

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

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

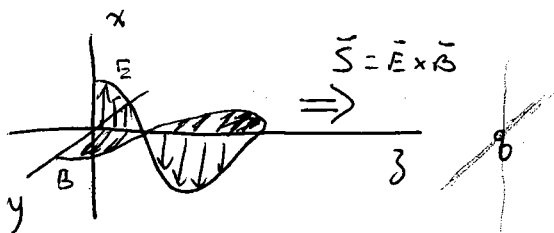
EM waves carry energy

Power incident is the intensity $\equiv \frac{\text{Energy/Time/Area}}{\text{unit Area}}$

- 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

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

Force is along direction of wave propagation

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

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

Intensity = Energy/Time/Area

Momentum/Time = Force

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

13-7782 500 SHEETS FILLER 5 SQUARE
 42-281 50 SHEETS CLEAR 5 SQUARE
 42-282 100 SHEETS CLEAR 5 SQUARE
 42-283 200 SHEETS CLEAR 5 SQUARE
 42-284 100 SHEETS CLEAR 5 SQUARE
 42-285 200 SHEETS CLEAR 5 SQUARE
 42-286 100 RECYCLED WHITE 5 SQUARE
 42-287 200 RECYCLED WHITE 5 SQUARE
 Made in U.S.A.



I/c

Radiation exerts pressure on charged particles!

- Sailing Space ships
- radiation Pressure \leftrightarrow gravity

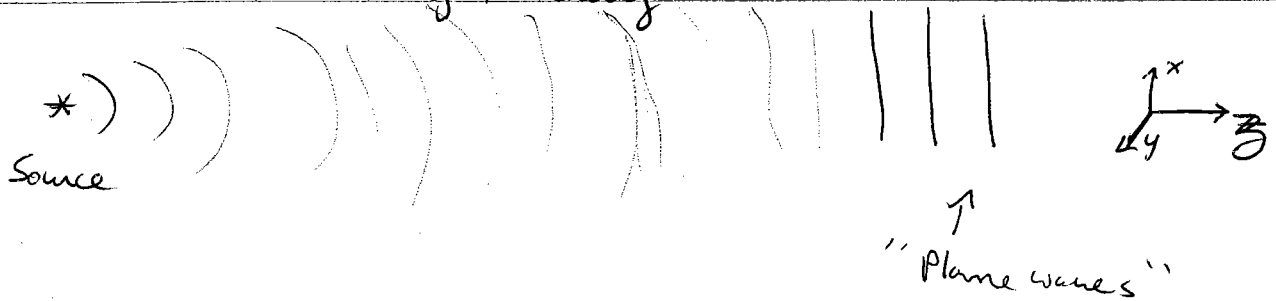
Equilibrium in Sun

stellar evolution in a nutshell

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42-382 100 SHEETS EYE-EASE® 5 SQUARE
42-383 200 SHEETS EYE-EASE® 5 SQUARE
42-384 200 RECYCLED WHITE 5 SQUARE
42-385 200 RECYCLED WHITE 5 SQUARE
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Source very far away



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:

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

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

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

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

NOTE:

1) 2 sep coupled waves

→ E_x & B_y

→ E_y & 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

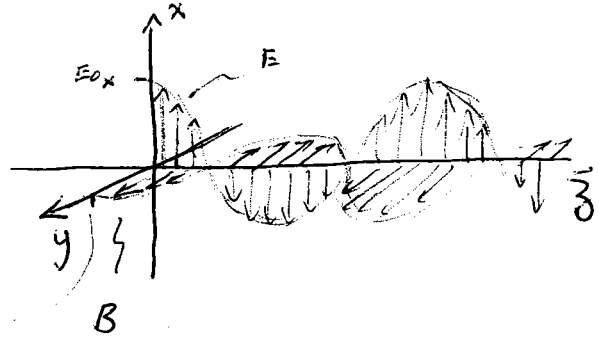
- $|\vec{E}| = c|\vec{B}|$

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

e.g.

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

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

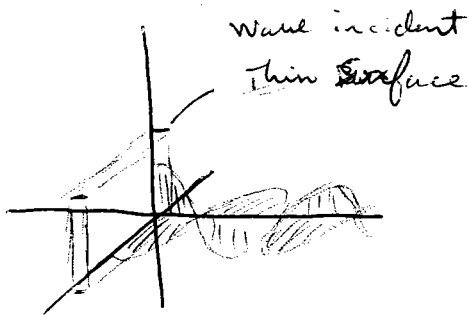


$$\frac{E_{0x}}{c} = B_{0y}$$

ω is frequency of the electromagnetic radiation

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

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



- What is Power incident = intensity?
Area

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

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

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

$$= \epsilon_0 E^2$$

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

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

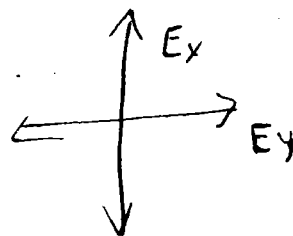
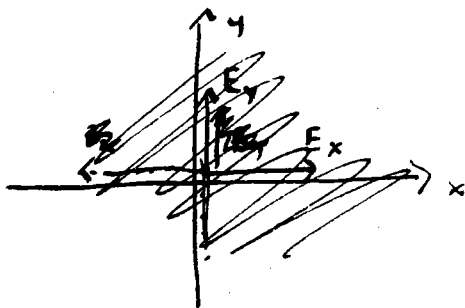
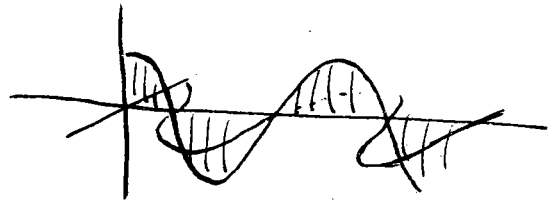
- ⇒ How they are produced
- ⇒ How they interact w/ matter
- ⇒ What absorbs the radiation etc

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)

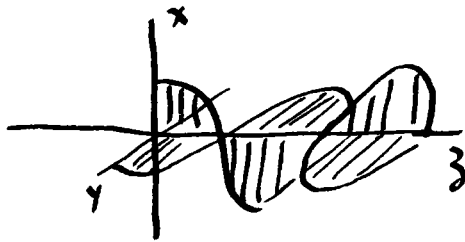
1 plane polarized along y



Each has an accompanying B

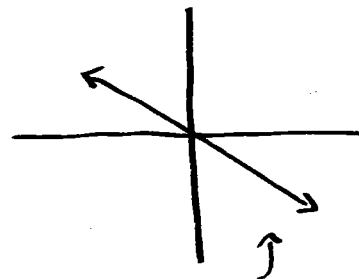
Linear polarization

if



⇒

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



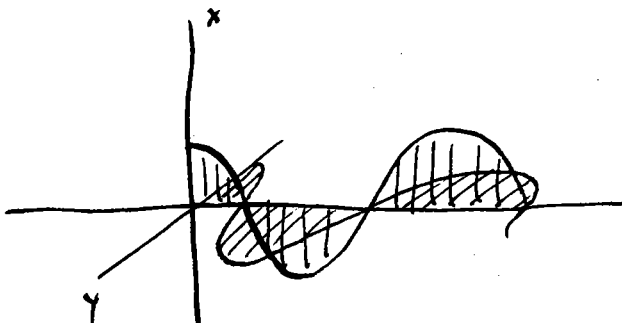
Superposition of \vec{E}_x, \vec{E}_y

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

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

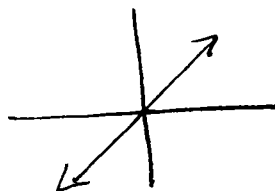
↑
Phase difference

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



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

$$\epsilon = \pi$$

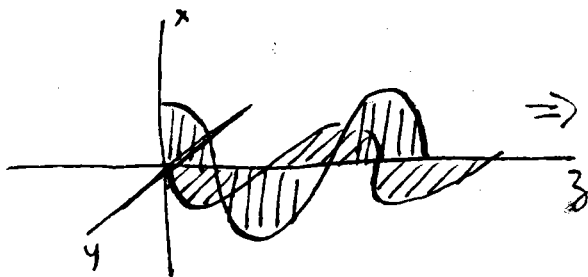


Superposition

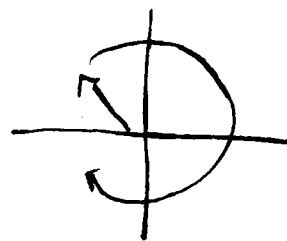
Suppose

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

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



⇒



Clockwise - RT
Circular
Polarization

16 SHEETS PAPER 150 MM
42 SHEETS PAPER 150 MM
60 SHEETS PAPER 150 MM
80 SHEETS PAPER 150 MM
100 SHEETS PAPER 150 MM
120 SHEETS PAPER 150 MM
150 SHEETS PAPER 150 MM
200 SHEETS PAPER 150 MM
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