Announcements

- Homework
  - Webwork 20 due tonight!
  - Changing it up a little and you just have a WebWorK due on Monday
    - Don't want to disappoint you more by falling any further behind in grading...
    - There will be only one more video homework this semester, but it will be right at the end.
- No class next Wednesday (SSRD)
- Test 3 a week from today!
  - I'm making progress through the Test 2 submissions
  - Will probably be doing similar for Test 3
  - Should have more details once I get through the rest of Test 2 this weekend
- Polling: `rembold-class.ddns.net`

Bonus Power Review Question!

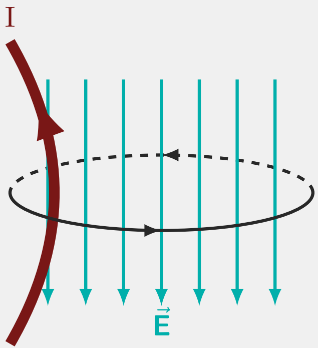
A current of $10\,\mu\text{A}$ is running through the wire in the direction shown. At the same time, an electric field is pointing in the negative y direction with a magnitude of

$$\left|\vec{\mathbf{E}}\right| = 500t^3$$

In what direction would a magnetic field be pointing around the shown loop ($A = 1\,\text{m}^2$) at $t = 10\text{s}$?

A. Clockwise as seen from above (opposite direction of arrows)

B. Counterclockwise as seen from above (same direction of arrows)



Solution: Counterclockwise as seen from above (same direction of arrows)

Remembering Maxwell

Since we'll be using them a lot today, let's remember Maxwell's Laws:

$$\oint \vec{\mathbf{E}} \cdot \hat{\mathbf{n}} \, \mathrm{d}A = \frac{q_{enc}}{\epsilon_0}$$

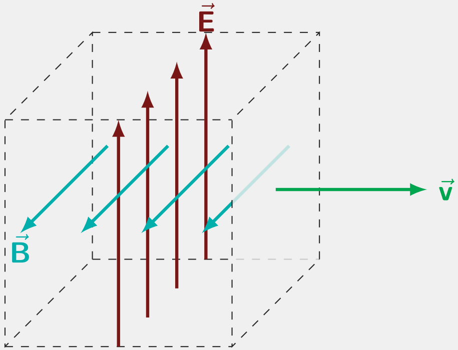
$$\oint \vec{\mathbf{B}} \cdot \hat{\mathbf{n}} \, \mathrm{d}A = 0$$

$$\oint \vec{\mathbf{E}} \cdot \mathrm{d}\vec{\ell} = -\frac{\mathrm{d}\Phi_B}{\mathrm{d}t}$$

$$\oint \vec{\mathbf{B}} \cdot \mathrm{d}\vec{\ell} = \mu_0 \mathrm{I}_{enc} + \mu_0 \epsilon_0 \frac{\mathrm{d}\Phi_E}{\mathrm{d}t}$$

We are looking for a configuration of magnetic and electric fields that self-perpetuate.

Gauss's Laws Holding?



Gauss's Laws Holding?

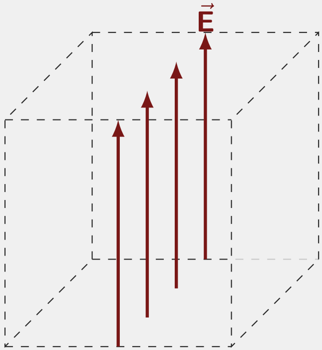
$$\oint \vec{\mathbf{E}} \cdot \hat{\mathbf{n}} \, \mathrm{d}A = \frac{q_{enc}}{\epsilon_0}$$

No charge enclosed

$\Rightarrow q_{enc} = 0$

Fluxes equal

✓

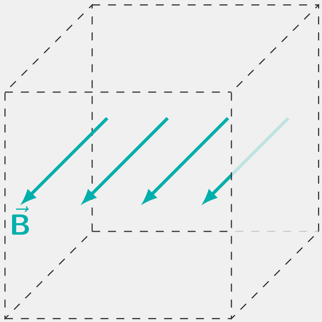


Gauss's Laws Holding?

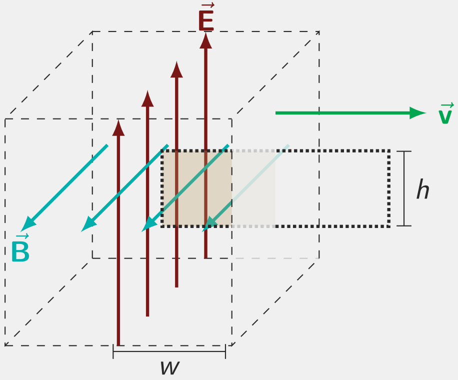
$$\oint \vec{\mathbf{B}} \cdot \hat{\mathbf{n}} \, \mathrm{d}A = 0$$

Fluxes equal

✓



Faraday's Law



$$\oint \vec{\mathbf{E}} \cdot \mathrm{d}\hat{\ell} = -\frac{\mathrm{d}\Phi_B}{\mathrm{d}t}$$

$$Eh = \frac{\mathrm{d}}{\mathrm{d}t}(Bhw)$$

$$Eh = Bhv$$

$$E = vB$$

✓

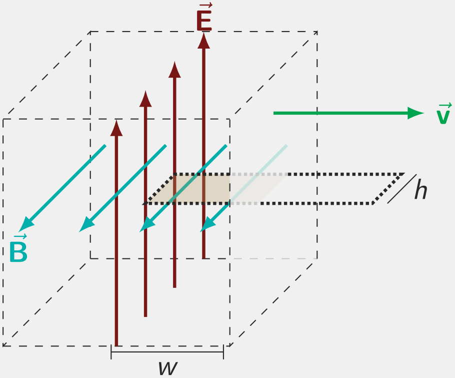
$$\oint \vec{\mathbf{B}} \cdot d\hat{\ell} = \mu_0 I_{enc} + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

$$Bh = \mu_0 \epsilon_0 \frac{d}{dt}(Ehw)$$

$$Bh = \mu_0 \epsilon_0 Ehv$$

$$B = \mu_0 \epsilon_0 Ev$$

✓



Let There Be Light

- We have two requirements for Maxwell's Equations to be satisfied:

$$E = vB$$
$$B = \mu_0 \epsilon_0 E v$$

- Plugging one into the other, we get a requirement for the speed:

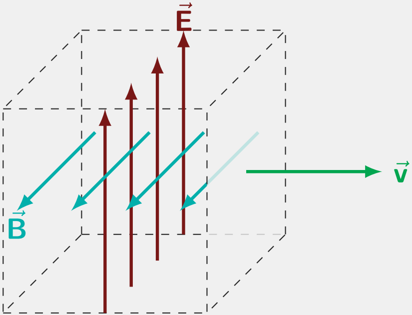
$$v = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

- Remember that ϵ_0 and μ_0 were 100% independently derived from observations of electric and magnetic fields

$$\frac{1}{\sqrt{\mu_0 \epsilon_0}} = 2.998 \times 10^8 \,\mathrm{m/s} = c$$

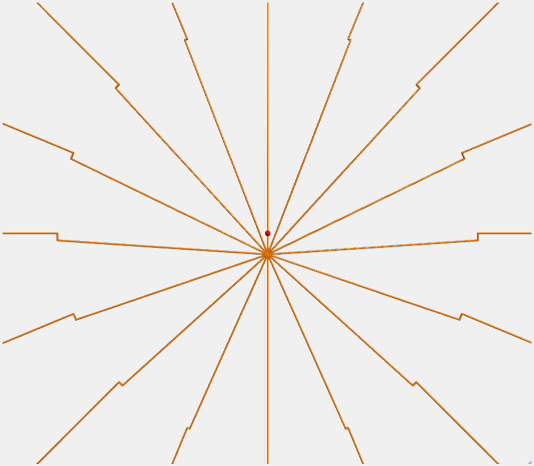
  - How you know you've hit it big in physics: When your discovery manages to precisely related fundamental constants from totally disparate topics!

- Putting all the pieces together, we find that light is a moving electromagnetic wave
  - with $\vec{\mathbf{E}}$ and $\vec{\mathbf{B}}$ at right angles to one another
  - with $|\vec{\mathbf{E}}| = c|\vec{\mathbf{B}}|$
  - traveling in the direction $\vec{\mathbf{E}} \times \vec{\mathbf{B}}$
  - at the speed of light c



Kickstarting the Process

- So we see that our configuration can propagate outwards forever
- But how do we setup that configuration in the first place?



Energetics

- Previously have discussed energy density for electric fields:

$$\frac{\text{Energy}}{\text{Volume}} = \frac{1}{2}\epsilon_0 E^2 \quad \text{or} \quad \frac{1}{2}\frac{1}{\mu_0}B^2$$

- Using that $E = cB$, we find that, for electromagnetic radiation:

$$\frac{\text{Energy}}{\text{Volume}} = \epsilon_0 E^2 = \frac{B^2}{\mu_0}$$

- Often times interested in how much energy arrives in a given time
  - Called the energy flux
  - Described by the Poynting Vector

$$\vec{\mathbf{S}} = \frac{1}{\mu_0}\vec{\mathbf{E}} \times \vec{\mathbf{B}}$$

A Sunny Example

At the surface of the Earth, the energy intensity of the Sun is about $1400\,\mathrm{W/m^2}$.

- What is the magnitude of the electric field of sunlight striking Earth?
- Assuming perfect efficiency, how much energy could a $10\,\mathrm{m} \times 10\,\mathrm{m}$ solar panel generate in $8\,\mathrm{h}$?

Solution: $726.5\,\mathrm{V/m}$, $4.03\,\mathrm{GJ}$