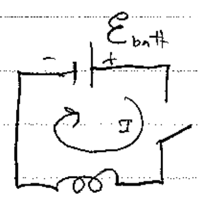
$\boxed{\text{Ph262}}$ Lecture 4 : Monday 8/28/06

Corrections:

① $\frac{dU}{dt} = P = IV = -LI\frac{dI}{dt} \Rightarrow U = -\frac{1}{2}LI^2$ eh?

Should be: $P_{\text{to create field}} = \frac{dU_{\text{field}}}{dt}$

Kirchoff's voltage law

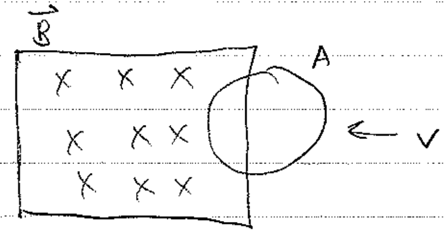


$L \rightarrow \mathcal{E}_L$ is a back emf

$$\mathcal{E}_{batt} + \mathcal{E}_L = 0$$

$$\mathcal{E}_{batt} - L\frac{dI}{dt} = 0 \Rightarrow \mathcal{E}_{batt} = L\frac{dI}{dt}, \quad P_{batt} = I\,\mathcal{E}_{batt}.$$

②



Emf in conducting disc?

(Overhead)

a) No: $\vec{B}$, A fixed

b) Yes: $\vec{B} \neq 0$

c) No: other reason

d) Yes: other reason

$\vec{B}$ fixed, A fixed, flux changing.

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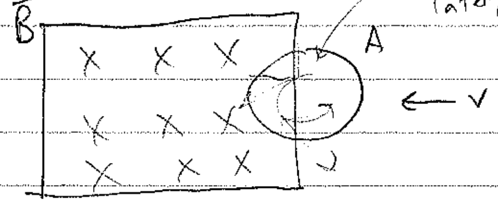
Draw ccw arrow later, when discussing CPS question's answer,



Which way does force go?

(Overhead)

a) $\leftarrow$ e) $\times$

b) $\rightarrow$ f) $\odot$

c) $\uparrow$ g) It is zero

d) $\downarrow$

Might have thought d) $\downarrow$, since $q\vec{v} \times \vec{B}$ is down,

Charges circulate, $\vec{v}$ above cancels $\vec{v}$ below.

Only part of disc in $\vec{B}$ field $\rightarrow$ net $\vec{v}$ down,

$q\vec{v} \times \vec{B}$ is to the right (b) $\rightarrow$).

<Eddy Pendulum demo>

1) Al disc, $\vec{B} = 0$

2) Al disc, $\vec{B} \neq 0$ Disc brakes

3) Al slotted disc, $\vec{B} \neq 0$ (like laminated transformer)

PNM now charging ~\$1500 for transformers for new ACs
-\$3500

(Stop power meter story?)

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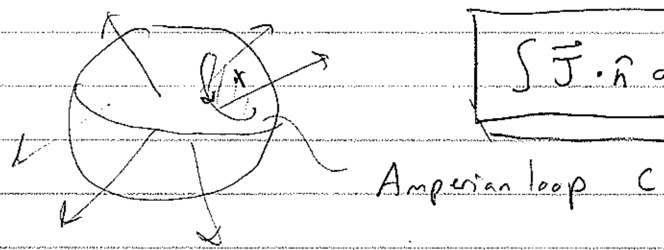
Electrodynamics

Charge is conserved!



$$\boxed{\int \vec{J}\cdot\hat{n}\,da = -\frac{dQ_{in}}{dt}}$$

Disagrees with Ampere's Law!

Uniform spherical charge flux:

$$\int \vec{J}\cdot\hat{n}\,da = 4\pi r^2 J_r(r) = \frac{-dQ}{dt}$$

$$\boxed{\vec{J} = -\frac{1}{4\pi r^2}\frac{dQ}{dt}\hat{r}}$$

Ampere's Law:

$$\oint_c \vec{B}\cdot d\vec{l} = \mu_0 \int \vec{J}\cdot\hat{n}\,da \neq 0$$

Violates symmetry of sphere!

Can't appeal to superposition – Ampere's law is complete!

Gauss' Law:

$$\int \vec{E}\cdot\hat{n}\,da = 4\pi r^2 E_r(r) = \frac{Q}{\varepsilon_0}$$

$$\frac{\partial\vec{E}}{\partial t} = \frac{1}{\varepsilon_0}\frac{1}{4\pi r^2}\frac{\partial Q}{\partial t}\hat{r} = -\frac{1}{\varepsilon_0}\vec{J}$$

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Maxwell's solution: Ampere-Maxwell law

$$\boxed{\oint \vec{B}\cdot d\vec{l} = \mu_0 \int \vec{J}\cdot\hat{n}\,da + \mu_0 \varepsilon_0 \frac{d}{dt}\int \vec{E}\cdot\hat{n}\,da}$$

$\vec{B}$ flux charge $\rightarrow$ $\vec{E}$ field

$\vec{E}$ flux charge $\rightarrow$ $\vec{B}$ field

Nice symmetry

HW: Capacitor at high freq. less than ideal.

⟨(PDF)⟩

All of physics, circa 1905

- Point out Maxwell's eqns
- Point out charge conservation built in
- Point out field version of gravity
- Point out fields connect to forces connect to motion via Newton,
- Point out mass conservation
- Point out SR will modify last 3 eqns, not Maxwell
- Point out GR will modify gravity
- Point out QM changes everything

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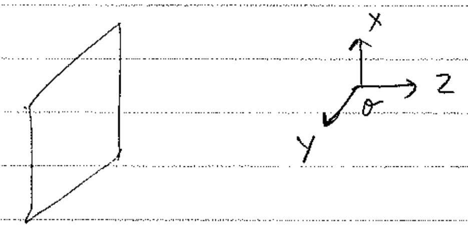
Plane wave solutions: (Finish Ch29, this is Ch 32)



$$\vec{E} = E_x(z,t)\,\hat{x} + E_y(z,t)\,\hat{y} + E_z(z,t)\,\hat{z}$$
$$\vec{B} = B_x(z,t)\,\hat{x} + B_y(z,t)\,\hat{y} + B_z(z,t)\,\hat{z}$$

Assume: ① $\vec{E}, \vec{B}$ const. in xy plane

② $\vec{J}, \rho = 0$

Will show: ① Dynamical $\vec{E}, \vec{B}$ confined to xy plane.

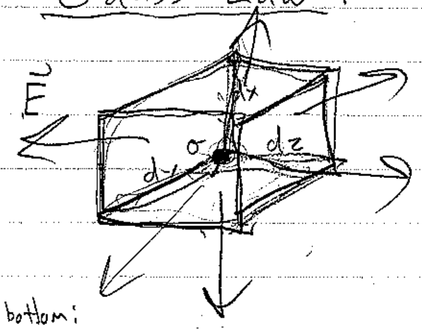
② $\vec{E} \perp \vec{B}$

③ $\vec{E}, \vec{B}$ satisfy wave equation.

④ Waves move at speed $c \cong 3\times10^8$ m/s

You will be asked to do a similar derivation in your homework, so pay attention & ask questions if you don't understand.

Gauss' Law: Cube $dx \times dy \times dz$



$$\oint \vec{E}\cdot\hat{n}\,da = \overset{\text{bottom}}{-\cancel{E_x}\,dy\,dz} + \overset{\text{top}}{\left(\cancel{E_x} + \frac{\partial E_x}{\partial x}dx\right)dy\,dz}$$
$$\overset{\text{back}}{-\cancel{E_y}\,dx\,dz} + \overset{\text{front}}{\left(\cancel{E_y} + \frac{\partial E_y}{\partial y}dy\right)dx\,dz}$$
$$\overset{\text{left}}{-\cancel{E_z}\,dx\,dy} + \overset{\text{right}}{\left(\cancel{E_z} + \frac{\partial E_z}{\partial z}dz\right)dx\,dy}$$

e.g., bottom:

$$\vec{E}\cdot\hat{n} = \vec{E}\cdot(-\hat{x}) = E_x(z,t)\,\underbrace{\cancel{\hat{x}\cdot(-\hat{x})}}_{-1}$$
$$= -E_x(z,t)$$

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$$\oint \vec{E}\cdot\hat{n}\,da = (\underbrace{\cancel{\partial_x E_x}}_{0\text{ (no x variation)}} + \underbrace{\cancel{\partial_y E_y}}_{0\text{ (no y variation)}} + \partial_z E_z)\,dx\,dy\,dz = 0$$

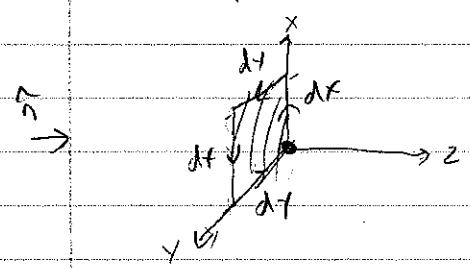
(I'll write ∂_x for $\frac{\partial}{\partial x}$ to save writing.)

$$\boxed{E_z = \text{const in space}}$$

$$\frac{\partial A}{\partial z} = 0 \Rightarrow A \neq f(z)$$

E_z already assumed not to depend on x, y.

Ampere-Maxwell law: ccw loop $dx \times dy$



$$\underbrace{\cancel{\oint \vec{B}\cdot d\vec{l}}}_{0\text{ (B const in x y)}} = \mu_0 \varepsilon_0 \frac{d}{dt}\int \underbrace{\vec{E}\cdot\hat{n}}\,da$$

$$0 = \cancel{\mu_0 \varepsilon_0}\,\frac{dE_z}{dt}\,\cancel{dx\,dy}$$

$$\boxed{E_z = \text{const in time}}$$

Gauss' Law for magnetism, Faraday's Law:

$$\boxed{B_z = \text{const in space + time}}$$

Dynamical $\vec{E}, \vec{B}$ confined to xy plane

Orient coordinates so that dynamical $\vec{E}, \vec{B}$ are

$$\vec{E} = E_x(z,t)\,\hat{x} \qquad \vec{B} = B_x(z,t)\,\hat{x} + B_y(z,t)\,\hat{y}$$

(The net $\vec{E}$ points in <u>some</u> direction in the xy plane)

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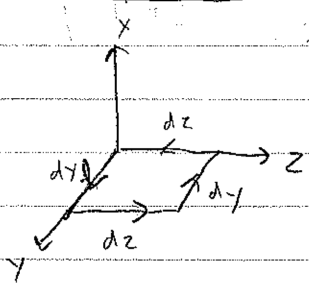
Faraday's Law: ccw loop dy x dz



0 (E ⊥ to loop)

$$\oint \cancel{\vec{E} \cdot d\vec{l}} = -\frac{d}{dt} \int \vec{B} \cdot \hat{n}\, da$$

$$0 = -\frac{dB_x}{dt}\, dy\, dz$$

$$\boxed{B_x = \text{const in time}}$$

B_x is not dynamical, $\vec{E} = E_x \hat{x}$, $\vec{B} = B_y \hat{y}$

$$\boxed{\vec{E} \perp \vec{B}}$$