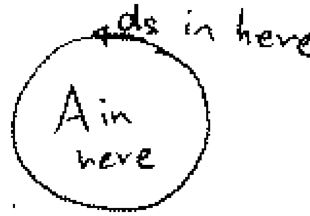
We've seen that you can create an E field from a changing B field

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

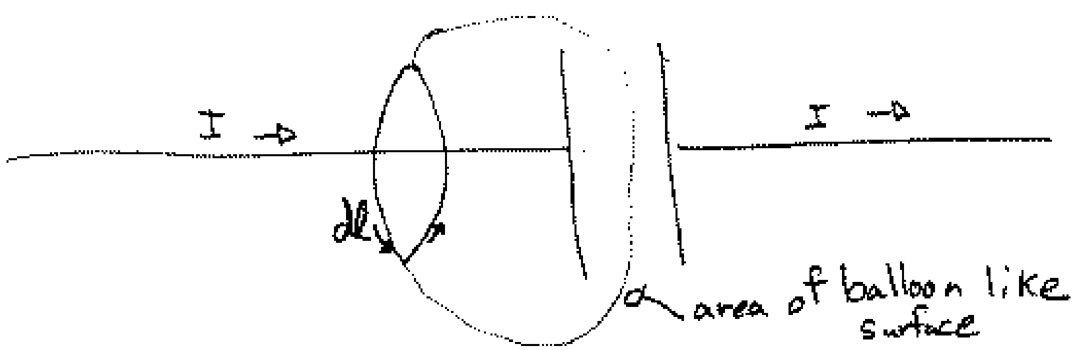
area bounded by



& we've seen
$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enc} = \mu_0 \int \vec{J}\cdot d\vec{A}$$

current density

Turns out though, there is a problem
consider a charging capacitor



Can draw your area so that $I = 0$ through the area

But $\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enc}$ right?

How can we fix this

consider $Q = CV$ $\quad I = \frac{dQ}{dt} = C\frac{dV}{dt} = Cd\frac{dE}{dt}$

$$= \frac{\varepsilon_0 A}{\cancel{d}}\cancel{d}\frac{dE}{dt} = \varepsilon_0\frac{d}{dt}(EA)$$

so $\oint \vec{B}\cdot d\vec{l} = \mu_0\varepsilon_0\frac{d\Phi_E}{dt} + \mu_0 I_{enc}$

Ex B 6mm from a wire & inbetween the plates of a capacitor of radius 3.00 mm $B = 2.0\times10^{-7}$ T

$\frac{dE}{dt} = ?$

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 \varepsilon_0 \frac{d}{dt}\Phi_E \qquad \Phi_E = \pi(3mm)^2 E$$

$$\frac{2\times10^{-7}\,T\,(2\pi(0.006m))}{4\pi\times10^{-7}\frac{Tm}{A}\;8.85\times10^{-12}\frac{C^2}{Nm^2}\;\pi\,(0.003m)^2}$$

$$= \quad 2.4\times10^{13} \quad \frac{N}{Cs} \qquad \text{huge}$$

in terms of current this is just

$$\frac{2.0\times10^{-7}\,T(2\pi)(0.006m)}{4\pi\times10^{-7}\frac{Tm}{A}} = 0.006A$$

Now, it turns out you can make a self-propagating wave by making a changing E field or B field.

This is a very useful concept for understanding things like radio and light.

As you recall, a self propagating wave can be described by

$$E(x,t) = E_0 \sin(kx - \omega t) \qquad k = \frac{1}{2\pi\lambda} \quad \omega = 2\pi f$$

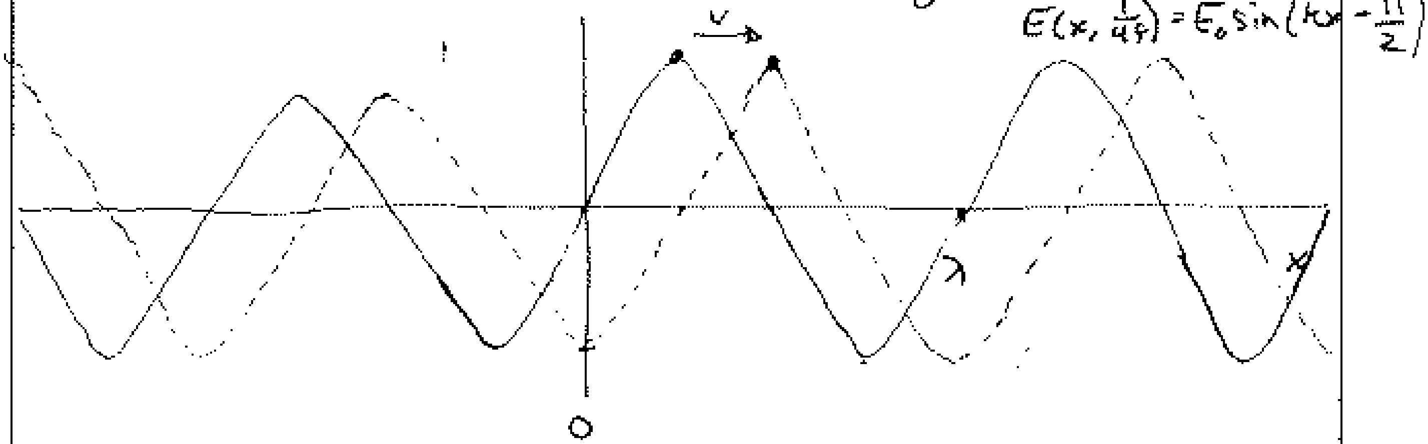
λ = wavelength ω = frequency

lets examine this equation a little bit

at $t=0$ $\quad E(x,0) = E_0 \sin(kx - 0)$

at $t = \frac{1}{4}\frac{1}{f}$ (one quarter period)

$E(x, \frac{1}{4f}) = E_0 \sin(kx - \frac{\pi}{2})$



the peak moves to the right

$$\theta = \frac{\pi}{2} = kx - \omega t$$

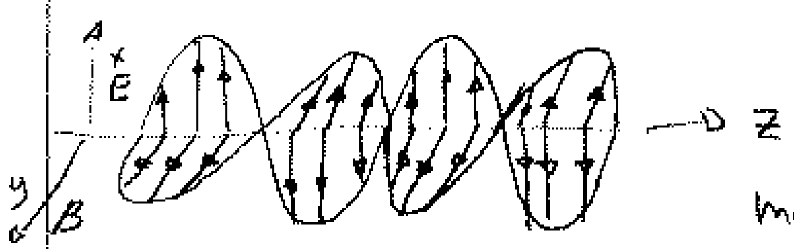
$$\frac{d\theta}{dt} = 0 = kv - \omega \qquad kv = \omega$$

$$v = \frac{\omega}{k} = \lambda f$$

This wave propagates because the changing

E field produces a B field
B field produces an E field } snake eating its own tail

& There is a particular way these waves behave



moves along the z

direction is given by

$\vec{E} \times \vec{B}$ $\perp$ to E & B

E is $\perp$ to B, moves @ $\frac{1}{\sqrt{\mu_0 \epsilon_0}} = c$

<u>waves</u>

add like waves

have frequency & wavelengths

Waves

- can bend them by changing their velocity

- waves carry energy such that

$$u_E = u_B$$

$$\cancel{\tfrac{1}{2}}\epsilon_0 E^2 = \cancel{\tfrac{1}{2}} \frac{1}{\mu_0} B^2$$

$$\frac{E^2}{B^2} = \frac{1}{\epsilon_0 \mu_0} \quad \frac{E}{B} = c \quad \text{in vacuum}$$

we can define a vector using E & B

$$\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$$

$$|S| = \frac{EB}{\mu_0} = c\,\frac{B^2}{\mu_0} \quad \text{at a point in time}$$

$$= \text{velocity} \cdot \frac{\text{Energy}}{\text{Volume}} \Rightarrow \frac{\text{Energy}}{\text{time}} \frac{1}{\text{Area}}$$

$$\frac{\text{instantaneous Power}}{\text{Area}} = \text{Intensity} \quad \left(\begin{array}{l}\text{get warm in}\\ \text{the sun}\end{array}\right)$$

Another cool thing

$$\frac{\text{Energy}}{\text{Volume}} \rightarrow \frac{\text{Force } \cancel{\text{distance}}}{\text{Area } \cancel{\text{distance}}} = \text{Pressure}$$

$$|S|c = \text{pressure}$$

on average $B^2_{avg} = B^2_{max} \sin^2(\theta)_{avg}$ $\left(\frac{1}{2}\theta - \frac{1}{4}\sin 2\theta\right)$

$$\sin^2(\theta)_{avg} = \frac{\int_0^{2\pi} \sin^2\theta \, d\theta}{d\theta} = \frac{1}{2}$$

$$S_{avg} = \left(\frac{c}{2}\right)\frac{B^2_{max}}{\mu_0}$$

IF 50W of a 100W light bulb go into making Em radiation what are P, B, E @ 3m

$$I = \frac{Power}{Area} = \frac{50w}{4\pi(3m)^2} = 0.442\ W/m^2$$

$$P = \frac{I}{c} = \frac{0.442\ W/m^2}{3\times10^8 m/s} = 1.47\times10^{-9}\ Pa \quad (\text{tiny})$$

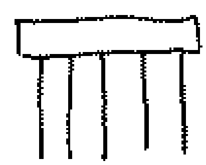
10^5 Pa vs $\frac{N}{m^2}$

$$B_{max}^2 = 2\frac{\mu_0}{c} I = 2\frac{4\pi\times10^{-7}\ \frac{Tm}{A}}{3\times10^8 \frac{m}{s}}\ 0.442\ \frac{W}{m^2} = 37\times10^{-16}\ T^2$$

$$B_{max} = 6\times10^{-8}\ T$$

$$E = cB = 18\ V/m$$

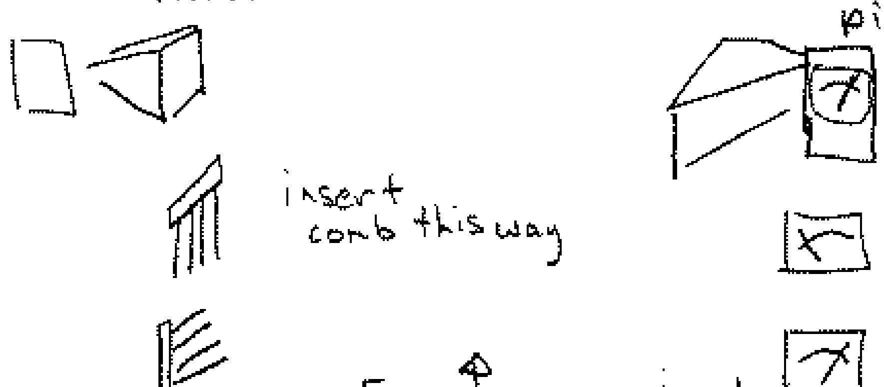
Now, I want to impress on you the vector nature of E & B fields

we will absorb $\updownarrow$ E fields with  wires

we will absorb in & out B fields with a sheet of metal (remember the sheets moving in the b field)

horn emits Em

detector horn picks them up

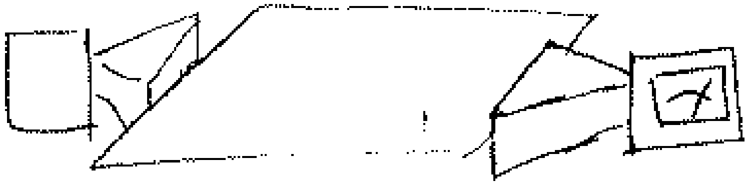


insert comb this way

signal goes $\Rightarrow$ 0

no effect

means E is $\updownarrow$ and B is in out we can confirm this with a slab of conductor



B moving in $\mathcal{E}$ out
induces an EMF
$\mathcal{E}$ eats up the
energy of the wave

another way to see this is with a
polarizer

lets through only one component of
the E field (the component along the
transmission axis)