Announcements

- Homework
  - Video Homework due tonight!
  - Online HW will be due on Wednesday
- Grade reports have been posted!
  - Today is the last day to choose credit/no credit
  - Everything factored in except lab scores
- Lab this week on Magnetic Fields
- Polling: `rembold-class.ddns.net`

Review Question

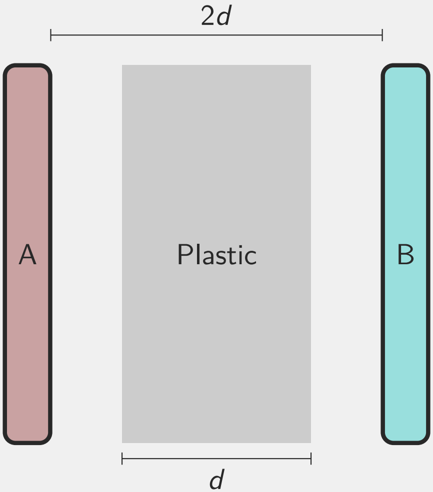
Originally ΔV was $-1000\,\mathrm{V}$. A plastic slab is inserted with a width equal to half the distance between the plates. Now, $\Delta V = V_B - V_A$ is:

A. between $-500\,\mathrm{V}$ to $-1000\,\mathrm{V}$

B. between $500\,\mathrm{V}$ to $1000\,\mathrm{V}$

C. $-500\,\mathrm{V}$

D. Not enough information to tell



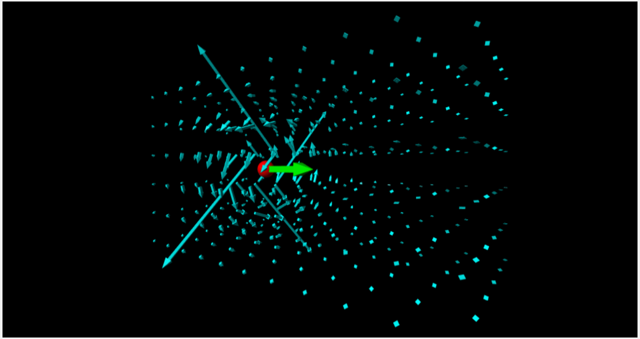
Solution: between $-500\,\mathrm{V}$ to $-1000\,\mathrm{V}$

Origin Story

- Charged particles have two fields associated with them
  - Stationary charges: electric fields
  - Moving charges: electric fields and magnetic fields
- Can quantify with the electron current, the number of electrons per second that enter a conductor
- Magnetic fields create a torque on a compass needle exactly like electric fields create a torque on dipoles.
- Can let us “see” the directions of the fields
- Evidence that moving charges create or interact with magnetic fields:
  - Demos!

Understanding the Magnetic Field

- We deduced the electric field from careful observations near a stationary point charge
- We do similar for the magnetic field near a moving point charge
- We see that magnetic fields point in loops around a moving charge!



Enter Biot-Savart

- Need a way to quantify the magnetic field created by a moving charge
- Want to account for both a magnitude and a direction

The Biot-Savart Law

The magnetic field for a single moving charge is described by:

$$\vec{\mathbf{B}} = \frac{\mu_0}{4\pi} \frac{q\vec{\mathbf{v}} \times \hat{\mathbf{r}}}{|\vec{\mathbf{r}}|^2}$$

where

$$\frac{\mu_0}{4\pi} = 1 \times 10^{-7}\, \frac{\mathrm{T} \cdot \mathrm{m} \cdot \mathrm{s}}{\mathrm{C}}$$

Criss Cross

- Cross products come up a lot in magnetic fields, so worth reviewing!
- Can calculate in two ways:
  - Method 1:
    $$\left|\vec{\mathbf{A}} \times \vec{\mathbf{B}}\right| = \left|\vec{\mathbf{A}}\right|\left|\vec{\mathbf{B}}\right| \sin\theta$$
    Here the direction must be determined by the right-hand-rule!
    - Hand points towards $\vec{\mathbf{A}}$
    - Fingers curl towards $\vec{\mathbf{B}}$
    - Thumb points towards $\vec{\mathbf{A}} \times \vec{\mathbf{B}}$
  - Method 2:
    $$\vec{\mathbf{A}} \times \vec{\mathbf{B}} = \langle A_y B_z - A_z B_y, A_z B_x - A_x B_z, A_x B_y - A_y B_x \rangle$$

A Right Good Example

Given the three vectors below, use the right-hand rule to determine the direction of the resulting cross products:

$$\vec{\mathbf{A}} = \langle 1, 0, 0 \rangle$$
$$\vec{\mathbf{B}} = \langle 0, 0, -1 \rangle$$
$$\vec{\mathbf{C}} = \langle 1, 1, 0 \rangle$$

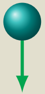
Determine the direction of:

- $\vec{\mathbf{A}} \times \vec{\mathbf{B}}$
- $\vec{\mathbf{B}} \times \vec{\mathbf{C}}$
- $\vec{\mathbf{C}} \times \vec{\mathbf{A}}$

Solution: $+\hat{\mathbf{y}}$, $\langle 1, -1, 0 \rangle$, $-\hat{\mathbf{z}}$

Right Hand Rule and Magnetic Fields

An electron is traveling in the $-\hat{\mathbf{y}}$ direction. Sketch out the direction of the magnetic field lines surrounding it.



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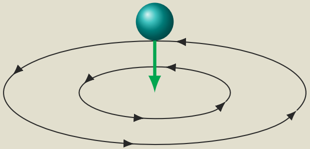


Understanding Check

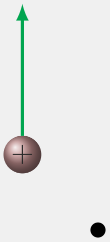
What is the direction of the magnetic field at the indicated position? You can assume our usual coordinate system of $\hat{\mathbf{x}}$ to the right, $\hat{\mathbf{y}}$ upward, and $\hat{\mathbf{z}}$ out of the board towards you.

A. $+\hat{\mathbf{x}}$

B. $-\hat{\mathbf{z}}$

C. $+\hat{\mathbf{z}}$

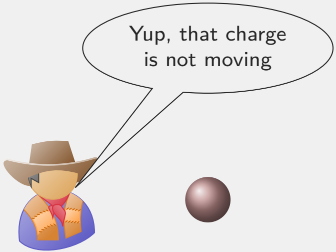
D. $-\hat{\mathbf{y}}$



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

A Frame of Reference Matters!

- Velocity is a relative measurement. What reference frame to measure it in?



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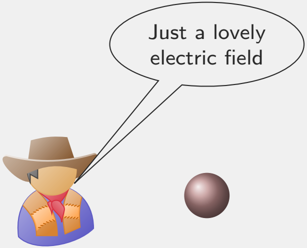

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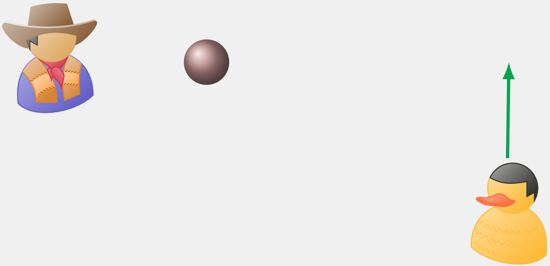

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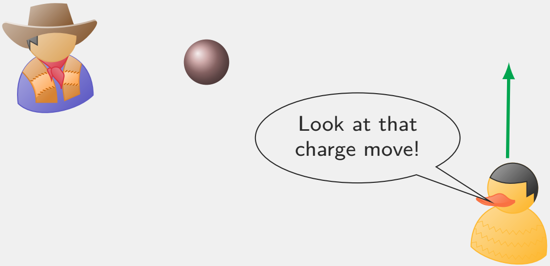

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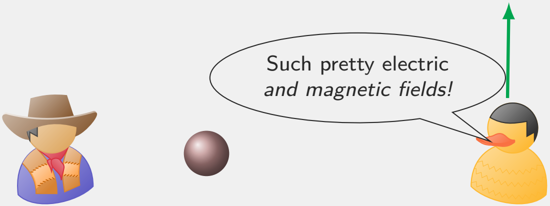

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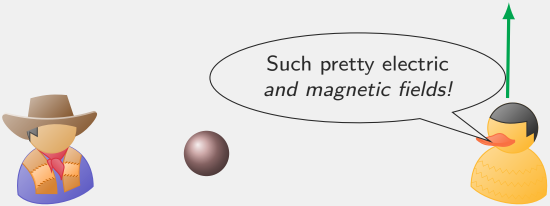

- Moving observers see a mixture of electric magnetic fields!

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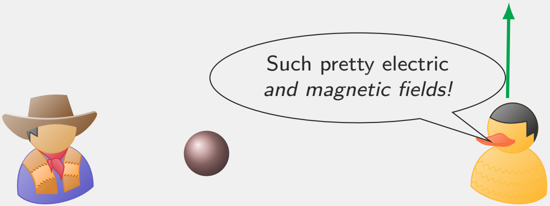

- Moving observers see a mixture of electric magnetic fields!
- Electric and Magnetic fields must be more closely related than we realize. . .

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:

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