Apr 8

Get clicker, kit, galvanometer, one magnet, multimeter, stopwatch, ruler and coil

Mini-Lab: Faraday's Law

$N = 400$

Discussion: Maxwell Equations

Gauss' Law for Electricity

$$\oint \vec{E}\cdot\hat{n}\, dA = \frac{\sum q_{enclosed}}{\epsilon_0}$$

outward pointing normal

charge enclosed by 3D surface

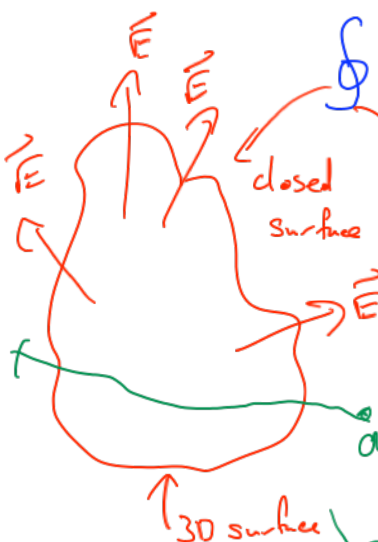
closed surface

add up

$E_{\perp}$ pointing out of surface

Electric flux through dA

const of proportionality "fixes units"



outside charges contribute to $\vec{E}$ but not flux

Total electric flux through a closed 3D surface is proportional to $(1/\epsilon_0)$ the total electric charge inside that surface.

Gauss' Law for Magnetism

$$\oint \vec{B}\cdot\hat{n}\,da \propto \sum q_{magnetic} = 0$$

↑ magnetic charges

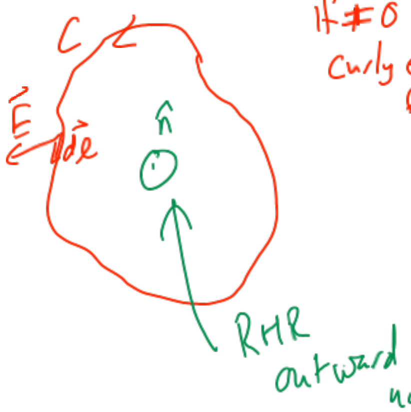
$$\oint \underbrace{\vec{B}\cdot\hat{n}}_{B_\perp}\,dA = 0$$ → no magnetic charges

Total magnetic flux through a closed 3D surface is zero since there are no magnetic charges

Faraday's Law

$$\text{EMF} = \oint_C \vec{E}\cdot d\vec{\ell} = -\frac{d\Phi_{mag}}{dt} = -\frac{d}{dt}\left[\int_S \vec{B}\cdot\hat{n}\, dA\right]$$

- $\oint_C$: entire closed path C
- $d\vec{\ell}$: line integral, not surface integral
- $\vec{E}\cdot d\vec{\ell}$: $E_{\parallel}$ — not flux
- If $\neq 0$: curly electric field
- $\vec{B}\cdot\hat{n}$: $B_{\perp}$
- $\int_S$: not closed surface — integrate over any 2-D surface with the curve C as boundary



EMF is equal to the negative of rate of change of magnetic flux through area enclosed by path

Ampere's Law

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \sum I_{enclosed}$$

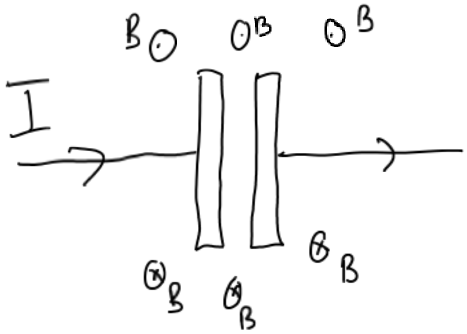
↑ Current passing through surface bounded by C

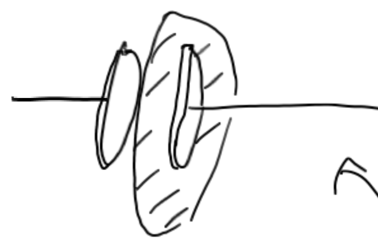
Integral of curly magnetic field dotted into path is equal to μ_0 times the sum of all electric current running through path

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 \sum I_{enc} + \ldots$$

look like

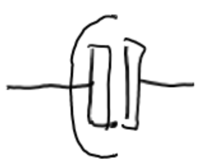
$$\oint \vec{E}\cdot d\vec{l} = -\frac{d}{dt}\left[\int \vec{B}\cdot\hat{n}\,dA\right] + 0$$





no current passing through path

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 \sum I_{encl} = 0$$



$$\oint \vec{B}\cdot d\vec{l} = \mu_0 \sum I_{enc} \neq 0$$

Need extra piece

"displacement current"

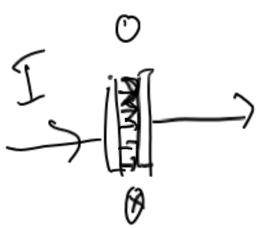
$$\oint \vec{E}\cdot d\vec{l} = -\frac{d}{dt}\left[\vec{B}\cdot\hat{n}\,dA\right] + \{0\}$$

↳ no magnetic monopoles

$$\oint \vec{B}\cdot d\vec{l} = \mu_0\left[\ ?\ + \sum I_{enclosed}\right]$$

↳ $\epsilon_0 \frac{d}{dt}\left[\int \vec{E}\cdot\hat{n}\,dA\right]$

↑



$$\oint \vec{E}\cdot\hat{n}\,dA = \frac{\sum q_{enc}}{\epsilon_0}$$

$$\oint \vec{B}\cdot\hat{n}\,dA = 0$$

$$\oint \vec{E}\cdot d\vec{l} = -\frac{d}{dt}\left[\int \vec{B}\cdot\hat{n}\,dA\right]$$

$$\oint \vec{B}\cdot d\vec{l} = \mu_0\left[\epsilon_0\frac{d}{dt}\left[\int \vec{E}\cdot\hat{n}\,dA\right] + \sum I_{encl}\right]$$

Maxwell's equ

$\vec{\nabla}\cdot\vec{E} = \frac{\rho}{\epsilon_0}$ Gauss' law for electric field

$\vec{\nabla}\cdot\vec{B} = 0$ Gauss' Law for magnetic field

$\vec{\nabla}\times\vec{E} = -\frac{\partial \vec{B}}{\partial t}$ Faraday's law

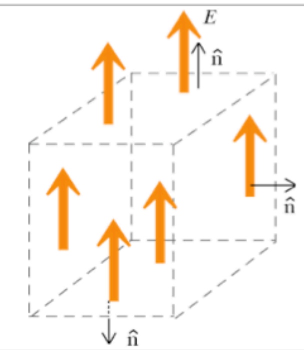
$\vec{\nabla}\times\vec{B} = \mu_0\left[\vec{J} + \epsilon_0\frac{\partial \vec{E}}{\partial t}\right]$

Amper-Maxwell Law

Ponderable: Predicting EM radiation

Clicker Questions

Q23.2a

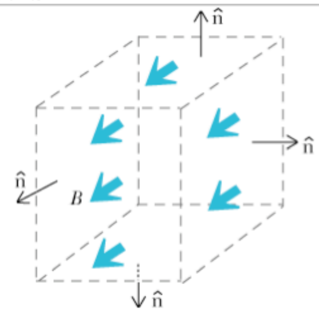


Region of nonzero electric field moving to right, at speed *v*.

What is inside the box?

A) Positive charge
B) Negative charge
C) Zero net charge

Q23.2b



Region of nonzero magnetic field moving to right, at speed *v*.

What is inside the box?

A) Positive charge
B) Negative charge
C) Zero net charge