces electric field.
- Ex- transformer (flux varying with respect to time produces emf)

Difference between Circuit Theory and Field Theory

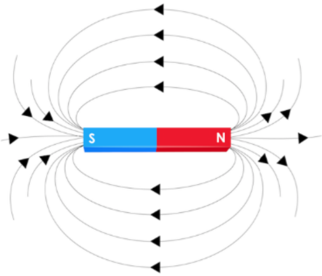
Circuit Theory	Field Theory
Deals with Voltage and Current	Deals with the Electric field and magnetic field
V & I are scalar	E and H are Vector quantity
Radiation and effect are neglected	Radiation effect is considered
Its useful only in low frequency	Independent of frequency

Static electric field

- Constant fields, which do not change in intensity or direction over time, in contrast to low and high frequency alternating fields.

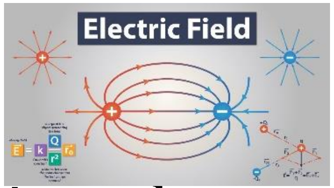
Static Magnetic field:

- A static magnetic field is created by a magnet or charges that move as a steady flow (as in appliances using direct current).
- Also called magnetostatics.



Static electric field

- **Electromagnetic field**, a property of space caused by the motion of an electric charge.
- A stationary charge will produce only an electric field in the surrounding space.
- If the charge is moving, a magnetic field is also produced.
- An electric field can be produced also by a changing magnetic field.



- The mutual interaction of electric and magnetic fields produces an electromagnetic field.

APPLICATIONS

- Microwave
- Analysis of Antennas
- Electric machine, transformers
- Analysis of power system
- Electromechanical Energy Conversion
- Wireless communication Engineering
- Optical fiber

Scalar Quantity

- Physical quantity with magnitude and no direction.
- Some physical quantities can be described just by their numerical value (with their respective units) without directions (they don’t have any direction).
- Examples of Scalar Quantities

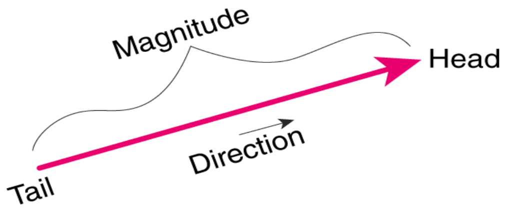
Mass	Speed
Distance	Time
Area	Volume
Density	Temperature

Vector Analysis

- Physical quantities which can be represented by magnitude and Direction both.

  – Zero Vector
  – Position Vector
  – Like and Unlike Vectors
  – Collinear Vector
  – Displacement Vector

  -Unit Vector
  -Co-initial Vector
  -Co-planar Vector
  -Equal Vector
  -Negative of a Vector



Examples of Vector Quantities

Linear momentum	Acceleration
Displacement	Momentum
Angular velocity	Force
Electric field	Polarization

Unit vector

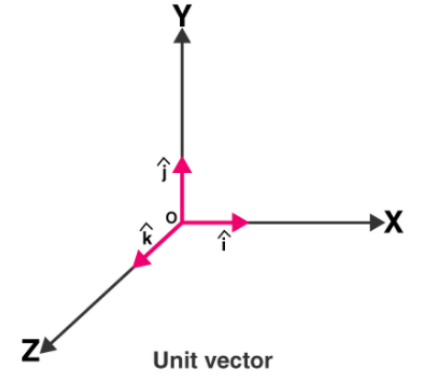
A vector which has a magnitude of unit length is called a unit vector.

Suppose if $\vec{x}$ is a vector having a magnitude x then the unit vector is denoted by $\hat{\mathbf{x}}$ in the direction of the vector $\vec{x}$ and has the magnitude equal to 1 .

Its used to indicate the direction of vector quantity.

1.a⃗ = (x, y, z) using the brackets
2. a⃗ = xi^ + y j^ +z k^

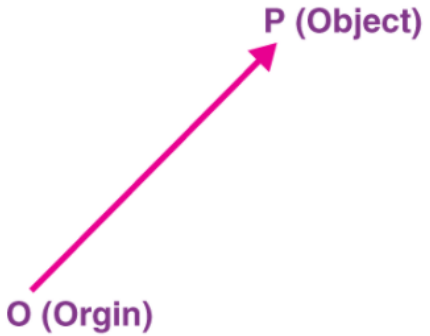
$$\therefore \hat{x} = \frac{\vec{x}}{|x|}$$



Position Vector

If O is taken as reference origin and P is an arbitrary point in space then the vector $\overrightarrow{OP}$ is called as the position vector of the point.

Position vector simply denotes the position or location of a point in the three-dimensional Cartesian system with respect to a reference origin.



Properties of Vectors

If A, B, C are vectors and m, n are scalars then

(1) Addition

$A + B = B + A$ Commutative law

$A + (B + C) = (A + B) + C$ Associative law

(2) Subtraction

$A - B = A + (-B)$

Properties of Vectors

(3) Multiplication by a scalar

m A = A m Commutative law

m (n A) = n (m A) Associative law

(m + n) A = m A + n A Distributive law

m (A + B) = m A + m B Distributive law

A Position vector‘ is represented graphically by a directed line segment.

A Unit vector‘ is a vector of unit magnitude and directed along that vector‘.

aˆ A is a Unit vector along the direction of A .

Thus, the graphical representation of A and $\hat{a}_A$ are

Vector A

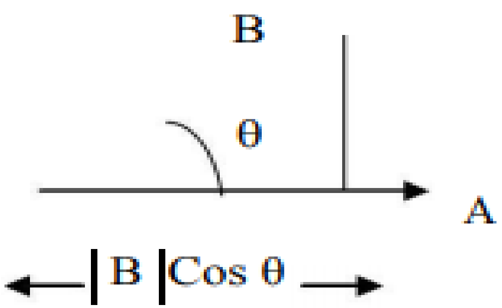
Unit vector $\hat{a}_A$

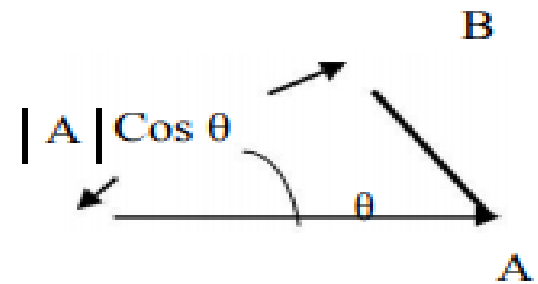
Also $\hat{a}_A = A / |A|$ or $A = \hat{a}_A |A|$

Product of two or more vectors :

(1) Dot Product (.)

$$A \cdot B = |A||B| \cos\theta \quad \text{OR} \quad \{ |A| \cos\theta \} |B|, \; 0 \le \theta \le \pi$$





A . B = B . A

(A Scalar quantity)

(2) CROSS PRODUCT (X)

$C = A \times B = |A||B| \, \text{SIN}\, \theta \, \hat{}$

Ex ,

where ' θ ' is angle between A and B ($0 \leq \theta \leq \pi$)

and $\hat{n}$ is unit vector perpendicular to plane of A and B

directed such that A B C form a right handed system of vectors

$A \times B = - B \times A$

$A \times (B + C) = A \times B + A \times C$

Coordinate system

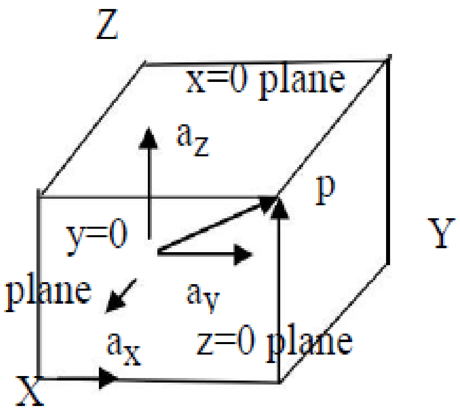
- For an explicit representation of a vector quantity, a ‗co-ordinate system‘ is essential.

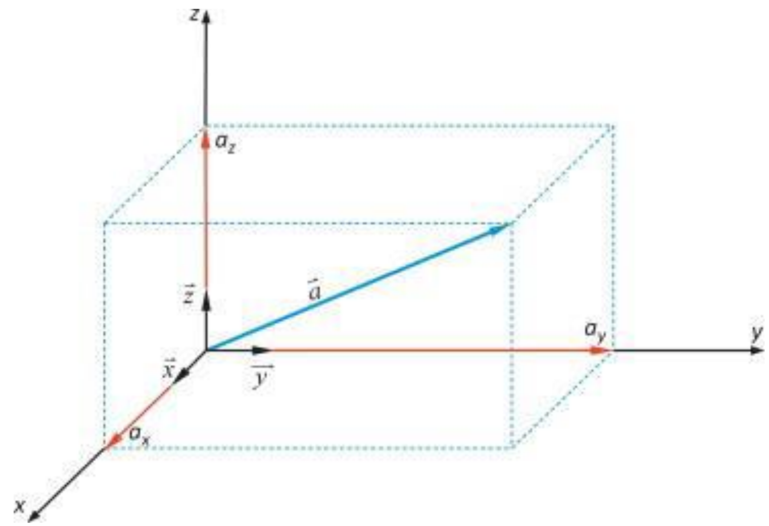
Different systems used :

Sl.No.	System	Co-ordinate variables	Unit vectors
1.	Rectangular	x, y, z	a_x , a_y , a_z
2.	Cylindrical	ρ, ϕ, z	a_ρ , a_ϕ , a_z
3.	Spherical	r, θ, ϕ	a_r , a_θ , a_ϕ

These are ‗ORTHOGONAL‘ i.e., unit vectors in such system of co-ordinates are mutually perpendicular in the right circular way.

RECTANGULAR CO-ORDINATE SYSTEM :





$a_x \cdot a_y = a_y \cdot a_z = a_z \cdot a_x = 0$ a

$_x$ X $a_y = a_z$

a_y X $a_z = a_x$

a_z X $a_x = a_y$

a_z is in direction of _advance' of a right circular screw as is turned from a_x to a_y

Co-ordinate variable _x' is intersection of planes OYX and OXZ .e, $z = 0$ & $y = 0$

Location of point P :

If the point P is at a distance of r from O, then

If the components of r along X, Y, Z are x, y, z then

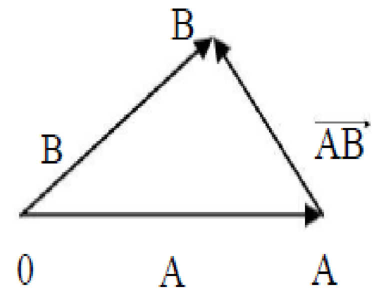
$$r = x\,a_x + y\,a_y + z\,a_z = |r|\,a_r$$

Equation of Vector $\overrightarrow{AB}$:

If $\overrightarrow{OA} = A = A_x\ a_x + A_y\ a_y + A_z\,a_z$

and $\overrightarrow{OB} = B = B_x\ a_x + B_y\,a_y + B_z\ a_z$ then

$A + \overrightarrow{AB} = B$ or $\overrightarrow{AB} = B - A$



where A_s , A_y & A_z are components of A along X, Y and Z

and B_s , B_y & B_z are components of B along X, Y and Z

Dot and Cross Products :

$$A \cdot B = (A_x\, a_x + A_y\, a_y + A_z\, a_z) \cdot (B_x\, a_x + B_y\, a_y + B_z\, a_z) = A_x B_x + A_y B_y + A_z C_z$$

$$A \times B = (A_x\, a_x + A_y\, a_y + A_z\, a_z) \times (B_x\, a_x + B_y\, a_y + B_z\, a_z)$$

Taking 'Cross products' term by term and grouping, we get

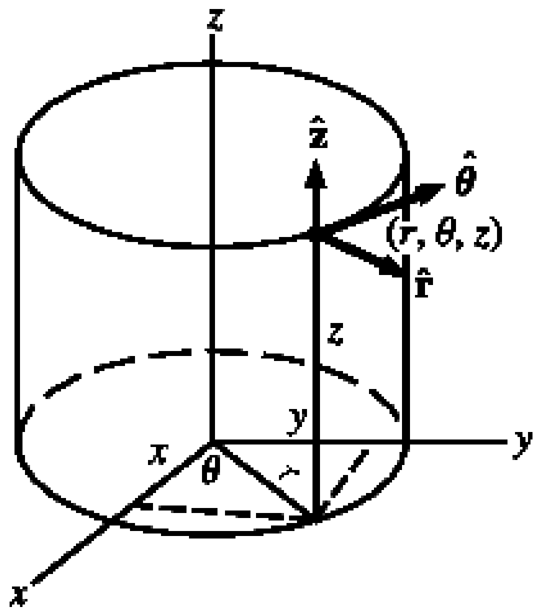
$$A \times B = \begin{vmatrix} a_x & a_y & a_z \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

$$A \cdot (B \times C) = \begin{vmatrix} A_x & A_y & A_z \\ B_x & B_y & B_z \\ C_x & C_y & C_z \end{vmatrix}$$

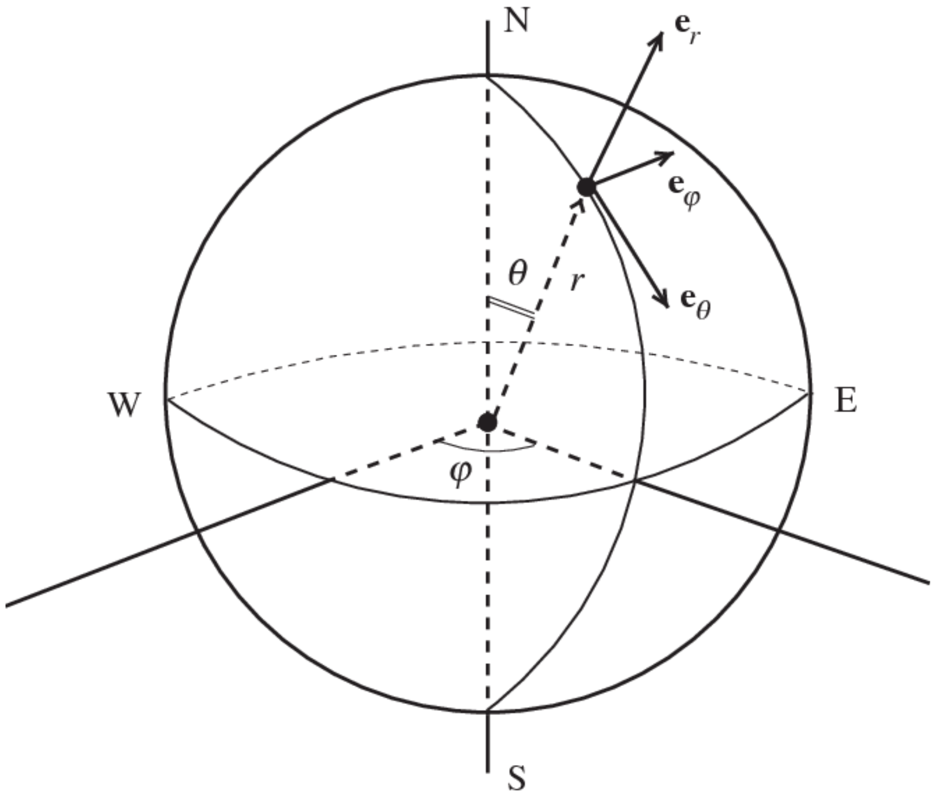
If A, B and C are non zero vectors,

(i) $A \cdot B = 0$ then $\cos\theta = 0$ .e., $\theta = 90^0$ A and B are perpendicular

CYLINDRICAL COORDINATE SYSTEM



SPHERICAL COORDINATE SYSTEM



$$\nabla V = \frac{\partial V}{\partial x}\mathbf{a}_x + \frac{\partial V}{\partial y}\mathbf{a}_y + \frac{\partial V}{\partial z}\mathbf{a}_z \qquad \text{(cartesian)}$$

$$\nabla V = \frac{\partial V}{\partial \rho}\mathbf{a}_\rho + \frac{1}{\rho}\frac{\partial V}{\partial \phi}\mathbf{a}_\phi + \frac{\partial V}{\partial z}\mathbf{a}_z \qquad \text{(cylindrical)}$$

$$\nabla V = \frac{\partial V}{\partial r}\mathbf{a}_r + \frac{1}{r}\frac{\partial V}{\partial \theta}\mathbf{a}_\theta + \frac{1}{r\sin\theta}\frac{\partial V}{\partial \phi}\mathbf{a}_\phi \qquad \text{(spherical)}$$

$$V(\mathbf{r}) = \frac{1}{4\pi\varepsilon_o} \int_L \frac{\rho_L(\mathbf{r}')dl'}{|\mathbf{r} - \mathbf{r}'|} \qquad \text{(line charge)}$$

$$V(\mathbf{r}) = \frac{1}{4\pi\varepsilon_o} \int_S \frac{\rho_S(\mathbf{r}')dS'}{|\mathbf{r} - \mathbf{r}'|} \qquad \text{(surface charge)}$$

$$V(\mathbf{r}) = \frac{1}{4\pi\varepsilon_o} \int_v \frac{\rho_v(\mathbf{r}')dv'}{|\mathbf{r} - \mathbf{r}'|} \qquad \text{(volume charge)}$$


Thank you