Chapter 12: Electromagnetism

Mini Investigation: How Strong is Electromagnetism?, page 547

A. Answers may vary. Sample answer:
No, when the power was first turned on, I could not pull apart the electromagnet and the soft-iron plate, even when pulling with great force.
B. Answers may vary. Sample answer:
The current necessary to just prevent me from pulling apart the electromagnet and the plate was approximately 0.20 A. Yes, it is surprising that a small current can generate a large force using an electromagnet.

Section 12.1: Magnetic Fields

Research This: The Maglev Train, page 551

A. The main advantage of Maglev technology is that it allows trains to travel at much greater speeds than conventional trains while remaining quiet and smooth.
B. Maglev train technology is not commonly used because Maglev train systems are currently far more expensive to build and maintain compared to conventional train systems. In addition, new conventional trains can use existing tracks but Maglev trains require special tracks to be built.
C.

Comparing conventional train technology to Maglev technology	
Similarities	**Differences**
Both reduce greenhouse gas emissions by reducing number of cars and the trucks on the road.	Maglev trains need new, special tracks while conventional trains can use existing tracks.
Both can move a large number of passengers.	Maglev trains are faster than conventional trains.
Both may reduce reliance on airplanes for long distance travel.	Maglev trains are more expensive than conventional trains.

D. The Maglev train in Shanghai provides people travelling between Shanghai and the international airport with extremely fast and reliable transportation. Its use has reduced pollution by requiring less power because it has less friction. It also reduces overcrowding by transporting large numbers of people quickly.

Section 12.1 Questions, page 552

1. Answers may vary. Sample answer:
The compass is an important tool in navigation because it enables navigators to measure the direction in which they are travelling relative to magnetic north. This is especially valuable at night or when the sky is overcast and the Sun cannot be used to estimate direction.
2. If the magnetic north pole were moved to a point on the equator, navigation would become very difficult. Compass needles would point toward the new pole location on the equator, so all directions shown on the compass would be inaccurate. Also, compasses would be difficult to use near the new poles on the equator because the direction the needle points would change a lot. It would probably be easiest to redefine north and south in terms of the new magnetic poles.
3. I would suspend a small sliver of the magnetite on a string to allow the sliver to align itself with Earth's magnetic field and point in the direction of magnetic north. I would not be able to determine magnetic north by only using the magnetite because either end of the sliver may be pointing toward the north pole. I could use the magnetite as well as other clues, such as the orientation of the Sun, to find the direction of magnetic north. Once I know which way is north (or south), then the opposite end is pointed south.
4. (a) If Earth had no magnetic field the northern lights would not exist because they are caused by charged particles interacting with Earth's magnetic field.
(b) If Earth had no magnetic field, animals that use the magnetic field to navigate when migrating might lose their way and not reach their destination. Some examples animals thought to use Earth's magnetic field to navigate are spiny lobsters, loggerhead sea turtles, and big brown bats.
5. (a) The needles of the top and bottom compasses should be parallel to the magnet. The needle of the left compass should be parallel to the magnet and point to the right. The needle of the right compass should be parallel to the magnet and point to the left.
(b) The needle of he compass would point downward toward the south pole of the magnet.

6. (a) The magnetic field lines should flow from the north end of one magnet to the south end of the other magnet. Magnetic field lines should also flow from the north end of one magnet to the south end of the same magnet.
(b) Magnetic field lines should flow from the north end of one magnet to the south end of the same magnet.
(c) The magnetic field lines should flow from the north ends of both magnet to the south ends of the magnet. Between the south ends of the two magnets, the magnetic field lines get close to parallel.
(d) The magnetic field lines should flow from the north ends of the magnets to the south ends of the magnets. Between the south ends of the two bottom magnets, the magnetic field lines get close to parallel.
7. Answers may vary. Sample answer:
I found that magnetic fields are used in cathode ray tubes (CRTs), which are the main component inside of some television sets and computer monitors. Electrons are fired by an electron gun inside the tube and travel from the back of the device toward the screen at the front of the device. As the electrons travel, they are deflected by a magnetic field inside the tube and they hit the front of the screen at a specified position, creating dots on the screen, or "pixels". All the electrons shot to different positions on the screen create a grid of pixels, which make an image that can be viewed.

Section 12.2: Oersted's Discovery

Section 12.2 Questions, page 556

1. (a) The diagram should be similar to Figure 8(a) on page 556 of the textbook. There should be an arrow pointing to the right above the diagram.
(b) The diagram should be similar to Figure 9 on page 556 of the textbook.
2. (a) The diagram should be similar to Figure 8(a) on page 556 of the textbook. There should be an arrow pointing to the right above the diagram.
(b) The diagram should be similar to Figure 8(a) on page 556 of the textbook. There should be an arrow pointing to the left above the diagram.
(c) The diagram should be similar to Figure 5(b) on page 555 of the textbook. Students should draw a large dot in the centre of the conductor.
3. The student's diagram is inaccurate because the concentric circles are equally spaced. The spacing of the concentric circles represents the strength of the magnetic field around the conductor, so they should be drawn farther apart as they move away from the wire to represent the weakening magnetic field.
4. If I use the right-hand rule, the conventional current model would be used. The diagram would not change, since it shows the conventional current directed into the page and the magnetic field lines directed clockwise around the conductor.
If I use the left-hand rule, the electron flow model would be used, so the diagram would change. The current would be directed out of the page, so the conductor in the diagram would have a dot instead of an X. Using the left-hand rule, if your left thumb points in the direction of the current, which is out of your page, then your fingers will curl around the conductor in a clockwise direction. This is the direction of the magnetic field lines, so their direction in the diagram would not change.
5. If the compass displays north when travelling east under the wire, the magnetic field lines must be in the east direction underneath the wire. Using the right-hand rule, for the magnetic field lines to be in the east direction underneath the wire, the conventional current must be flowing south in the wire.
6. I can control whether the magnetic field is on or off by starting or stopping the electric current. I can control the strength of the magnetic field by increasing or decreasing the electric current. And I can control the direction of the magnetic field by changing the direction of the electric current.
7. (a) The conventional current is pointing to the left so, using the right-hand rule, my thumb would point to the left and my fingers would curl around the conductor from above. My fingers represent the magnetic field lines, and they show that the direction of the magnetic field is through the compass from south to north, so the compass would point north.
(b) The conventional current is pointing to the left so, using the right-hand rule, my thumb would point to the left and my fingers would curl around the conductor from above. My fingers represent the magnetic field lines, and they show that the direction of the magnetic field is through the compass from north to south, so the compass would point south.

Section 12.3: Physics Journal
Section 12.3 Questions, page 558

1. Answers may vary. Sample answer:
Some drawbacks of using wireless electricity in Tesla's time were that the arcing was unpredictable and, therefore, unreliable.

2. Answers may vary. Sample answer:
Some environmental concerns about disposable batteries are the following: a large number of disposable batteries are discarded of into landfills every year, and the heavy metals in these batteries can leach into the ground water and harm wildlife and people.

3. Answers may vary. Sample answer:
It is surprising that only 2 % of household batteries are recycled. Some reasons for this could include a lack of awareness about recycling batteries and a lack of recycling programs in certain areas.

4. Some of the implications of using wireless electricity are a great increase in the use of portable electronic devices, an increase in the capabilities of these devices, and also an increase in these devices' life spans.

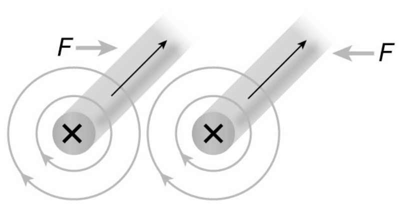
5. Batteries and adapters may not be needed in homes if wireless electricity becomes prevalent. All electronic devices in the home could be directly powered by wireless electricity.

6. Tesla may have been perceived by other scientists as having too many unconventional and impractical ideas. He may have been treated as an outsider and as someone whose ideas are not worth investigating, when his ideas may have actually been very important.

Section 12.4: Solenoids

Section 12.4 Questions, page 562

1. (a) The diagram should have a large X in the centre of the right conductor and a large dot in the centre of the left conductor.
(b) The diagram should be similar to the solution for part (a). The field lines should point up.
(c) The diagram should have an arrow labelled "direction of conventional current" pointing to the positive end of the wire. The top of the solenoid should be labelled "north" and the bottom labelled "south." Magnetic field lines should flow from the north end of the solenoid to the south end.
(d) The diagram should have an arrow labelled "direction of conventional current" pointing parallel to the wire on the battery and downward to the right. The top of the solenoid should be labelled "north," the bottom should be labelled "south." Magnetic field lines should flow from the north end of the battery to the south end.
2. (a) The diagram should have both compass needles pointing directly east (right).
(b) The diagram should have both compass needles pointing directly east (right).
3. If the current is sent down both wires in the same direction, the magnetic field lines will go in opposite directions in between the two wires, as shown in the diagram. This means that the wires will attract one another.



4. (a) Electromagnet B is stronger. Increasing the number of loops and the electric current increases the strength of an electromagnet. Electromagnet B has more loops and a greater electric current than electromagnet A.
(b) Yes. Electromagnet B is only slightly stronger than electromagnet A. Adding a soft-iron core to electromagnet A would increase its strength by a significant amount, so it would be stronger than electromagnet B.
5. (a) When the switch in the circuit containing the solenoids is closed, the conventional current flows from the positive terminal of the source and into the lower solenoid. The current then flows through the solenoids, exits at the top and returns to the negative terminal of the source. Using the right-hand rule for a solenoid, the upper solenoid will have its north pole on its left side, and the lower solenoid will have its south pole on its left side. The soft-iron armature will experience an attractive force by the lower solenoid and the spring will bend, allowing the armature to come in contact with the contact point and completing the second circuit. When the switch is then opened, the solenoids will no longer exert a force on the armature, and the spring will pull it away from the contact point, which will disrupt the second circuit.
(b) An electromagnetic relay allows two circuits to be created that are triggered by the same switch. Two circuits may be necessary if one circuit requires a larger current to power its loads. Devices that are sensitive to high currents cannot be placed in this circuit, so they can instead be placed in their own circuit, which has a smaller current. Then this circuit can be connected to the other with an electromagnetic relay.
6. You could remove the bell and striking tool and add a light bulb somewhere along the circuit to create a flashing light.
7. Table 1

Factor	An electromagnet can be made stronger by	An electromagnet can be made weaker by
loops	increasing the number of loops	decreasing the number of loops
electric current	increasing the amount of electric current	decreasing the amount of electric current
core material	including a core material like soft iron	not including a core material

Section 12.5: The Motor Principle

Mini Investigation: Moving Wires, page 564

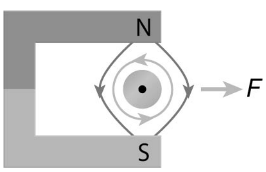
A. Answers may vary. Sample answer:
My prediction was correct. When the power was turned on, the wire experienced a force to the side, twisting the wire toward becoming horizontal.

B. Answers may vary. Sample answer:
The wire was carrying a current vertically because it was passing through external magnetic field lines that ran vertically from one pole of the horseshoe magnet to the other. The motor principle states that the current-carrying wire should experience a force perpendicular to both the magnetic field and the direction of the current, which in this case was horizontal.

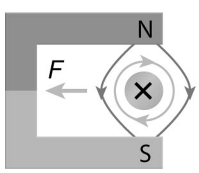
C. If the horseshoe magnet is flipped over so that the north magnetic pole is above its south magnetic pole, the wire will twist in the opposite direction and become taut against the magnet.

Section 12.5 Questions, page 566

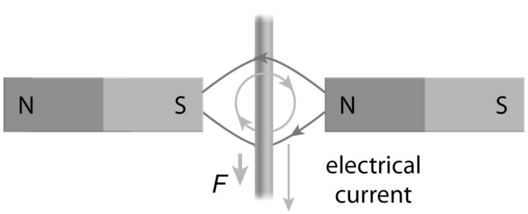
1. (a) The force on the conductor is directed to the right.



(b) The force on the conductor is directed to the left.



(c) The force on the conductor will be directed into the page.



2. To increase the force on a current-carrying conductor, increase the magnitude of the external magnetic field or increase the magnitude of the electric current through the conductor.

3. Increasing the number of loops in the looped conductor of a galvanometer would increase the sensitivity of the galvanometer. With a greater number of loops, the electric current has more paths to flow through so there are more magnetic fields forcing the coil to rotate. Therefore, the galvanometer will show a higher reading for the same amount of current.

4. (a) The direction of the magnetic field is the same whether you use the right-hand rule or the left-hand rule, so the needle on a galvanometer would move in the same direction if the electron flow model is used.

(b) The needle would move in the opposite direction if the leads connected to the galvanometer were reversed, since the direction of the magnetic field lines around the wire loops would be reversed.

5. If an ammeter is connected in parallel instead of in series, the current will have a separate path to follow, so not all of the current will flow through the ammeter. The ammeter will display a value for the current of the circuit that is incorrect and less than the true value.

6. If the resistor in the voltmeter is replaced with one of a much lower resistance than the original, the amount of current going into the voltmeter when the voltmeter is connected to a circuit will greatly increase. This will possibly damage the galvanometer. A voltmeter is designed to have a resistor with a high resistance to allow only a small amount of current to pass through to the galvanometer.

Section 12.6: The Direct Current Motor

Mini Investigation: Observing a DC Motor, page 570

A. Answers may vary. Sample answer:

Parts recognized	Parts not recognized
• external magnets • split ring commutator • brushes and connectors for external circuit	• soft-iron core (because it is a different shape) • axles

B. Answers may vary. Sample answer:
Yes, the design of the hobby motor was very similar to the designs I have studied. The parts of the hobby motor were very compact and in a small space, which made them difficult to recognize at first. However, after investigating, I noticed that each part that I studied was included in the motor.
C. The split ring commutator and armature were on an axle, which is different than the motor designs I studied so far. The other difference I noticed was that the armature was not in the form of a solid cylinder, but had space in between each coil.

Research This: Brushless Motors, page 571

A. Answers may vary. Sample answer:

Brush-type motors	Brushless motors
• permanent magnets are placed on the stator • electromagnets are placed on the rotor • electromagnet is powered directly by the circuit	• permanent magnets are placed on the rotor • electromagnets are placed on the stator • electromagnet is controlled by a microprocessor

B. Answers may vary. Sample answers:
Brushless motors work by having the permanent magnets placed on the stator and the electromagnets placed on the rotor. The electromagnets are controlled by a small computer called a microprocessor. The magnetic field the electromagnets produce across the permanent magnets is varied in a precise way. The permanent magnets experience a force and continually rotate with the rotor.
C. Answers may vary. Sample answers:
Microprocessor-controlled brushless motors are quieter, more efficient, and longer lasting than brush-type motors. They can also be cooled easier and stopped in more precise positions than brush-type motors.
D. Answers may vary. Sample answers:
Brushless motors can be used in consumer electronics such as computer hard drives and DVD players. A widespread application of brushless motors is the cooling fan found in almost every computer.

Section 12.6 Questions, page 571

1. (a) A: external magnet
B: armature
C: split ring commutator
D: brush
E: coil of wire
F: battery
(b) The motor will spin clockwise. The conventional current is directed into the split ring at the brush labelled D. As a result, the charges go down the coil at the front of the coil and exit from the split ring through the opposite brush. Using the right-hand rule for a coil, my fingers go down the coil following the conventional current, and my right thumb points right, indicating that the right side of the coil is a north magnetic pole. The north pole from the external magnet and the north pole from the armature repel one another and cause a clockwise rotation. A similar thing happens with the two south magnetic poles.
(c) Reversing the current will make the left side of the coil a north magnetic pole, and the motor will spin in the opposite direction (counterclockwise).
2. (a) The loop will rotate clockwise. The conventional current is directed from the positive terminal toward the brushes, making contact with the split ring commutator on the right side of the loop. Charges flow into the right of the loop and exit from the left and flow back to the negative terminal. Using the right-hand rule for the motor principle, the force is downward at the right of the loop and upward at the left of the loop. This will start a clockwise rotation.
(b) The purpose of the split ring commutator is to interrupt the circuit when the loop is perpendicular to the magnetic field of the external magnets. This allows the current to flow in the opposite direction in the loop once the split ring comes in contact with the brushes again. This, in turn, changes the direction of the magnetic field and keeps the motor spinning continuously.

3. (a) Increasing the number of loops in the coil would increase the strength of the motor, since the magnetic field of the coil would be stronger. This causes a greater force on the armature.
(b) Using a plastic core instead of a soft-iron core would decrease the strength of the motor, since the magnetic field of the coil would be weaker. This causes a lesser force on the armature.
(c) Decreasing the current would decrease the strength of the motor, since the magnetic field of the coil would be weaker. This causes a lesser force on the armature.
(d) Reversing the polarity of the external magnets would cause the armature to rotate in the opposite direction. If the external magnetic pole nearest to the north pole of the coil were attracting the north pole of the coil, it would now be repelling it. If it were repelling the north pole of the coil, it would now be attracting it. This is similar to what would happen for the external magnetic pole nearest to the south pole of the coil, so the armature would begin to rotate in the opposite direction.
(e) Reversing the polarity of the external magnets and reversing the direction of the current would have no effect on a DC motor. The magnetic fields from the external magnet and the loop would remain the same strength but change to the opposite direction. These changes in magnetic field direction mean that if magnetic fields are aligned, they stay aligned, and if they are in opposite directions, they stay in opposite directions. So the DC motor would not be affected.

Chapter 12 Review, pages 580–585

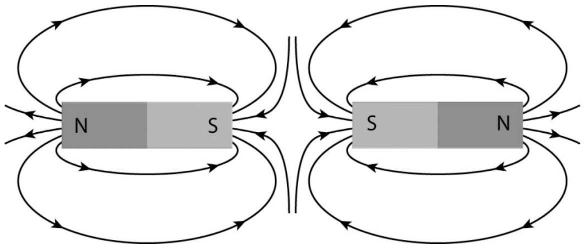
Knowledge

1. (d)
2. (d)
3. (d)
4. (c)
5. (b)
6. (d)
7. (a) (iii)
(b) (i)
(c) (iv)
(d) (ii)
8. Magnetic fields are present around a massive magnet, such as Earth. A compass could be used to detect the presence and direction of at least one of the fields.
9. By Oersted's principle, the current directed into the straight conductor produces a circular magnetic field around the conductor. Using the right-hand rule for a straight conductor, the direction of the magnetic field lines is clockwise as viewed by looking directly into the page.
10. The magnetic fields of two coils of wire that have the same resonant frequency can be used to efficiently transfer electrical energy without wires.
11. The magnetic fields must align in opposite directions between the wires for the wires to attract each other.
12. The circular magnetic fields around each loop of the coil in a solenoid combine to form an overall magnetic field that is a close approximation to the magnetic field of a bar magnet. The magnetic field lines of a solenoid point from its north pole to its south pole outside of the solenoid, with small irregularities close to the coiled conductor. The magnetic field lines inside the solenoid point from the south pole to the north pole, with small irregularities close to the coiled conductor. Disregarding the irregularities, the magnetic field lines of a solenoid are almost identical to those of a bar magnet.
13. The right-hand rule for a solenoid states that the fingers of your right hand curl around the coil in the direction of the conventional current, while your right thumb points in the direction of the north magnetic pole of the coil.
14. The magnetic field in the current-carrying copper wire interacted with the field of the bar magnet, which caused the wire to rotate around the bar magnet.
15. (a) As a current-carrying conductor cuts across external magnetic field lines, the conductor experiences a force perpendicular to both the magnetic field and the direction of the electric current.
(b) The magnitude of the force depends on the external magnetic field, the current, and the angle between the conductor and the magnetic field it cuts across.
16. An analog meter allows you to easily observe the rate at which changes in readings occur, while a modern digital meter does not allow you to do this.
17. (a) A split ring commutator allows a DC motor to rotate continuously. Without a split ring commutator in a motor, the armature would spin halfway around its axle. Then it would be locked in position or would slow dramatically. The north magnetic pole of the coil would first be repelled by the north magnetic pole of the external magnet and would then rotate. The north magnetic pole of the magnet would be attracted by the south pole of the external magnet. This attraction would continue even after passing the midpoint of the south pole of the external magnet. A similar thing would happen with the magnetic south pole of the coil and the north pole of the external magnet.
(b) Increasing the number of loops, using a soft-iron core, and using a split ring commutator with several splits and several coils are developments that have improved the design of DC motors.

Understanding

18. (a) Earth's magnetic field causes a force that is nearly parallel to Earth's surface at positions not near its magnetic poles and is directed from the south magnetic pole to the north magnetic pole. At positions near its magnetic poles, Earth's magnetic field causes a force that is nearly perpendicular to Earth's surface and is directed toward Earth at its south magnetic pole and away from Earth at its north magnetic pole. Earth's gravitational field causes a force that is always towards Earth's centre.
(b) Earth's magnetic field only exerts a force on magnetic objects. Earth's gravitational field exerts a force on any object with mass.

19. (a) The diagram should have magnetic field lines similar to Figure 4(b) on page 549 of the textbook, with the magnetic field lines flowing from the north end of one magnet to the south end of the other magnet. Magnetic field lines should also flow from the north end of one magnet to the south end of the same magnet.
(b) The diagram should have magnetic field lines similar to Figure 5(b) on page 550 of the textbook. Magnetic field lines should flow from the north end of one magnet to the south end of the same magnet.

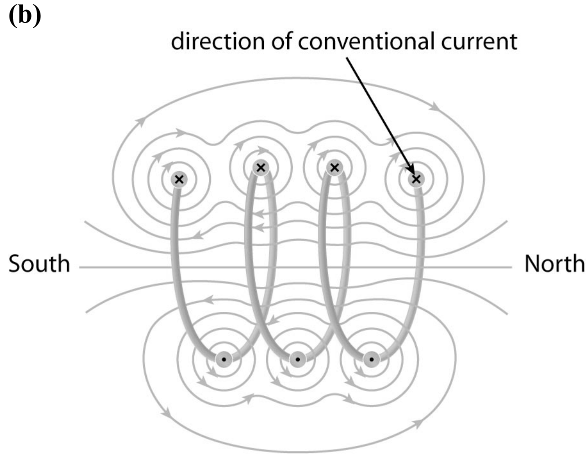


(c) The illustration would look very similar, but the magnetic field lines would flow in the opposite direction.

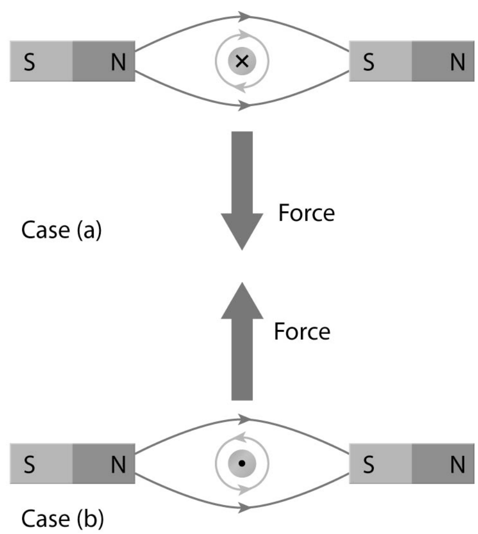
20. (a) The magnetic field lines are in the incorrect direction. The magnetic field lines should flow from the north end of the magnet to the south end of the magnet. So the arrowheads need to point in the opposite direction.
(b) The magnetic field lines should not be equally spaced. The magnetic field decreases in strength as you move away from the magnet, so the magnetic field lines should be increasingly farther apart.
(c) The north magnetic poles of the magnet should be repelling instead of attracting.
21. A magnetic field exerts a force on an iron filing. Iron filings are light and can be moved independently. When placed in the presence of a magnet field, the filings are free to be forced into position along the magnetic field lines. The pattern of iron filings can be used to visualize the magnetic field lines, which helps us understand magnetic fields.
22. The Maglev train in Shanghai uses support magnets mounted on a train support mechanism that curves beneath the track. The support magnets are attracted upward toward the bottom of the track, so they experience a magnetic force acting vertically upward. This causes the train to levitate. The train also has guidance magnets, which exert a force horizontally on the steel track to help keep the train centred over the track. There is also a magnet on the front of the train that is attracted forward toward the section of track immediately in front of it, so it experiences a magnetic force horizontally forward, which pulls the train forward. Finally, there is a magnet on the back of the train that is repelled by the section of track immediately behind it, so it experiences a force horizontally forward, which pushes the train forward.
23. (a) Oersted aligned a conducting wire in an electric circuit with Earth's magnetic field and held a compass near it. When the current was switched on, an electric current was present in the wire and the compass needle was deflected perpendicular to the wire. When the current was switched off, the compass needle went back to its original position. This confirmed that electric currents produce magnetic fields.
(b) Oersted was able to test his hypothesis further to show that the magnetic field surrounding a current-carrying wire is in the shape of concentric circles, and that the strength of the magnetic field is weaker farther away from the conducting wire. He was also able to show, by reversing the electric current in his test, that the direction of the magnetic field depends on the direction of the current. Reversing the direction of the current also reverses the direction of the magnetic field.
24. Like charged particles (positive and positive or negative and negative) repel each other and unlike charged particles (positive and negative) attract each other. This is similar to magnetic poles since like magnetic poles (north and north or south and south) repel each other and unlike magnetic poles (north and south) attract each other.
25. (a) In the model of conventional current, electric current is directed from the positive terminal to the negative terminal of a power source. In the model of electron flow, electric current is directed from the negative terminal to the positive terminal of a power source.
(b) To determine the direction of a magnetic field around a straight wire using the conventional current model, the right-hand rule for a straight conductor is used. To determine its direction using the electron flow model, the left-hand rule for a straight conductor is used. The direction of the magnetic field is always the same in both cases.
26. (a) Using the right-hand rule for a straight conductor, if the fingers of my right hand curl counterclockwise on the page, my thumb will point out of the page. So the direction of the current is out of the page.

(b) Using the right-hand rule for a straight conductor, if my right thumb points in the direction of the conventional current, which is into the page, then my fingers will curl around the conductor in a clockwise direction. So the direction of the magnetic field is clockwise.
27. (a) Using the right-hand rule for a straight conductor, if my right thumb points in the direction of the conventional current, which is into the page, then my fingers will curl around the conductor in a clockwise direction. So the direction of the magnetic field is clockwise.
(b) Using the right-hand rule for a straight conductor, if my right thumb points in the direction of the conventional current, which is out of the page, then my fingers will curl around the conductor in a counterclockwise direction. So the direction of the magnetic field is counterclockwise.
28. (a) The magnetic field lines will be directed to the right across the top of the conductor, so the compass needle will point east.
(b) The magnetic field lines will be directed to the left across the top of the conductor, so the compass needle will point west.
29. Using the right-hand rule for a straight conductor, if my right fingers curl around the conductor in a clockwise direction, then my thumb will point into the page, which is the direction of the conventional current. So the direction of the current is into the page.
30. Ampère concluded from his experiments that two parallel current-carrying wires with opposing currents repel each other.
31. (a) For the two parallel wires to experience a magnetic force of attraction, the magnetic field lines between them must point in opposite directions. For this to happen, the currents in the wires must both be in the same direction.
(b) If both currents in the wires were reversed, the currents would still be in the same direction and produce an attractive magnetic force.
(c) If only one current was changed, the currents would be in opposite directions. The magnetic field lines between the wires would now be in the same direction, so the wires would experience a repulsive magnetic force.
(d) If the currents were increased, the wires would experience a greater magnetic force.
(e) If one current were switched off, there would only be magnetic field lines around the other wire. There would be no interacting magnetic field lines so there would be no magnetic force between the wires.

32. (a) Answers may vary. Sample answer:
A solenoid is a conductor that is in the shape of a coil spring.
(b)

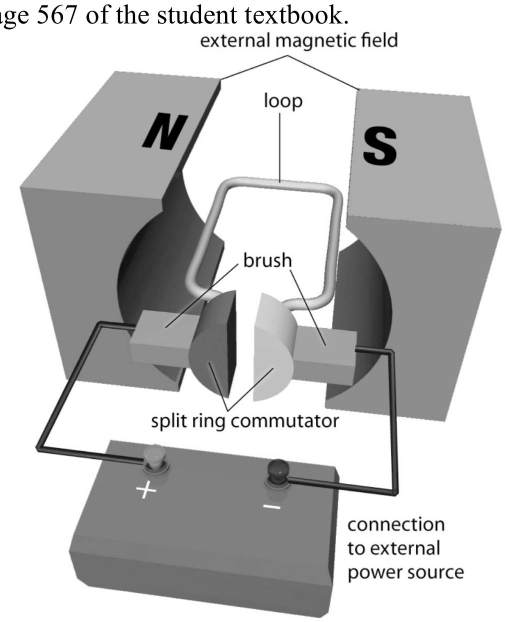


33. There should be an X in each circle on the right.
34. A solenoid can be used as an electromagnet, that is, an electrically powered bar magnet. The right-hand rule for a solenoid helps us to understand the operation of a solenoid by allowing us to determine which end of the electromagnet is a magnetic north pole and which end is a magnetic south pole.
35. (a) The wire will experience a force that is perpendicular to both the magnetic field and the direction of the electric current.
(b) If the current is reversed, the wire will experience a force in the opposite direction to the force originally experienced by the wire.
(c)



36. Figure 6 shows a current-carrying conductor with the conventional current directed into the page suspended between the north pole of one

magnet and the south pole of another magnet. The magnetic field lines above the conductor are pointed in the same direction as the magnetic field lines between the external magnets. This causes a repulsion force on the conductor that is directed downward. The magnetic field lines below the conductor are pointed in the opposite direction to the magnetic field lines between the external magnets. This causes an attractive force on the conductor that is directed downward.
It can be seen that the force on the conductor is perpendicular to both the magnetic field and the direction of the electric current. The facts that there is a force on a current-carrying conductor that cuts across external magnetic field lines, and that this force is perpendicular to both the magnetic field and the direction of the current, are the fundamentals of the motor principle. The diagram shows one example of this.
37. (a) The right-hand rule for the motor principle is as follows. To determine the direction of the force on a current-carrying conductor placed in an external magnetic field, point the fingers of your open right hand in the direction of the external magnetic field and your thumb in the direction of the conventional current. Your palm will now face the direction of the force on the conductor.
(b) Your right hand would be flat in a vertical plane, with your thumb pointing to the right and your fingers pointed upward. Your palm would be facing toward you, so that would be the direction of the force on the conductor.
(c) Since the direction of the force is toward you, it is directed out of the page.
38. (a) An ammeter contains a galvanometer and it measures current in an electric circuit. A voltmeter contains a galvanometer and it measures electric potential difference in an electric circuit.
(b) In an ammeter, a galvanometer is placed in parallel with a resistor that has a much smaller resistance than the resistance of the galvanometer itself. The ammeter is then connected in series with the device for which the current is to be measured. In a voltmeter, a galvanometer is placed in series with a resistor with a very high resistance. The voltmeter is then connected in parallel with the device for which the voltage is to be measured.
39. (a) Answers may vary. Sample answer:
A galvanometer is a meter that measures electric current using the temporary slight rotation of a coiled conductor. A DC motor is a device that causes mechanical movement using a coiled conductor that continuously rotates.
(b) A split ring commutator was used to make the transition between a galvanometer and a DC motor. The split ring commutator works by interrupting the current through the circuit when the wire loop in the DC motor is perpendicular to the external magnetic field, and then allowing the current to flow in the opposite direction through the wire loop once the split ring comes in contact with the circuit again. This allows the wire loop to continuously rotate.
(c) The diagram should be similar to Figure 2 on page 567 of the student textbook.



40. (a) The external magnets are a stationary part of a DC motor and the wire loop is a rotating part of a DC motor.
(b) The stationary parts of a DC motor are the stator. The rotating parts of a DC motor are the rotor.
41. (a) The design of a DC motor can be improved by increasing the number of loops, increasing the current, or including a soft-iron core.
(b) If increasing the current is taken to an extreme, a large amount of thermal energy will be produced as a side effect. This is a risk because too much thermal energy can cause the failure of the mechanical or electronic system the DC motor is a part of, or the DC motor itself.
42. Answers may vary. Sample answer:
A split ring commutator with one split is not ideal. If the split ring is not in contact with the brushes before the DC motor is turned on then the motor will not work because the circuit is incomplete. To overcome this problem, DC motor designers made the split ring commutator have several splits, with

each segment of the split ring connected by its own coil to its corresponding segment on the opposite side. This ensures a segment of the split ring is always in contact with the brushes, even when the motor is turned off.

43. Answers may vary. Sample answer:
Oersted was the first scientist to confirm that electric current in a wire produces magnetic fields. This new knowledge led to further investigation of the magnetic fields produced by current-carrying conductors and their applications. Faraday showed that a magnetic field causes a current-carrying wire to move. Subsequent scientists wanted to use the motor principle (the principle that magnetic fields cause current-carrying conductors to move) to create a device that was electrically powered and created continuous motion. The device these scientists created was the DC motor, which had a coiled loop of wire placed between external magnets. A device called a split ring commutator allowed the rotating parts of the DC motor to rotate continuously. Further improvements of the DC motor design allow modern DC motors to be powerful, efficient, reliable, and versatile devices that are found in countless machines and electronic devices.

44. X-rays provide images of bones in your body but cannot provide images of soft tissue effectively. X-rays are also potentially harmful if done too often or during pregnancy. Ultrasound provides good images of soft tissue but cannot provide images of bones effectively. Magnetic resonance imaging technology provides images that show both bone and soft tissue in good detail, but the machines are very expensive.

Analysis and Application

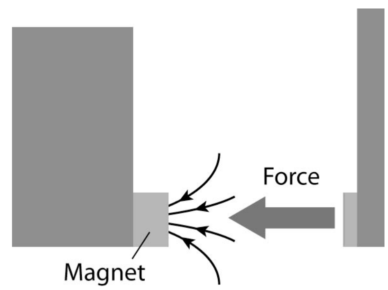
45. Answers may vary. Sample answer:
The aurora borealis is a display of light that is caused by charged particles from the Sun interacting with Earth's magnetic field.

46. (a) This illustrates that magnetic field lines get farther apart as you move away from the magnet, meaning that the magnetic field gets weaker.
(b) No matter how the compass is moved, its position relative to Earth will barely change. The magnetic force from Earth's magnetic field on the compass needle will be approximately the same at all positions. The needle's return to Earth's magnetic north pole illustrates that magnetic field lines get farther apart as you move away from the magnet. So, when the compass is moved away from the conductor, it must eventually reach a point where the strength of the magnetic force from the conductor is decreased and is less than the strength of the magnetic force from Earth.

47. Answers may vary. Sample answer:

Advantage of electromagnet	Useful example
can be turned on and off	starter motor in a car
pick things up and then let go	electromagnetic relay
cause motion and then reverse the motion	electric bell

48. Answers may vary. Sample answers:
(a) A magnetic latch on a cabinet.
(b) The latch uses its magnetic field to produce a force on a metal piece on the door of the cabinet.
(c) The magnet used is a permanent magnet.
(d)



49. (a) The voice coil is surrounded by a permanent magnet. Current is directed through the voice coil by the amplifier, which creates a magnetic field that interacts with a permanent magnet's magnetic field and repels the voice coil away from the magnet. The amplifier then reverses the direction of the current and the solenoid's poles reverse, causing the voice coil to be attracted toward the magnet. The process repeats continually.
(b) A high-quality speaker should have a strong solenoid, so its solenoid should have a large number of loops, a large current, and a core made from a material that is quickly magnetized.

50. The magnetic pole on the bottom of the lower coil is a magnetic north pole and the magnetic pole on the bottom of the upper coil is a magnetic south pole. The shape of the magnetic field at the side of the bottoms of the cores is similar to that of a horseshoe magnet.

51. With many windings and a large electric current, the loops in the electromagnet of the MRI machine will produce a large amount of thermal energy as a side effect. This is not desirable for an MRI machine because the large amount of thermal energy could damage the machine.

52. The fundamental difference is that the magnetic object in a compass is a permanent magnet and the magnetic object in Faraday's motor is a current-carrying conductor.
53. The magnetic field lines from the external magnet are directed from the north pole to the south pole, or from left to right. The conventional current flowing through the conductor on the left side is directed into the page. Using the right-hand rule for the motor principle, the loop (not shown) is forced down on this side. The conventional current flowing through the conductor on the right side is directed out of the page. Using the right-hand rule for the motor principle, the loop (not shown) is forced up on this side. This indicates that the galvanometer needle will rotate to the left.
54. The loop will rotate counterclockwise. The conventional current is directed from the positive terminal toward the brushes, making contact with the split ring commutator on the left side of the loop. Charges flow into the left of the loop and exit from the right and flow back to the negative terminal. Using the right-hand rule for the motor principle, the force is downward at the left of the loop and upward at the right of the loop. This will start a counterclockwise rotation.
55. The conventional current is directed into the split ring at the bottom of the armature. As a result, the charges go down the coil at the front of the coil and exit from the split ring through the opposite side. Using the right-hand rule for a coil, my fingers go down the coil following the conventional current, and myright thumb points right, indicating that the right side of the coil is a north magnetic pole. For the motor to spin counterclockwise, the external magnet pole next to this end of the coil must repel the armature, so it should be a north pole. So the external magnet pole on the right should be a north pole and the external magnet pole on the left should be a south pole.
56. A variable resistor could be placed in series with a DC motor in a variable speed electric drill to control the amount of current entering the motor. When the drill is switched on, increasing the resistance of the variable resistor (by rotating the dial) would decrease the amount of current entering the motor and so would decrease the speed of the drill. Decreasing the resistance of the variable resistor would increase the amount of current entering the motor and so would increase the speed of the drill.

57. Table 1

Variable	**Increase the motor strength/speed**	**Decrease the motor strength/speed**
current	**increasing**	**decreasing**
number of loops	**increasing**	**decreasing**
type of armature	**soft-iron armature**	**no armature**
strength of external magnets	**increasing**	**decreasing**

58. No, it would not be possible to reverse the direction of rotation of this motor design. Reversing the current direction in the external circuit would reverse the direction of the current in the electromagnets, causing their poles to switch sides. Reversing the current direction in the external circuit would also cause the direction of the current through the wire loop to be reversed, and so the magnetic field lines would all still align in the same way and the motor would rotate in the same direction.
59. (a) An electric motor in a gasoline-electric hybrid car runs on a battery stored inside the car and propels the vehicle until the battery runs low.
(b) An automobile running on an electric motor is not burning gasoline or diesel fuel, so the automobile is not polluting the atmosphere directly.
(c) A hybrid car cannot be completely pollution free for several reasons. If the battery that the electric motor runs on is charged by a gasoline engine, then the gasoline engine must be running at some point and this produces pollution. If the battery is not charged by a gasoline motor, then the electricity used to charge the battery may be generated using a method that produces pollution. Finally, electric motors contain heavy metals, which can be toxic to living things. If old electric motors are not disposed of properly, these heavy metals can pollute the environment.

Evaluation

60. Answers may vary. Sample answers:
(a) Magnets can be used to attract or repel moving metal components in a machine, and in this manner they could be used to slow motion rather than produce motion. This use could be applied to design magnetic brakes that replace traditional brakes in an automobile.

(b) One benefit of magnetic brakes over conventional parts is that they can produce a strong stopping force without any wear on the parts, since the parts of the magnetic brakes do not need to come in contact with each other to exert a force. One drawback of magnetic brakes is that they are more expensive to build and maintain than conventional brakes.
(c) Magnets could be used to launch satellites instead of rockets.
61. Answers may vary. Sample answer:

Comparison of natural magnetic phenomena and technologies involving magnetism	
Similarities	**Differences**
Earth's magnetic field is similar in shape to that of an electromagnet.	A DC motor causes continuous motion, which is usually not found with magnetic phenomena in nature.
Earth's magnetic field interacts with particles from the Sun in the atmosphere. This is similar to particle accelerators accelerating subatomic particles and colliding them with a target or other particles.	An MRI machine exposes the human body to strong magnetic fields. Magnetic fields this strong are usually not found in nature.
Some animals can use Earth's magnetic field to navigate, which is similar to the technology of a compass.	Magnetic fields are used to levitate heavy Maglev trains. Magnetism in nature usually does not create forces that have such a dramatic effect.

62. Answers may vary. Sample answer:
One innovation that uses electromagnetism is the electromagnet. Electromagnetism is used by an electromagnet to turn things on and off, pick things up and then let go, or cause motion and then reverse the motion. Electromagnets impact daily life and society by simplifying and enhancing the design of some common devices, such as speakers, electric bells, car locking mechanisms, and car starters. Another innovation that uses electromagnetism is the DC motor. Electromagnetism is used by a DC motor to cause mechanical movement, usually in the form of a rotation. DC motors impact daily life and society by allowing electrical devices to produce mechanical motion, which allows the devices to perform a wide range of tasks, such as a power tool drilling, a computer fan cooling, or a DVD player spinning.

Reflect on Your Learning

63. Answers may vary. Sample answer:
Oersted's experiment showed that an electric current in a conductor produces a magnetic field. This understanding of electromagnetism led to the development of the solenoid, a type of electromagnet found in many common electric devices today. Oersted's experiment also inspired other scientists to learn more about the connection between electricity and magnetism. This led to Faraday's experiment and eventually to the development of the modern DC motor, which is a key part of many electric devices that produce mechanical movement.
64. Answers may vary. Sample answer:
Over the course of a day I interacted with the following objects that use DC motors: an electric toothbrush; a rotating plate in a microwave; a rotating blade in a blender; a car starter; a mechanism that operates electric car windows; a computer fan, hard drive and an optical disk drive in a computer; a DVD drive; a fan in my video game console; and a vacuum cleaner.
65. Answers may vary. Sample answer:
Without electromagnetism, car starter motors would not work. Cars and trucks would have to be started with a hand crank, which is time-consuming, unreliable, and potentially dangerous.

Research

66. Answers may vary. Students should clearly indicate the topic of their report, how their topic is currently being investigated by the LHC, and the future implications of the research by the LHC.
67. Answers may vary. Students should compare a mythological explanation of the northern lights to a modern scientific explanation of the phenomenon.
68. Answers may vary. Topics could include using wireless electricity to power common household electric devices, transmitting energy into outer space, or the development of new military weapons. Students should indicate how these applications could affect our everyday lives. Slide presentations should be colourful and pages logically laid out for ease of reading. Audio and narration of each slide could be provided.
69. Answers may vary. Students' reports should include a brief history of the company of their choice, its technological advances or strategies for

staying competitive, its successes and failures, and students' impression of the company's vehicles.

70. Answers may vary. Students could provide a list of where or how solenoids are used. Students should select one use and discuss its application. A diagram of the solenoid should be provided.

71. Answers may vary. Students' reports should include a description of how a mass spectrometer works and how it uses magnetic fields to separate compounds or elements in a mixture. Students should include how the mass spectrometer is used when attached to a gas chromatograph. A description of a gas chromatograph should also be provided, as well as the types of information that can be obtained from the chromatograph.