Physics 123 - February 27, 2013

- Exam 1 tomorrow 8 am B+L 106
- Q + A session Today 3:30-5 pm B+L 109

Last Time —

Maxwell's eqns plus vector calc Identities

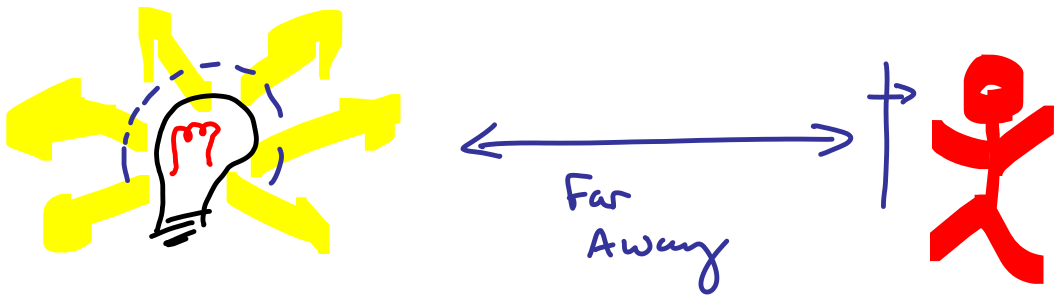
$$\nabla^2 \vec{B} = -\mu_0 \epsilon_0 \frac{\partial^2 \vec{B}}{\partial t^2}$$

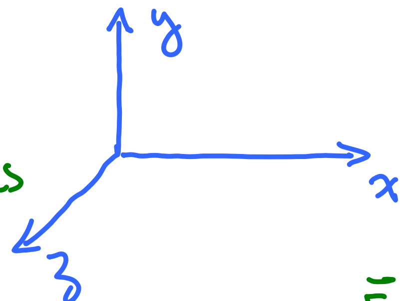
$$\nabla^2 \vec{E} = \mu_0 \epsilon_0 \frac{\partial^2 \vec{E}}{\partial t^2}$$

- 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

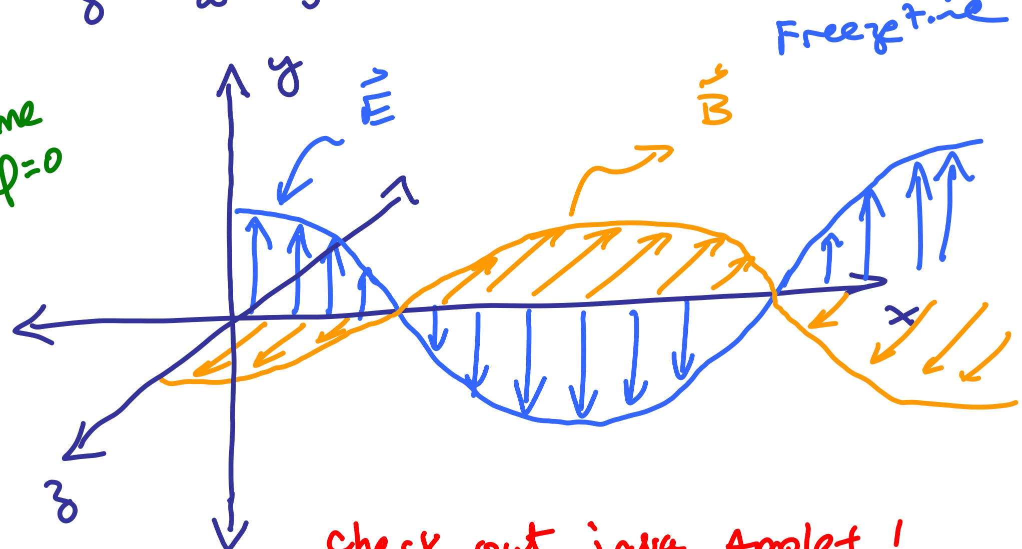
- $\vec{E}, \vec{B}$ are transverse and mutually $\perp$
- $\vec{E}, \vec{B}$ are in phase
- $|\vec{E}| = c|\vec{B}|$

$$E_y(x,t) = E_{0y}\cos(kx - \omega t + \phi)$$

$k = \frac{2\pi}{\lambda}$ $\quad \omega = \frac{2\pi}{T}$ $\quad \phi$: Phase (initial condition)

$$B_z = \frac{k}{\omega} E_{0y} \cos(kx - \omega t + \phi)$$

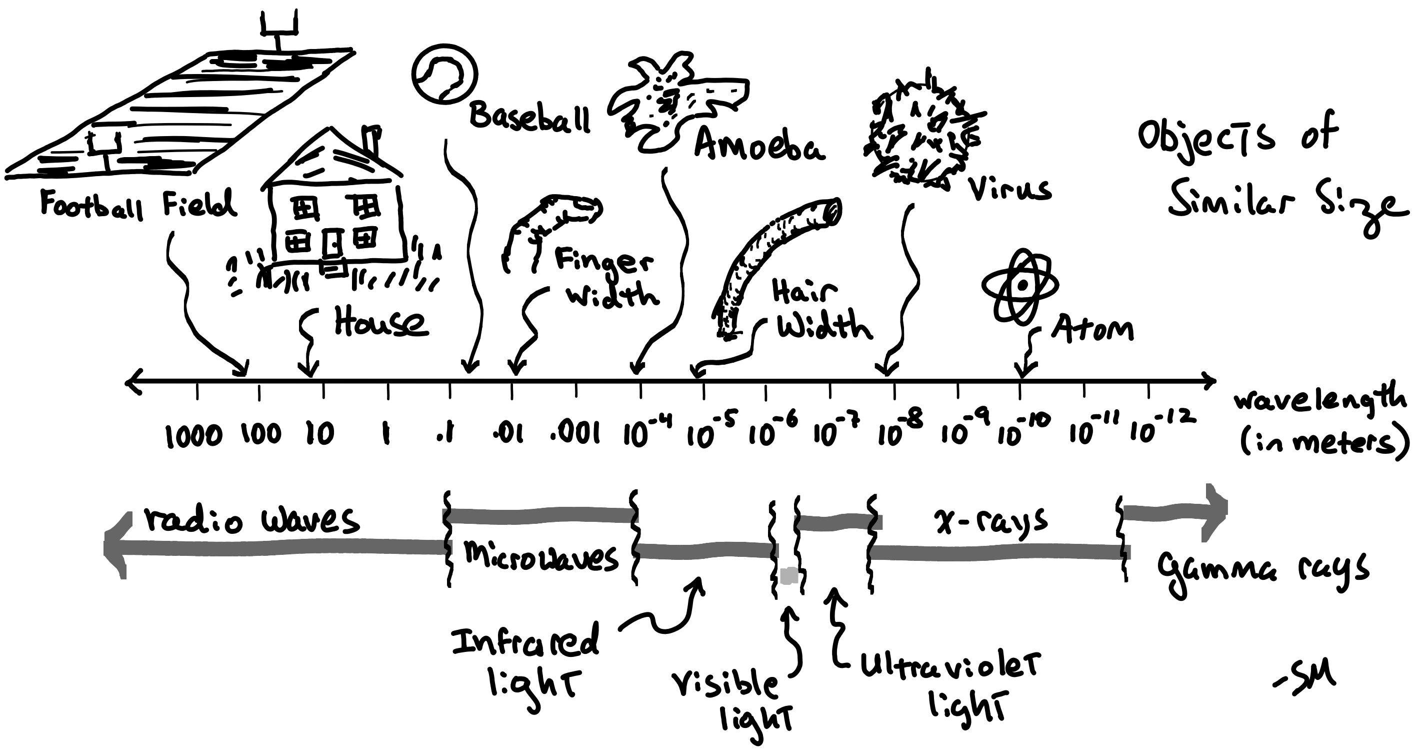
Assume $\phi = 0$



check out java Applet !

interference demos

The variety of electromagnetic waves



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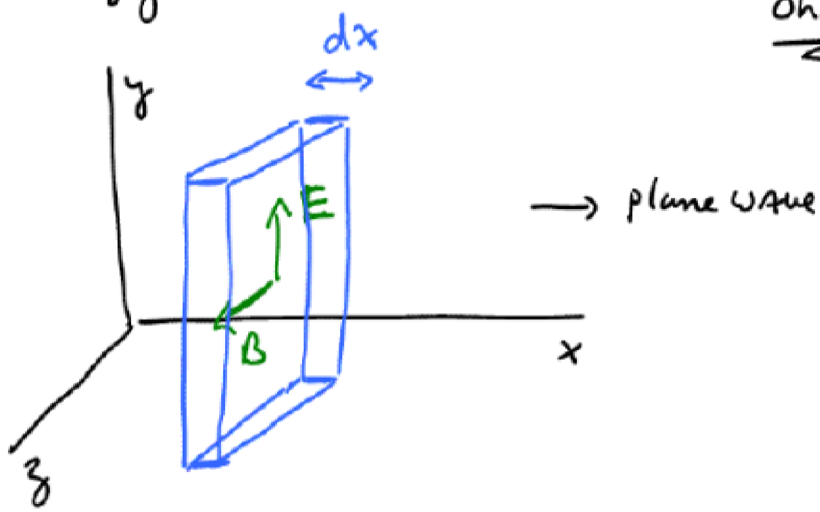
Energy Flow in EM Waves



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

dU = Energy in Volume $= (u_E + u_B)$ Volume Box

Ohanian

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

$$E = cB \qquad \epsilon_0 = \frac{1}{\mu_0 c^2} \qquad c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

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

dU diff energy moves thru box in time $dx/c = dt$

$$dU = \left(\frac{1}{\mu_0 c} EB\right) \text{Area}\, dx$$

$$\frac{dU}{dt} = \frac{1}{\mu_0 c} EB\, (\text{Area})\, c$$

$$\frac{dU}{dt}\frac{1}{\text{Area}} = \frac{EB}{\mu_0} \quad \frac{\text{Watts}}{m^2} \equiv \text{Intensity (Energy flux)}$$

power

can use $E = cB$
to put in terms of E or B
alone.

This energy flows in direction of $\vec{E} \times \vec{B}$

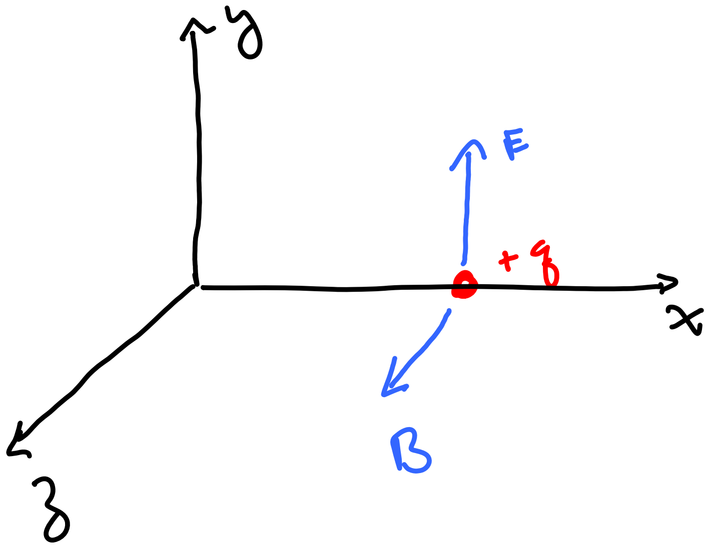
$$\text{Poynting vector} \equiv \vec{S} = \frac{\vec{E} \times \vec{B}}{\mu_0}$$

$|\vec{S}|$ varies w/ time

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

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

Average intensity



No B_y component

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

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

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

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

$$\frac{dW}{dt} = q\vec{E} \cdot \vec{V} = q V_y E_y$$

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

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

momentum in EM Wave

EM wave gets Absorbed

Poynting vector

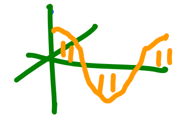
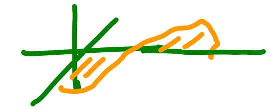
$$\vec{F} = \frac{d\vec{p}}{dt} = \frac{dU}{dt}\frac{1}{c} = \frac{1}{c}\,\frac{E/\text{Area}}{t}\,(\text{Area})$$

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

Radiation Pressure

$$\boxed{\begin{aligned} \frac{F}{\text{area}} &= \text{Pressure} = \frac{S}{c} \\ \langle \text{Pressure} \rangle &= \frac{\langle S \rangle}{c} \end{aligned}}$$

x2 if reflected

gen Soln = (A)  + (B) 

Most general Soln

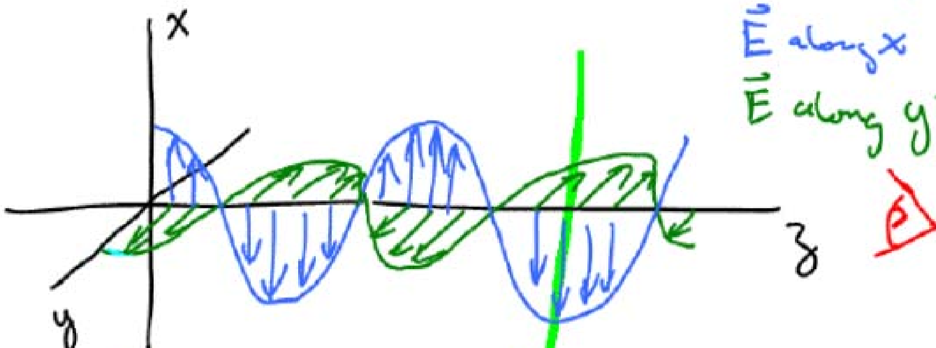
Superposition of two orthogonal waves
(basis in Mathematics)

1 – plane polarized along x-axis

1 – " " " y-axis

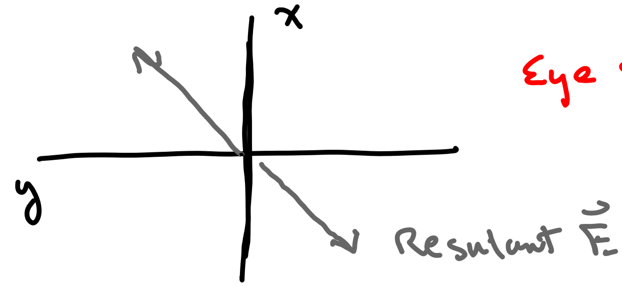
$\vec{E}$ along x

$\vec{E}$ along y



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

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



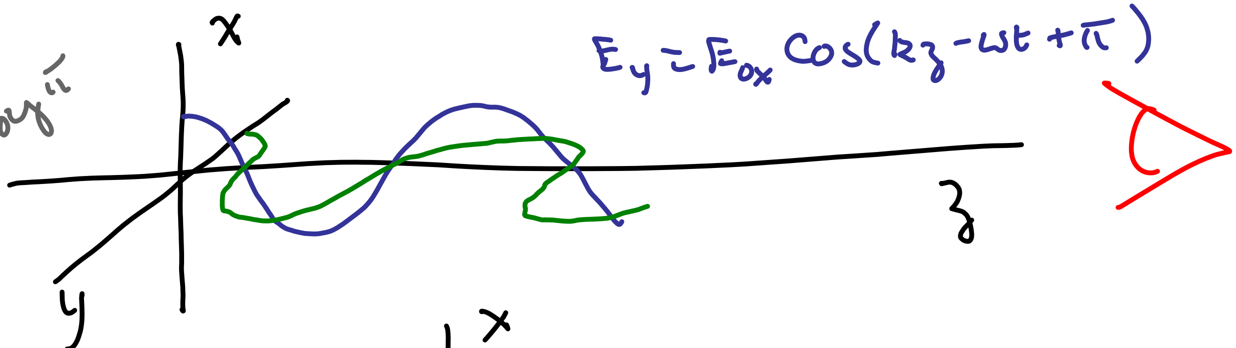
Eye sees w/ time

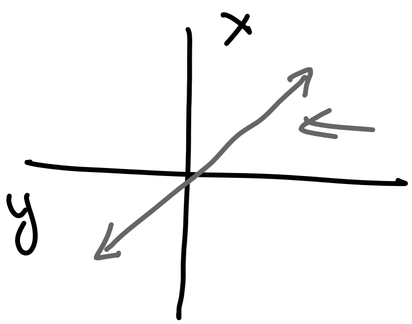
linearly polarized light

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

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

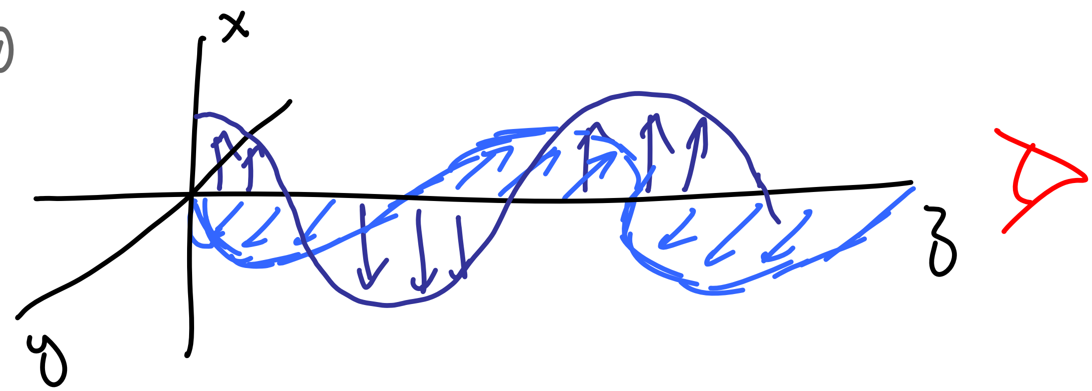
Shift E_y by π

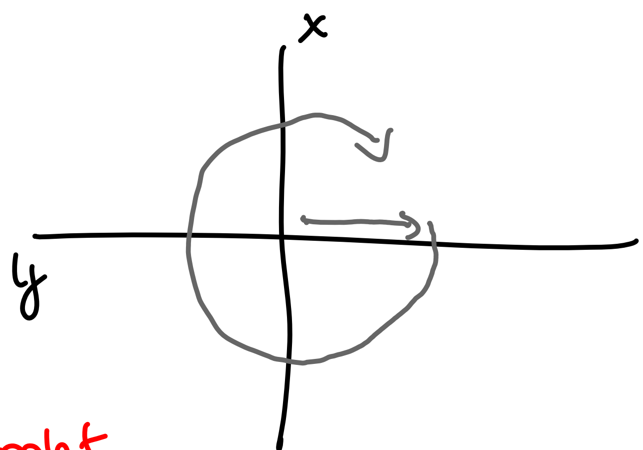




Resultant $\vec{E}$

Shift by $\pi/2$





Clockwise rotation

Right circular polarization

(Anti right hand rule)

↳ is negative helicity

See Java Applet For Polarized E+M waves

Anti: RH Rule

negative helicity