

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

direction of \vec{S} gives the direction of propagation of EM wave

$|\vec{S}| = \text{intensity}$

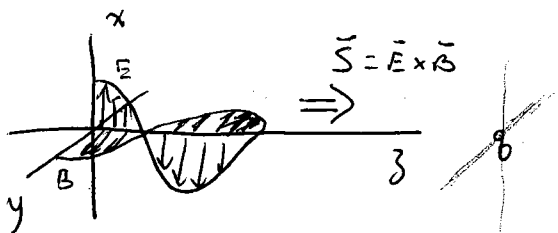
EM waves carry energy

Power incident is the intensity \equiv Energy/Time/Area
 unit Area

- radio station energy to run radio (usually amplified where picked up)
- Energy from sun for photosynthesis
- Energy to cause a photochemical reaction of film for X rays
- etc.

EM waves carry momentum

$$F = \frac{dP}{dt}$$



When

Force due to E is $qE\hat{i}$

q gets $\vec{v} = v\hat{i}$

F from $\vec{B} = (B)\hat{j}$

is

$$F_B = q\vec{v} \times \vec{B} = qvB\hat{i} \times \hat{j} = qvB\hat{k}$$

Force is along direction of wave propagation

Relativity $E^2 = (mc^2)^2 + (pc)^2$
 $E = pc$

$|P| \equiv$ Momentum carried by EM wave = $\frac{\text{Energy}}{c}$

Intensity = Energy/Time/Area

Momentum/Time = Force

$\frac{I}{c} = \frac{\text{Energy}}{c \cdot \text{Time} \cdot \text{Area}} = \frac{\text{Force}}{\text{Area}} = \text{Pressure}$

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 42-381 50 SHEETS CLEAR 5 SQUARE
 42-382 100 SHEETS CLEAR 5 SQUARE
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I/c

Radiation exerts pressure on charged particles!

- Sailing Space ships
- radiation Pressure \leftrightarrow gravity

Equilibrium in Sun

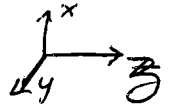
Stellar evolution in a nutshell

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Source very far away

*))))
Source



↑
"Plane waves"

E, B fns of z, t only

Maxwell's eqns - 6 complicated eqns simplifying to

$$\frac{\partial^2 E_x}{\partial z^2} = \epsilon_0 \mu_0 \frac{\partial^2 E_x}{\partial t^2}$$

$$\frac{\partial^2 B_x}{\partial z^2} = \epsilon_0 \mu_0 \frac{\partial^2 B_x}{\partial t^2}$$

$$\frac{\partial^2 E_y}{\partial z^2} = \epsilon_0 \mu_0 \frac{\partial^2 E_y}{\partial t^2}$$

$$\frac{\partial^2 B_y}{\partial z^2} = \epsilon_0 \mu_0 \frac{\partial^2 B_y}{\partial t^2}$$

$$B_z, E_z = 0$$

Fields are TRANSVERSE to Motion

Coupled Wave equations

A solution:

$$E_x = E_{0x} \cos \left[\omega_x \left(t \pm \frac{z}{c} \right) \right]$$

$$E_y = E_{0y} \cos \left[\omega_y \left(t \pm \frac{z}{c} \right) \right]$$

$$B_x = \pm \frac{E_{0y}}{c} \cos \left[\omega_y \left(t \pm \frac{z}{c} \right) \right]$$

$$B_y = \mp \frac{E_{0x}}{c} \cos \left[\omega_x \left(t \pm \frac{z}{c} \right) \right]$$

NOTE:

1) 2 sep coupled waves

$$\rightarrow E_x \text{ \& } B_y$$

$$\rightarrow E_y \text{ \& } B_x$$

2) harmonic in
Both time or
Space

3) E, B in phase

4) $B = \frac{1}{c} E$ (magnitudes)

where $c \equiv \frac{1}{\sqrt{\epsilon_0 \mu_0}}$

~~Eq~~ - \vec{E}, \vec{B} in phase w/ one another

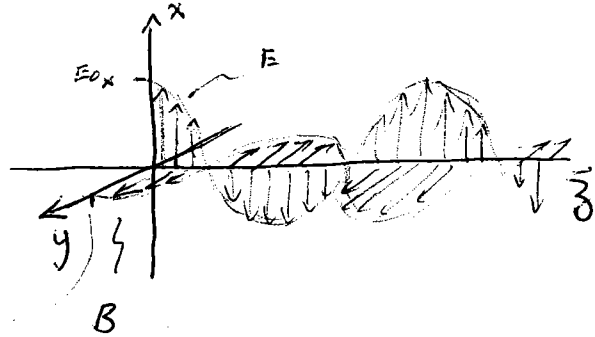
- $|\vec{E}| = c|\vec{B}|$

- Harmonic in both space + Time
(waves w/ space + Time dependence)

e.g.

$$E_x = E_{0x} \cos[\omega_x (t \pm z/c)]$$

$$B_y = \frac{E_{0x}}{c} \cos[\omega_x (t \pm z/c)]$$

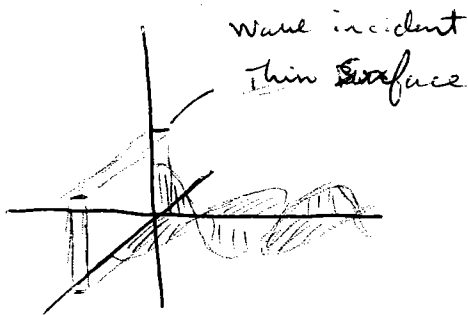


$$\frac{E_{0x}}{c} = B_{0y}$$

ω is frequency of the electromagnetic radiation

some eqns \rightarrow $\nu = \frac{1}{T}$ $\omega = \frac{2\pi}{T}$ $t = \frac{2\pi}{\omega}$ $c = \omega/\lambda$ $c = \lambda\nu$

Sometimes see phase written as $\omega t \pm k z$



- What is Power incident = intensity?
Area

$$I = U_{\text{ave}} c$$

$$U = U_E + U_M = \frac{1}{2} \epsilon_0 E^2 + \frac{B^2}{2\mu_0}$$

$$c^2 = \frac{1}{\mu_0 \epsilon_0} \text{ and } E = cB$$

$$= \epsilon_0 E^2$$

$$= \frac{EB}{\mu_0 c}$$

Replace $E_{\text{instantaneous}}, B_{\text{instantaneous}}$
w/ RMS values ~ Average values

$$E_{\text{RMS}} = E_0/\sqrt{2} \quad B_{\text{RMS}} = B_0/\sqrt{2}$$

$$I = \frac{1}{2} \frac{E_0 B_0}{\mu_0 c}$$

Nature of the Electromagnetic Spectrum

★ Show/hand out a table of EM Spectrum

$$c = \nu \lambda$$

differences in $\nu(\lambda)$ have important physical consequences

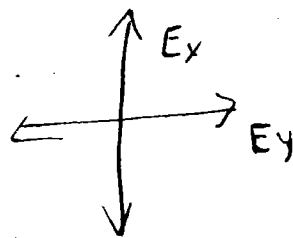
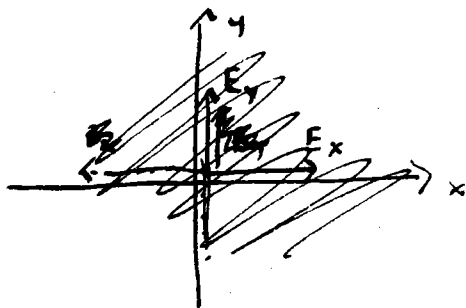
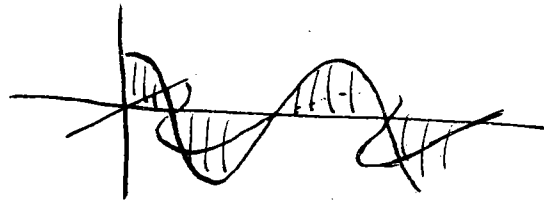
- ⇒ How they are produced
- ⇒ How they interact w/ matter
- ⇒ What absorbs the radiation etc

Microwaves - water/cooking
 X rays
 γ rays
 Communicating w/ submarines } etc.

Polarization

Most general wave is a superposition of two orthogonal waves → 1 plane polarized along x
(A basis in Mathematics)

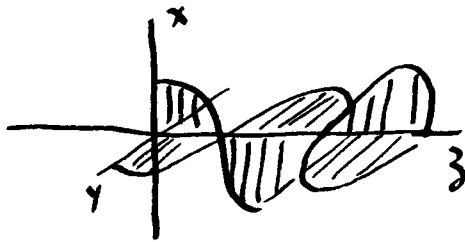
1 plane polarized along y



Each has an accompanying B

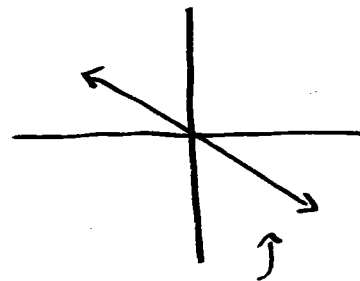
Linear polarization

if



$$E_{0x} = E_{0y}$$

$$\epsilon = 0$$



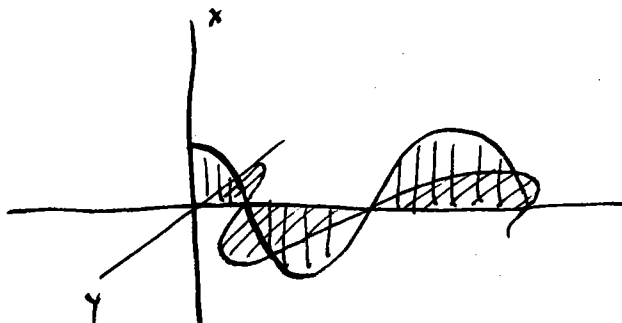
Superposition
of
 \vec{E}_x, \vec{E}_y

$$E_x = E_{0x} \cos(\omega t - k_z) \hat{i}$$

$$E_y = E_{0y} \cos(\omega t - k_z + \epsilon) \hat{j}$$

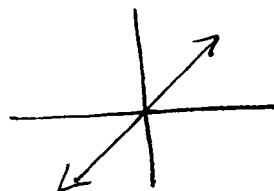
↑
Phase difference

Here $\epsilon = 0$ E_x, E_y are in phase



$$E_{0x} = E_{0y}$$

$$\epsilon = \pi$$

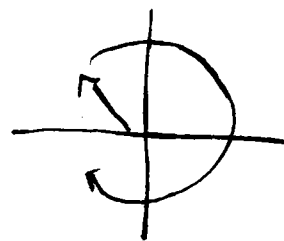
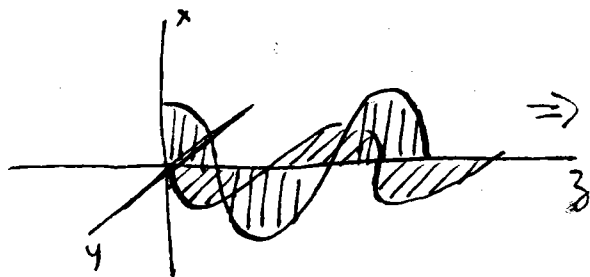


Superposition

Suppose

$$E_{0x} = E_{0y}$$

$$\epsilon = +\frac{\pi}{2}$$



Clockwise - RT
Circular
Polarization

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