MADE EASY

Electrical Engineering

Toppers Handwritten Notes

E M T

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ELECTRO MAGNETIC THEORY

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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]

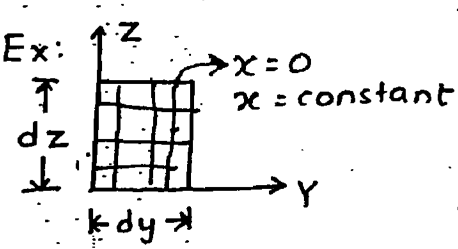
$$\left.\begin{aligned} x &= 1 \\ y &= 4 \\ z &= 7 \end{aligned}\right\} \begin{matrix}\text{3 constants} \\ \text{or} \\ \text{No variables}\end{matrix}$$

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.

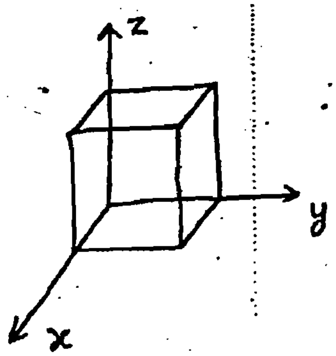
→ Surface vector is defined as

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

where, $\hat{a}_N \to$ 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) <u>Volume</u>: Ex:



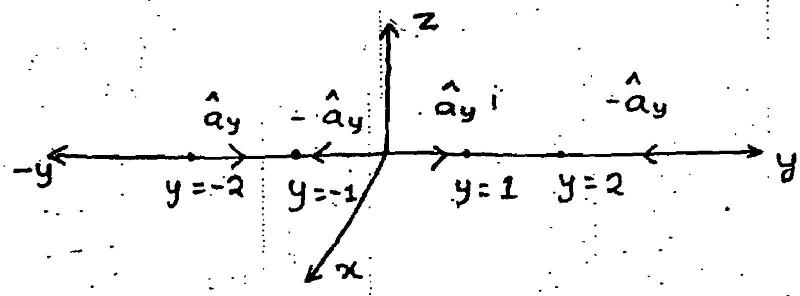
No constants
or
3 variables (x, y, z) $\iiint$

by definition volume is a scalar.

vi) <u>Unit vector</u>:

$\hat{a}_y$ → $|\hat{a}_y| = 1$
→ $\hat{a}_y$ 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

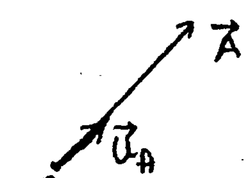


$\hat{a}_x$, $\hat{u}_x$, $\hat{x}$, $\hat{i}$	→ unit vector in x direction
$\hat{a}_y$, $\hat{u}_y$, $\hat{y}$, $\hat{j}$	→ unit vector in y direction
$\hat{a}_z$, $\hat{U}_z$, $\hat{z}$, $\hat{k}$	→ unit vector in z direction

$\boxed{\text{NOTE}}$ 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

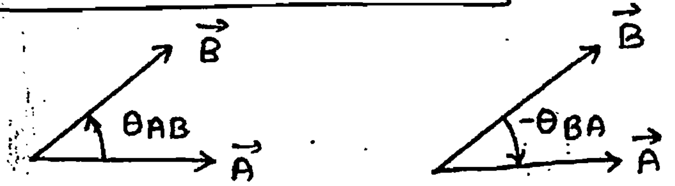
$$\vec{U}_A = \frac{\vec{A}}{|\vec{A}|} = \frac{A_x \hat{a}_x + A_y \hat{a}_y + A_z \hat{a}_z}{\sqrt{A_x^2 + A_y^2 + A_z^2}}$$

$\vec{U}_A$ 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 : $\hat{a}_x\cdot\hat{a}_x = |\hat{a}_x||\hat{a}_x|\cos 0 = 1\cdot 1\cdot 1 = 1$

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

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

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

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

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

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

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

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

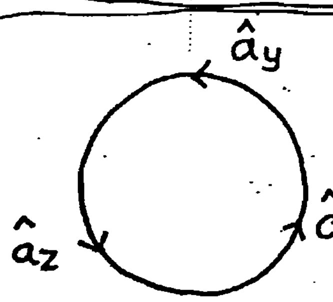
Ex: $\hat{a}_x \times \hat{a}_x = |\hat{a}_x||\hat{a}_x| \sin(0)\, \hat{a}_N = 0$

Cross product of same unit vectors is zero

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

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

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



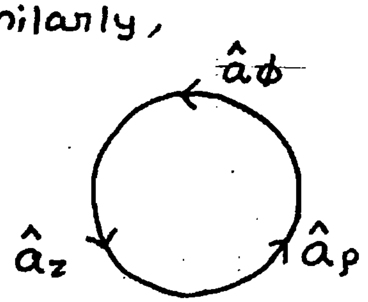
⇒

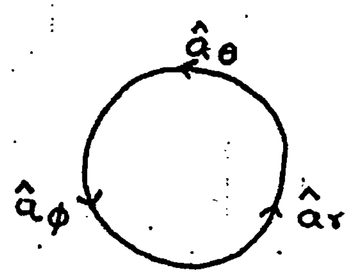
$\hat{a}_x \times \hat{a}_y = \hat{a}_z$ $\hat{a}_y \times \hat{a}_x = -\hat{a}_z$

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

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

Similarly,





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

Ex: $Q \to$ charge (Coulomb)

$t \to$ time (second)

$I \to$ current (Ampere)

$V \to$ Voltage (Volt)

$\psi \to$ Electric flux (coulomb)

$\phi \to$ Magnetic flux (weber)

Vector: is a quantity having magnitude and direction

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

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

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

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

$\vec{H} \to$ 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 $\iint d\vec{s}$

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

Scalar

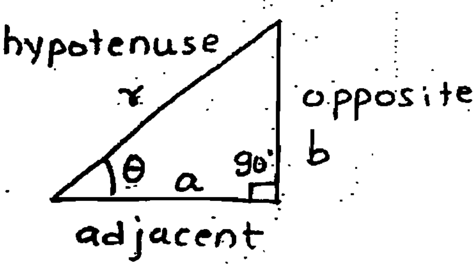
$$\underbrace{\underset{(A)}{I} = \iint \vec{J} \cdot d\vec{s}_{\;(A/m^2)\,(m^2)}}_{\text{If } \vec{J} \text{ is non uniform}} \qquad \underbrace{I = \vec{J} \cdot \iint d\vec{s} = \vec{J} \cdot \vec{s}}_{\text{If } \vec{J} \text{ is uniform}}$$

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

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

$$\underbrace{\underset{C}{Q} = \iiint \rho_v \, dv_{\;(C/m^3)(m^3)}}_{\text{If } \rho_v \text{ is non uniform}} \qquad \underbrace{Q = \rho_v \iiint dV = \rho_v \,(\text{Volume})}_{\text{If } \rho_v \text{ is uniform}}$$

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



By definition

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

$$b = r\sin\theta \rightarrow ①$$

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

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

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

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

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

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

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

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