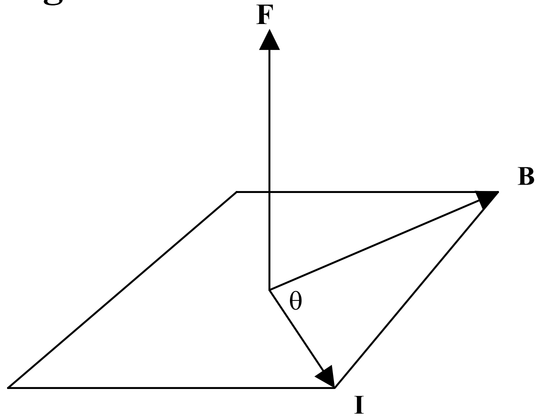
Investigating the Force on a Current-Carrying Wire



We have learned that the direction of the force on a current-carrying conductor is perpendicular both to the direction of the current and to the direction of the "external" magnetic field. (Note that this is ***not*** the magnetic field produced by ***this*** current, but is one produced by "outside" sources.) The exact direction of the force can be determined by a "right-hand rule," where the fingers of the right hand first point in the direction of the current, and then "curl" in the direction of the magnetic field. The right thumb then points in the direction of the force. The magnitude of the force is given by the equation $F = ILB \sin\theta$, where θ is the angle between the directions of the current and the magnetic field. (The angle θ may vary between 0° and 180°.)

The current vector and the field vector form a plane (as shown in the above diagram). For instance, they might be vectors lying in the *x-y* plane. Let us suppose that the initial value of the angle θ is 90°. ***We will assume that the current and the field are always in the same, unvarying plane, although the angle between them may change. So, if they begin in the*** **x-y** ***plane, they will always remain in the*** **x-y** ***plane.***

i) As the angle θ is decreased from 90° toward 0°, will the magnitude of the force increase, decrease, or remain the same?

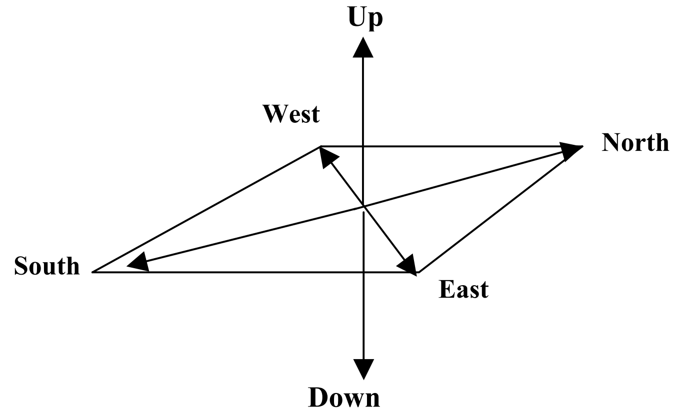
ii) While the angle is decreasing from 90° toward 0°, will the direction of the force change, or not? Explain.

iii) If, after reaching an angle of 0°, you continue rotating the direction of the current ***past*** the direction of the magnetic field (now ***increasing*** the angle, but going the other way), will the direction of the force change? Explain.

iv) What angle will give a force of maximum magnitude? Which angles will give a force of minimum magnitude?

v) Suppose the direction of the current is ***reversed from the original direction*** shown in the diagram above. That is, the angle is again 90° but the current flows in the opposite direction. What is the direction of the force on the current in this case? Explain.

In order to explore the space inside an apparently empty room, you bring a straight wire 2-m long attached to a resistor and variable power supply, along with a device to measure the force experienced by the wire (such as a spring scale). (Directions in the room are defined by the diagram as shown.) You then carry out the following series of experiments:



1. By adjusting your power supply, you get a 10-A current flowing in your wire. You set up your wire in an up-down direction, so that the current flows ***from the bottom of the wire toward the top*** (direction ***down-to-up***). You find that there is a 5N force pulling the wire toward the ***east.***
   A. Is this information consistent with the presence of a magnetic field in the room?

   B. You now adjust your power supply so that the current that flows through the wire is increased to 30 A, but you keep its direction the same as before. What magnitude force do you now expect to measure acting on the wire?

2. Going back to the 10-A current, you now begin to vary the direction of the current by rotating your wire. As you rotate it slowly you find that the force acting on it decreases in magnitude until, when the wire is aligned along the north-south direction, the force on it is zero.
   A. Based only on this "zero force" observation, what are the possible directions in which a magnetic field might be pointing?

   B. If possible, determine the exact direction of the magnetic field at the location of your wire. If it is not possible, state what additional information is needed to make this determination. Explain. *(Hint: Review the direction information given in #1.)*

   C. If there is a magnetic field present, determine its magnitude.

   D. Taking into consideration the direction of the force mentioned in #1, which of the directions you gave as an answer to 2 (A) ***could be*** the actual direction of the magnetic field?

3. If you now continue to rotate your wire until it is aligned in the top-down direction again (but with the current now flowing in the ***up-to-down*** direction), what should you measure for the magnitude and direction of the force on the wire?

4. What are the different orientations for your wire that would result in a zero-magnitude force acting on it?

5. If you orient your wire in the east-west direction (10-A current flowing ***east-to-west***), what magnitude and direction of force on your wire do you expect to observe?

6. Now you go back to the original orientation: 10-A current flowing ***down-to-up.*** Maintaining both this direction of the wire and the 10-A current, you check the force acting on the wire when you place it at many different locations around the room. At all tested locations, you find that the force is 5 N and pulls the wire toward the east.

   Which of these possible magnetic fields in the room would be consistent with your measurements:

   a) uniform direction, nonuniform magnitude
   b) uniform magnitude, nonuniform direction
   c) uniform magnitude and uniform direction
   d) zero magnitude

   Explain your answer.

7. Suppose you now put your wire away and bring in a different wire, one 4 m long with a 15-A current, and orient it in the east-west direction with the current flowing ***west-to-east***. Describe the magnitude and direction of the force you expect to observe acting on that wire.

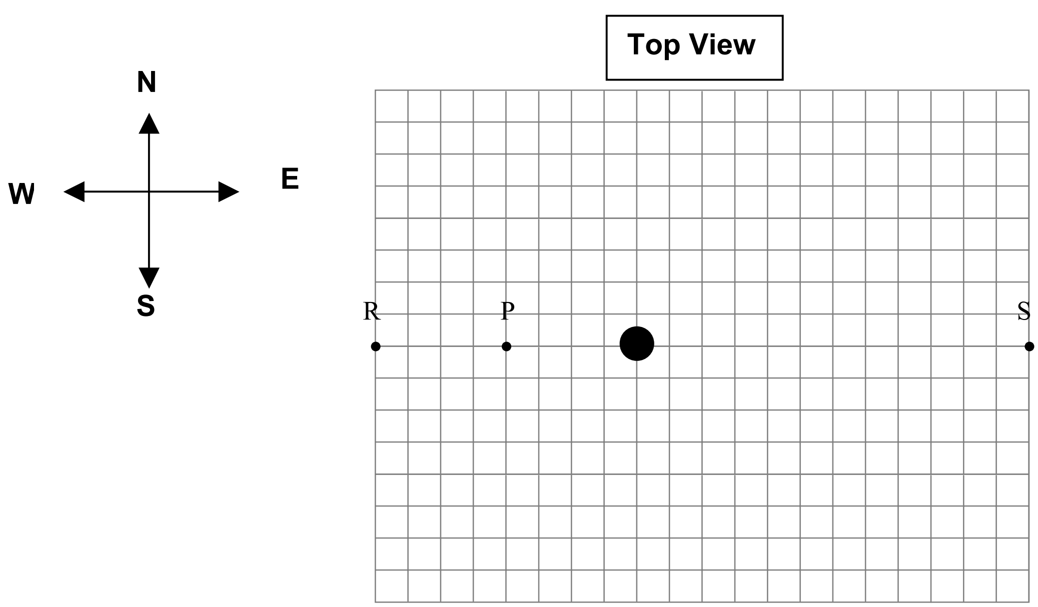
In the following series of experiments, you go into a different room in which you find a long wire located near the center of the room and oriented in a top-down direction. (This wire is indicated by the black dot in the diagram below.) You use a straight wire carrying a 10-A current to investigate the situation in this room. ***Assume that there is <u>no</u> external magnetic field present in the room created by any sources <u>outside</u> the room.***

8. First, you orient your wire in the top-down direction (current flowing ***top-to-down***) at a location "P" 4 m from the center of the "black dot" wire. ***(See diagram below.)***You measure a 4 N force pushing your wire toward the east. You slowly move away from the "black dot" wire (keeping location "*P*" between yourself and the wire, and maintaining the top-down orientation of your wire) until you reach point "*R*" 8 m from the wire. Here you measure a 2-N force pushing your wire again toward the east. What is the direction of current flowing in the "black dot" wire?

9. If you now move to the opposite side of the long wire (see diagram), to a point "*S*" 12 m away from it, what magnitude and direction of force do you expect to measure on your wire?

10. Indicate on the diagram where you would have to locate your wire for it to experience a 6-N force pushing it (A) toward the south, and (B) toward the north. Label these locations (A) and (B).

11. What current would you need to have flowing in your wire for it to experience a 12-N force when it is located at point P?



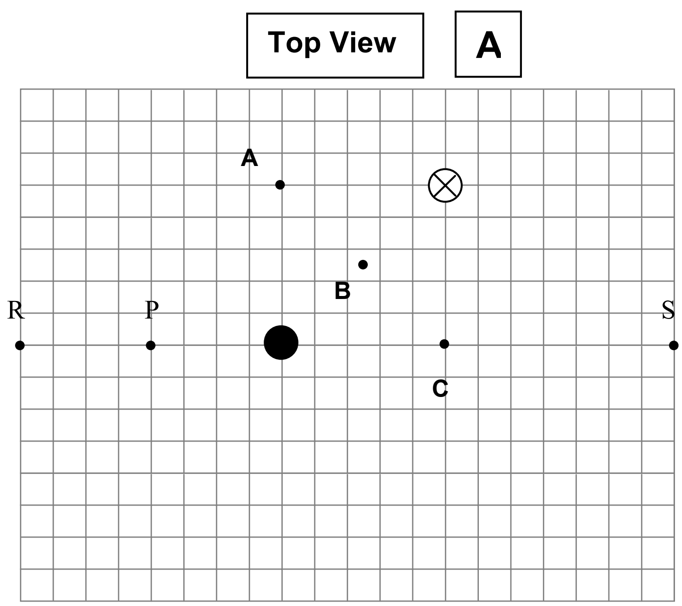
12. (A) Now, a current-carrying wire identical to the “black dot” wire (same length, same current) is placed at the location marked by the “X.” The “X” indicates that the current in this wire is going in the ***top-to-down*** direction. The original “black dot” wire still has the same direction of current flow as it did before.

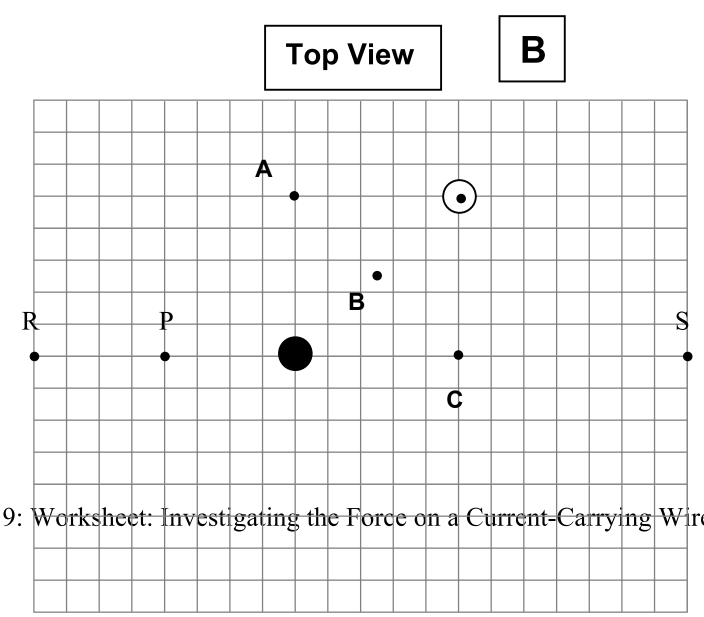
i) Recall from #8: What is the direction of current flow in the “black dot” wire?

ii) At point A, draw an arrow representing the magnetic field at that point due to the “black dot” wire, and another arrow representing the field due to the “X” wire. Make your shortest arrow one grid square long. Draw all arrows so their relative lengths are proportional to their relative magnitudes.

iii) Draw the ***net magnetic field vector*** at points A, B, and C. If the field at a certain point is zero, write “zero.”

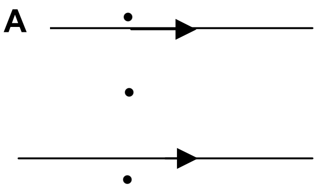
(B) Here, the only change made is that the current in the additional wire reverses direction, so it is now going ***down-to-up*** (as indicated by the dot symbol). The “black dot” wire still has current flowing in the same direction as it did before. Draw only the ***net*** magnetic field vectors at points A, B, and C. If the field is zero at a certain point, write “zero.”



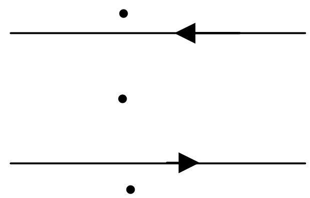


13. Wire segments are shown with equal-magnitude currents flowing in the directions indicated. Using the cross or dot symbols, indicate the direction of the net magnetic field at the points indicated in arrangements A, B, C, D, and E. If the field is zero (or nearly zero), write "zero."

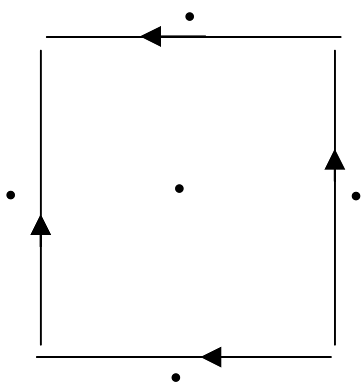
A



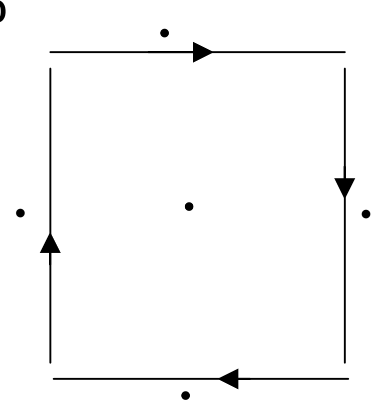
B



C



D



E