1. EM waves: general properties
2. Poynting Vector, Intensity, Pressure
3. Polarization of EM waves

- Review Cross Product

\[ \vec{A} \times \vec{B} = \vec{C} \]

* Odd PID's:
  Do survey #2 by Tonight

Electric Field: \[ \vec{E} \times \vec{B} = \text{(dir. of wave)} \]
An EM wave is moving in the $+y$ direction. At a certain time/position in space, the electric field is pointing in the $-z$ direction. What is the direction of the magnetic field at this same time/position?

A) $+x$ direction  
B) $-x$ direction  
C) Neither of these

(also, write down a possible equation for the electric field)

$$\vec{E} = E_0 \cos\left[ (ky - wt + \phi_0) \right]$$

$$\vec{B} = B_0 \cos\left[ ky - wt + \phi_0 \right]$$
Properties of EM Waves

1. Maxwell’s equations predict the existence of sinusoidal electromagnetic waves that travel through empty space independent of any charges or currents.
2. The waves are transverse waves, with \( \vec{E} \) and \( \vec{B} \) perpendicular to the direction of propagation \( \vec{v}_{em} \).
3. \( \vec{E} \) and \( \vec{B} \) are perpendicular to each other in a manner such that \( \vec{E} \times \vec{B} \) is in the direction of \( \vec{v}_{em} \).
4. All electromagnetic waves, regardless of frequency or wavelength, travel in vacuum at speed \( v_{em} = 1/\sqrt{\varepsilon_0 \mu_0} = c \), the speed of light.
5. The field strengths are related by \( E = cB \) at every point on the wave.

6. \( \vec{E} \) and \( \vec{B} \) are in phase!

\[ \#1-5 \text{ from the book!} \]

\[ \#6 \text{ is in a picture in the book!} \]
Which of the following could describe the B-field of an EM wave traveling in the +z direction?

A) \( \mathbf{B}(x, y, z, t) = (1.00 \text{ nT}) \cos \left[ (1.26 \times 10^7 \text{ m}^{-1})z - (3.77 \times 10^{15} \text{ s}^{-1})t \right] (\hat{y}) \)

B) \( \mathbf{B}(x, y, z, t) = (1.00 \text{ nT}) \cos \left[ (3.77 \times 10^7 \text{ m}^{-1})z - (1.26 \times 10^{15} \text{ s}^{-1})t \right] (\hat{y}) \)

C) \( \mathbf{B}(x, y, z, t) = (1.00 \text{ nT}) \cos \left[ (1.26 \times 10^7 \text{ m}^{-1})y + (3.77 \times 10^{15} \text{ s}^{-1})t \right] (\hat{z}) \)

D) \( \mathbf{B}(x, y, z, t) = (1.00 \text{ nT}) \cos \left[ (3.77 \times 10^7 \text{ m}^{-1})y - (1.26 \times 10^{15} \text{ s}^{-1})t \right] (\hat{z}) \)

E) \( \mathbf{B}(x, y, z, t) = (1.00 \text{ nT}) \cos \left[ (1.26 \times 10^7 \text{ m}^{-1})z + (3.77 \times 10^{15} \text{ s}^{-1})t \right] (\hat{y}) \)

(also, given this magnetic field, what would the electric field be?)

\[
\mathbf{E} = \mathbf{E}_0 \cos \left[ (1.26 \times 10^7 \text{ m}^{-1})z - (3.77 \times 10^{15} \text{ s}^{-1})t \right] (\hat{x})
\]

\[
\mathbf{E}_0 = c\mathbf{B}_0 = (3 \times 10^8 \text{ m/s}) (1.00 \times 10^{-9} \text{ T})
\]

\[
= 0.300 \text{ V/m}
\]
2. Poynting Vector: \( \vec{S} = \frac{\vec{E} \times \vec{B}}{\mu_0} \)

\[ I = S_{\text{avg}} = \frac{E_0 B_0}{2 \mu_0} = \frac{E_0^2}{2 \omega \mu_0} \]

Intensity of wave

Pressure: \( P_{\text{rad}} = \frac{I}{c} \)
STOP TO THINK 31.5  The amplitude of the oscillating electric field at your cell phone is 4.0 $\mu$V/m when you are 10 km east of the broadcast antenna. What is the electric field amplitude when you are 20 km east of the antenna?

a. 1.0 $\mu$V/m  
b. 2.0 $\mu$V/m  
c. 4.0 $\mu$V/m  
d. There's not enough information to tell.

ANS:
Polarization

2 Facts

1. When unpolarized light goes through a linear polarizer, intensity $I_0$

2. Polarized light $I_0$

$\frac{I_f}{I_0} = \cos^2 \theta$
Suppose you have three polarizers: one that will polarize along the y-axis, one along the x-axis, and one along an axis that is 45 degrees with respect to both the y and x axes. (in any order)

Can initially-unpolarized light pass through all three polarizers?

A) Yes, definitely (no matter the order)
B) No, definitely not (no matter the order)
C) Maybe – depends on the order of the polarizers
Suppose you have three polarizers: one that will polarize along the y-axis, one along the x-axis, and one along an axis that is 45 degrees with respect to both the y and x axes.

If the initial intensity of unpolarized light is $I_0$, what is the maximum possible final intensity after the light has gone through all three polarizers?

A) $(0.125) I_0$
B) $(0.25) I_0$
C) $(0.50) I_0$
D) None of the above

$\frac{I_f}{I_0} = (\frac{1}{2})^2 (\cos^2 45^\circ)(\cos^2 45^\circ)$

$\frac{I_f}{I_0} = \frac{1}{8} I_0$
Suppose you have three polarizers: one that will polarize along the y-axis, one along the x-axis, and one along an axis that is 45 degrees with respect to both the y and x axes.

If the initial intensity of polarized light (along the y-direction) is $I_0$, what is the maximum possible final intensity after the light has gone through all three polarizers?

A) $(0.125) I_0$
B) $(0.25) I_0$
C) $(0.50) I_0$
D) None of the above

ANS: B