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

direction gives the direction of propagation of EM wave

$|\vec{S}|$ = intensity

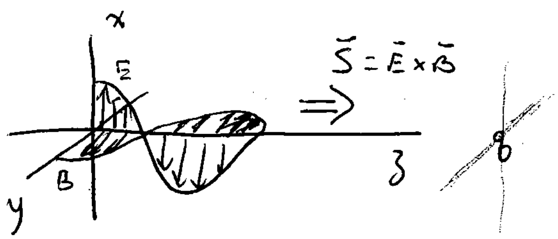
Em waves carry energy

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 w/ film for x rays

etc.

Em waves carry momentum $F = \dfrac{dP}{dt}$



when

For q 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 $= \dfrac{\text{Energy}}{c}$

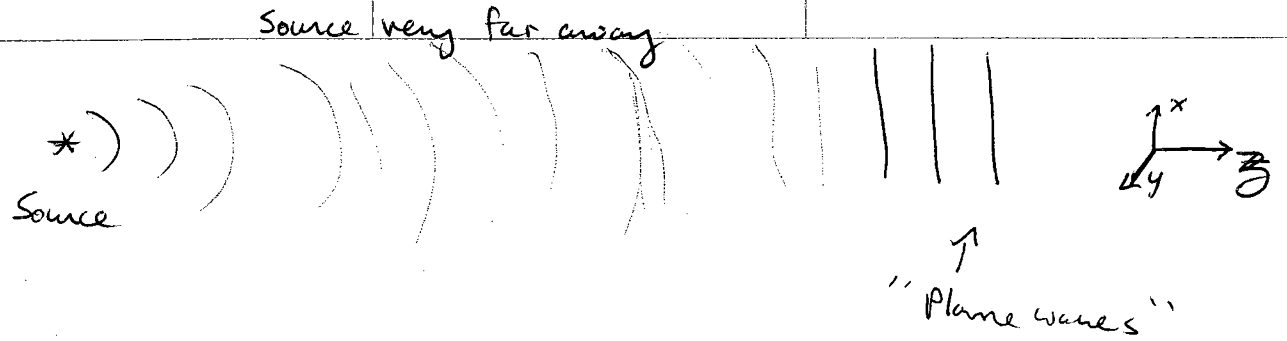
Intensity = Energy/Time/Area Momentum/Time = Force

$\dfrac{I}{c}$ = Energy/c/Time/Area = $\dfrac{\text{Force}}{\text{Area}}$ ~~Momentum~~ = Pressure radiation exerts pressure on charged particles!

- Sailing Space ships
- radiation Pressure $\longleftrightarrow$ gravity

  Equilibrium in SUN

  Stellar evolution in a nutshell



E, B fns of z, t only

Maxwell's Eqns – 6 complicated eqns simplify to

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

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

$B_z, E_z = 0$ Fields are transverse to Motion

Coupled Wave equations

A Solution:

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

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

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

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

Where $c \equiv \dfrac{1}{\sqrt{\epsilon_0 \mu_0}}$

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)

~~eg.~~ - $\vec{E}$, $\vec{B}$ in phase w/ one another

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

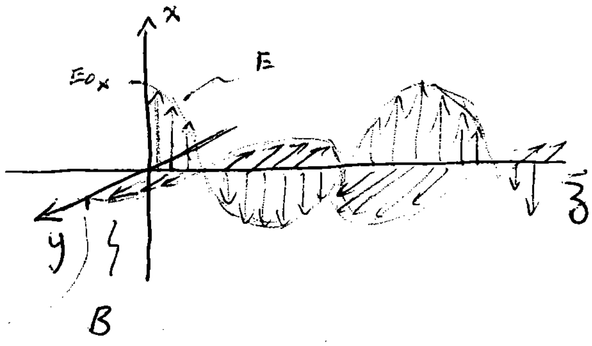
- Harmonic in both space + Time

(Waves w/ space + Time dependence)

e.g.

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

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

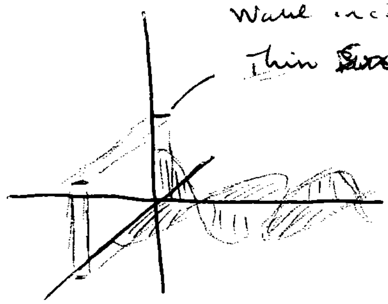


$\frac{E_{0x}}{c} = B_{0x}$

ω is frequency of the electromagnetic radiation

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

sometimes see phase written as $\omega t \pm kz$



Wave incident
Thin ~~surface~~ surface

- What is $\frac{\text{Power incident}}{\text{Area}}$ = intensity?

$$I = u_{ave}\, c$$

$$u = u_E + u_m = \frac{1}{2}\epsilon_0 E^2 + \frac{B^2}{2\mu_0}$$

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

$= \epsilon_0 E^2$

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

Replace $E_{instantaneous}$, $B_{instantaneous}$

w/ RMS values ~ Average values

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

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

Nature of the Electromagnetic Spectrum

☆ Show/hand out a table of EM Spectrum

$c = \nu\lambda$

differences in ν (λ) have important physical consequences

⇒ How they are produced

⇒ How they interact w/ matter

⇒ what absorbs the radiation

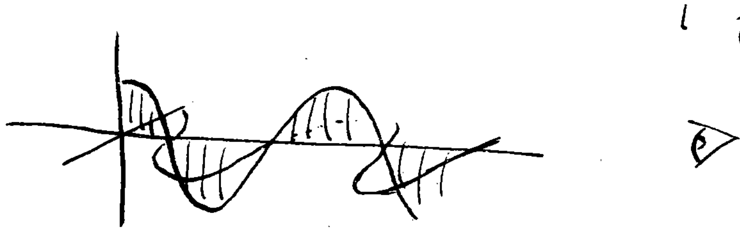
etc

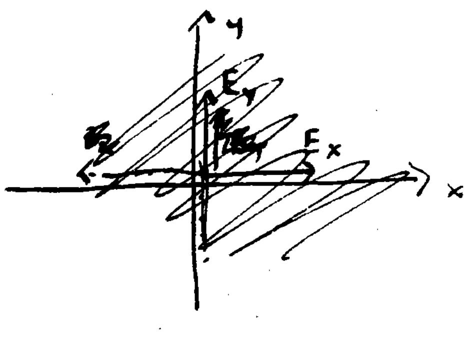
Microwaves – water/cooking
x rays
γ rays
Communicating w/ submarines
} etc.

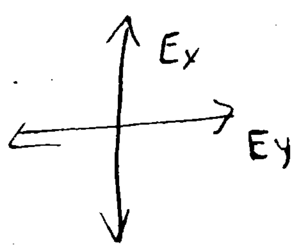
Polarization

Most general wave is a superposition of two orthogonal waves → 1 plane polarized along x
1 plane polarized along y

(A basis in Mathematics)





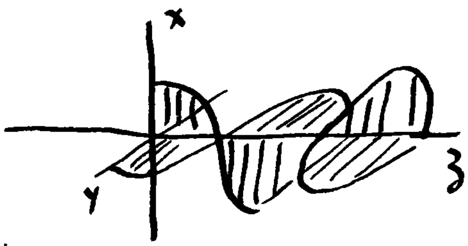


Each has an accompanying B

Linear polarization

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

if



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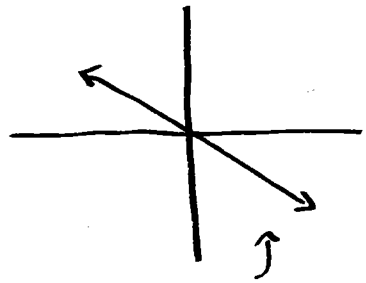


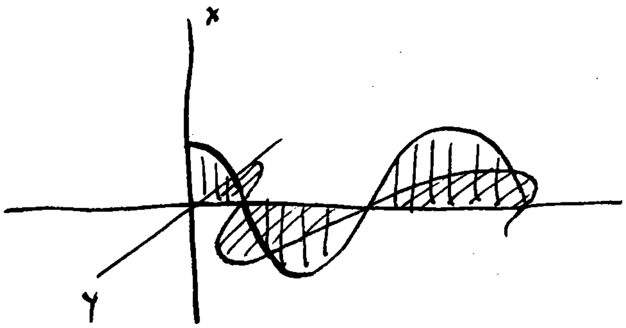
Superposition of $\vec{E}_x, \vec{E}_y$

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

$$E_y = E_{0y} \cos(\omega t - kz + \varepsilon)\,\hat{j}$$

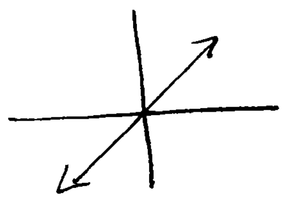
phase difference

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



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

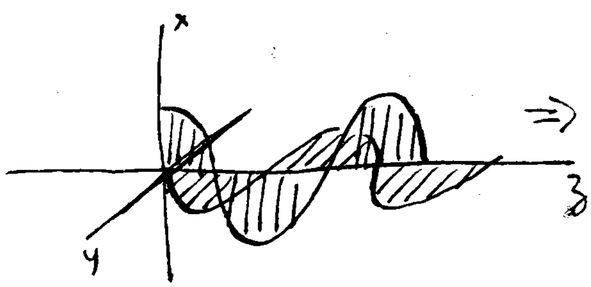
$\varepsilon = \pi$



Superposition

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

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



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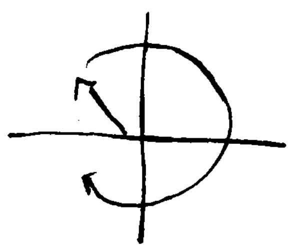

Clockwise – RT circular Polarization