Physics 142 – November 25, 2008

Happy Thanksgiving

- Presentations coming up

group	topic	2-Dec	4-Dec	9-Dec	11-Dec
1	Animals and electromagnetism				
2	Wireless communication devices				
3	light-saber				
4	relativity and electromagnetism				
5	Electromagnetism in chemistry and medicine				
6	Particle accelerators and detectors				
7	Superconductivity				
8	Electrical musical instruments				

Last Time —

Maxwell's eqns plus vector calc Identities

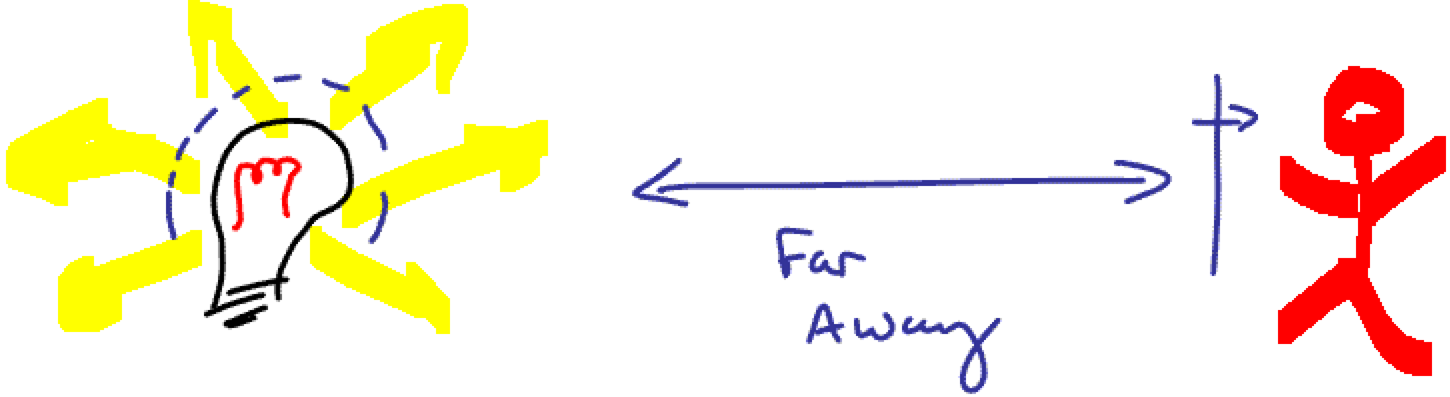
$$\nabla^2 \vec{B} = -\mu_0 \epsilon_0 \frac{\partial^2 \vec{B}}{\partial t^2}$$

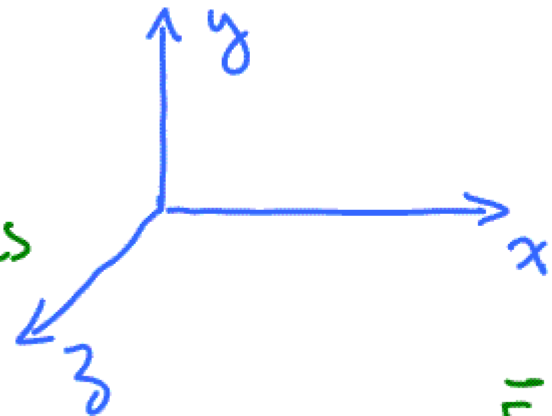
$$\nabla^2 \vec{E} = \mu_0 \epsilon_0 \frac{\partial^2 \vec{E}}{\partial t^2}$$

- Wave equations for $\vec{E}, \vec{B}$
- Coupled equations because of mixing of $\vec{E}, \vec{B}$ in Maxwell's eqns

What can we learn?

- Harmonic Wave Solutions to eqns above
- Maxwell's equations
- Boundary conditions





Impose Boundary Conditions

$\vec{E} = \vec{E}(x,t)$

$\vec{E} = E(x,t)\,\hat{j}$

"polarization"

with no loss in generality

We Find

- $\vec{E}, \vec{B}$ are transverse and mutually $\perp$
- $\vec{E}, \vec{B}$ are in phase
- $|\vec{E}| = c|\vec{B}|$

$$E_y(x,t) = E_{oy}\cos(kx - \omega t + \phi)$$

k: $\frac{2\pi}{\lambda}$

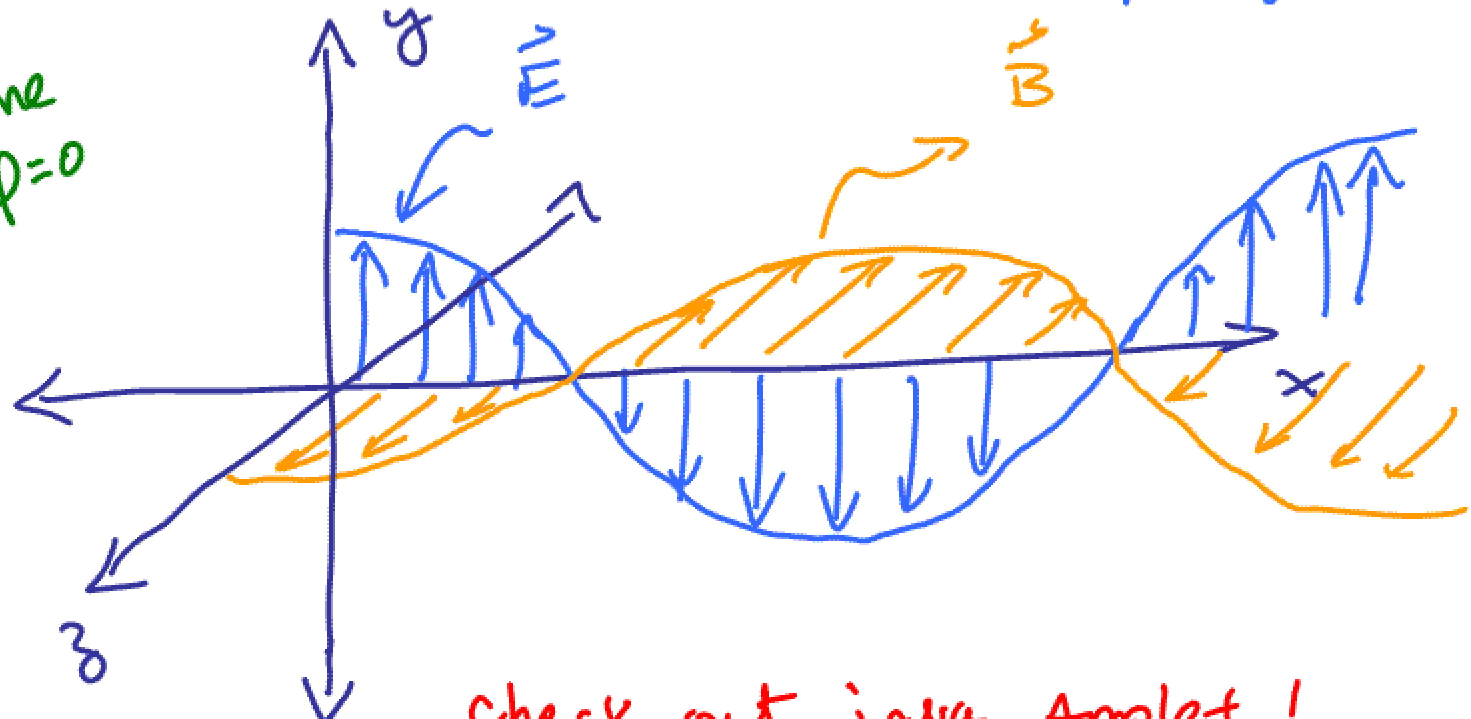
ω: $\frac{2\pi}{T}$

ϕ: Phase (initial condition)

$$B_z = \frac{k}{\omega} E_{oy}\cos(kx - \omega t + \phi)$$

Freez time

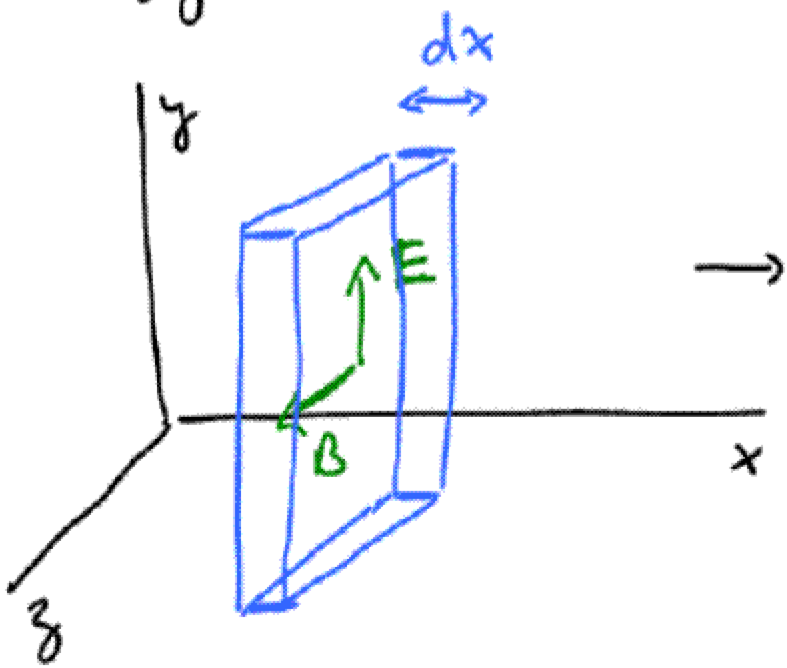
Assume $\phi = 0$



Check out java Applet!

Energy Flow in EM Waves

Ohanian



$\longrightarrow$ plane wave

$$u_E = \frac{\epsilon_0}{2} E^2 \qquad u_B = \frac{1}{2\mu_0} B^2$$

$$dU = \text{Energy in Volume} = (u_E + u_B)\, \text{volume}_{\text{Box}}$$

$$dU = \left(\frac{\epsilon_0}{2}E^2 + \frac{1}{2\mu_0}B^2\right)(\text{Area})\,dx$$

little work
$c = dx/dt$
$E = cB$

$$\frac{dU}{dt}\frac{1}{\text{Area}} = \frac{EB}{\mu_0} = \frac{\text{Watts}}{m^2}$$

Power

$\equiv$ Intensity

Energy flux

$$\text{Poynting vector} \equiv \vec{S} \equiv \frac{\vec{E}\times\vec{B}}{\mu_0}$$

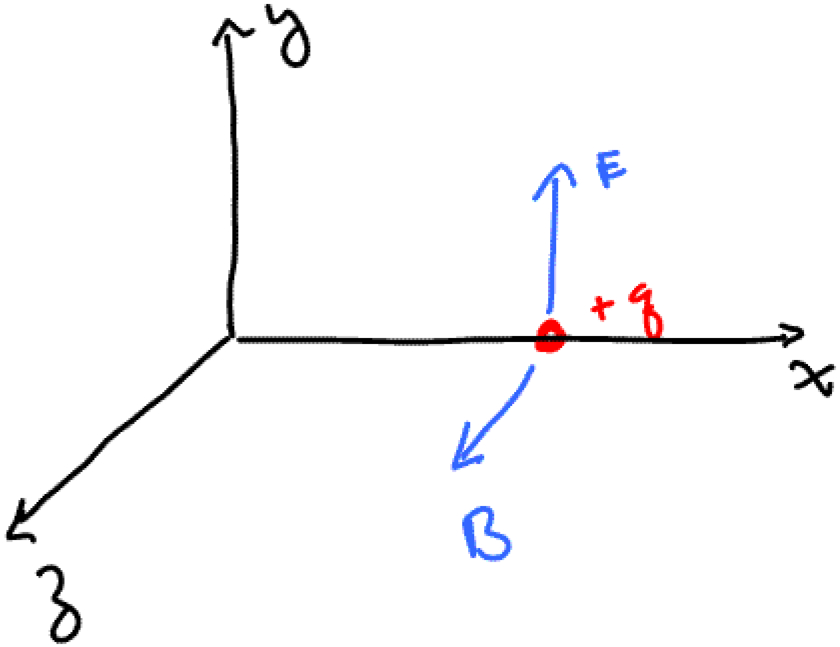
E, B vary w/ time $\rightarrow$ $|\vec{S}|$ varies w/ time

$E = E_0 \sin \omega t$

$B = \frac{E_0}{c} \sin \omega t$

$$S = \frac{1}{\mu_0 c} E_0^2 \sin^2 \omega t$$

$$\bar{S} = \langle S \rangle = \frac{E_0^2}{2\mu_0 c} = \frac{c}{2\mu_0} B^2$$



$$\frac{dp_x}{dt} = F_x = q(\vec{v}\times\vec{B})_x = q\left(v_y B_z - \cancelto{0}{v_z B_y}\right)$$

$$\frac{dp_x}{dt} = q\, v_y B_z \qquad B_z = \frac{E_y}{c}$$

$$= \frac{q}{c} v_y E_y$$

$$W \sim F \cdot d \sim qE\frac{d}{t}t$$

$$\qquad\qquad\qquad \underbrace{}_{v}$$

$$\frac{dW}{dt} = q\vec{E}\cdot\vec{v} = q\,v_y E_y$$

$$F_x = \frac{dP_x}{dt} = \frac{1}{c}\frac{dW}{dt} \qquad dP_x = \frac{1}{c}\overbrace{dW}^{\text{energy}}$$

$$\boxed{P = \frac{U}{c}}$$

momentum in EM Wave

EM Wave get Absorbed

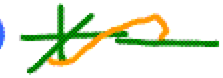
$$\vec{F} = \frac{d\vec{P}}{dt} = \frac{dU}{dt}\frac{1}{c} = \frac{1}{c}\underbrace{\frac{E/\text{Area}}{t}}_{\text{Poynting vector}}(\text{Area})$$

$$F = \frac{1}{c} S\,(\text{Area})$$

$$\frac{F}{\text{Area}} = \text{Pressure} = \frac{S}{c}$$

x 2 if wave is reflected

$$\langle P_{ress} \rangle = \frac{\langle S \rangle}{c}$$

gen soln = (A)  + (B) 

Most general Soln

Superposition of two orthogonal waves

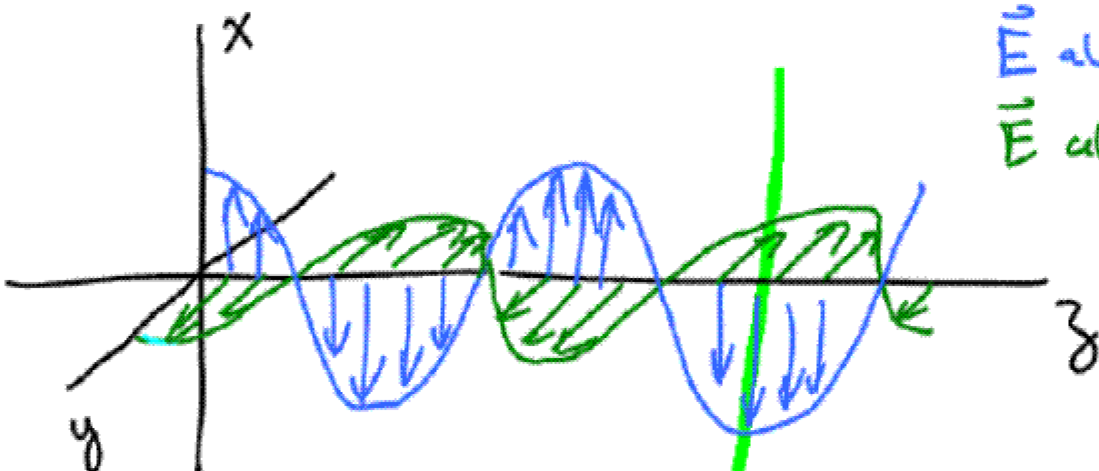
(basis in Mathematics)

1 - plane polarized along x-axis

1 - " " " y-axis

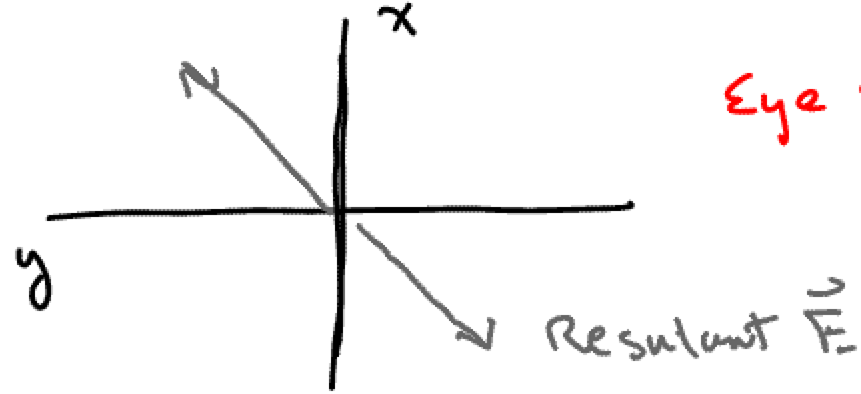
$\vec{E}$ along x

$\vec{E}$ along y



$\vec{E}_x = E_{0x} \cos(kz - \omega t)\,\hat{i}$

$\vec{E}_y = E_{0\cancel{x}} \cos(kz - \omega t)\,\hat{j}$



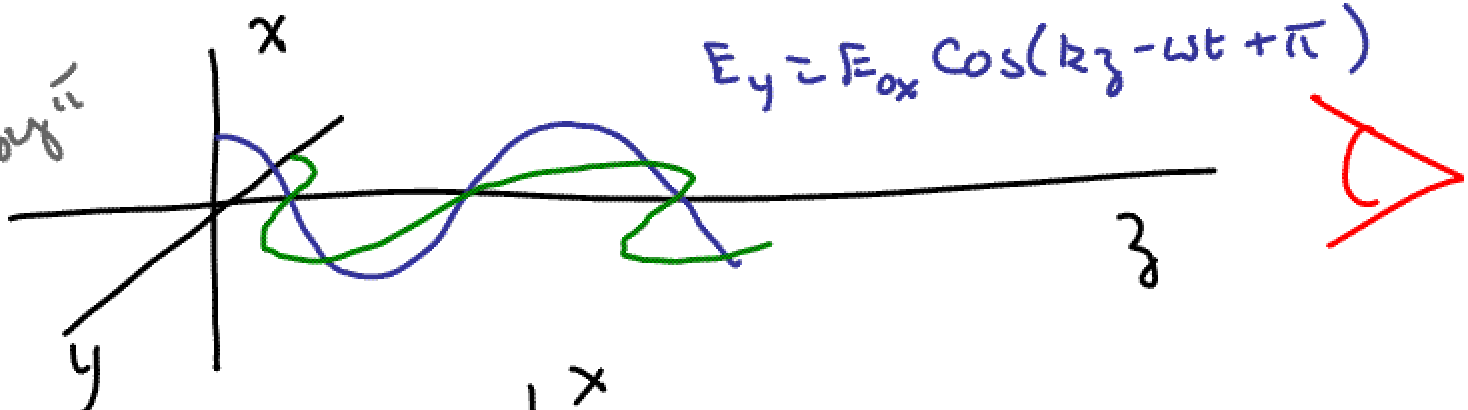
Eye sees w/ Time

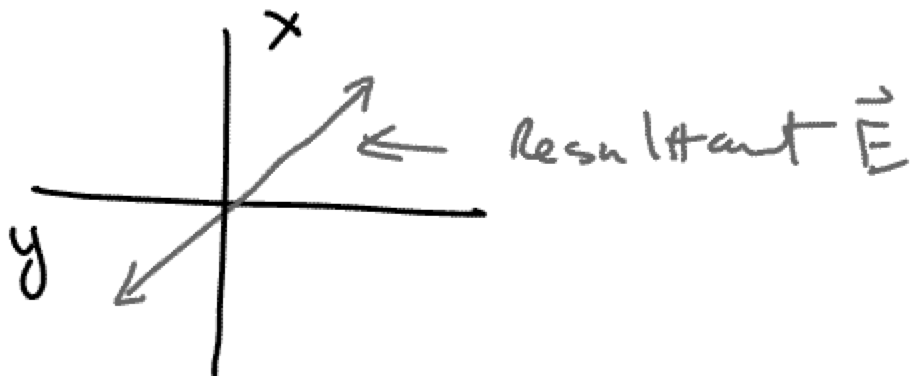
linearly polarized light

$E_x = E_{0x} \cos(kz - \omega t)$

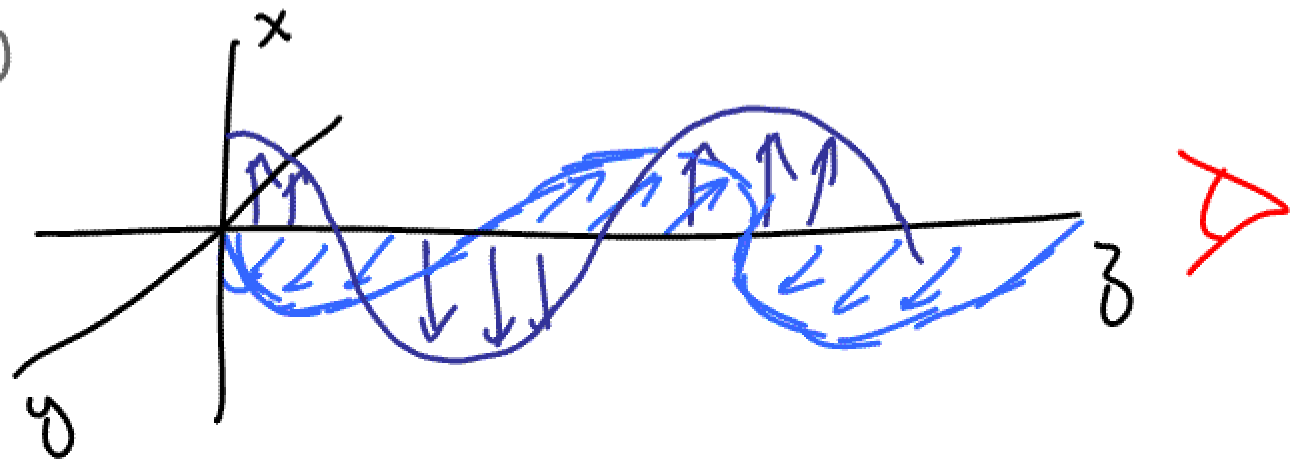
$E_y = E_{0x} \cos(kz - \omega t + \pi)$

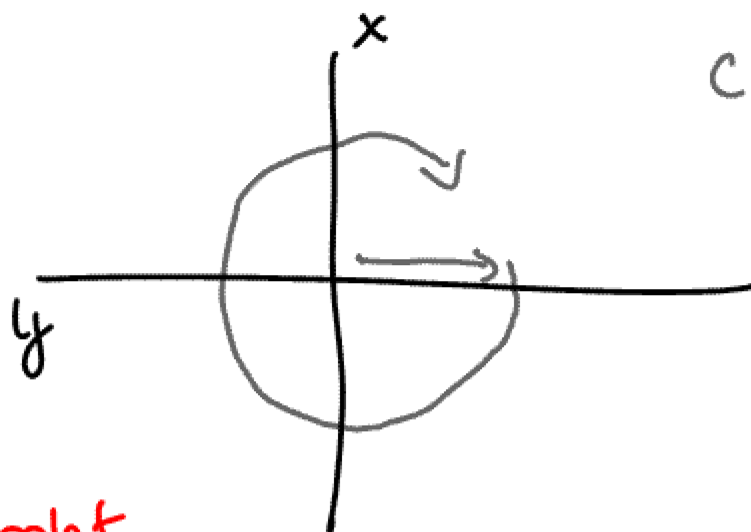
Shift E_y by π





Shift by $\pi/2$





Clockwise Rotation

Right circular polarization

See Java Applet for Polarized E+M waves

Anti: RH Rule

negative helicity

Demo w/ layers of Polaroid Film