MADE EASY

ELECTRICAL ENGINEERING

E.M.T

By.V.Kumar Sir

- Theory
- Explanation
- Derivation
- Example
- Shortcuts
- Previous Years Question With Solution

EEE V. KUMAR SIR

ELECTRO MAGNETIC THEORY

ELECTRO MAGNETIC THEORY

i) Basics
ii) Static Electric Fields
iii) Static Magnetic Fields
iv) Time Varying Fields and Maxwell equations

Book: Principles of Electromagnetics by Matthew N. O. Sadiku

Basics:

i) x, y, z are 3 distance variables, which represents 3-Dimensions (3-D)

ii) Point: • P(1, 4, 7) [Zero dimension]

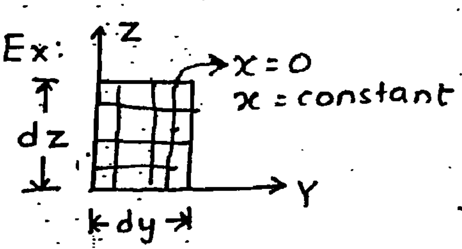
$$\left.\begin{array}{l} x = 1 \\ y = 4 \\ z = 7 \end{array}\right\} \begin{array}{c} \text{3 constants} \\ \text{or} \\ \text{No variables} \end{array}$$

point is a sphere of radius $r \to 0$.

iii) Line: Ex: $y=0$ ———— $y=1$ } 2 constants (x, z) or 1 variable (y) '$\int$'

→ line is a cylinder of radius $\rho \to 0$
→ by definition length is a vector
For above example $\vec{l} = 1\,\hat{a}_y$

iv) Surface: Ex:



} 1 constant (x) or 2 variables (y, z) '$\iint$'

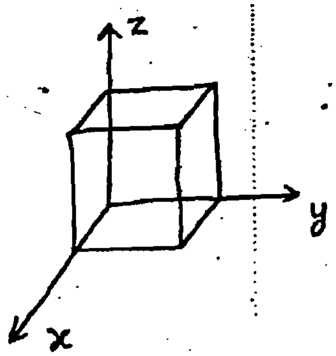
→ by definition, surface is a vector.
→ Surface vector is defined as

$$\vec{S} = (\text{area})\,\hat{a}_N$$

where, $\hat{a}_N$ → Normal unit vector to the surface in outward direction

For above example $\underbrace{d\vec{S}}_{\text{differential surface vector}} = dy\,dz\,\hat{a}_x$

v) **Volume**: Ex:



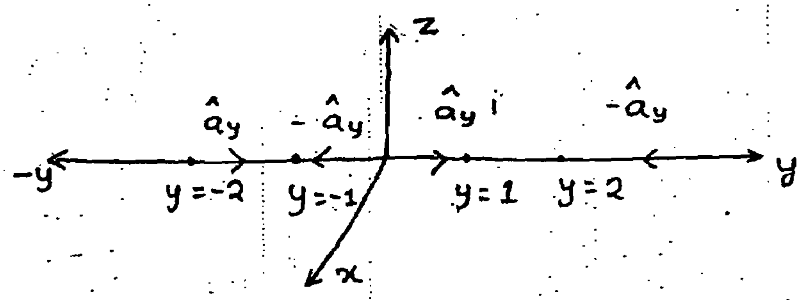
No constants or 3 variables (x, y, z) $\iiint$

by definition volume is a scalar.

vi) **Unit vector**:

$\hat{a}_y$ → $|\hat{a}_y| = 1$
→ $\hat{a}_y$ is in the direction of increasing y value

$-\hat{a}_y$ → $|-\hat{a}_y| = 1$
→ $-\hat{a}_y$ is in the direction of decreasing y value

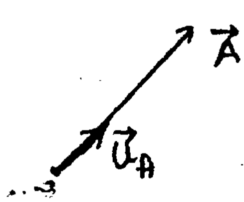


$\hat{a}_x$, $\hat{u}_x$, $\hat{x}$, $\hat{i}$	→ unit vector in x direction
$\hat{a}_y$, $\hat{u}_y$, $\hat{y}$, $\hat{j}$	→ unit vector in y direction
$\hat{a}_z$, $\hat{u}_z$, $\hat{z}$, $\hat{k}$	→ unit vector in z direction

NOTE If $\vec{A} = A_x\hat{a}_x + A_y\hat{a}_y + A_z\hat{a}_z$ is any vector then unit vector in $\vec{A}$ direction is

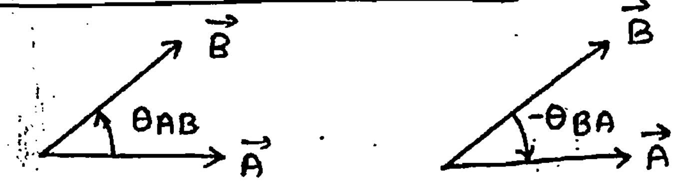
$$\vec{U}_A = \frac{\vec{A}}{|\vec{A}|} = \frac{A_x\hat{a}_x + A_y\hat{a}_y + A_z\hat{a}_z}{\sqrt{A_x^2 + A_y^2 + A_z^2}}$$

$\vec{U}_A$ is unit vector in $\vec{A}$ direction (or) direction of $\vec{A}$



Dot product (or) Scalar product :- of A, B vectors is defined as

$$\boxed{\vec{A}\cdot\vec{B} = |\vec{A}||\vec{B}|\cos(\theta_{AB})}$$



$\theta_{AB} = -\theta_{BA}$ or $\theta_{BA} = -\theta_{AB}$

$$\vec{B}\cdot\vec{A} = |\vec{B}||\vec{A}|\cos(\theta_{BA})$$
$$= |\vec{A}||\vec{B}|\cos(-\theta_{AB}) = |\vec{A}||\vec{B}|\cos(\theta_{AB}) = \vec{A}\cdot\vec{B}$$

$\boxed{\vec{A}\cdot\vec{B} = \vec{B}\cdot\vec{A}}$ → commutative Law

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

Ex : $\hat{a}_x\cdot\hat{a}_x = |\hat{a}_x||\hat{a}_x|\cos 0 = 1\cdot 1\cdot 1 = 1$

$$\boxed{\begin{aligned} \hat{a}_x\cdot\hat{a}_x &= \hat{a}_y\cdot\hat{a}_y = \hat{a}_z\cdot\hat{a}_z = 1 \\ \hat{a}_\rho\cdot\hat{a}_\rho &= \hat{a}_\phi\cdot\hat{a}_\phi = \hat{a}_z\cdot\hat{a}_z = 1 \\ \hat{a}_r\cdot\hat{a}_r &= \hat{a}_\theta\cdot\hat{a}_\theta = \hat{a}_\phi\cdot\hat{a}_\phi = 1 \end{aligned}}$$

Ex: $\hat{a}_x\cdot\hat{a}_y = |\hat{a}_x||\hat{a}_y|\cos(90^\circ) = 0$

$\hat{a}_x \perp \hat{a}_y \perp \hat{a}_z$	$\hat{a}_\rho \perp \hat{a}_\phi \perp \hat{a}_z$	$\hat{a}_r \perp \hat{a}_\theta \perp \hat{a}_\phi$

$$\boxed{\hat{a}_x \perp \hat{a}_y \perp \hat{a}_z \Rightarrow \underbrace{\hat{a}_x\cdot\hat{a}_y = \hat{a}_y\cdot\hat{a}_z = \hat{a}_x\cdot\hat{a}_z = 0}_{\text{orthogonal (perpendicular) property}}}$$

- A phasor

→ may be scalar or vector

[Voltage phasor is a scalar & Electric field Phasor is a vector]

→ is a time or space dependent quantity.

→ is complex with Amplitude and phase variation.

Cross product (or) Vector product: of $\vec{A}, \vec{B}$ vectors is defined as

$$\boxed{\vec{A} \times \vec{B} = |\vec{A}|\,|\vec{B}| \sin(\theta_{AB})\, \hat{a}_N}$$

$\hat{a}_N$ is Normal unit vector to the surface in outward direction

$$\vec{B} \times \vec{A} = |\vec{B}|\,|\vec{A}| \sin(\theta_{BA})\, \hat{a}_N = |\vec{B}|\,|\vec{A}| \sin(-\theta_{AB})\, \hat{a}_N$$

$$= -|\vec{A}|\,|\vec{B}| \sin(\theta_{AB})\, \hat{a}_N$$

$$= -\vec{A} \times \vec{B}$$

$\boxed{\vec{A} \times \vec{B} = -\vec{B} \times \vec{A}} \rightarrow$ Anti commutative law

$$|\vec{A} \times \vec{B}| = |\vec{A}|\,|\vec{B}|\,|\sin(\theta_{AB})|\,|\hat{a}_N|$$

$$\theta_{AB} = \sin^{-1}\left(\frac{|\vec{A} \times \vec{B}|}{|\vec{A}|\,|\vec{B}|}\right)$$

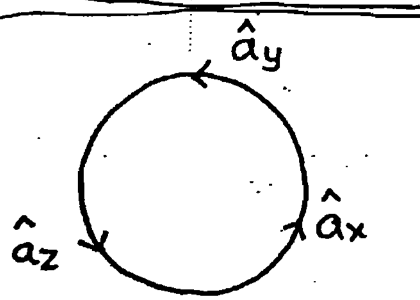
Ex: $\hat{a}_x \times \hat{a}_x = |\hat{a}_x|\,|\hat{a}_x| \sin(0)\, \hat{a}_N = 0$

Cross product of same unit vectors is zero

Ex: $\hat{a}_x \times \hat{a}_y = |\hat{a}_x|\,|\hat{a}_y| \sin 90^\circ\, \hat{a}_z = \hat{a}_z$

$\hat{a}_y \times \hat{a}_x = |\hat{a}_y|\,|\hat{a}_x| \sin(-90^\circ)\, \hat{a}_z = -\hat{a}_z$

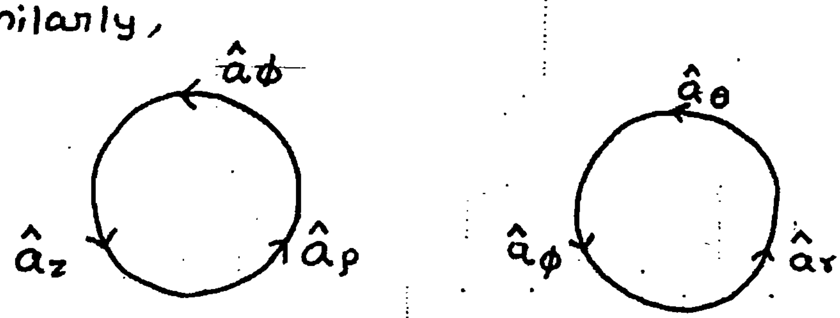
$\boxed{\hat{a}_x \times \hat{a}_y = \hat{a}_z \rightarrow \text{ortho normal property}}$



$\Rightarrow$

$\hat{a}_x \times \hat{a}_y = \hat{a}_z$	$\hat{a}_y \times \hat{a}_x = -\hat{a}_z$
$\hat{a}_y \times \hat{a}_z = \hat{a}_x$	$\hat{a}_z \times \hat{a}_y = \hat{a}_x$
$\hat{a}_z \times \hat{a}_x = \hat{a}_y$	$\hat{a}_x \times \hat{a}_z = -\hat{a}_y$

Similarly,



Scalar: is a quantity having magnitude and sign ($\pm$)

Ex: $Q \rightarrow$ change (Coulomb)

$t \rightarrow$ time (second)

$I \rightarrow$ current (Ampere)

$V \rightarrow$ Voltage (Volt)

$\psi \rightarrow$ Electric flux (coulomb)

$\phi \rightarrow$ Magnetic flux (weber)

Vector: is a quantity having magnitude and direction

Ex: $\vec{J} \rightarrow$ current density (A/m^2)

$\vec{B} \rightarrow$ magnetic flux density (Wb/m^2)

$\vec{D} \rightarrow$ Electric flux density (Coulomb/m^2)

$\vec{E} \rightarrow$ Electric Field Intensity (Volt/m)

$\vec{H} \rightarrow$ Magnetic Field Intensity (Amp/m)

observation

i) given $\vec{J} = 10\,\hat{a}_x$ then $\vec{J}$ is uniform and static

ii) given $\vec{J} = 10x\,\hat{a}_x$ then $\vec{J}$ is non-uniform and static

iii) given $\vec{J} = 10\cos\omega t\,\hat{a}_x$ then $\vec{J}$ is uniform and time varying

iv) given $\vec{J} = 10x^2\cos\omega t\,\hat{a}_x$ then $\vec{J}$ is nonuniform and time varying

NOTE

1) To multiply with meter, take $\int \vec{dl}$

Ex: given $\vec{H}$ (A/m) then current I is

$$\underbrace{\underset{\substack{(A)\\ \uparrow \\ \text{Scalar}}}{I} = \int \underset{(A/m)}{\vec{H}} \cdot \underset{(m)}{\vec{dl}}}_{\text{If } \vec{H} \text{ is non uniform}}$$

$$I = \underbrace{\vec{H} \cdot \int \vec{dl} = \vec{H} \cdot \vec{l}}_{\text{If } \vec{H} \text{ is uniform}}$$

2) To multiply with meter² (m^2) take $\iint \vec{ds}$

Ex: given $\vec{J}$ then I is

$$\underbrace{\underset{(A)}{I} = \iint \vec{J} \cdot \vec{ds}}_{\text{If } \vec{J} \text{ is non uniform}} \quad \text{Scalar, } (A/m^2)(m^2)$$

$$\underbrace{I = \vec{J} \cdot \iint \vec{ds} = \vec{J} \cdot \vec{S}}_{\text{If } \vec{J} \text{ is uniform}}$$

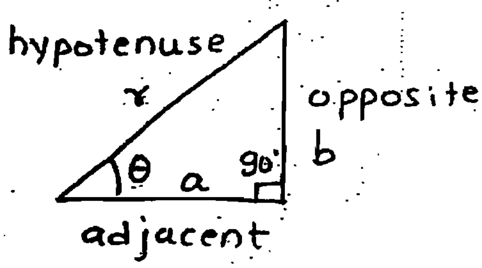
3) To multiply with meter³ (m^3) take $\iiint dV$

Ex: given volume charge density ρ_v (C/m^3) then Q is

$$\underbrace{\underset{C}{Q} = \iiint \rho_v \, dv \quad (C/m^3)(m^3)}_{\text{If } \rho_v \text{ is non uniform}}$$

$$\underbrace{Q = \rho_v \iiint dV = \rho_v \,(\text{Volume})}_{\text{If } \rho_v \text{ is uniform}}$$

<u>Pythagoras Theorem</u>: a, b, r scalars & same units



By definition

$$\sin\theta = \frac{opp}{hyp} = \frac{b}{r}$$

$$b = r\sin\theta \rightarrow ①$$

$$\boxed{(opp) = (hyp)\sin(angle)}$$

$$\cos\theta = \frac{adj}{hyp} = \frac{a}{r} \Rightarrow a = r\cos\theta \rightarrow ②$$

$$\boxed{(adj) = (hyp)\cos(angle)}$$

$$①^2 + ②^2 = a^2 + b^2 = r^2(\cos^2\theta + \sin^2\theta)$$

$$r = \sqrt{a^2 + b^2}$$

$$\boxed{hyp = \sqrt{(adj)^2 + (opp)^2}}$$

NOTE: Any vector $\vec{A}$ is sum of its tangential vector ($\vec{A}_t$) and its Normal vector ($\vec{A}_N$)

$$\vec{A} = \vec{A}_t + \vec{A}_N$$