

Unit-1

Electromagnetic Theory

- Scalar field :- Eg: Temperature gradient
 - Vector field :- which have both magnitude and direction
- [\vec{E}, \vec{B}] fitting direction to number → (x, y, z) A ⋅ ⋅
- Ex:- Direction Magnitude

$\frac{d\vec{B}}{dt}, \frac{d\vec{E}}{dt}$, Maxwell Equation

- charge density :- ρ (ρ) is best to understand.

There are 3 types of charge density's.

i. Linear (λ)

charge density with respect to length to stand.

ii. Surface (σ)

charge density with respect to area to stand.

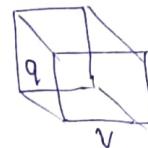
iii. Volume (ρ)

charge density with respect to volume to stand.

$$\text{i. Linear } (\lambda) : \lambda = \frac{q}{l} \quad q = \int \lambda dl \quad \text{where } l = \sqrt{x^2 + y^2 + z^2}$$

$$\text{ii. Surface } (\sigma) : \sigma = \frac{q}{A} \quad q = \int \sigma dA$$

$$\text{iii. Volume } (\rho) : \rho = \frac{q}{V} \quad q = \int \rho dV$$



$$q = \int_S \sigma dA$$

$$q = \int_V \rho dV$$

(Dell Operator ($\vec{\nabla}$))

It is also known as differential operator.

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

The Dell operator is used for differentiation.

* $F(x, y, z) \rightarrow$ 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 $\bar{A} \rightarrow$ curl \bar{A} [vector]

- Gradient of field F :-

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

$$F(x, y, z)$$

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

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

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

$$dF = |\bar{\nabla} F| |\vec{u}| \cos \theta$$

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

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

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

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

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

$\Rightarrow \vec{A} = \frac{\partial}{\partial z} [3xy - yz]$ Then compare with above

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

so it is taking surface to a non-singular point $(x,y,z) = 1, 2, -1$.

$\vec{\nabla}\phi = 12\hat{i} + 2\hat{j} + 4\hat{k}$ [singular, if taking field

Divergence :-

→ Gauss Theorem :- $\int \int \int_A \vec{A} \cdot dV = \int \int_S \vec{A} \cdot d\vec{s}$

which is used to convert volume integral to surface integral.

+ This is used to volume integral to surface integral with vice versa.

$$\vec{A} = \vec{A}(x, y, z)$$

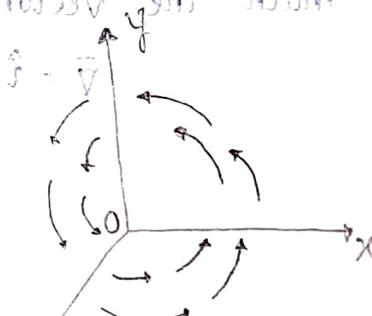
→ Stoke's Theorem :- It is to convert surface integral to circulation

→ These is used to convert surface integral to circulation

$$\int_S (\vec{\nabla} \times \vec{A}) \cdot d\vec{s} = \int_C \vec{A} \cdot d\vec{l} + \int_C \vec{A} \cdot d\vec{l} + \int_C \vec{A} \cdot d\vec{l}$$

Divergence :-

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

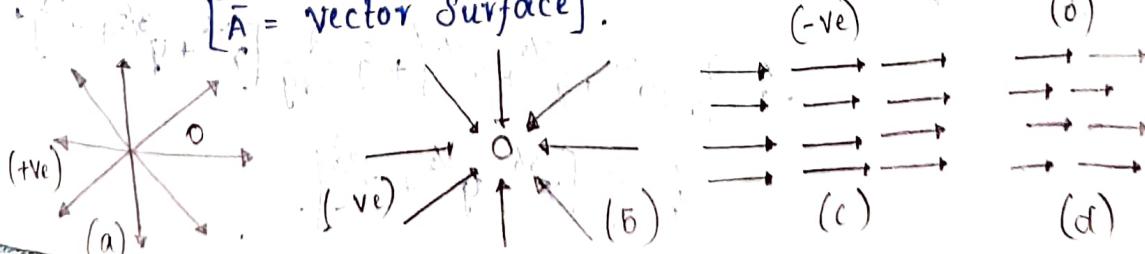


$$\vec{\nabla} \cdot \vec{A} = \text{div } \vec{A} = \left(\hat{i} \frac{\partial}{\partial x} + \hat{j} \frac{\partial}{\partial y} + \hat{k} \frac{\partial}{\partial z} \right) \cdot \vec{A} = \left(A_x \frac{\partial}{\partial x} + A_y \frac{\partial}{\partial y} + A_z \frac{\partial}{\partial z}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

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

+ Divergence of \vec{A} is defined as net outward flux per unit volume over a closed surface.

[\vec{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].

→ Curvilinear :-

$$\oint_S (\bar{\nabla} \times \bar{A}) \cdot d\bar{s} = \oint_C \bar{A} \cdot d\bar{l}$$

$\Rightarrow \bar{\nabla} \times \bar{A}$ → Circulation.

• Single line contour 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.

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

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

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

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

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

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

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

$$e = \frac{\partial \phi}{\partial r}$$

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

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

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

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

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

$$\boxed{\nabla \cdot \bar{A} \neq 0}$$

\rightarrow Solenoidal field.

$$(\hat{i} + \hat{j} + \hat{k}) \cdot \bar{A} = 0$$

Q) $(\text{curl } \bar{A}) \cdot \hat{r} = ?$

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

$$\frac{\partial}{\partial x} \hat{i} + \frac{\partial}{\partial y} \hat{j} + \frac{\partial}{\partial z} \hat{k} = 0. \quad \nabla \cdot \bar{A} = 0$$

These is a solenoidal field.

Q) The $\bar{A} = x^2\hat{i} + y^2\hat{j} + z^2\hat{k}$ is the field solenoidal?

Q) Is the field irrotational?

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

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

It is also a solenoidal field.

$$(6). \nabla \times \bar{A} = 0.$$

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

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

$$\text{Sol. } \nabla \cdot \bar{A} = \text{Solenoidal.}$$

$$\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ yz & xz & xy \end{vmatrix} = \hat{i}(x-x) - \hat{j}(y-y) + \hat{k}(z-z) = 0.$$

$$\nabla \times \bar{A} = 0$$

$$\nabla \times \bar{A} = 0$$

$$\nabla \times \bar{A} = 0$$

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

a) $n r^{n-1} \vec{r}$ b) $n r^{n-2} \vec{r} + \vec{r} \cdot \vec{r}^{n-2}$

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

$$|\vec{r}| = r(x^2 + y^2 + z^2)^{1/2}$$

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

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

+ Gauss's Law of Electricity :-

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

$$\phi_c = \oint_S \vec{E} \cdot d\vec{s} = \frac{q_{\text{enc}}}{\epsilon_0}$$

Differential form of Gauss Law :-

$$\nabla \cdot \vec{D} = \rho$$

\vec{D} = Electric displacement vector.

charge & charge density are related.

$$q = \int_V \rho dV \rightarrow ①$$

+ Gauss's Law in Electricity :-

$$\oint_S \vec{E} \cdot d\vec{s} = \frac{q}{\epsilon_0}$$

$$\oint_S \vec{E} \cdot d\vec{s} = \frac{1}{\epsilon_0} \int_V \rho dV$$

$$\oint_S (\epsilon_0 \vec{E}) \cdot d\vec{s} = \int_V \rho dV$$

$$\oint \vec{D} \cdot d\vec{s} = \int_V \rho dV.$$

By using gauss law divergence theorem in left hand side.

$$\oint_V (\nabla \cdot \vec{D}) dV = \int_V \rho dV \Rightarrow \frac{\partial E}{\partial r} = 5 \times 10^{-5}$$

for some arbitrary volume

$$[\nabla \cdot \vec{D} = \rho] \rightarrow 1^{\text{st}} \text{ max. equation}$$

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

$$\nabla E = - \frac{\partial V}{\partial r} \hat{r} = \vec{E} = \left(\hat{i} \frac{\partial V}{\partial x} + \hat{j} \frac{\partial V}{\partial y} + \hat{k} \frac{\partial V}{\partial z} \right)$$

$$[\vec{E} = -\nabla V] \quad \frac{\partial V}{\partial r} = \Phi \quad \frac{\partial V}{\partial r} = \Phi$$

Poisson's Equation and Laplace Equation:

Gauss's Law in electricity is given by

$$(\nabla \cdot \vec{D} = \rho) \quad \vec{D} = \epsilon_0 \vec{E}$$

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

$$\nabla \cdot (\epsilon_0 \vec{E}) = \rho$$

$$\nabla \cdot (\epsilon_0 \nabla V) = -\rho$$

$$\nabla^2 V = -\frac{\rho}{\epsilon_0}$$

→ These is called Poisson Equation.

For charge free region $\rho = 0$.

$$\nabla^2 V = 0 \rightarrow \text{These is called Laplace eqn.}$$

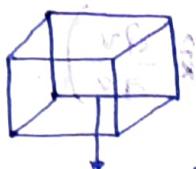
With sufficient

$$\frac{\partial V}{\partial r} = 0$$

(leads to boundary)

- Maxwell's Eqn in Differential form :-
1. $\nabla \cdot \vec{D} = \rho$ Gauss law in electricity. $\left\{ \begin{array}{l} \text{div } \vec{D} \\ \text{div } \vec{B} \end{array} \right.$
 2. $\nabla \cdot \vec{B} = 0$ Gauss law in Magnetism.
 3. $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ Faraday's law of electric magnetic induction.
 4. $\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$ Modified ampere's law $\vec{J} = \text{curl operator}$

* Continuity Equation :



$$\vec{D} = -\frac{d\vec{q}}{dt}$$

$$\vec{D} = -\frac{d}{dt} \int_V \vec{S} dV \rightarrow \textcircled{1}$$

$$\text{we know that } \vec{q} = \int_V \vec{S} dV \rightarrow \textcircled{2}$$

charge is leaving the volume. Current & current density are related with,

$$\nabla \cdot \vec{J} = \frac{d\rho}{dt} = 0$$

$$\Phi = \oint_S \vec{J} \cdot d\vec{s} \rightarrow \textcircled{4}$$

Conservation of charge,

from $\textcircled{3} \& \textcircled{4}$ Equations:

$$-\frac{d\vec{q}}{dt} = \vec{J}$$

$$\oint_S \vec{J} \cdot d\vec{s} = -\frac{d}{dt} \int_V \vec{S} dV$$

$$\int_S \vec{J} \cdot d\vec{s} = -\int_V \frac{df}{dt} dV$$

Only depends on time.

use Gauss law divergence theorem in left hand theorem

$$\int_V (\nabla \cdot \vec{J}) dV = -\int_V \frac{df}{dt} dV$$

for any arbitrary volume

$$\boxed{\nabla \cdot \vec{J} = -\frac{ds}{dt}}$$

continuity eqn

(conservation of charge)

If there is stationary Current $\frac{d\vec{B}}{dt} = 0$

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

Derivation of 2nd Maxwell Equation :-

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

Proof : Gauss Law in magnetism.

$$\oint \vec{B} \cdot d\vec{s} = 0$$

use gauss's law divergence theorem,

$$\oint (\nabla \cdot \vec{B}) dV = 0$$

form an arbitrary volume,

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

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

Derivation of 3rd Maxwell Equation :-

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

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

$$E_{\text{emf}} = - \frac{d\phi_B}{dt}$$

$$\boxed{\phi_B = \oint \vec{B} \cdot d\vec{s}}$$

$$E_{\text{emf}} = - \frac{d}{dt} \oint \vec{B} \cdot d\vec{s} \rightarrow ①$$

* Induced emf can also be calculated :

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

$$E_{\text{emf}} = \oint \vec{E} \cdot d\vec{l} \rightarrow ②$$

from ① & ② eq'n.

$$\oint \vec{E} \cdot d\vec{l} = - \frac{d}{dt} \oint \vec{B} \cdot d\vec{s}$$

use stoke's theorem,

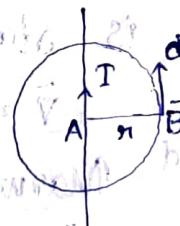
$$\oint (\nabla \times \vec{E}) d\vec{l} = - \oint \frac{\partial \vec{B}}{\partial t} \cdot d\vec{s}$$

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

is not given

Ampere's Circuit Law

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



Proof : use Biot's Savarts Law.

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

$$LHS = \oint_c \bar{B} \cdot d\bar{l} = \oint_c \bar{B}(dl)$$

($\bar{B} \perp \bar{dl}$), minor problems no impact

$$\oint_c \bar{B} \cdot d\bar{l} = \oint_c B dl = B \oint dl = B \cdot 2\pi r$$

$$\therefore \text{RHS} = \frac{\mu_0}{4\pi} \cdot \frac{2I}{r} \cdot 2\pi r = \mu_0 I \text{ (no problem)} \\ \therefore LHS = \text{RHS.}$$

No face boundary term appears for pathlength $\oint dl$.

$$\Rightarrow \oint_c \bar{v} \times \bar{H} = \bar{J} + \frac{\partial \bar{B}}{\partial t} \quad \text{D.P.} = \epsilon_0 \bar{E}$$

Proof of 4th Maxwell Eqn:

According to Ampere's circuit law,

Inductionless case was the boundary current free case.

$$\Rightarrow \oint_c \frac{\bar{B}}{\mu_0} \cdot d\bar{l} = I = \oint_s \bar{J} \cdot d\bar{s}$$

$$\oint_c \bar{H} \cdot d\bar{l} = \oint_s \bar{J} \cdot d\bar{s}$$

use Stoke's theorem, $\bar{H} = \frac{\bar{B}}{\mu_0}$ Magnetic field strength.

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

For an arbitrary Surface,

$$\textcircled{1} \leftarrow \bar{v} \times \bar{H} = \bar{J} \rightarrow \text{accepts only for the stationary Current.}$$

Take div. Both sides of ①

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

$$0 = \text{div} \bar{T} \Rightarrow \nabla \cdot \bar{T} = 0.$$

Continuity equation is given by, $\bar{J} = \bar{B} \times \bar{V}$

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

$$\boxed{\nabla \cdot \bar{J} = 0} \quad \text{if} \quad \frac{dp}{dt} = 0.$$

stationary current.

For changing electric field :-

According to Maxwell,

$$\nabla \times \bar{H} = \bar{J} + \bar{T}' \quad \text{Because of } I_d.$$

Because of Current (I)

Take div. of both sides of eq ②

$$\text{div}(\nabla \times \bar{H}) = \text{div} \bar{T}' + \text{div} \bar{T}^*$$

$$0 = -\frac{d\phi}{dt} (\nabla \cdot \bar{D}).$$

$$\nabla \cdot \bar{T}' = \nabla \cdot \left(\frac{d\phi}{dt} \bar{D} \right) \Rightarrow \bar{T}' = \frac{d\phi}{dt} \bar{D}.$$

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

$$\Rightarrow \nabla \times \bar{H} = \bar{J} + \frac{d\phi}{dt} \bar{D}$$

⇒ Integral form of Maxwell's Eqn :-

$$1. \nabla \cdot \bar{D} = \rho$$

$$\int_S \bar{D} \cdot d\bar{s} = q.$$

Gauss's Law in Electricity

$$2. \nabla \cdot \bar{B} = 0$$

$$\int_S \bar{B} \cdot d\bar{s} = 0$$

$$(\nabla \cdot \bar{B})$$

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

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

Proof of 1st Maxwell's Eqn

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

Take volume integration both sides.

$$\int_V (\bar{D} \cdot \bar{D}) dV = \int_V \rho dV$$

$$\oint_S \bar{D} \cdot d\bar{s} = q$$

$$q = \int_V \rho dV$$

$$\int (\bar{D} \cdot \bar{A}) dV = \oint A dS$$

proof of 2nd Eqn: Gauss div.

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

Take volume integration both sides.

$$\int (\bar{D} \cdot \bar{B}) dV = 0$$

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

Proof of 3rd Maxwell Eqn

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

Take the surface integration b.s.

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

$$\oint_S (\bar{D} \cdot \bar{B}) dV = 0 \Rightarrow \oint_S \bar{B} \cdot d\bar{s} = 0$$

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

Proof In the equation $\oint_s (\nabla \times \vec{E}) \cdot d\vec{s} = - \frac{d}{dt} \oint_s \vec{B} \cdot d\vec{s}$, we will prove the right-hand side is zero.

$$\oint_s (\nabla \times \vec{E}) \cdot d\vec{s} = \oint_s \left(J + \frac{\partial \vec{B}}{\partial t} \right) \cdot d\vec{s}$$

$$\Rightarrow \oint_s \vec{H} \cdot d\vec{i} = \oint_s \left(J + \frac{\partial \vec{B}}{\partial t} \right) \cdot d\vec{s}$$

Now we will prove the left-hand side is zero.

Physical Significance of Maxwell Eqn 3

It is known as Gauss law in electricity.

First, Maxwell Eqn → It states that electric flux out of any closed surface is proportional to the charge enclosed by that surface.

→ Integrat form of 1st maxwell's equation is used

to find electric field around charged objects.

→ $\oint_s (\vec{E} \cdot d\vec{s}) = Q_{enclosed}$ → Net electric flux out of any closed surface is zero.

→ $\oint_s (\vec{B} \cdot d\vec{s}) = 0$ → Gauss law in magnetism.

→ There are no magnetic monopoles.

⇒ By changing magnetic field ($d\vec{B}$) with time we can induce electric field.

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

→ 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. $\rightarrow \oint_C \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \oint_B d\vec{s}$.

$$4. \nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{B}}{\partial t}$$

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

→ Ratio of EM waves

→ Heat transfer

→ Rate of absorption

→ Rate of reflection

→ Rate of transmission

→ Rate of scattering

→ Rate of absorption

→ Rate of reflection

→ Rate of transmission

→ Rate of scattering