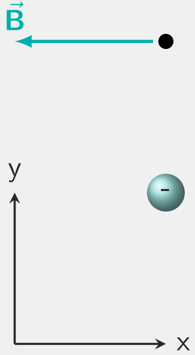
Announcements

- Homework
  - Webwork due tonight!
  - New Webwork to be due on Friday
- Video HW comments
- Starting Ch 18 on Friday probably
- Polling: `rembold-class.ddns.net`

Review Question!

The electron to the right is moving in some direction that is causing a magnetic field at the indicated position to point as shown. Which of the following would be a possible direction the electron could be moving in?

A. $+\hat{\mathbf{z}}$
B. $-\hat{\mathbf{y}}$
C. $-\hat{\mathbf{z}}$
D. $+\hat{\mathbf{x}}$



Solution: $-\hat{\mathbf{z}}$

Drifting Onward

- We can describe electric fields due to a single charge, but what about distributions?
- Hearken back to our definition of drift speed
  - How fast the electron sea "flows" under an electric field
  - How many electrons in a cross-section of the sea?
- We can derive the electron current in terms of drift speed:

$$\begin{aligned} \text{number of electrons} &= N_e = n \times (\text{volume}) \\ &= n(A\bar{v}\Delta t) \\ \Rightarrow \frac{N_e}{\Delta t} &= nA\bar{v} \\ i &= nA\bar{v} \end{aligned}$$

Current Events

- So we have the rate at which electrons flow past
- Want the rate at which charge flows past...
  - Just need to multiply by the charge of an electron!
  - Sorta.
- Charge carriers
  - Electrons are usually the dominant charge carriers
  - In some metals though, "holes" behave like the charge carrier
    - Technically lack of an electron
    - Act just like positive charges
- Traditionally, current is defined in terms of the positive hole current
  - Let's us not worry about figuring out negative signs
  - Blame Ben Franklin

Current Facts

Conventional Current

We define conventional current (I) as:

$$\mathrm{I} = |q| n A \bar{v}$$

- Current has units of C/s which we call amperes: A
- Conventional current flows *opposite* electron current.
- Remember drift speed is relate to the electric field, so can also write:

$$\mathrm{I} = |q| n A (uE)$$

Wired Up

So we have a copper wire with a diameter of 1 mm in which a current of 1 A is flowing. Copper has an electron density of about $8.4 \times 10^{28}\,\mathrm{m}^{-3}$. What is the drift speed in the wire?

Solution: $9.47 \times 10^{-5}\,\mathrm{m/s}$

Biot-Savart for Currents!

- Much more frequently have moving system of charge
- Working with currents to find magnetic fields generally more commonplace
- $q\vec{\mathbf{v}}$ has units of
$$\frac{\mathrm{C}\cdot\mathrm{m}}{\mathrm{s}} = \mathrm{A}\cdot\mathrm{m}$$
- We can transition to talking about how much of a current travels through a small distance!

Biot-Savart for Currents

We can rewrite the magnetic field due to a small amount of current as:

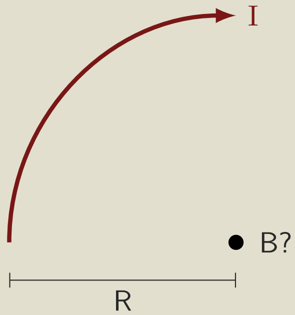
$$\Delta\vec{\mathbf{B}} = \frac{\mu_0}{4\pi}\frac{\mathrm{I}\Delta\vec{\ell}\times\hat{\mathbf{r}}}{|\vec{\mathbf{r}}|^2}$$

Back to Distributions!

- Uhoh, this $\Delta\vec{\mathbf{B}}$ looks a lot like when we had $\Delta\vec{\mathbf{E}}$...
- ...Back to adding up distributions!
    - Same idea, same process, just with currents this time
        - Cut your wire into pieces and determine $\Delta\vec{\mathbf{B}}$ direction
        - Write out the $\Delta\vec{\mathbf{B}}$ for a single chunk
        - Add or integrate over all chunks to get the net $\vec{\mathbf{B}}$
        - Check yo'self!

A Familiar Example

Suppose we have an arc of current as seen to the right. What would be the magnetic field at the given location?



Solution: $-\frac{\mu_0 I}{8R}\hat{\mathbf{z}}$

Other Distributions Near and Dear!

- **Line Current:**

$$B_{wire} = \frac{\mu_0}{4\pi} \frac{L\mathrm{I}}{r\sqrt{r^2 + (L/2)^2}}$$

Or, if $L \gg r$:

$$B_{wire} \approx \frac{\mu_0}{4\pi} \frac{2\mathrm{I}}{r}$$

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- **Ring Current:**

$$B_{ring} = \frac{\mu_0}{4\pi} \frac{2\pi R^2 \mathrm{I}}{(z^2 + R^2)^{3/2}}$$

  Or, if $z \gg r$:

$$B_{ring} \approx \frac{\mu_0}{4\pi} \frac{2\pi R^2 \mathrm{I}}{z^3}$$

Magnetic Dipoles

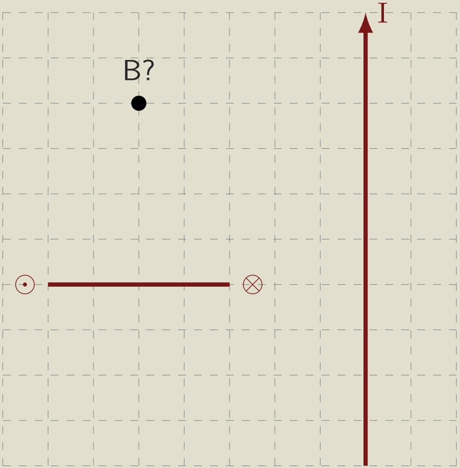
- Ring currents are the "dipoles" of the magnetic kingdom!
- Create similar patterns with magnetic fields to the electric fields seen in electric dipoles
- Can define the magnetic dipole moment $\mu = IA$ such that:

$$B_{axis} = \frac{\mu_0}{4\pi}\frac{2\mu}{r^3}$$

  where A is the area formed by the loop.
- Will give us a way to talk about "poles" of a magnet
- Curling fingers in direction of current will tell you the direction of the dipole moment (and the $\vec{\mathbf{B}}_{axis}$)

Distribution Example

Consider the case to the right where we have an extremely long wire near a small loop of wire. Both wires happen to have a current of 3 A running through them, with the current running upward in the long straight wire and the current flowing counterclockwise when viewed from above in the loop of wire. Each grid-line represents a centimeter. What is the magnetic field vector at the point indicated?



Solution: $\langle 0, 42.15, 1.2\rangle \times 10^{-5}\,\mathrm{T}$