Concept Questions: Modeling Auroral Currents

Description: These questions with selected response answers probe student thinking about the magnetic fields produced by line currents. The entire sequence of questions provided here is intended to guide students to use their knowledge about long current-carrying wires to model the magnetic effects of currents in the Earth's ionosphere associated with aurorae. This resource is designed to be used either as homework or in small discussions with methods such as *Peer Instruction*, *Teaching with Clickers*, or *CAE Think-Pair-Share*.

Prerequisite:

- Understand how an appropriate "right hand rule" relates the current in a long straight wire to the magnetic field that that current produces.
- Understand how the magnitude of this magnetic field varies with perpendicular distance from the wire (as would be derived from Ampère's law).

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This resource was developed by R. Lopez, J. Bailey, R. Vieyra, & S. Willoughby. The co-authors acknowledge useful discussions with B. Ambrose, X. Cid, & K. Sheridan, and the support of a subcontract from the NASA Heliophysics Education Activation Team to Temple University and the AAPT under NASA Grant/Cooperative Agreement Number NNX16AR36A.

Concept Questions:

1. Imagine that you and a friend are studying magnetic fields by straight-line currents in a physics lab. Suppose that you were to define a coordinate system in which the directions of due north and due east are defined to be the $+x$ and $+y$ directions, respectively. Which direction should you select for $+z$, so that your coordinate system is *right-handed?*
    a. Vertically upward
    b. Vertically downward
    c. Either (a) or (b) would work, it's your choice
    d. I don't know

Questions 2 – 4 below pertain to the following situation: Imagine that you and a friend are studying magnetic fields by straight-line currents in a physics lab. You have defined a *right-handed* coordinate system in which the directions of due north and due east are defined to be the $+x$ and $+y$ directions, respectively. You begin your experiments by setting up a long, straight wire so that it is oriented horizontally, at a uniform height (a few cm) above your lab table such that it carries a steady (conventional current) flowing in the $\boldsymbol{+y}$ direction (eastward). (In all questions ignore the earth's magnetic field.)

2. Consider a location *P* on the table that is directly beneath the wire. What is the direction of the magnetic field (due to just the current) at point *P?*
    a. Due north (+x direction)
    b. Due south (–x direction)
    c. Due west (–y direction)
    d. Due east (+y direction)
    e. Vertically downward (+z direction)
    f. Vertically upward (–z direction)
    g. I don't know

3. Consider a location *A* on the table that is slightly east of the wire (that is, not directly under the wire, but slightly away from it in the +y direction). What is the direction of the magnetic field (due to just the current) at point *A?*
    a. Due north (+x direction)
    b. Due south (–x direction)
    c. Due west (–y direction)
    d. Due east (+y direction)
    e. Vertically downward (+z direction)
    f. Vertically upward (–z direction)
    g. Don't know

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4. Consider a location *C* on the table that is slightly east of the wire (that is, not directly under the wire, but slightly away from it in the +x direction). Which statement below best describes the components of the magnetic field (due to just the current) at point *C?*
    a. $B_x = 0, B_y > 0, B_z = 0$
    b. $B_x = 0, B_y < 0, B_z = 0$
    c. $B_x > 0, B_y = 0, B_z > 0$
    d. $B_x > 0, B_y = 0, B_z < 0$
    e. None of the above
    f. I don't know

Questions 5 – 6 below pertain to the following situation: Imagine that you and a friend are studying magnetic fields by straight-line currents in a physics lab. You have defined a *right-handed* coordinate system in which the directions of due north and due east are defined to be the +*x* and +*y* directions, respectively. You set up a long, straight wire so that it is oriented horizontally, at a uniform height (a few cm) above your lab table in either the +*y* (eastward) or –*y* (westward) direction. At an observation point *P* on the table, you and your friend find that the components of the magnetic field at point *P* have the following signs: $B_x < 0, B_y = 0, B_z < 0$.

5. In which direction must the (conventional) current be flowing through the wire?
    a. In the +y direction (east).
    b. In the –y direction (west).
    c. Either is possible, more information is needed.
    d. Trick question! The current is neither eastward nor westward.
    e. I don't know.

6. Where must the wire be located relative to the observation *P* on the table?
    a. The wire must be directly above point *P.*
    b. The wire must be above and to the north of point *P*.
    c. The wire must be above and to the south of point *P*.
    d. Either is possible, more information is needed.
    e. I don't know.

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7. Imagine now that you and your partners—working as physicists for the U.S. Geological Survey—are reviewing magnetic field data from an observatory near Fairbanks, AK, on a day when a strong magnetic disturbance produced auroral electrojet activity. Your results suggest that a perturbation of the magnetic field of magnitude 2,000 nT occurred at the observatory, and that this disturbance was caused by an electric current in the ionosphere directly above the observatory, about 100 km (10^5 m) overhead. By modeling this current as flowing in a long, straight wire, what do you deduce to be the magnitude of this current?
   a. 1 A
   b. 10^2 A
   c. 10^4 A
   d. 10^6 A

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