Unit-1.

Electromagnetic Theory.

→ Scalar field :- Eg: Temperature gradient.

→ Vector field :- Which have both magnitude and direction.

$[\vec{E}, \vec{B}]$

Ex: Direction Magnitude

$\frac{dB}{dt}, \frac{dE}{dt}$ → Maxwell Equation

→ Charge Density :-

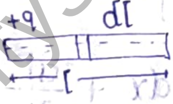
There are 3 types of charge density's.

i. Linear (λ)

ii. Surface (σ)

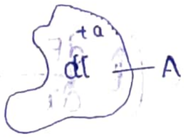
iii. Volume (ρ)

i. Linear (λ) :- $\lambda = \frac{q}{l}$



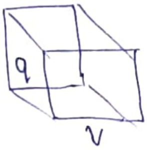
$q = \int_0^l \lambda \, dl$

ii. Surface (σ) :- ~~chare~~ $\sigma = \frac{q}{A}$



$q = \int_s \sigma \, ds$

iii. Volume (ρ) :- $\rho = \frac{q}{V}$



$q = \int_v \rho \, dv$.

Dell Operator ($\bar{\nabla}$) :-

It is also known as differential operator.

$\frac{d}{dx} f(x)$

$$\bar{\nabla} = \hat{i} \frac{d}{dx} + \hat{j} \frac{\partial}{\partial y} + \hat{k} \frac{\partial}{\partial z}.$$

* $F(x,y,z) \rightarrow$ Scalar field, $\bar{A}(x,y,z) \rightarrow$ vector field.

* $\bar{\nabla}\cdot\bar{\nabla} = \nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \rightarrow$ These is called Laplacian operator.

* $\bar{\nabla}\cdot F(x,y,z) \rightarrow$ Gradient of F [vector quantity].

* $\bar{\nabla}\cdot\bar{A}(x,y,z) \rightarrow$ Divergence of $\bar{A} \rightarrow$ divergence $\bar{A}$.

* $\bar{\nabla}\times\bar{A}(x,y,z) \rightarrow$ Curl q $\bar{A}$ = Curl $\bar{A}$ [vector].

→ Gradient of field $\bar{F}$:-

$$\frac{dy}{dx}$$

→ Rate of change of these quantity with distance (or) length.

$F(x,y,z)$.

$$dF = \frac{\partial F}{\partial x}dx + \frac{\partial F}{\partial y}dy + \frac{\partial F}{\partial z}z.$$

$$= \left(\hat{i}\frac{\partial F}{\partial x} + \hat{j}\frac{\partial F}{\partial y} + \hat{k}\frac{\partial F}{\partial z}\right)\cdot\left(\hat{i}dx + \hat{j}dy + \hat{k}dz\right)$$

$= (\bar{\nabla}F)d\bar{l}$ where, $d\bar{l} = \hat{i}dx + \hat{j}dy + \hat{k}dz$.

$$dF = |\nabla F|\,|\bar{\mu}|\cos\alpha.$$

$\alpha = 0$. Then dF will be max.

1) $\phi = 3x^2y - yz^2$ find gradient of ϕ at $(1, 2, -1)$.

$$\bar{\nabla}\phi = \left(\hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}\right)\phi.$$

$$= \hat{i}\frac{\partial\phi}{\partial x} + \hat{j}\frac{\partial\phi}{\partial y} + \hat{k}\frac{\partial\phi}{\partial z}.$$

$$= \hat{i}\frac{\partial}{\partial x}(3x^2y - yz^2) + \hat{j}\frac{\partial}{\partial y}(3x^2y - yz^2) +$$

$$+\hat{k}\frac{\partial}{\partial z}[3x^2y - yz^2]$$

$$= \hat{i}(6xy) + \hat{j}(3x^2 - z^2) + \hat{k}(-2yz).$$

$$(x, y, z) = 1, 2, -1.$$

$$\bar{\nabla}\phi = 12\hat{i} + 2\hat{j} + 4\hat{k}$$

Divergence :-

→ **Gauss Theorem :-**

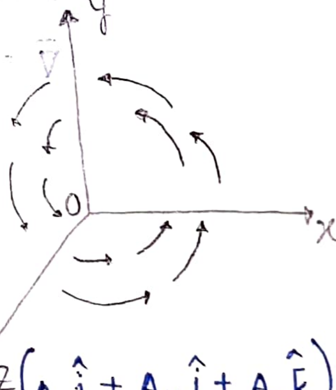
$$\int_v (\bar{\nabla}\cdot\bar{A})\,dv = \oint_s \bar{A}\cdot d\bar{s}.$$

→ These is used to volume integral to Surface with vice versa.

→ **Stoke's Theorem :-**

→ These is used to Surface integral to Circulation

$$\int_s (\bar{\nabla}\times\bar{A})\cdot ds = \oint_c \bar{A}\cdot d\bar{l}$$



Divergence :-

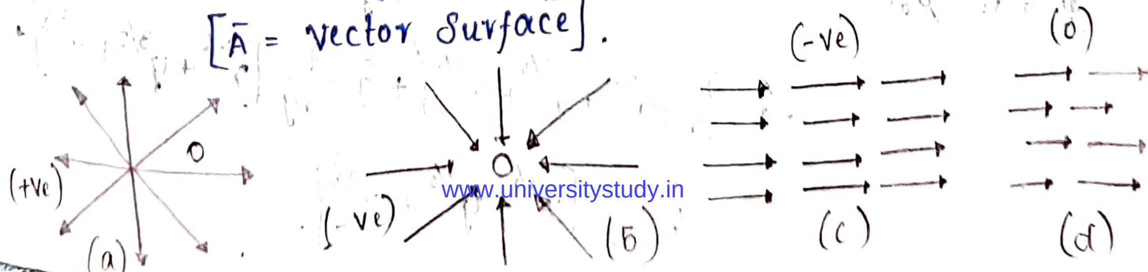
$$\bar{A}(x, y, z) = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$$

$$\bar{\nabla}\cdot\bar{A} = \mathrm{div}\,\bar{A} = \left(\hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}\right)\cdot\left(A_x\hat{i} + A_y\hat{j} + A_z\hat{k}\right)$$

$$= \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}.$$

→ Divergence of $\bar{A}$ is defined as net outword flux per unit volume over a closed Surface.

[$\bar{A}$ = vector Surface].



* In which the divergence will take place at positive, negative and zero?

→ Divergence of $\bar{A}$ at given point is a measure of how much a vector $\bar{A}$ spread out from that point [i.e., divergence].

⇒ Curval :-

$$\oint_S (\bar{\nabla} \times \bar{A}) \cdot ds = \oint_c \underbrace{\bar{A} \cdot d\bar{l}}_{\text{Circulation}}$$

· Single line out integral says that circulation.

$$\bar{A} = A_x \hat{i} + A_y \hat{j} + A_z \hat{k}$$

$$\bar{\nabla} \times \bar{A} = ?$$

* Curve of $\bar{A}$ at some point o is a measure of how much the vector $\bar{A}$ curves around point o.

$$\bar{\nabla} = \hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}$$

$$\bar{A} = A_x \hat{i} + A_y \hat{j} + A_z \hat{k}$$

$$\bar{\nabla} \times \bar{A} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ A_x & A_y & A_z \end{vmatrix}$$

$$\oint = \oint_S \bar{E} ds = \frac{q}{\varepsilon_0}$$

$$\oint_S = \oint \bar{B} \cdot d\bar{s} = 0$$

$$e = \frac{-\partial \phi}{\partial t}$$

$$\oint_c \bar{B} \cdot d\bar{l} = \mu_0 I$$

Q.) $\phi = x^{3/2} + y^{3/2} + z^{3/2}$ find gradient of $\bar{\nabla}\phi$.

Sol.) $$\bar{\nabla}\phi = \left(\hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}\right)\phi$$

$$= \hat{i}\frac{\partial \phi}{\partial x} + \hat{j}\frac{\partial \phi}{\partial y} + \hat{k}\frac{\partial \phi}{\partial z}$$

$$= \hat{i}\frac{\partial}{\partial x}\left[x^{3/2} + y^{3/2} + z^{3/2}\right] + \hat{j}\frac{\partial}{\partial y}\left[x^{3/2} + y^{3/2} + z^{3/2}\right] + \hat{k}\frac{\partial}{\partial z}\left[x^{3/2} + y^{3/2} + z^{3/2}\right].$$

$$= \frac{3}{2}\left[x^{1/2}\hat{i} + y^{1/2}\hat{j} + z^{1/2}\hat{k}\right].$$

Q.) prove that $\bar{A} = 3y^2z^2\hat{i} + 3x^2z^2\hat{j} + 3x^2y^2\hat{k}$ is a Solenoidal vector?

$\boxed{\bar{\nabla}\cdot\bar{A} = 0} \longrightarrow$ Solenoidal field.

$\text{div}\,\bar{A} = ?$

$$\bar{\nabla}\cdot\bar{A} = \left(\hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}\right)\bar{A}.$$

$$= 0 + 0 + 0 = 0.$$

. These is a Solenoidal field.

Q.) The $\bar{A} = x^2\hat{i} + y^2\hat{j} + z^2\hat{k}$ (a) Is the field Solenoidal?

(b) Is the field irrational?

Sol. (a.) $\bar{A} = x^2\hat{i} + y^2\hat{j} + z^2\hat{k}$.

$$\bar{\nabla}\cdot\bar{A} = \left(\hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}\right)\bar{A}$$

It is also a Solenoid field.

(b). $\bar{\nabla}\times\bar{A} = 0$.

Q) $\bar{A} = yz\hat{i} + xz\hat{j} + xy\hat{k}$.

i. $\bar{\nabla}\cdot\bar{A} = ?$ ii. $\bar{\nabla}\times\bar{A} = ?$

Sol. $\bar{\nabla}\cdot\bar{A} =$ Solenoid.

$$\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ yz & xz & xy \end{vmatrix} = \hat{i}(x - x) - \hat{j}(y - y) + \hat{k}(z - z).$$

$$= 0.$$

Q.) $\bar{r} = x\hat{i} + y\hat{j} + z\hat{k}$ find $\nabla r^n = ?$

a) $nr^{n-1}\bar{r}$ b) $nr^{n-2}\bar{r}$.

Sol) $\bar{r} = x\hat{i} + y\hat{j} + z\hat{k}$.

$|r| = r\,(x^2+y^2+k^2)^{n/2}$.

$\phi = r^n = (x^2+y^2+z^2)^{n/2}$.

$\bar{\nabla}\cdot\phi = \hat{i}\frac{\partial\phi}{\partial x} + \hat{j}\frac{\partial\phi}{\partial y} + \hat{k}\frac{\partial\phi}{\partial z}$

$= \frac{n}{2}\,2x\,(x^2+y^2+z^2)\left(\frac{n-2}{2}\right)\hat{i}$.

$\frac{\partial}{\partial x}(x^2+y^2+z^2)^{n/2}$

$= \frac{n}{2}(x^2+y^2+z^2)^{n/2-1}(2x)$

$= \frac{n}{2}(x^2+y^2+z^2)^{n/2-1}(2y)$

$= \frac{n}{2}(x^2+y^2+z^2)^{n/2-1}(2z)$

+ **Gauss's Law of Electricity :-**

Flux is emerging out from the closed surface is equal to charge enclosed by the surface per 'ϵ_0'

$$\phi_E = \oint_s \bar{E}\cdot d\bar{s} = \frac{q}{\epsilon_0}.$$

Differential form of Gauss law :-

$\bar{\nabla}\cdot\bar{D} = \rho$. $\bar{D}$ = Electric displacement vector.

$\bar{D} = \epsilon_0 \cdot \bar{E}$.

charge & charge density are related.

$$q = \int_v \rho\, dv \rightarrow (1)$$

+ **Gauss's Law in Electricity :-**

$$\oint_s \bar{E}\cdot d\bar{s} = \frac{q}{\epsilon_0}.$$

$$\oint_s \bar{E}\cdot d\bar{s} = \frac{1}{\epsilon_0}\int_v \rho\, dv.$$

$$\oint_s (\epsilon_0 \bar{E})\, d\bar{s} = \int_v \rho\, dv$$

$$\oint_c \bar{D}.\bar{ds} = \int_v \rho\, dv$$

By using gauss law divergence theorem in left hand side.

$$\int_v (\bar{\nabla}.\bar{D})\, dv = \int_v \rho\, dv$$

for an arbitrary volume

$$\boxed{\bar{\nabla}.\bar{D} = \rho} \rightarrow 1^{st} \text{ max. equation}$$

Relation b/w electric field & Potential :- $[\bar{E}$ & $V]$.

$$E = \frac{-\partial v}{\partial x} \qquad \bar{E} = -\left(\hat{i}\frac{\partial v}{\partial x} + \hat{j}\frac{\partial v}{\partial y} + \hat{k}\frac{\partial v}{\partial z}\right)$$

$$\boxed{\bar{E} = -\bar{\nabla}.V}$$

Poisson's Equation and Laplace Equation :-

Gauss's Law in electricity is given by

$$(\bar{\nabla}.\bar{D} = \rho)$$

where, $\bar{D} = \epsilon_0 \bar{E}$

$$\bar{\nabla}(\epsilon_0 \bar{E}) = \rho$$

$$\bar{\nabla}.(\bar{\nabla}.v) = \frac{-\rho}{\epsilon_0}$$

$$\boxed{\nabla^2 v = \frac{-\rho}{\epsilon_0}} \rightarrow \text{These is called poisson equation.}$$

For charge free region $\rho = 0$.

$$\boxed{\nabla^2 v = 0} \rightarrow \text{These is called laplace eq}^n.$$

Maxwell's Eq^n in Differential form :-

$\begin{Bmatrix} \text{Div } \bar{D} \\ \text{Div } \bar{B} \end{Bmatrix}$

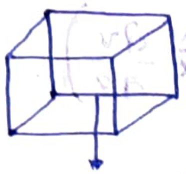
1. $\bar{\nabla}\cdot\bar{D} = \rho$ Gauss law in electricity.
2. $\bar{\nabla}\cdot\bar{B} = 0$ Gauss law in Magnetism.
3. $\bar{\nabla}\times\bar{E} = \frac{-\partial\bar{B}}{\partial t}$ Faraday's law of electric magnetic induction.
4. $\bar{\nabla}\times\bar{H} = \bar{J} + \frac{\partial\bar{D}}{\partial t}$ Modified ampere's law

$\bar{\nabla}$ - dell operator

$\begin{cases} \nabla f(x,y,z) \rightarrow \text{gradient of } f \\ \nabla\cdot A(x,y,z) = \text{divergence of } \bar{A} \\ \nabla\times A(x,y,z) = \text{curl of } A \end{cases}$

→ **Continuity Equation :-**

$$I = \frac{-dq}{dt} \longrightarrow (1)$$



$I = \frac{-dq}{dt}$

charge is leaving the volume.

we know that $q = \int_v \rho\, dv \longrightarrow (2)$

$$I = \frac{-d}{dt}\int_v \rho\, dv \longrightarrow (3)$$

Current & current density are related with,

$$I = \oint_s \bar{J}\cdot d\bar{s} \longrightarrow (4)$$

$\bar{\nabla}\cdot\bar{J} = \frac{\partial \rho}{\partial t} = 0$

Conservation of charge,

$\frac{-dq}{dt} = I.$

from (3) & (4) Equations

$$\oint_s \bar{J}\cdot d\bar{s} = \frac{-d}{dt}\int_v \rho\, dv.$$

$$\int_s \bar{J}\cdot d\bar{s} = -\int_v \frac{\partial \rho}{\partial t}\, dv.$$

Only depends on time.

Use Gauss law divergence theorem in left hand theorem

$$\int_v (\bar{\nabla}\cdot\bar{J})\, dv = -\int_v \frac{\partial}{\partial t}\, dv.$$

for any arbitary volume

$$\boxed{\bar{\nabla}\cdot\bar{J} = \frac{-d\rho}{dt}}$$ Continuity Eq^n (Conservation of charge)

If there is Stationary Current $\frac{d\rho}{dt} = 0$.

$$\boxed{\bar{\nabla} \cdot \bar{J} = 0}$$

Derivation of 2nd Maxwell Equation :-

$$\boxed{\bar{\nabla} \cdot \bar{B} = 0}$$

Proof : Gauss law in magnetism.

$$\oint_s \bar{B} \cdot d\bar{s} = 0 .$$

use gauss's law divergence theorem,

$$\int (\bar{\nabla} \cdot \bar{B})\, dv = 0$$

form an arbitary volume, $\boxed{\bar{\nabla} \cdot \bar{B} = 0}$

Magnetic monopoles do not exist $\boxed{\text{div}\,\bar{B} = 0}$

Derivation of 3rd Maxwell Equation :-

$$\bar{\nabla} \times \bar{E} = \frac{-\partial \bar{B}}{dt}$$

Proof : According to faraday's law, induced emf in closed loop is given by

$$E_{emf} = \frac{-d\phi_B}{dt} \qquad \boxed{\phi_B = \oint_s \bar{B} \cdot d\bar{s}}$$

$$E_{emf} = \frac{-d}{dt} \oint_s \bar{B} \cdot d\bar{s} \rightarrow ①$$

* Induced emf can also be Caluculated :

E_{emf} = work done in carrying out a unit charge around a closed loop.

$$E_{emf} = \oint_c \bar{E} \cdot d\bar{l} \rightarrow ②$$

from ① & ② eqn's.

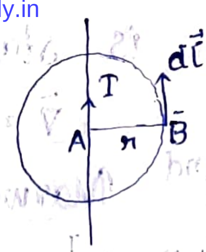
$$\oint_c \bar{E} \cdot d\bar{l} = -\frac{d}{dt} \oint_s \bar{B} \cdot d\bar{s}$$

Use stoke's theorem,

$$\oint_s (\bar{\nabla} \times \bar{E})\, d\bar{s} = -\oint_s \frac{\partial \bar{B}}{\partial t} \cdot d\bar{s}$$

$$\boxed{\bar{\nabla} \times \bar{E} = \frac{-\partial \bar{B}}{\partial t}}$$

Ampere's Circuit Law :



$$\Rightarrow \boxed{\oint_c \bar{B}\cdot d\bar{l} = \mu_0 I}$$

Proof : use Biot's Savarts Law.

$$\bar{B} = \frac{\mu_0}{4\pi} \cdot \frac{2I}{r}$$

$$LHS = \oint \bar{B}\cdot d\vec{l}$$

$$= \oint B\,dl\cos 0 = B\oint dl = B\cdot 2\pi r$$

$$= \frac{\mu_0}{4\pi}\cdot\frac{2I}{r}\cdot 2\pi r = \mu_0 I$$

$$= RHS.$$

$$\Rightarrow \oint \bar{\nabla}\times\bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t}\ \frac{d\bar{D}}{dt} \quad [\bar{D} = \epsilon_0 \bar{E}]$$

Proof of 4^{th} maxwell Eqn :

According to Ampere Circuit Law

$$\oint \bar{B}\cdot d\bar{l} = \mu_0 I$$

$$\Rightarrow \oint \frac{\bar{B}}{\mu_0} d\bar{l} = I = \oint \bar{J}\,d\bar{s}$$

$$\oint_c \bar{H}\cdot d\bar{l} = \oint_s \bar{J}\cdot d\bar{s} \qquad \left[\bar{H} = \frac{\bar{B}}{\mu_0}\right.$$

H - Magnetic field Strength.]

Use Stoke's theorem,

$$\oint_s (\bar{\nabla}\times\bar{H})\,d\bar{s} = \oint_s \bar{J}\cdot d\bar{s}$$

For an arbitary Surface,

$$① \leftarrow \boxed{\bar{\nabla}\times\bar{H} = \bar{J}} \rightarrow$$ accepts only for the Stationary Current.

Take div. both sides of ①

$$\text{div}(\bar{\nabla}\times\bar{H}) = \text{div}\,\bar{J}$$

$$0 = \text{div}\,J \Rightarrow \boxed{\bar{\nabla}J = 0.}$$

Continuity equation is given by,

$$\bar{\nabla}\cdot\bar{J} + \frac{d\rho}{dt} = 0.$$

$$\boxed{\bar{\nabla}\cdot\bar{J} = 0} \quad \text{if} \quad \frac{\partial\rho}{\partial t} = 0.$$

→ Stationary Current.

For changing electric field :-

According to Maxwell,

$$② \quad \boxed{\bar{\nabla}\times\bar{H} = J + J'}$$

→ becoz of J_d.

Because of Current (I)

Current in wire becoz changing electric field.
→ Displacement Current.

Take div. of both sides of eq ②   [div. – diversion]

$$\text{div}(\bar{\nabla}\times\bar{H}) = \text{div}\,\bar{J} + \text{div}.\,J'$$

$$0 = \frac{-\partial\rho}{\partial t}\,(\nabla\cdot\bar{D})$$

$$\bar{\nabla}\cdot J' = \bar{\nabla}\cdot\left(\frac{\partial\bar{D}}{\partial t}\right) \Rightarrow J' = \frac{\partial D}{\partial t}.$$

** The rate of change of electric field is known as displacement current.

$$\Rightarrow \bar{\nabla}\times\bar{H} = J + \frac{\partial\bar{D}}{\partial t}$$

⇒ Integral form of Maxwel's Eqⁿ :-

1. $\bar{\nabla}\cdot\bar{D} = \rho$ $\quad \oint_S \bar{D}\cdot d\bar{s} = q.$ [Gauss's Law in electricity] $(\bar{\nabla}\cdot\bar{D})$

2. $\bar{\nabla}\cdot\bar{B} = 0$ $\quad \oint_S \bar{B}\cdot d\bar{s} = 0$

3. $\bar{\nabla} \times \bar{E} = -\frac{\partial \bar{B}}{\partial t}$ $\quad \oint_c \bar{E} \cdot d\bar{l} = -\frac{\partial}{\partial t} \oint_s \bar{B} \cdot d\bar{s}$

4. $\bar{\nabla} \times \bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t}$ $\quad \oint_c \bar{H} \cdot d\bar{l} = \oint_s \left(J + \frac{\partial \bar{D}}{\partial t}\right) \cdot d\bar{s}$.

Proof of I^{st} Maxwell's Eq^n :

$$\bar{\nabla} \cdot \bar{D} = \rho.$$

Take volume integration both sides.

$$\int_v (\bar{\nabla} \cdot \bar{D}) dv = \int_v \rho dv$$

$q = \int \rho dv$.

$$\boxed{\oint_s \bar{D} \cdot d\bar{s} = q}$$

$\int (\bar{\nabla} \cdot A) dv = \oint A ds$

↓

Gauss div. theorem

Proof of II^{nd} Eq^n :

$$\bar{\nabla} \cdot \bar{B} = 0.$$

Take volume integration both sides.

$$\int (\bar{\nabla} \cdot \bar{B}) dv = 0$$

$$\boxed{\oint_S B ds = 0}$$

Proof of 3rd Maxwell Eq^n

$$\bar{\nabla} \times \bar{E} = -\frac{\partial \bar{B}}{\partial t}$$

Take the surface integration b. s.

$$\oint_s (\bar{\nabla} \times \bar{E}) \cdot d\bar{s} = -\frac{\partial}{\partial t} \oint_s \bar{B} \cdot d\bar{s}$$

$\oint.$ $\quad \int (\bar{\nabla} \cdot \bar{B}) dv = 0 \Rightarrow \boxed{\oint_S B ds = 0}$

$$\oint_s (\nabla \times \bar{E}) \cdot d\bar{s} = -\frac{d}{dt} \oint_s \bar{B} \cdot d\bar{s}$$

$$\boxed{\oint_c \bar{E} \cdot d\bar{l} = -\frac{d}{dt} \oint \bar{B} \cdot d\bar{s}}$$

Proof IV^{th} Eqn :-

$$\bar{\nabla} \times \bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t}$$

$$\int (\bar{\nabla} \times H) \cdot d\bar{s} = \int \left(J + \frac{\partial D}{\partial t}\right) d\bar{s}$$

$$\Rightarrow \boxed{\oint_c H \cdot d\bar{l} = \oint_s \left(J + \frac{\partial D}{\partial t}\right) d\bar{s}}$$

→ Physical Significance of Maxwel Eqn :-

→ First, Maxwell eqn is gauss law in electricity it states that electric flux out of any closed Surface is proportional to the charge enclosed by that Surface.

→ Integral form of Dst maxwell's equation is used to find electric field around charged objects.

→ $(\bar{\nabla} \cdot \bar{B})$ → Net Magnetic flux out of any closed Surface is zero.

→ $(\bar{\nabla} \cdot \bar{D})$ → Gauss law in electricity.

→ There are no magnetic mono poles.

→ By changing magnetic field ($d\bar{B}$) by time we can induce electric field.

3. $\bar{\nabla} \times \bar{E} = \frac{-d\bar{B}}{dt}$

→ Line integral of the electric field around a closed loop is equal to negative rate of change of magnetic flux through the area enclosed by the loop. → $\oint_c \bar{E} \cdot d\bar{l} = \frac{-\partial}{\partial t} \oint \bar{B} \, d\bar{s}$.

4. $\bar{\nabla} \times \bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t}$

By changing electric field with time we can induce magnetic field.

→ Line integral of the magnetic field around a closed loop is proportional to the current flowing through the loop.

→ application of EM waves

→ Role of EM waves