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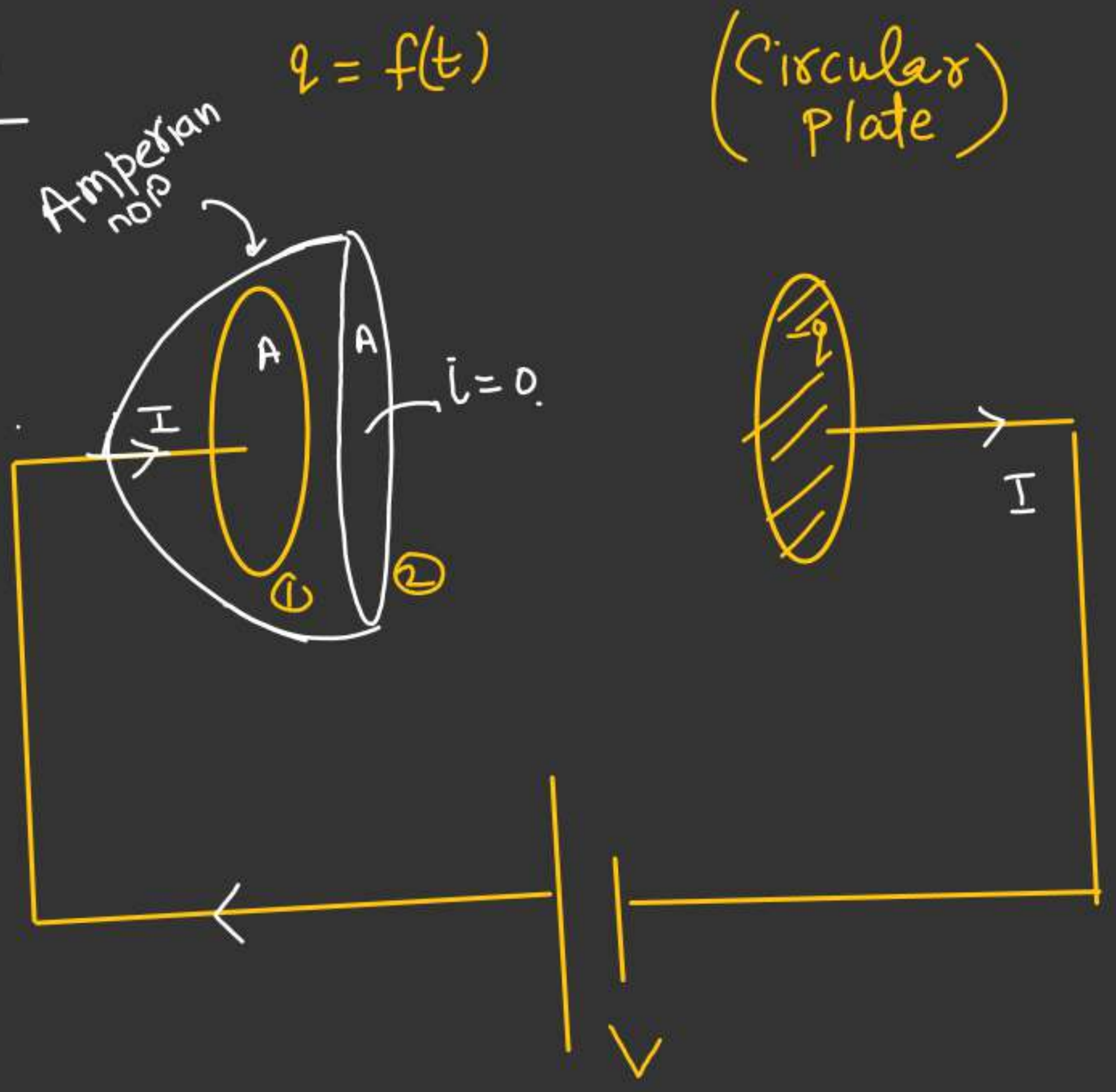
E.M WAVE (JEE MAINS ONLY)

E.M = (Electromagnetic)

Inconsistancy of Ampere's Law

$$\left[\begin{aligned} \oint_1 \vec{B}\cdot d\vec{l} &= \mu_0 i \\ \oint_2 \vec{B}\cdot d\vec{l} &= 0 \end{aligned}\right.$$

Inconsistancy in Ampere's Law.



Actually $\oint_1 \vec{B}\cdot d\vec{l} = \oint_2 \vec{B}\cdot d\vec{l}$

[there Contradiction in Ampere's law]

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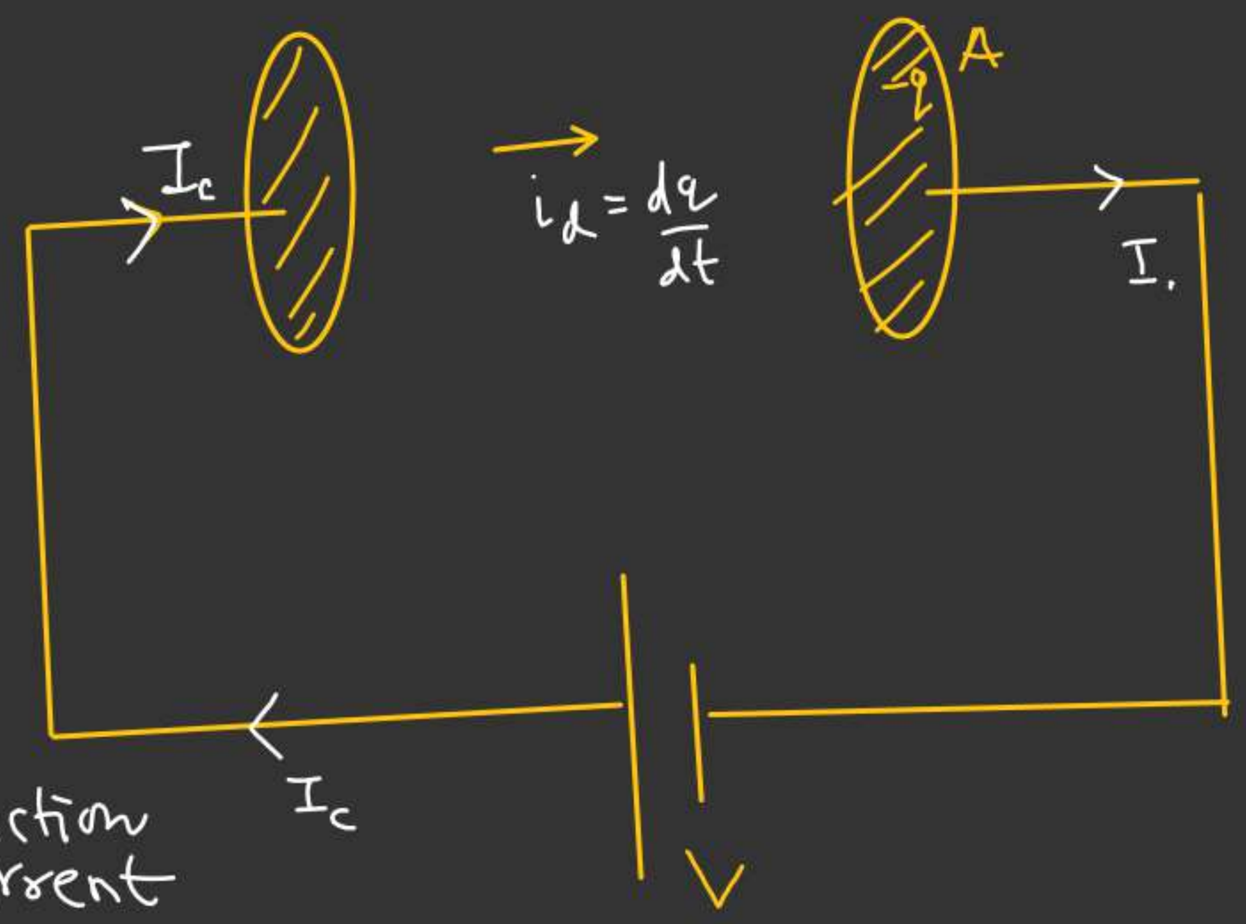
Displacement Current

$\Downarrow$ Displacement Current b/w the two plates is due to Change in Electric flux

$$\boxed{i_d = \varepsilon_0 \frac{d(\phi_E)}{dt}}$$

$q = f(t)$ ✓

(Circular plate)



$$\phi_E = EA$$

$$i_d = \varepsilon_0 \frac{d}{dt}(EA)$$

$$i_d = \varepsilon_0 \frac{d}{dt}\left(\frac{q}{\varepsilon_0 A} \times A\right)$$

$$\boxed{i_d = \left(\frac{dq}{dt}\right) = i_c}$$

i_c = Conduction Current

i_d = displacement current

Consitancy of Ampere's law

$q = f(t)$ ✓

$$\oint_1 \vec{B}\cdot d\vec{l} = \mu_0 i_c$$

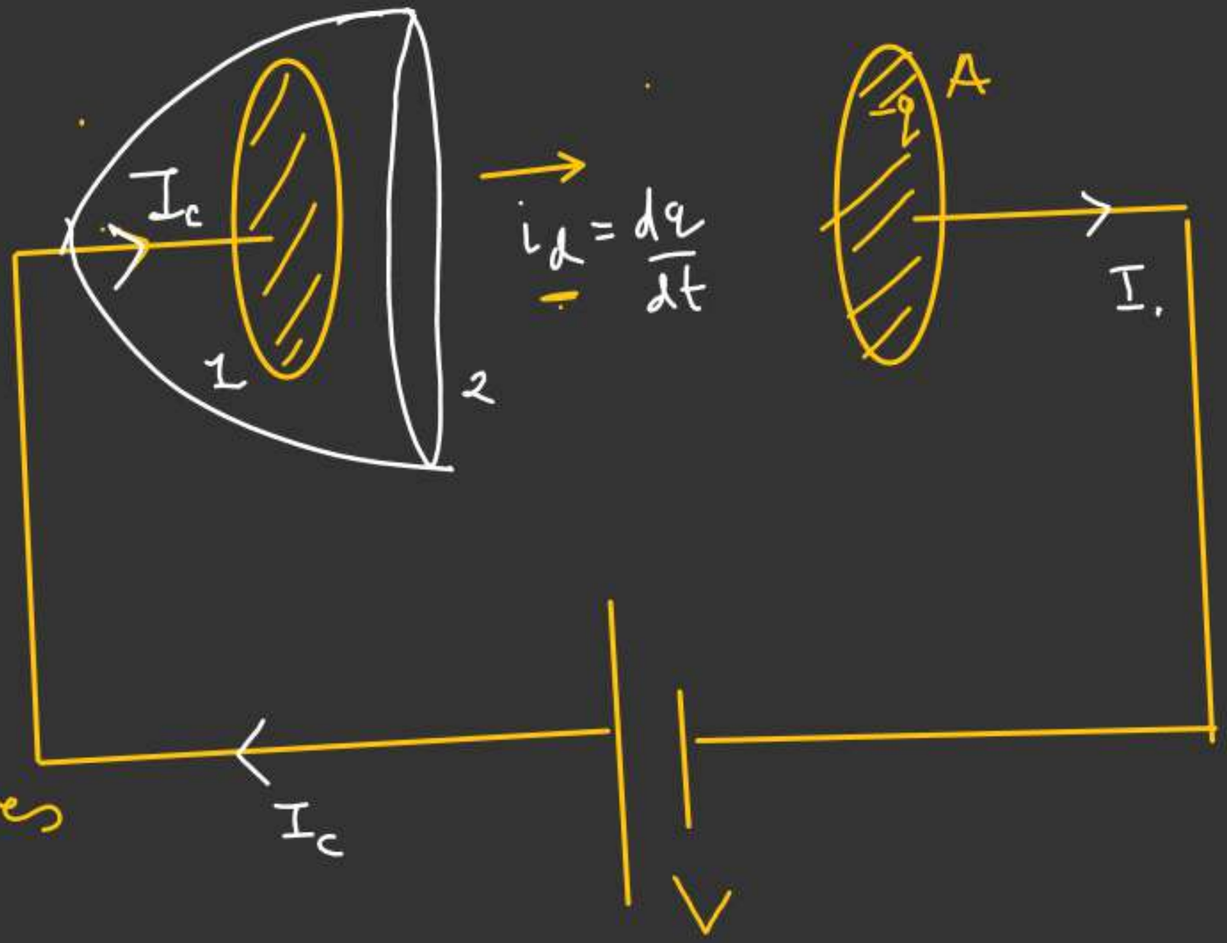
$$i_d = \varepsilon_0\left(\frac{d\phi_E}{dt}\right) = \frac{dq}{dt} = i_c$$

(Circular plate)

$$\oint_2 \vec{B}\cdot d\vec{l} = \mu_0 i_d$$

$$\left(i_c = i_d = \frac{dq}{dt}\right)$$

$$\oint_1 \vec{B}\cdot d\vec{l} = \oint_2 \vec{B}\cdot d\vec{l}$$



Note :- [An Electric field produces Magnetic field]

[A Magnetic field produces Electric field]

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MAXWEL EQUATIONS

① Gauss's Law of Electrostatic

$$\boxed{\oint \vec{E}\cdot d\vec{s} = \frac{q_{enc}}{\varepsilon_0}}$$

$$F \propto \frac{1}{r^2}$$

↳ Important Consequence

- Charge on the Conductor always resides at the surface of the conductor
- Force of interaction b/w two charges is inversly proportional to square of the distance b/w them.

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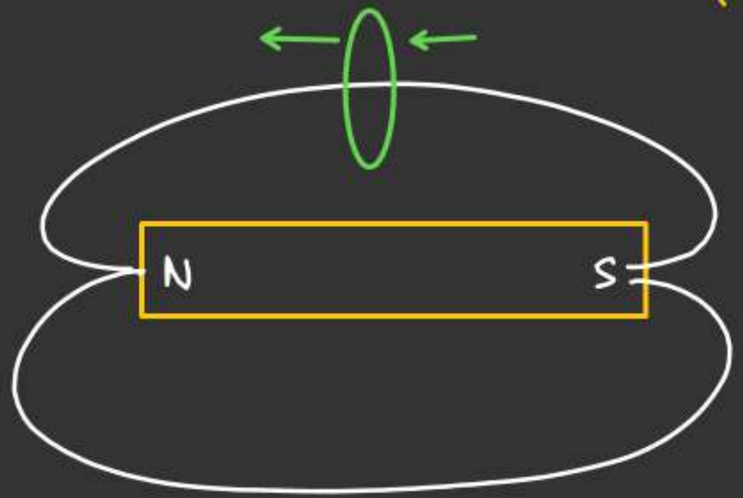
Q. 2nd Maxwell Equation

Gaus's Law in Magnetism:-

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



$\Downarrow$

Magnetic Monopole doesn't exist

3rd Law

Faraday's Law of Electromagnetic induction

$$\mathcal{E}_{ind} = -\left(\frac{d\phi}{dt}\right)$$

$\Downarrow$

$$\boxed{\int \vec{E} \cdot d\vec{l} = -\frac{d\phi}{dt}}$$

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Maxwell's 4^{th} Law

Modified Ampere's law.

$$\boxed{\oint \vec{B}\cdot d\vec{l} = \mu_0 (i_c + i_d)}$$

i_c = Conduction Current

i_d = displacement current

$$i_d = \varepsilon_0 \frac{d(\phi_E)}{dt} = \frac{dq}{dt} = i_c$$

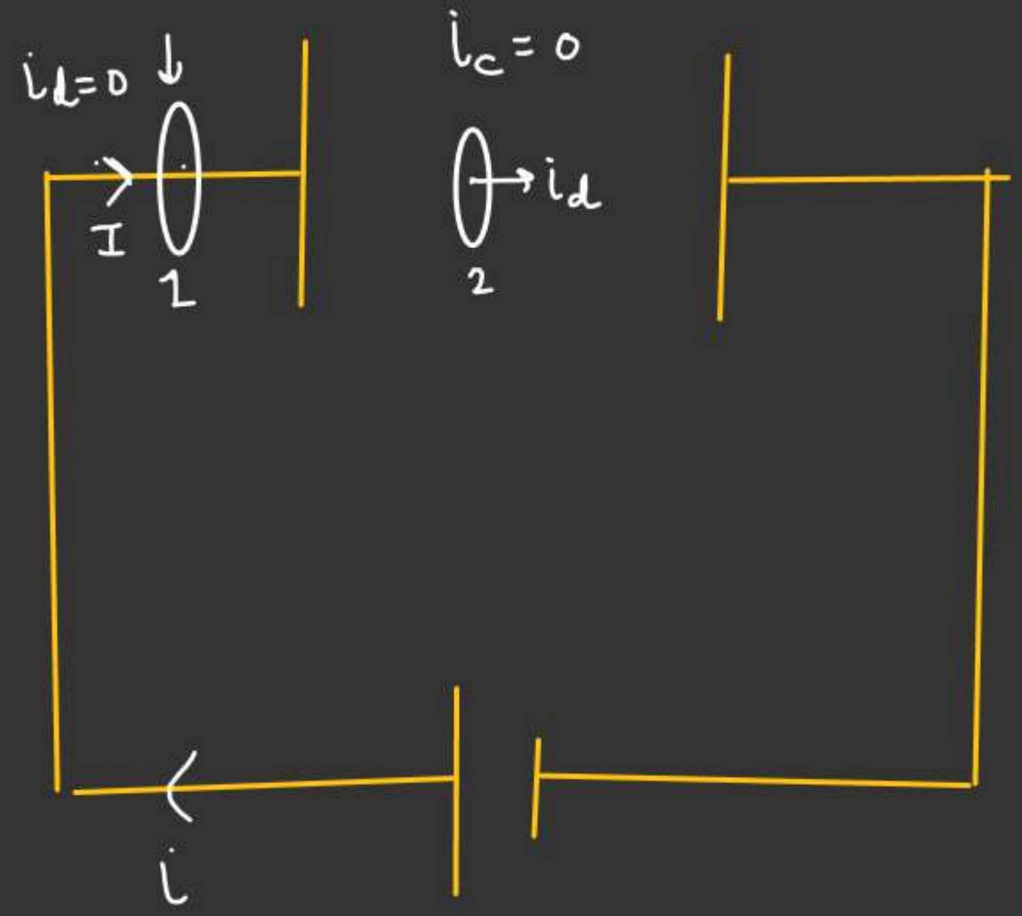
$$i_c + i_d = i$$

For loop-1

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 i_c = \mu_0 i$$

For loop-2

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 i_d = \mu_0 i$$



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E.M WAVE (Electromagnetic Wave)

- ↳ Doesn't required Medium for propagation.
- ↳ Propagation of E.M Wave is due to oscillation of Electric field and Magnetic field.
- ↳ Electric field, Magnetic field and direction of propagation all three are mutually perpendicular to each other
- ↳ Direction of propagation of EM Wave is $(\vec{E} \times \vec{B})$

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↳ Speed of propagation is equal to Speed of light in air

$$C = \left(\frac{E_0}{B_0}\right),$$

E_0 & B_0 are Amplitude of Electric field & Magnetic field.

↳ $$C = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

↳ Speed of propagation in a Medium

$$v_m = \frac{1}{\sqrt{\mu_m \varepsilon_m}} = \frac{1}{\sqrt{\mu_0 \mu_r \varepsilon_0 \varepsilon_r}} = \frac{C}{\sqrt{\mu_r \varepsilon_r}}$$

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In general travelling wave

$$y = A \sin(\underbrace{kx - \omega t}_{\text{phase}}) \rightarrow \text{Travelling in } +x \text{ direction}$$

y ⇓ Displacement of particle

A → Amplitude

$$k = \frac{2\pi}{\lambda} = \text{wave No.}$$

$$\omega = \frac{2\pi}{T} = 2\pi f$$

ω ⇓ Angular frequency.

$$y = A \sin(kx + \omega t) \Rightarrow \text{Travelling in } -ve \ x\text{-direction}$$

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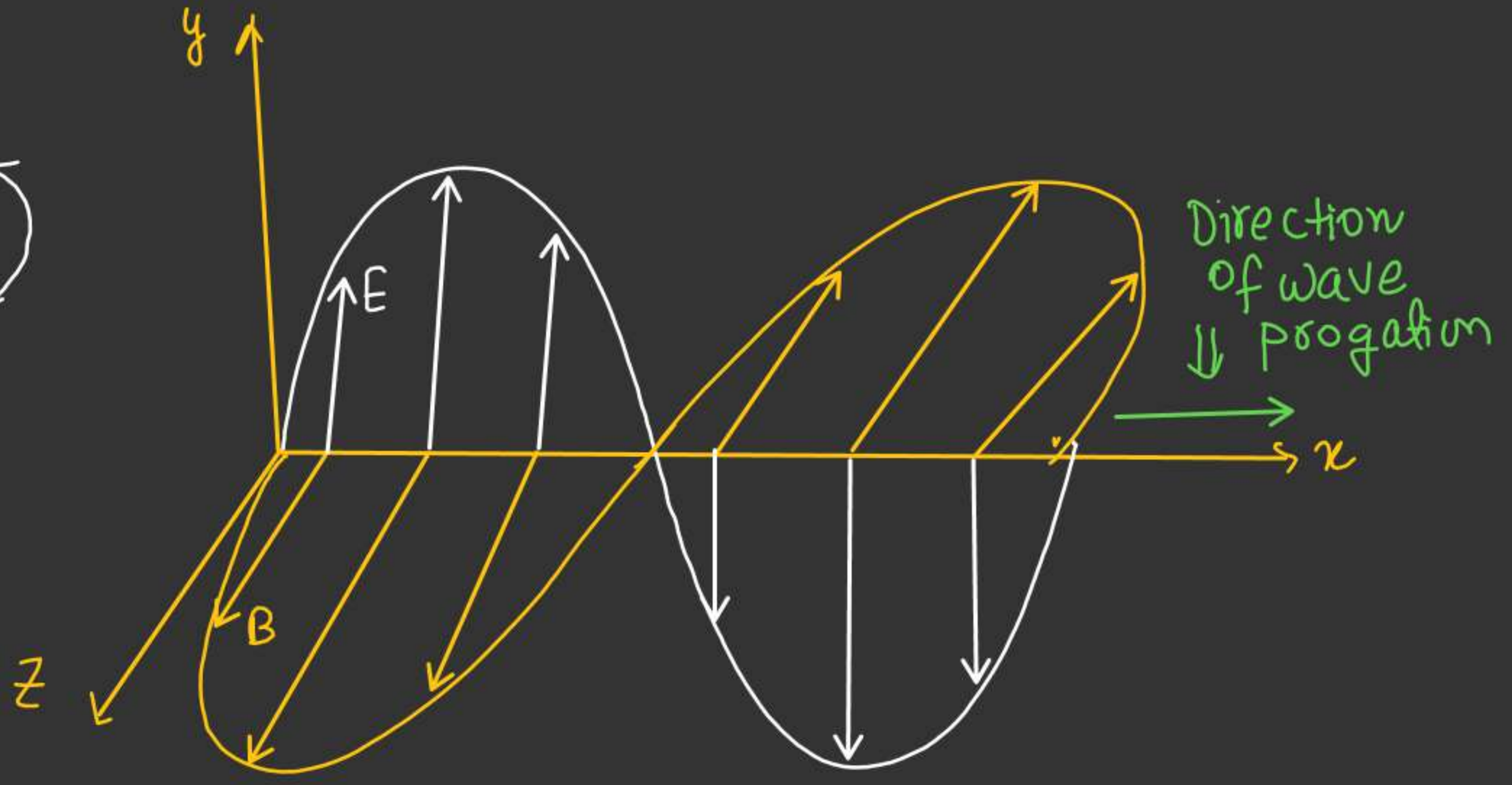
Equation of E.M Wave

$$\vec{E} = E_0 \sin(kx - \omega t)\,\hat{j}$$

$$\vec{B} = B_0 \sin(kx - \omega t)\,\hat{k}$$

$$\hat{v} = \hat{j} \times \hat{k} = \hat{i}$$

$$\boxed{\frac{E_0}{B_0} = C}$$



(*) E.M transverse in Nature

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ENERGY DENSITY OF E.M WAVE :-

↳ In E.M wave energy is equally distributed in the Magnetic & Electrostatic Energy

$$u = \left(\frac{1}{2}\varepsilon_0 E_0^2\right) + \left(\frac{B_0^2}{2\mu_0}\right)$$

[Energy density of E.M wave]

$$E_{rms} = \frac{E_0}{\sqrt{2}}$$

$$B_{rms} = \frac{B_0}{\sqrt{2}}$$

$$u_{avg} = \frac{1}{2}\varepsilon_0 E_{rms}^2 + \frac{B_{rms}^2}{2\mu_0}$$

Avg Energy density

$$= \left(\frac{1}{4}\varepsilon_0 E_0^2 + \frac{B_0^2}{4\mu_0}\right)$$

$$\frac{E_0}{B_0} = C$$

$$B_0 = \left(\frac{E_0}{C}\right)$$

$$C^2 = \frac{1}{\mu_0 \varepsilon_0}$$

$$u_{avg} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{E_0^2}{C^2} \times \frac{1}{4\mu_0}$$

$$= \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\varepsilon_0 E_0^2$$

$$\boxed{u_{avg} = \frac{1}{2}\varepsilon_0 E_0^2 = \frac{B_0^2}{2\mu_0}}$$

$$\boxed{u_{avg} = \varepsilon_0 E_{rms}^2 = \frac{B_{rms}^2}{\mu_0}}$$

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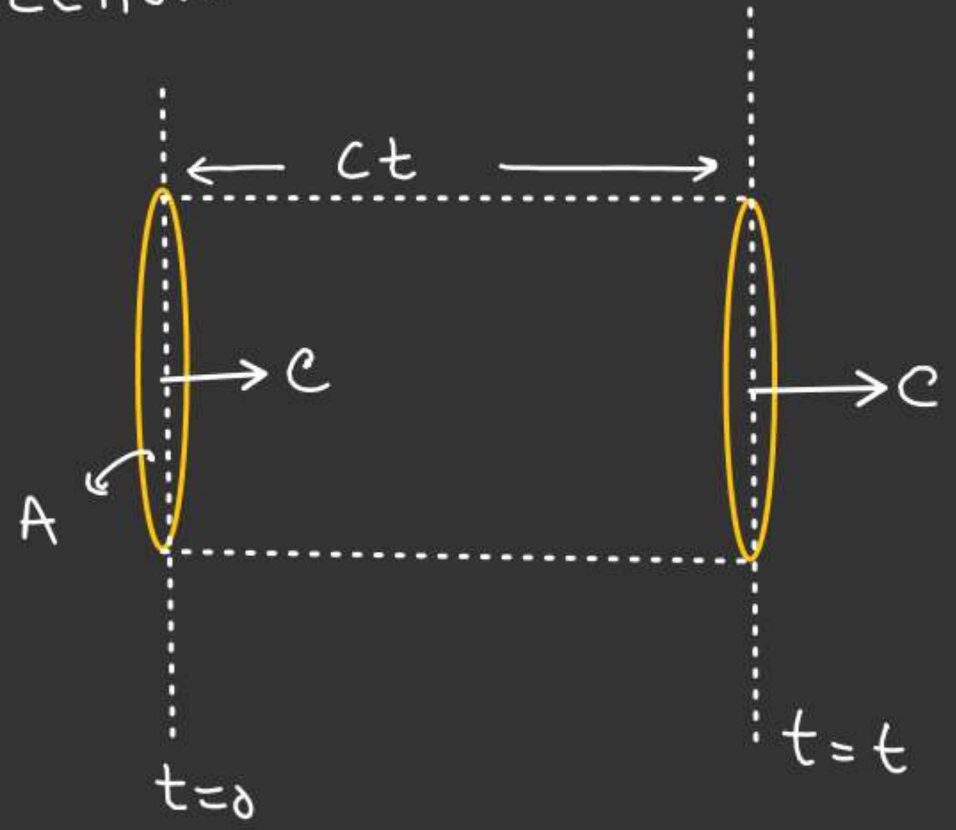
☆☆: Intensity of E.M Wave :-

↳ Energy Crossing per unit time per unit Area

[Area is perpendicular to the direction of wave propagation].

$$\frac{E}{\text{Volume}} = (\mu)$$ Energy density.



$$\frac{E}{A(ct)} = \mu$$

$$\left(\frac{E}{A\cdot t}\right) = \mu c$$

⇓

$$\boxed{I = \mu c}$$

☆☆

$$\boxed{\begin{aligned} I &= \frac{1}{2}\varepsilon_0 E_0^2 \cdot c \\ &= \frac{B_0^2}{2\mu_0} \times c \end{aligned}}$$

☆☆