EM Waves; Interference Revisted

Knight Sections 31.6-31.7, 17.7
Knight Ch. 33

Physics 2C, Spring 2025

Agenda Today (May 8, 2025)

- Properties of EM Waves
  - Electric and Magnetic field directions
  - Polarization of EM Waves / Law of Malus
  - Energy/Momentum flow & Poynting Vector
- Interference of Waves in 2D: Path Length Difference and Phase difference (if time)

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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 $\overrightarrow{\mathbf{E}}$ and $\overrightarrow{\mathbf{B}}$ perpendicular to the direction of propagation $\vec{v}_{\text{em}}$.
3. $\overrightarrow{\mathbf{E}}$ and $\overrightarrow{\mathbf{B}}$ are perpendicular to each other in a manner such that $\overrightarrow{\mathbf{E}} \times \overrightarrow{\mathbf{B}}$ is in the direction of $\vec{v}_{\text{em}}$.
4. All electromagnetic waves, regardless of frequency or wavelength, travel in vacuum at speed $v_{\text{em}} = 1/\sqrt{\epsilon_0 \mu_0} = c$, the speed of light.
5. The field strengths are related by $E = cB$ every point on the wave.

Clicker/Poll Question

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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?

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

A. +x direction

B. –x direction

C. Neither of these

Clicker/Poll Question

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Which of the following could describe the B-field of an EM wave traveling in the +z direction?

(Also, given this is the magnetic field, write down an equation for the electric field)

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

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

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

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

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

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Clicker/Poll Question (cont.)

Polarization / Law of Malus

Passing light through a grating can polarize the light (keeping the polarization along one direction and blocking the perpendicular direction).

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Clicker/Poll Question

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.

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

Clicker/Poll Question

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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's the maximum possible final intensity after the light has gone through all three polarizers?

A. $(0.125)\,I_0$
B. $(0.250)\,I_0$
C. $(0.500)\,I_0$
D. None of the above

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Clicker/Poll Question

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. $(0.250)\,I_0$

C. $(0.500)\,I_0$

D. None of the above

Poynting Vector Points in the dir. of the wave!

$\vec{\mathbf{S}} = \frac{1}{\mu_0} \vec{\mathbf{E}} \times \vec{\mathbf{B}}$ is the power per unit area of the wave, pointing in the direction of the wave.

- Time-averaged Poynting vector is the intensity of the EM-wave:

$$< S > = \frac{1}{2} S_{\text{max}} = \frac{1}{2\mu_0} E_0 B_0 = \frac{E_0^2}{2\mu_0 c}$$

- Radiation pressure (force per unit area…. EM waves carry a very small amount of momentum) is given by $P_{\text{rad}} = \frac{< S >}{c}$. This is if an object absorbs all light incident on it; if it reflects 100% of this light, then we multiply this by a factor of 2.

Example

The amplitude of the oscillating electric field at your cell phone is $4.0\,\mu\mathrm{V/m}$ when you are 10 km east of the broadcast antenna. What's the electric field amplitude when you are 20 km east of the antenna?

Example

Assume we have the wave in the clicker question from earlier today (the one with 5 options for $\overrightarrow{\mathbf{B}}(x, y, z, t)$), incident on a person. Estimate the energy delivered to the person in 1 second and the force on this person from the EM wave.

Example with path-length difference (if time)

2 sound sources not necessarily in phase.