Electrical and Instrumentation Engineering

ELECTROMAGNETIC FIELD THEORY

Lecture No. 1

CO-ORDINATE SYSTEM

By- Sonu Lal Sir

1. Nothing
2.
3.
4.
5.
6.

Slide 2

1. Co-ordinate system
2.
3.
4.
5.
6.

Slide 3

[redacted]

CO-ORDINATE SYSTEM

1. BASIC
2. CARTESIAN CO-ORDINATE SYSTEM
3. CYLINDRICAL CO-ORDINATE SYSTEM
4. SPHERICAL CO-ORDINATE SYSTEM [redacted]
5. POINT CONVERSION
6. UNIT VECTOR CONVERSION
7. length, Area, Volume
8. Position Vector.

→ NOTES
→ GATE-O-PEDIA
→ SHORT NOTES
→ WORKBOOK
→ PYQ

→ 5 Marks – 7 Marks

→ CLASS WORK + PRACTICE SHEET

BASICS

1. SCALER :- It has magnitude but no direction.

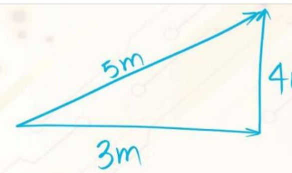
eg:- Distance, speed, potential, flux, Current etc.

2. VECTOR :- It has magnitude + Direction. It follows vector Law of addition

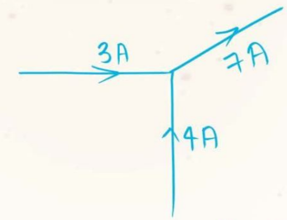
eg. E.F, M.F, Magnetic vector potential, etc

3. TENSOR :- It has magnitude & Direction. It does not follow vector Law of addition.

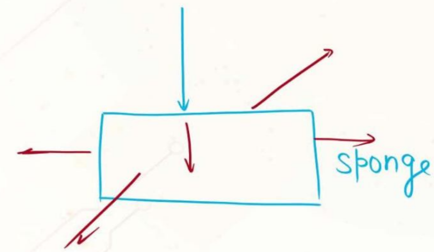
eg. Conductivity, Permittivity, Permeability etc.



Vector Law of addition ✓



Vector Law of addition X (Scaler)



$I \rightarrow$ current (Scaler)

$\bar{J} = \frac{I}{A}\hat{n}$

Current density

Vector quantity

Unit Vector

Magnitude $= 1$

Direction ✓

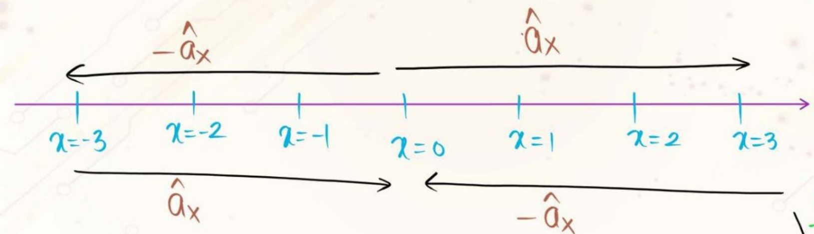
It has unit magnitude and gives direction only.

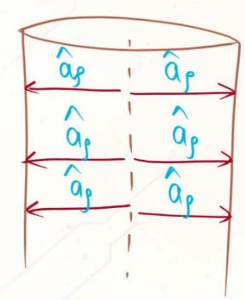
$$\boxed{\hat{A} = \frac{\bar{A}}{A}}$$

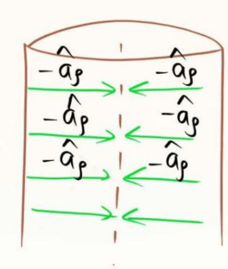
$$\bar{E} = \frac{Q}{4\pi\epsilon r^2}\hat{a}_r + \frac{Q}{4\pi\epsilon r^2}\hat{a}_\theta$$

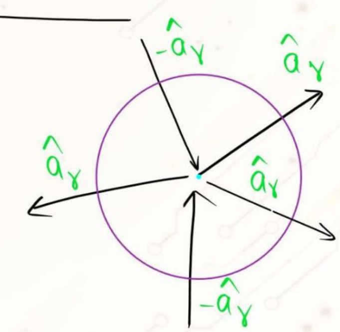
$$E = \sqrt{\left(\frac{Q}{4\pi\epsilon r^2}\right)^2 + \left(\frac{Q}{4\pi\epsilon r^2}\right)^2} = \frac{Q\sqrt{2}}{4\pi\epsilon r^2}$$

$$\hat{a}_E = \frac{\bar{E}}{E} = \frac{\hat{a}_r + \hat{a}_\theta}{\sqrt{2}}$$









SOME IMPORTANT POINTS

1. $x = 3,\ y = 4,\ z = 5$

When all three parameters are constant, then they will represent a point in space.

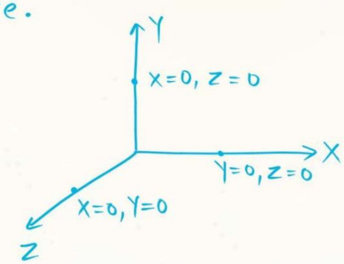
2. $x = 0,\ y = 0$

$\Downarrow$

z-axis

$\Downarrow$

A Curve



When two parameters are constants, then they will represent a curve.

3. (a) $X = 3,\ Y = 4 \Rightarrow$ Parallel to z-axis.

(b) $X = 3,\ z = 4 \Rightarrow$ Parallel to Y-axis.

(c) $Y = 3,\ z = 4 \Rightarrow$ Parallel to x-axis.

(d) $X = 0,\ Y = 0 \Rightarrow$ z-axis.

(e) $X = 0,\ z = 0 \Rightarrow$ Y-axis.

(f) $Y = 0,\ z = 0 \Rightarrow$ X-axis.

4. $X = 0 \Rightarrow$ YZ Plane $\Rightarrow Y, z \equiv$ Tang., $X =$ Normal

$Y = 0 \Rightarrow$ ZX Plane $\Rightarrow z, X \equiv$ Tang., $Y \equiv$ Normal

$Z = 0 \Rightarrow$ XY Plane $\Rightarrow X, Y \equiv$ Tang., $Z \equiv$ Normal.

$X = K \Rightarrow$ Parallel to YZ Plane $\Rightarrow Y, z \equiv$ Tang., $X =$ Normal

$Y = K \Rightarrow$ Parallel to ZX Plane $\Rightarrow z, X \equiv$ Tang., $Y \equiv$ Normal

$Z = K \Rightarrow$ Parallel to XY Plane $\Rightarrow X, Y \equiv$ Tang., $Z \equiv$ Normal.

When one parameter is constant, then it will represent a plane.

eg. $X = -3$. $\vec{E} = 3\hat{a}_x + 4\hat{a}_y + 5\hat{a}_z$

$\Downarrow$

Yz Plane $\vec{E}_{tang} = 4\hat{a}_y + 5\hat{a}_z$

$\Downarrow$

$Y, z \to T$

$X \longrightarrow N$ $\vec{E}_{normal} = 3\hat{a}_x$

5. Any vector parallel to the surface is directed in tangential direction.

6. Any vector which is perpendicular to the surface, is directed in normal direction.

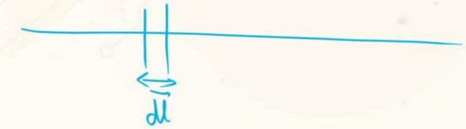
7. Surface (3D) $\Rightarrow$ unique $\Rightarrow$ Normal

   Curve (2D) $\Rightarrow$ unique $\Rightarrow$ Tangent.

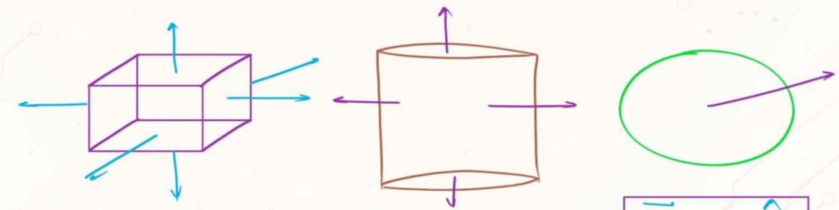
8. Differentiation occurs at a point.

9. Integration occurs in a range.

10. Differential displacement is directed in tagential direction. ($\vec{dl}$).



11.



Area will be directed in normal direction $\Rightarrow$ $\boxed{\vec{ds} = ds\,\hat{a}_n}$

12. Volume is a scalar quantity.

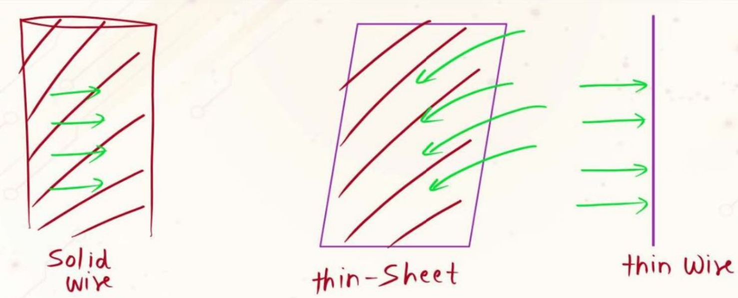
13.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad (Kg/m^3)$$

$$\text{Density} = \frac{\text{Mass}}{\text{Area}} \quad (Kg/m^2)$$

$$\text{Density} = \frac{\text{Mass}}{\text{length}} \quad (Kg/m)$$

14.



$$\text{Force density} = \frac{\text{Force}}{\text{Volume}}$$

$$\text{Force density} = \frac{\text{Force}}{\text{Area}}$$

$$\text{Force density} = \frac{\text{Force}}{\text{length}}$$

15. Energy $\xrightarrow{\text{Store}}$ Mass $\longrightarrow$ Volume

$$\boxed{\text{Energy density} = \frac{\text{Energy}}{\text{Volume}}}$$

1. Co-ordinate system → X
2. Vector Calculus → 2-3 marks
3. Maxwell Equation →
4. Electrostats →
5. Magnetostats →
6. FARADAY's LAW →

@SonusirPW

2 Minute Summary

1. BASIC

Thank you **GW** *Soldiers!*

Electrical and Instrumentation Engineering

ELECTROMAGNETIC FIELD THEORY

Lecture No. 2

CO-ORDINATE SYSTEM

By- Sonu Lal Sir

Recap of Previous Lecture

1. Basic
2.
3.
4.
5.
6.

Slide 2

Topics to be Covered

1. Basic
2. Cartesian co-ordinate s/m
3. Cylindrical Co-ordinate s/m
4. Spherical Co-ordinate s/m
5.
6.

Slide 3

$\boxed{\text{\# DOT PRODUCT}}$

$\vec{A} = a_1\hat{i} + a_2\hat{j} + a_3\hat{k}$

$\vec{B} = b_1\hat{i} + b_2\hat{j} + b_3\hat{k}$

$\vec{A}\cdot\vec{B} = a_1b_1 + a_2b_2 + a_3b_3$

$A = \sqrt{a_1^2 + a_2^2 + a_3^2}$

$B = \sqrt{b_1^2 + b_2^2 + b_3^2}$

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

$\hat{A} = \frac{\vec{A}}{A}$, $\hat{B} = \frac{\vec{B}}{B}$

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

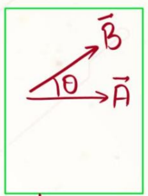
$\boxed{\cos\theta = \hat{A}\cdot\hat{B}}$

$\boxed{\text{\# CROSS PRODUCT}}$

$$\vec{A}\times\vec{B} = \begin{vmatrix} \hat{a}_x & \hat{a}_y & \hat{a}_z \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix}$$

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

$\hat{n}$ = Unit normal to the plane $\vec{A}$ and $\vec{B}$



↳ Plane Containing $\vec{A}$ and $\vec{B}$

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

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

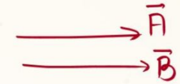
$\Rightarrow \sin\theta = \left|\dfrac{\vec{A}}{A} \times \dfrac{\vec{B}}{B}\right| = |\hat{A} \times \hat{B}|$

$$\boxed{\begin{aligned}\cos\theta &= \hat{A}\cdot\hat{B}\\ \sin\theta &= |\hat{A}\times\hat{B}|\end{aligned}}$$

Some Important Points :-

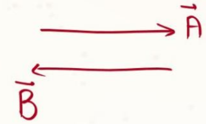
1. $\vec{A}\cdot\vec{B} = 0 \Rightarrow \vec{A} \perp_r \vec{B} \Rightarrow \theta = 90^\circ \Rightarrow \cos\theta = 0$

2. $\vec{A}\times\vec{B} = \vec{0} \Rightarrow \vec{A}$ & $\vec{B}$ are parallel



$\Rightarrow \theta = 0^\circ$

or $\vec{A}$ & $\vec{B}$ are antiparallel



$\Rightarrow \theta = 180^\circ$

3. $\vec{A}\cdot\vec{B} = \vec{B}\cdot\vec{A}$

4. $\vec{A}\times\vec{B} = -(\vec{B}\times\vec{A})$

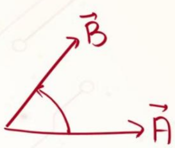
5. $\vec{0} = 0\hat{a}_x + 0\hat{a}_y + 0\hat{a}_z$
$= 0\hat{a}_\rho + 0\hat{a}_\phi + 0\hat{a}_z$
$= 0\hat{a}_r + 0\hat{a}_\theta + 0\hat{a}_\phi$

$|\vec{0}| = 0$

"$\hat{0} = \dfrac{\vec{0}}{0}$ = Not defined"

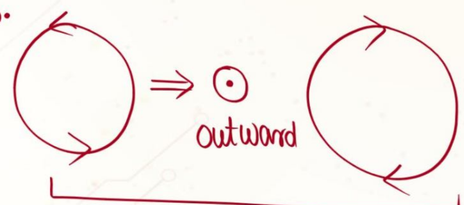
6. $(\vec{a}\cdot\vec{b})^2 + |\vec{a}\times\vec{b}|^2 = (ab\cos\theta)^2 + (ab\sin\theta)^2 = (ab)^2$

7. $\vec{C} = \vec{A}\times\vec{B} \Rightarrow \vec{C} \perp_r \vec{A},\ \vec{C} \perp_r \vec{B}$



$\odot \vec{C}$

8.

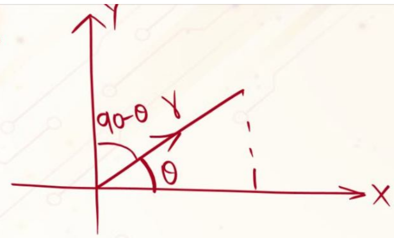


$\Rightarrow \odot$ outward

$\Rightarrow \otimes$ Inward

Right hand rule

9.



$r_x = r\cos\theta$

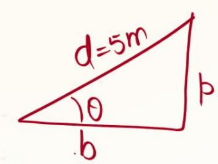
$r_y = r\cos(90-\theta) = r\sin\theta$

$\vec{r} = r_x\hat{a}_x + r_y\hat{a}_y$

$\vec{r} = r\cos\theta\,\hat{a}_x + r\sin\theta\,\hat{a}_y$

$$\boxed{\vec{r} = \vec{r}_{\parallel ar} + \vec{r}_{\perp r}}$$

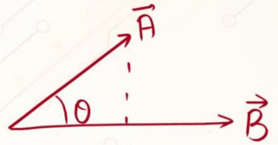
tang. Normal



$\dfrac{b}{d} = \cos\theta$

$\Rightarrow b = d\cos\theta$

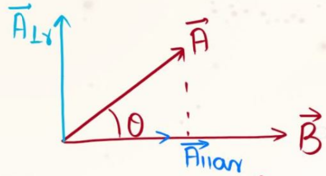
(10) Projection of $\boxed{A}$ along $\vec{B}$



$A\cos\theta = \cancel{A}\left(\frac{\vec{A}\cdot\vec{B}}{\cancel{A}B}\right) = \vec{A}\cdot\hat{B}$

$A_{\parallel ar} = A\cos\theta = \vec{A}\cdot\hat{B}$

(11) Projection of $\boxed{\vec{A}}$ along $\vec{B}$

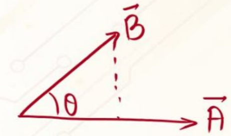


$\vec{A}_{\parallel ar} = (A\cos\theta)\hat{B} = (\vec{A}\cdot\hat{B})\hat{B}$

(12) Projection of $\vec{A}$ $\perp r$ $\vec{B}$.

$\vec{A} = \vec{A}_{\parallel ar} + \vec{A}_{\perp r}$

$\boxed{\vec{A}_{\perp r} = \vec{A} - \vec{A}_{\parallel ar} = \vec{A} - (\vec{A}\cdot\hat{B})\hat{B}}$



1. $B\cos\theta = \vec{B}\cdot\hat{A}$
2. $\vec{B}_{\parallel ar} = (\vec{B}\cdot\hat{A})\hat{A}$
3. $\hat{A} = \frac{\vec{A}}{A}$
4. $\vec{B}_{\perp r} = \vec{B} - \vec{B}_{\parallel ar} = \vec{B} - (\vec{B}\cdot\hat{A})\hat{A}$

1. $A\cos\theta = \vec{A}\cdot\hat{B}$
2. $\vec{A}_{\parallel ar} = (\vec{A}\cdot\hat{B})\hat{B}$
3. $\hat{B} = \frac{\vec{B}}{B}$
4. $\vec{A}_{\perp r} = \vec{A} - (\vec{A}\cdot\hat{B})\hat{B}$

$\vec{A}\cdot\hat{B} =$,

$\vec{A}\cdot\hat{a}_x =$

$\vec{A}\cdot\hat{a}_y =$

$\vec{A}\cdot\hat{a}_z =$

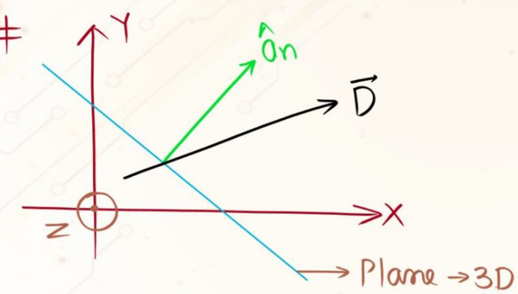
$\vec{A}\cdot\hat{a}_\rho =$

$\vec{A}\cdot\hat{a}_r =$

$\vec{A}\cdot\hat{a}_\theta =$

$\vec{A}\cdot\hat{a}_\phi =$

#



$\boxed{\hat{a}_n = \frac{\vec{\nabla}f}{|\vec{\nabla}f|}}$

$D_n = \vec{D}\cdot\hat{n}$

$\vec{D}_n = (\vec{D}\cdot\hat{n})\hat{n}$

$\vec{D} = \vec{D}_t + \vec{D}_n$

$\boxed{\vec{D}_t = \vec{D} - \vec{D}_n = \vec{D} - (\vec{D}\cdot\hat{n})\hat{n}}$

PROPERTIES OF UNIT VECTOR IN CO-ORDINATE SYSTEM

1. ORTHOGONAL :-

Ⓐ $X \perp_r Y \perp_r Z$

Ⓑ $\rho \perp_r \phi \perp_r Z$

Ⓒ $r \perp_r \theta \perp_r \phi$

$\hat{a}_x \cdot \hat{a}_y = 0$

$\hat{a}_x \cdot \hat{a}_z = 0$

$\hat{a}_y \cdot \hat{a}_z = 0$

$\hat{a}_\rho \cdot \hat{a}_\phi = 0$

$\hat{a}_\rho \cdot \hat{a}_z = 0$

$\hat{a}_\phi \cdot \hat{a}_z = 0$

$\hat{a}_r \cdot \hat{a}_\theta = 0$

$\hat{a}_r \cdot \hat{a}_\phi = 0$

$\hat{a}_\theta \cdot \hat{a}_\phi = 0$

$\hat{a}_x \cdot \hat{a}_x = 1$

$\hat{a}_y \cdot \hat{a}_y = 1$

$\hat{a}_z \cdot \hat{a}_z = 1$

$\hat{a}_\rho \cdot \hat{a}_\rho = 1$

$\hat{a}_\phi \cdot \hat{a}_\phi = 1$

$\hat{a}_r \cdot \hat{a}_r = 1$

$\hat{a}_\theta \cdot \hat{a}_\theta = 1$

2. ORTHONORMAL

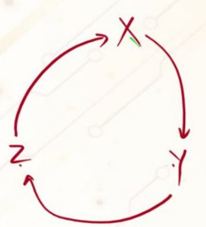
Plane	Normal
XY	Z
YZ	X
ZX	Y

Normal → ortho normal

→ $\perp_r$

$\boxed{XY \perp_r YZ \perp_r ZX}$

3. RIGHT HAND SCREW RULE



Ⓐ $(\hat{a}_x) \times (\hat{a}_x) = \vec{0}$

Ⓑ $\hat{a}_y \times \hat{a}_y = \vec{0}$

Ⓒ $\hat{a}_z \times \hat{a}_z = \vec{0}$

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

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

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

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

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

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

$X \to Y \to Z$

$\rho \to \phi \to Z$

$r \to \theta \to \phi$

① $\underset{①}{\hat{a}_x} \times \underset{②}{\hat{a}_y} = \hat{a}_z$

$\hat{a}_x = \underset{①}{\hat{a}_y} \times \hat{a}_z$

$\hat{a}_y = \hat{a}_z \times \underset{②}{\hat{a}_x}$

2 − 1

1 − 2

④ $\cancel{\vec{A} \times \vec{B} = \vec{C}}$

$\cancel{\vec{A} = \vec{B} \times \vec{C}}$

$\cancel{\vec{B} = \vec{C} \times \vec{A}}$

② $\underset{①}{\hat{a}_E} \times \underset{②}{\hat{a}_H} = \hat{a}_P$

$\hat{a}_E = \underset{①}{\hat{a}_H} \times \hat{a}_P$

$\hat{a}_H = \hat{a}_P \times \underset{②}{\hat{a}_E}$

③ $\underset{①}{\hat{A}} \times \underset{②}{\hat{B}} = \hat{C}$

$\hat{A} = \underset{①}{\hat{B}} \times \hat{C}$

$\hat{B} = \hat{C} \times \underset{②}{\hat{A}}$

⑤ $\hat{a}_{12} \times (\bar{H}_{t2} - \bar{H}_{t1}) = \vec{K}$

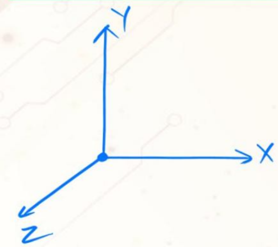
$(\bar{H}_{t2} - \bar{H}_{t1}) = \vec{K} \times \hat{a}_{12}$

TYPES OF CO-ORDINATE SYSTEM :-

1. Cartesian
2. Cylindrical
3. Spherical

CARTESIAN CO-ORDINATE SYSTEM

1. REFERENCE :- Plane



'X' - distance ⇒ YZ Plane

'Y' - distance ⇒ ZX Plane

'Z' - distance ⇒ XY Plane

2. UNIT VECTOR

$\hat{a}_x$ = It is directed in increasing direction of 'x'.

= It is unit normal to YZ Plane

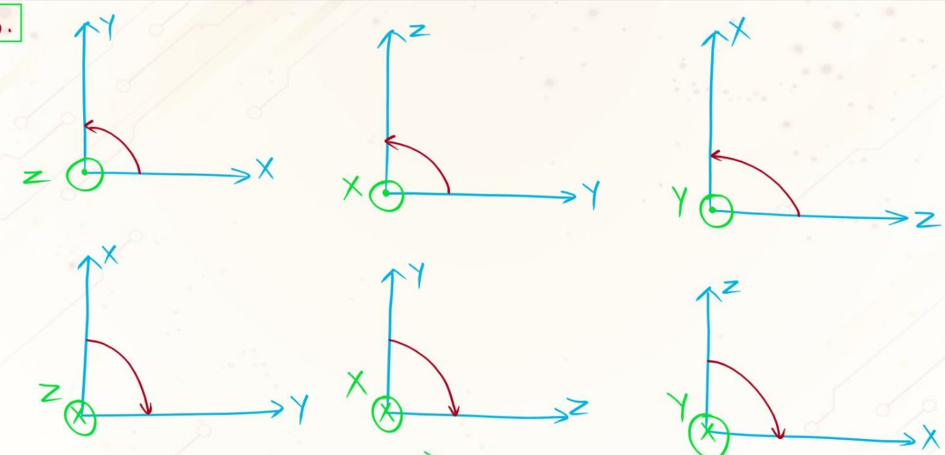
$\hat{a}_y$ = It is directed in increasing direction of 'y'.

= It is unit normal to ZX Plane.

$\hat{a}_z$ = It is directed in increasing direction of 'z'.

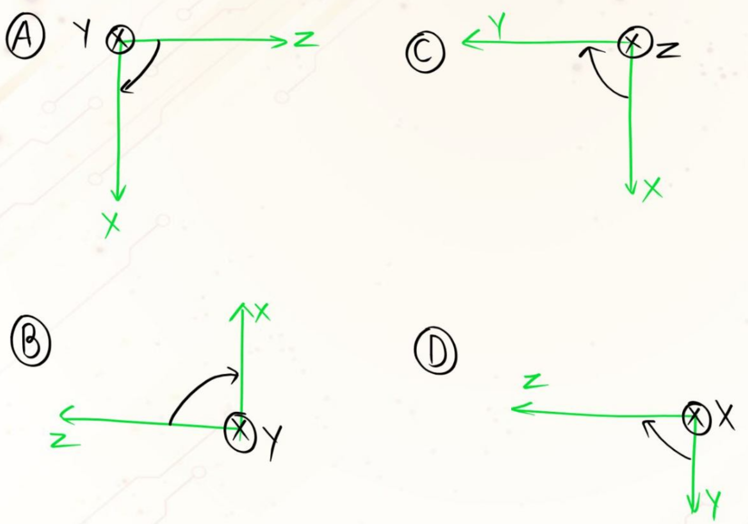
= It is unit normal to XY Plane.

3.



X → Y → Z

$\circlearrowleft \Rightarrow \odot$ $\circlearrowright \Rightarrow \otimes$



2 Minute Summary

1. Basic
2. Cartesian Co-ordinate S/m.

@SonusirPW

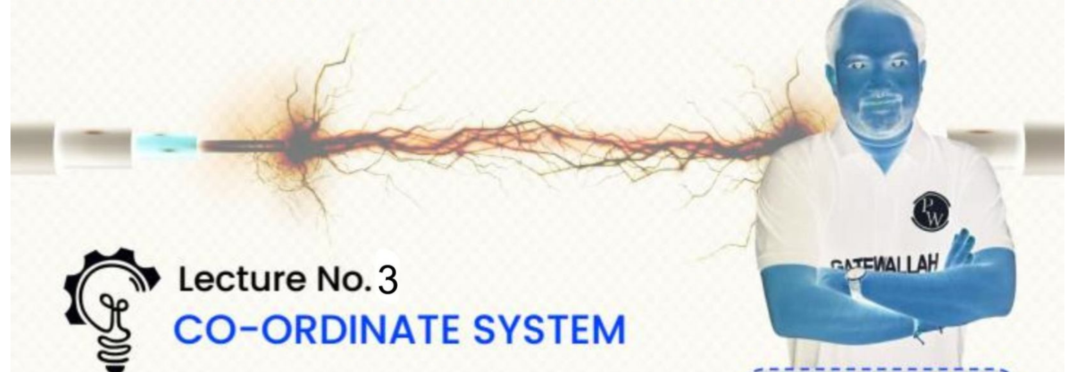
Thank you GW *Soldiers*!

Electrical and Instrumentation Engineering

ELECTROMAGNETIC FIELD THEORY

Lecture No. 3

CO-ORDINATE SYSTEM



By- Sonu Lal Sir

1. Basic
2. Cartesian Co-ordinate
3.
4.
5.
6.

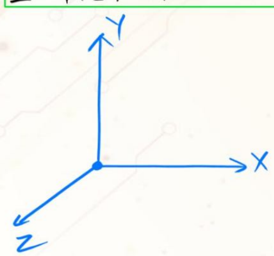
Slide 2

1. Cylindrical Co-ordinate s/m
2. Spherical Co-ordinate s/m
3. Unit Vector Conversion
4. Point Conversion
5.
6.

Slide 3

CARTESIAN CO-ORDINATE SYSTEM

1. REFERENCE :- Plane



'X'-distance ⇒ YZ Plane

'Y'- distance ⇒ ZX Plane

'Z' -distance ⇒ XY Plane

2. UNIT VECTOR

$\hat{a}_x$ = It is directed in increasing direction of 'x'.

= It is unit normal to YZ Plane.

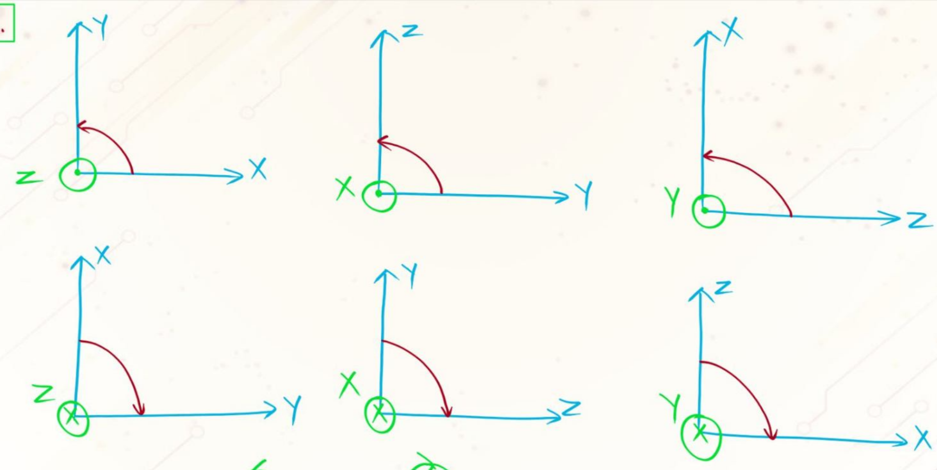
$\hat{a}_y$ = It is directed in increasing direction of 'y'.

= It is unit normal to ZX Plane.

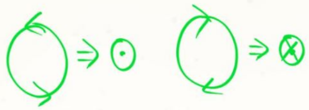
$\hat{a}_z$ = It is directed in increasing direction of 'z'.

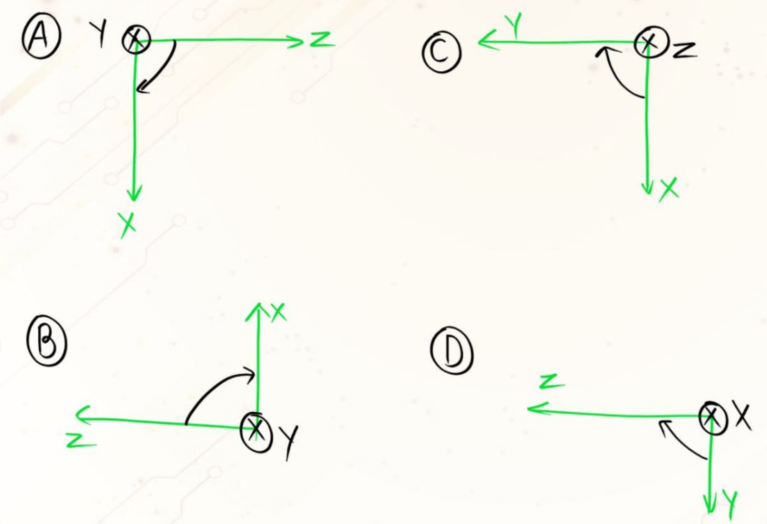
= It is unit normal to XY Plane.

3.



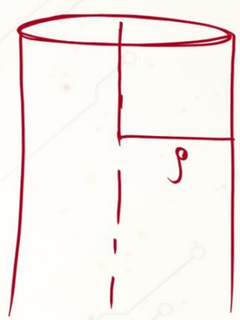
X → Y → Z





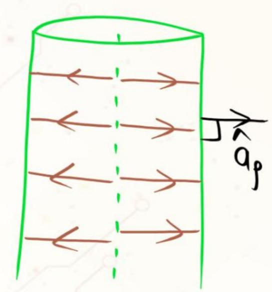
2. CYLINDRICAL CO-ORDINATE SYSTEM:-

1. REFERENCE :- "axis"



2. PARAMETERS:- (ρ, ϕ, z)

Ⓐ $\hat{a}_\rho$ = It is directed normal to curved cylindrical surface



= It is directed away from the axis.

= It is unit normal to the cylindrical Surface

= It is directed in increasing direction of 'ρ'.