1 Instructor's Guide

1.1 Introduction

Students move around the room acting out various prompts from the instructor regarding current densities of different dimensions.

Tell the students that they each represent a point charge. Then initiate a conversation with the whole class by asking the prompts listed in "Student Conversations," below. Be flexible about the order of the prompts, responding to the ideas brought up by the students.

We usually hold a voltmeter and pretend that it is set to measure "magnetic field". Don't forget to mention that this use of a voltmeter is metaphorical and unrealistic.

Note: It helps if the instructor stands on a chair or table so they are high enough to hold a meter stick above the "current" that the students make. The meter stick represents the "gate" used to measure the total current.

We usually do this activity sometime after the Activity: Acting Out Charge Densities. The embodied understanding here builds on the previous activity.

1.2 Student Conversations

Sample Prompts: "Stand up. Imagine you are each a point charge."

- "Make this magnetic field meter fluctuate."
- "Keep moving, but in a way that the magnetic field meter does not fluctuate."
- "Make the meter read a larger magnitude. What different things can you do to make it read a larger magnitude?"
- "Make a linear current density. How do we measure linear current density?"

Weave the following discussions in amongst the prompts at appropriate times:

- **Steady Currents:** Our students often already know that currents generate a magnetic field, so the instructor stands in the middle of the room (often on a table) and asks the students to move in such a way that her "magnetic field meter" doesn't fluctuate. The students quickly realize that their motion must be consistent so that at any point in space, the current doesn't change with time. The instructor then defines their motion as a *steady current*.
- **What can change?:** The students often respond by walking in a circle around the instructor. A nice conversation to have with the students is "Does it have to be a circle?."
- **Gates:** Current has dimensions of charge per unit time and "charge per time" may be the only concept of current that some students can state. Demonstrate that these words mean counting how many charges pass through a "gate".
- **What does linear current density mean?:** Students have effectively used the mneumonic "linear mass density is mass per unit length, surface charge density is mass per unit area, ..."" for both mass and charge densities. They are tempted to use the mneumonic again here, so linear

current density must be current per unit length. As they start to act this out, you will see the look of confusion on their faces. What is *linear* is that the current is caused by a *linear* charge density (times a velocity).

- **Dimensions of gates:** If the charge density is a linear charge density (i.e. 1-dimensional), then the gate is a point. If the charge density is a surface density, then the gate is a line segment. If the current density is a volume density, then the gate is a 2-D surface.
- **Total current:** Total current is the flux of the current density through the gate. Therefore, a linear current density is the "same" as the total current in an idealized 1-dimensional wire.
- **Current is a flux:** Make sure students get to see what happens if someone goes through a gate in a direction that is not perpendicular to the gate.

1.3 Wrap-up

Formalism: You might want to follow this conceptual activity with a brief lecture/discussion on the formalism and conventions. Write the symbols for linear, surface and volume density on the board ($\vec{I}$, $\vec{K}$ and $\vec{J}$), solicit from the class their appropriate units and dimensions and also write the formulas

$$\begin{aligned} \vec{I} &= \lambda\,\vec{v} \\ \vec{K} &= \sigma\,\vec{v} \\ \vec{J} &= \rho\,\vec{v} \end{aligned}$$

that show current density is an appropriate charge density times velocity.

If the students have already encountered the concept of flux, emphasize that TOTAL current is a *flux* through a gate.

$$\begin{aligned} I_{\text{total}} &= \vec{I}\cdot\hat{n} \\ I_{\text{total}} &= \int \vec{K}\cdot\hat{n}\,|d\vec{r}| \\ I_{\text{total}} &= \int \vec{J}\cdot\hat{n}\,dA \end{aligned}$$

where $\hat{n}$ is perpendicular to the gate. Associated reading: see Griffiths' *Introduction to Electrodynamics*, 3rd Ed., pp. 208-214 and Current