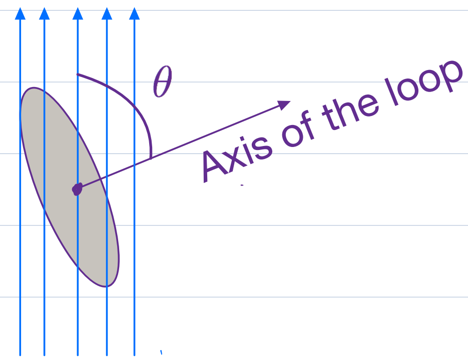
25.4: Faraday's Law

$$\Phi = N\vec{B}\cdot\vec{A} = NBA\cos(\theta)$$

$$\varepsilon = -\frac{d\Phi}{dt} = -\frac{\Delta\Phi}{\Delta t}$$

Lenz's law

N = # of turns



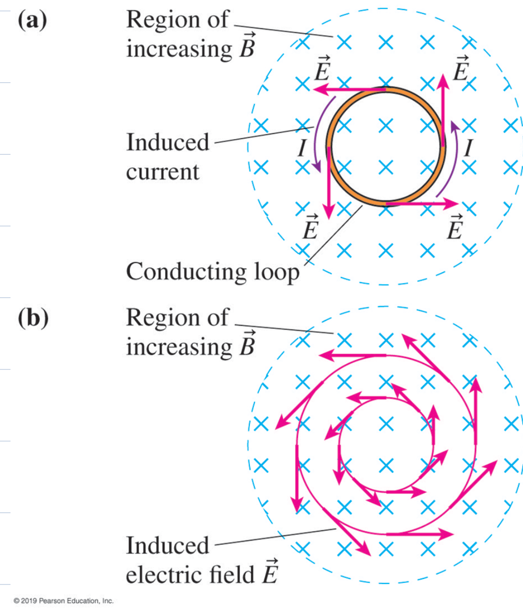
Applying Lenz's law to get the direction entails three steps:

1. What was the original flux through the loop?
2. How did that flux change?
3. Which direction should the current flow to *oppose* that change?

Examples posted on Moodle:

1. Ch25-Faraday-1
2. Ch25-Faraday-2
3. Ch25-generator. (Derivatives won't be on the test, but this does illustrate how flux can change due to the angle changing.)

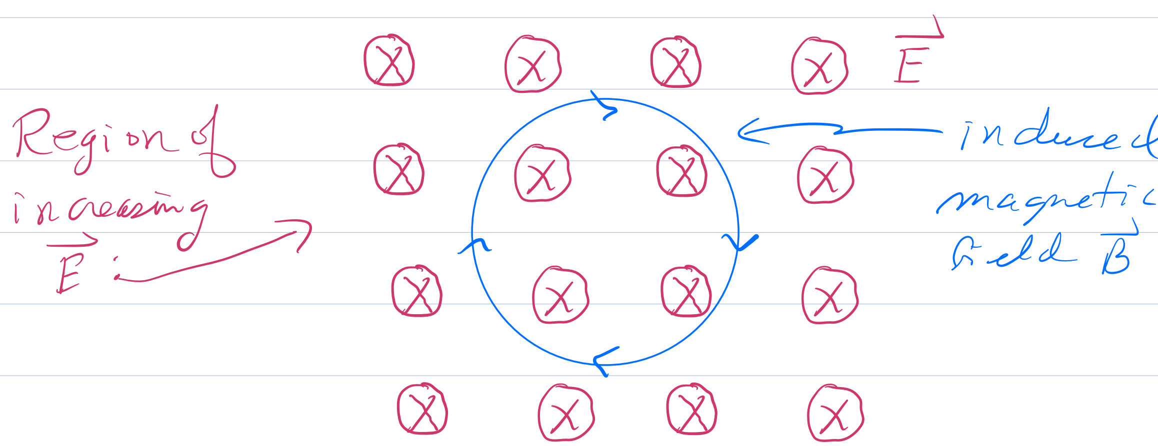
Faraday's Law ⇒ a time-changing $\vec{B}$ can create $\vec{E}$



25.5 Electromagnetic Waves

Even in the absence of a loop, that induced electric field is present. →

Similarly, it turns out a time-changing $\vec{E}$ can create a $\vec{B}$.



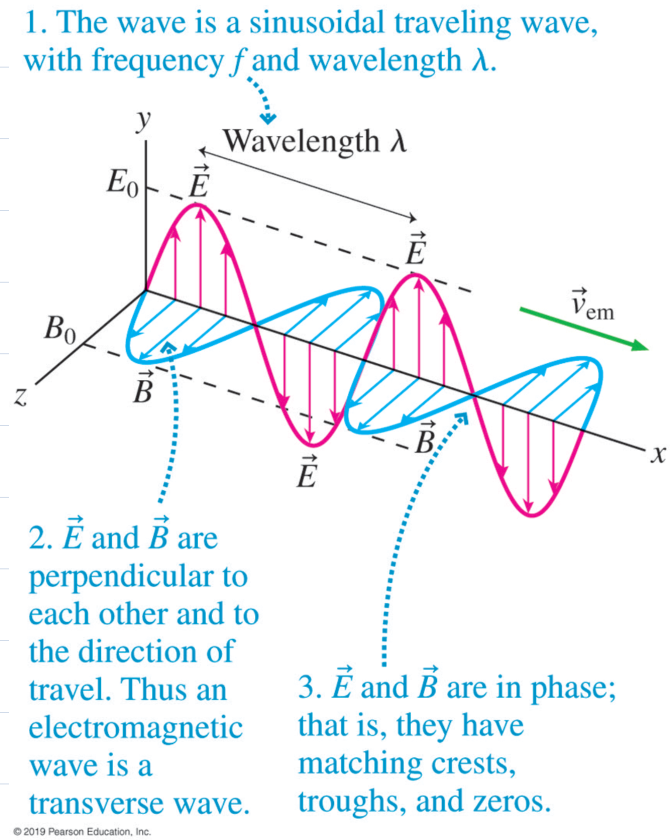
These two effects are coupled in the production of electromagnetic waves.

We discussed light as a wave back in Chapter 17.

$c = \lambda f$ still holds.

Here, we focus on E+M aspects.

1) Light is a transverse wave



2) The speed of light in a vacuum is constant:

$c \simeq 3.0 \times 10^8$ m/s

New: $c = \dfrac{1}{\sqrt{\mu_0 \varepsilon_0}}$ (i.e. related to basic E & M properties.)

3) $E = cB$ in magnitude

4) The direction of propagation is given by $\vec{E} \times \vec{B}$

5) The direction of $\vec{E}$ is called the polarization.

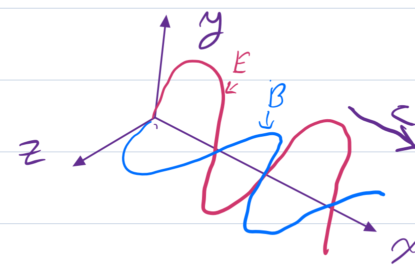
6) Electromagnetic waves carry energy.

$$\text{Intensity} = \frac{\text{Power}}{\text{Area}} = \frac{1}{2} c \epsilon_0 E^2 = \frac{1}{2\mu_0} c B^2$$

Simplest example: Sinusoidal wave in the $+x$ direction.

$$\vec{E} = \hat{j} E_0 \sin\left(2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right)$$

$$\vec{B} = \hat{k} B_0 \sin\left(2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right)$$



$\vec{E} \times \vec{B}$ points along $+x$

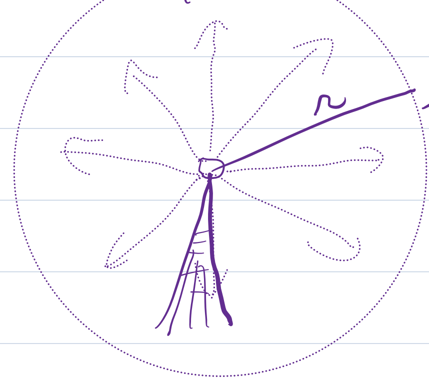
99.9 - The Hawk

The radio station broadcasts at 99.9 MHz with a power of 50,000 Watts. What is the wavelength of the radio waves? What are the maximum electric and magnetic fields at a distance of 1.25 kilometers from the station? (Assume the power radiates evenly in all directions.)

(a) $\lambda = ?$

$$\lambda = \frac{c}{f} = \frac{3\times10^{8}\,m/s}{99.9\times10^{6}/s} \approx 3.00\,m$$

(b) what are the amplitudes of the electric and magnetic fields 1.25 km away? (assume power radiates in all directions)



surface area $= 4\pi r^2$

$$I = \frac{P}{A} = \frac{50{,}000\,W}{4\pi\,(1250m)^2}$$

$$I = 0.00255\,W/m^2$$

$$I = \frac{1}{2}\epsilon_0 c E^2 \Rightarrow E = \sqrt{\frac{2I}{\epsilon_0 c}}$$

$$E = \sqrt{\frac{2\,(0.00255\,W/m^2)}{8.85\times10^{-12}\frac{C^2}{N\cdot m^2}\cdot 3\times10^{8}\,m/s}} \approx 1.39\,V/m$$

$$B = \frac{E}{c} = \frac{1.39\,V/m}{3\times10^{8}\,m/s} = 4.62\times10^{-9}\,T$$

Laser Pointer

A 0.24 mW red laser pointer (λ = 655 nm) is focused onto a spot 3 cm^2 a distance 5.0 m away. What is the frequency of the light wave? What is the intensity of the laser? What are the maximum values of the electric and magnetic field in the spot?

$$\lambda = 655\,nm = 655 \times 10^{-9}\,m$$

$$c = 3.0 \times 10^{8}\,m/s$$

$$f = c/\lambda = \frac{3.0 \times 10^{8}\,m/s}{655 \times 10^{-9}\,m} = 4.58 \times 10^{14}\,Hz$$

$$\text{area } A = 3.0\,cm^2 \times \left(\frac{1\,m}{100\,cm}\right)^2 = 3 \times 10^{-4}\,m^2$$

$$P = 0.24\,mW = 0.24 \times 10^{-3}\,W$$

$$I = \frac{P}{A} = \frac{0.24 \times 10^{-3}\,W}{3 \times 10^{-4}\,m^2} \simeq 0.8\,W/m^2$$

$$I = \frac{1}{2}\epsilon_0 c E^2 \Rightarrow E = \sqrt{\frac{2I}{\epsilon_0 c}} = 24.6\,V/m$$

$$B = \frac{E}{c} = \frac{24.6\,V/m}{3.0 \times 10^{8}\,m/s} = 8.19 \times 10^{-8}\,T$$

Lastly, note solar intensity on Earth's surface is ~ 1000 W/m^2 on a sunny day in Easton.