THE BIG IDEA

A moving electric charge is surrounded by a magnetic field.

Electricity and magnetism were regarded as unrelated phenomena until it was noticed that an electric current caused the deflection of the compass needle. Then, magnets were found to exert forces on current-carrying wires. The stage was set for a whole new technology, which would eventually bring electric power, radio, and television.

36.1 Magnetic Poles

Like poles repel; opposite poles attract.

36.1 Magnetic Poles

Magnets exert forces on one another.

They are similar to electric charges, for they can both attract and repel without touching.

Like electric charges, the strength of their interaction depends on the distance of separation of the two magnets.

Electric charges produce electrical forces and regions called **magnetic poles** produce magnetic forces.

36.1 Magnetic Poles

Which interaction has the greater strength—the gravitational attraction between the scrap iron and Earth, or the magnetic attraction between the magnet and the scrap iron?

36.1 Magnetic Poles

If you suspend a bar magnet from its center by a piece of string, it will act as a compass.

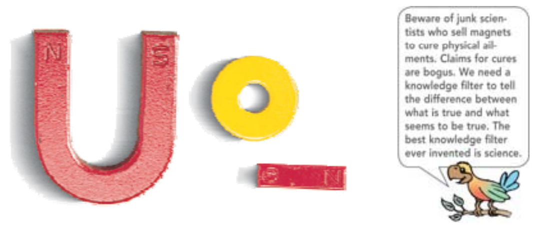
- The end that points northward is called the *north-seeking pole.*
- The end that points southward is called the *south-seeking pole.*
- More simply, these are called the *north* and *south poles.*
- All magnets have both a north and a south pole. For a simple bar magnet the poles are located at the two ends.

36.1 Magnetic Poles

If the north pole of one magnet is brought near the north pole of another magnet, they repel.

The same is true of a south pole near a south pole.

If opposite poles are brought together, however, attraction occurs.



36.1 Magnetic Poles

Magnetic poles behave similarly to electric charges in some ways, but there is a very important difference.

- Electric charges can be isolated, but magnetic poles cannot.
- A north magnetic pole never exists without the presence of a south pole, and vice versa.
- The north and south poles of a magnet are like the head and tail of the same coin.

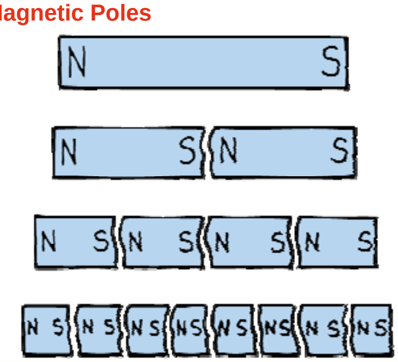
36.1 Magnetic Poles

If you break a bar magnet in half, each half still behaves as a complete magnet.

Break the pieces in half again, and you have four complete magnets.

Even when your piece is one atom thick, there are two poles. This suggests that atoms themselves are magnets.

36.1 Magnetic Poles



36.1 Magnetic Poles

think!

Does every magnet necessarily have a north and a south pole?

36.1 Magnetic Poles

think!

Does every magnet necessarily have a north and a south pole?

Answer:

Yes, just as every coin has two sides, a “head” and a “tail.” (Some “trick” magnets have more than two poles.)

36 Magnetism | Conceptual Physics

36.1 Magnetic Poles

CONCEPT CHECK **How do magnetic poles affect each other?**

36 Magnetism | Conceptual Physics

36.2 Magnetic Fields

The direction of the magnetic field outside a magnet is from the north to the south pole.

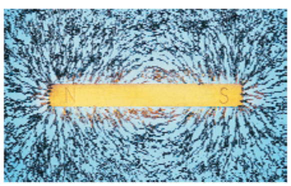
36 Magnetism | Conceptual Physics

36.2 Magnetic Fields

Iron filings sprinkled on a sheet of paper over a bar magnet will tend to trace out a pattern of lines that surround the magnet.

The space around a magnet, in which a magnetic force is exerted, is filled with a **magnetic field.**

The shape of the field is revealed by *magnetic field lines.*



36 Magnetism | Conceptual Physics

36.2 Magnetic Fields

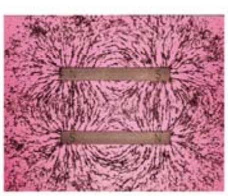
Magnetic field lines spread out from one pole, curve around the magnet, and return to the other pole.

36 Magnetism | Conceptual Physics

36.2 Magnetic Fields

Magnetic field patterns for a pair of magnets when

a. opposite poles are near each other



a

36 Magnetism | Conceptual Physics

36.2 Magnetic Fields

Magnetic field patterns for a pair of magnets when

a. opposite poles are near each other

b. like poles are near each other

a

b

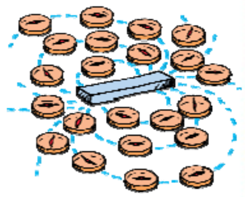
36.2 Magnetic Fields

The direction of the magnetic field outside a magnet is from the north to the south pole.

Where the lines are closer together, the field strength is greater.

The magnetic field strength is greater at the poles.

If we place another magnet or a small compass anywhere in the field, its poles will tend to line up with the magnetic field.



36.2 Magnetic Fields

CONCEPT CHECK

What is the direction of the magnetic field outside a magnet?

36.3 The Nature of a Magnetic Field

A magnetic field is produced by the motion of electric charge.

36.3 The Nature of a Magnetic Field

Magnetism is very much related to electricity.

Just as an electric charge is surrounded by an electric field, a moving electric charge is also surrounded by a magnetic field.

Charges in motion have associated with them both an electric and a magnetic field.

36.3 The Nature of a Magnetic Field

Electrons in Motion

Where is the motion of electric charges in a common bar magnet?

The magnet as a whole may be stationary, but it is composed of atoms whose electrons are in constant motion about atomic nuclei.

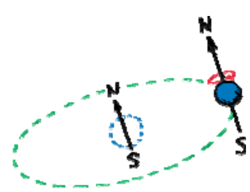
This moving charge constitutes a tiny current and produces a magnetic field.

36.3 The Nature of a Magnetic Field

More important, electrons can be thought of as spinning about their own axes like tops.

A spinning electron creates another magnetic field.

In most materials, the field due to spinning predominates over the field due to orbital motion.



36.3 The Nature of a Magnetic Field

Spin Magnetism

Every spinning electron is a tiny magnet.

- A pair of electrons spinning in the same direction makes up a stronger magnet.
- Electrons spinning in opposite directions work against one another.
- Their magnetic fields cancel.

36.3 The Nature of a Magnetic Field

Most substances are not magnets because the various fields cancel one another due to electrons spinning in opposite directions.

In materials such as iron, nickel, and cobalt, however, the fields do not cancel one another entirely.

An iron atom has four electrons whose spin magnetism is not canceled.

Each iron atom, then, is a tiny magnet. The same is true to a lesser degree for the atoms of nickel and cobalt.

36.3 The Nature of a Magnetic Field

CONCEPT CHECK **How is a magnetic field produced?**

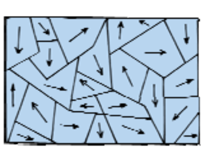
36.4 Magnetic Domains

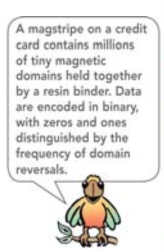
Permanent magnets are made by simply placing pieces of iron or certain iron alloys in strong magnetic fields.

36.4 Magnetic Domains

The magnetic fields of individual iron atoms are strong.

- Interactions among adjacent iron atoms cause large clusters of them to line up with one another.
- These clusters of aligned atoms are called **magnetic domains.**
- Each domain is perfectly magnetized, and is made up of billions of aligned atoms.
- The domains are microscopic, and there are many of them in a crystal of iron.

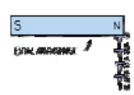


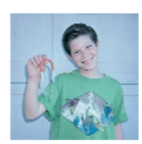


36.4 Magnetic Domains

The difference between a piece of ordinary iron and an iron magnet is the alignment of domains.

- In a common iron nail, the domains are randomly oriented.
- When a strong magnet is brought nearby, there is a growth in size of domains oriented in the direction of the magnetic field.
- The domains also become aligned much as electric dipoles are aligned in the presence of a charged rod.
- When you remove the nail from the magnet, thermal motion causes most of the domains to return to a random arrangement.





36.4 Magnetic Domains

Permanent magnets are made by simply placing pieces of iron or certain iron alloys in strong magnetic fields.

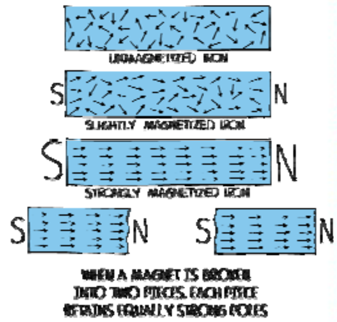
Another way of making a permanent magnet is to stroke a piece of iron with a magnet.

The stroking motion aligns the domains in the iron.

If a permanent magnet is dropped or heated, some of the domains are jostled out of alignment and the magnet becomes weaker.

36.4 Magnetic Domains

The arrows represent domains, where the head is a north pole and the tail a south pole. Poles of neighboring domains neutralize one another's effects, except at the ends.



36.4 Magnetic Domains

think!

Iron filings sprinkled on paper that covers a magnet were not initially magnetized. Why, then, do they line up with the magnetic field of the magnet?

36.4 Magnetic Domains

think!

Iron filings sprinkled on paper that covers a magnet were not initially magnetized. Why, then, do they line up with the magnetic field of the magnet?

Answer:

Domains align in the individual filings, causing them to act like tiny compasses. The poles of each "compass" are pulled in opposite directions, producing a torque that twists each filing into alignment with the external magnetic field.

36.4 Magnetic Domains

CONCEPT CHECK **How can you make a permanent magnet?**

36.5 Electric Currents and Magnetic Fields

An electric current produces a magnetic field.

36.5 Electric Currents and Magnetic Fields

A moving charge produces a magnetic field.

An electric current passing through a conductor produces a magnetic field because it has many charges in motion.

36.5 Electric Currents and Magnetic Fields

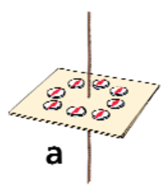
The magnetic field surrounding a current-carrying conductor can be shown by arranging magnetic compasses around the wire.

The compasses line up with the magnetic field produced by the current, a pattern of concentric circles about the wire.

When the current reverses direction, the compasses turn around, showing that the direction of the magnetic field changes also.

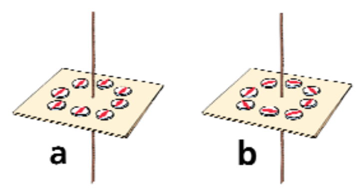
36.5 Electric Currents and Magnetic Fields

a. When there is no current in the wire, the compasses align with Earth's magnetic field.



36.5 Electric Currents and Magnetic Fields

a. When there is no current in the wire, the compasses align with Earth's magnetic field.
b. When there is a current in the wire, the compasses align with the stronger magnetic field near the wire.

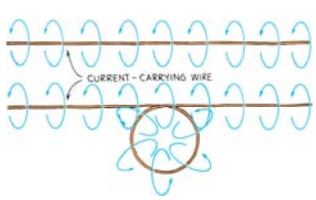


36.5 Electric Currents and Magnetic Fields

If the wire is bent into a loop, the magnetic field lines become bunched up inside the loop.

If the wire is bent into another loop, the concentration of magnetic field lines inside the double loop is twice that of the single loop.

The magnetic field intensity increases as the number of loops is increased.



36.5 Electric Currents and Magnetic Fields

A current-carrying coil of wire is an **electromagnet.**

36.5 Electric Currents and Magnetic Fields

Iron filings sprinkled on paper reveal the magnetic field configurations about

a. a current-carrying wire

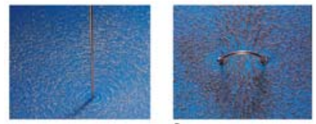
a

36.5 Electric Currents and Magnetic Fields

Iron filings sprinkled on paper reveal the magnetic field configurations about

a. a current-carrying wire

b. a current-carrying loop



a b

36.5 Electric Currents and Magnetic Fields

Iron filings sprinkled on paper reveal the magnetic field configurations about

a. a current-carrying wire

b. a current-carrying loop

c. a coil of loops

a b c

36.5 Electric Currents and Magnetic Fields

Sometimes a piece of iron is placed inside the coil of an electromagnet.

The magnetic domains in the iron are induced into alignment, increasing the magnetic field intensity.

Beyond a certain limit, the magnetic field in iron "saturates," so iron is not used in the cores of the strongest electromagnets.

36.5 Electric Currents and Magnetic Fields

A superconducting electromagnet can generate a powerful magnetic field indefinitely without using any power.

At Fermilab near Chicago, superconducting electromagnets guide high-energy particles around the four-mile-circumference accelerator.

Superconducting magnets can also be found in magnetic resonance imaging (MRI) devices in hospitals.

36.5 Electric Currents and Magnetic Fields

CONCEPT CHECK **Why does a current-carrying wire deflect a magnetic compass?**

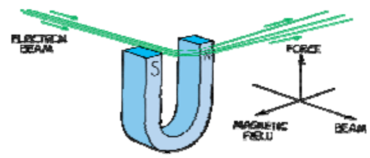
36.6 Magnetic Forces on Moving Charged Particles

A moving charge is deflected when it crosses magnetic field lines but not when it travels parallel to the field lines.

36.6 Magnetic Forces on Moving Charged Particles

If the charged particle *moves* in a magnetic field, the charged particle experiences a deflecting force.

- This force is greatest when the particle moves in a direction perpendicular to the magnetic field lines.
- At other angles, the force is less.
- The force becomes zero when the particle moves parallel to the field lines.
- The direction of the force is always perpendicular to both the magnetic field lines and the velocity of the charged particle.



36.6 Magnetic Forces on Moving Charged Particles

The deflecting force is different from other forces, such as the force of gravitation between masses, the electrostatic force between charges, and the force between magnetic poles.

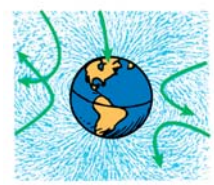
The force that acts on a moving charged particle acts perpendicular to both the magnetic field and the electron velocity.

36.6 Magnetic Forces on Moving Charged Particles

The deflection of charged particles by magnetic fields provides a TV picture.

Charged particles from outer space are deflected by Earth's magnetic field, which reduces the intensity of cosmic radiation.

A much greater reduction in intensity results from the absorption of cosmic rays in the atmosphere.



36.6 Magnetic Forces on Moving Charged Particles

CONCEPT CHECK

What happens when a charged particle moves in a magnetic field?

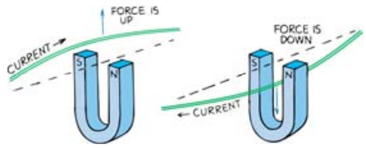
36.7 Magnetic Forces on Current-Carrying Wires

Since a charged particle moving through a magnetic field experiences a deflecting force, a current of charged particles moving through a magnetic field also experiences a deflecting force.

36.7 Magnetic Forces on Current-Carrying Wires

If the particles are inside a wire, the wire will also move.

- If the direction of current in the wire is reversed, the deflecting force acts in the opposite direction.
- The force is maximum when the current is perpendicular to the magnetic field lines.
- The direction of force is along neither the magnetic field lines nor the direction of current.
- The force is perpendicular to both field lines and current, and it is a sideways force.



36.7 Magnetic Forces on Current-Carrying Wires

Just as a current-carrying wire will deflect a magnetic compass, a magnet will deflect a current-carrying wire.

Both cases show different effects of the same phenomenon.

The discovery that a magnet exerts a force on a current-carrying wire created much excitement.

People began harnessing this force for useful purposes—electric meters and electric motors.

36.7 Magnetic Forces on Current-Carrying Wires

think!

What law of physics tells you that if a current-carrying wire produces a force on a magnet, a magnet must produce a force on a current-carrying wire?

36.7 Magnetic Forces on Current-Carrying Wires

think!

What law of physics tells you that if a current-carrying wire produces a force on a magnet, a magnet must produce a force on a current-carrying wire?

Answer:

Newton's third law, which applies to all forces in nature.

36.7 Magnetic Forces on Current-Carrying Wires

CONCEPT CHECK **How is current affected by a magnetic field?**

36.8 Meters to Motors

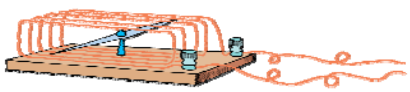
The principal difference between a galvanometer and an electric motor is that in an electric motor, the current is made to change direction every time the coil makes a half revolution.

36.8 Meters to Motors

The simplest meter to detect electric current consists of a magnetic needle on a pivot at the center of loops of insulated wire.

When an electric current passes through the coil, each loop produces its own effect on the needle.

A very small current can be detected. A sensitive current-indicating instrument is called a *galvanometer.*



36.8 Meters to Motors

Common Galvanometers

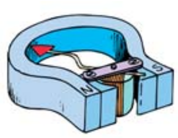
A more common design employs more loops of wire and is therefore more sensitive.

The coil is mounted for movement and the magnet is held stationary.

The coil turns against a spring, so the greater the current in its loops, the greater its deflection.

36.8 Meters to Motors

a. A common galvanometer consists of a stationary magnet and a movable coil of wire.



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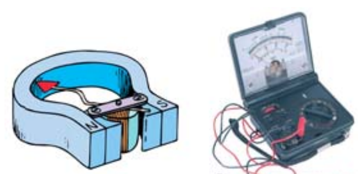
36.8 Meters to Motors

a. A common galvanometer consists of a stationary magnet and a movable coil of wire.

b. A multimeter can function as both an ammeter and a voltmeter.



a b

36.8 Meters to Motors

A galvanometer may be calibrated to measure current (amperes), in which case it is called an *ammeter.*

Or it may be calibrated to measure electric potential (volts), in which case it is called a *voltmeter.*

36.8 Meters to Motors

Electric Motors

If the design of the galvanometer is slightly modified, you have an electric motor.

The principal difference is that in an electric motor, the current changes direction every time the coil makes a half revolution.

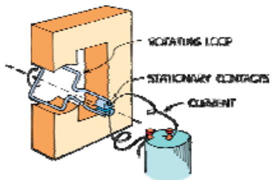
After it has been forced to rotate one half revolution, it overshoots just in time for the current to reverse.

The coil is forced to continue another half revolution, and so on in cyclic fashion to produce continuous rotation.

36.8 Meters to Motors

In a simple DC motor, a permanent magnet produces a magnetic field in a region where a rectangular loop of wire is mounted.

- The loop can turn about an axis.
- When a current passes through the loop, it flows in opposite directions in the upper and lower sides of the loop.
- The loop is forced to move as if it were a galvanometer.



36 Magnetism
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36.8 Meters to Motors

- The current is reversed during each half revolution by means of stationary contacts on the shaft.
- The parts of the wire that brush against these contacts are called *brushes.*
- The current in the loop alternates so that the forces in the upper and lower regions do not change directions as the loop rotates.
- The rotation is continuous as long as current is supplied.

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36.8 Meters to Motors

Larger motors, DC or AC, are made by replacing the permanent magnet with an electromagnet, energized by the power source.

Many loops of wire are wound about an iron cylinder, called an *armature,* which then rotates when energized with electric current.

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36.8 Meters to Motors

think!

How is a galvanometer similar to a simple electric motor? How do they fundamentally differ?

36 Magnetism
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36.8 Meters to Motors

think!

How is a galvanometer similar to a simple electric motor? How do they fundamentally differ?

Answer:

A galvanometer and a motor are similar in that they both employ coils positioned in magnetic fields. When current passes through the coils, forces on the wires rotate the coils. The fundamental difference is that the maximum rotation of the coil in a galvanometer is one half turn, whereas in a motor the coil (armature) rotates through many complete turns. In the armature of a motor, the current is made to change direction with each half turn of the armature.

36 Magnetism
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36.8 Meters to Motors

CONCEPT CHECK **What is the main difference between a galvanometer and an electric motor?**

36.9 Earth's Magnetic Field

A compass points northward because Earth itself is a huge magnet.

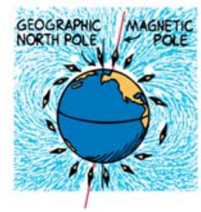
36.9 Earth's Magnetic Field

The compass aligns with the magnetic field of Earth, but the magnetic poles of Earth do not coincide with the geographic poles.

The magnetic pole in the Northern Hemisphere, for example, is located some 800 kilometers from the geographic North Pole.

This means that compasses do not generally point to true north.

The discrepancy is known as the *magnetic declination.*



36.9 Earth's Magnetic Field

Moving Changes Within Earth

The configuration of Earth's magnetic field is like that of a strong bar magnet placed near the center of Earth.

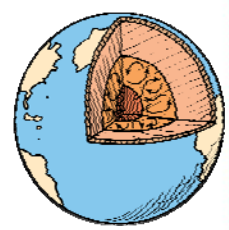
Earth is not a magnetized chunk of iron like a bar magnet. It is simply too hot for individual atoms to remain aligned.

36.9 Earth's Magnetic Field

Currents in the molten part of Earth beneath the crust provide a better explanation for Earth's magnetic field.

Most geologists think that moving charges looping around within Earth create its magnetic field. Because of Earth's great size, the speed of charges would have to be less than one millimeter per second to account for the field.

Another possible cause for Earth's magnetic field is convection currents from the rising heat of Earth's core. Perhaps such convection currents combined with the rotational effects of Earth produce Earth's magnetic field.



36.9 Earth's Magnetic Field

Magnetic Field Reversals

The magnetic field of Earth is not stable. Magnetic rock strata show that it has flip-flopped throughout geologic time.

Iron atoms in a molten state align with Earth's magnetic field. When the iron solidifies, the direction of Earth's field is recorded by the orientation of the domains in the rock.

36.9 Earth's Magnetic Field

On the ocean floor at mid-ocean ridges, continuous eruption of lava produces new seafloor.

This new rock is magnetized by the existing magnetic field.

Alternating magnetic stripes show that there have been times when the Earth's magnetic field has dropped to zero and then reversed.

36.9 Earth's Magnetic Field

More than 20 reversals have taken place in the past 5 million years. The most recent occurred 780,000 years ago.

We cannot predict when the next reversal will occur because the reversal sequence is not regular.

Recent measurements show a decrease of over 5% of Earth's magnetic field strength in the last 100 years. If this change is maintained, there may be another field reversal within 2000 years.

36.9 Earth's Magnetic Field

CONCEPT CHECK **Why does a magnetic compass point northward?**

Assessment Questions

1. For magnets, like poles repel each other and unlike poles
   a. also repel each other.
   b. attract each other.
   c. can disappear into nothingness.
   d. can carry a lot of energy.

Assessment Questions

1. For magnets, like poles repel each other and unlike poles
   a. also repel each other.
   b. attract each other.
   c. can disappear into nothingness.
   d. can carry a lot of energy.

Answer: B

Assessment Questions

2. The space surrounding a magnet is known as a(n)
   a. electric field.
   b. magnetic field.
   c. magnetic pole.
   d. electric pole.

Assessment Questions

2. The space surrounding a magnet is known as a(n)
   a. electric field.
   b. magnetic field.
   c. magnetic pole.
   d. electric pole.

Answer: B

Assessment Questions

3. Moving electric charges are surrounded by
   a. only electric fields.
   b. only magnetic fields.
   c. both magnetic and electric fields.
   d. nothing.

Assessment Questions

3. Moving electric charges are surrounded by
   a. only electric fields.
   b. only magnetic fields.
   c. both magnetic and electric fields.
   d. nothing.

Answer: C

Assessment Questions

4. The magnetic domains in a magnet produce a weaker magnet when the
   a. magnet is heated.
   b. magnet is brought in contact with steel.
   c. magnet is brought in contact with another strong magnet.
   d. magnetic domains are all in alignment.

Assessment Questions

4. The magnetic domains in a magnet produce a weaker magnet when the
   a. magnet is heated.
   b. magnet is brought in contact with steel.
   c. magnet is brought in contact with another strong magnet.
   d. magnetic domains are all in alignment.

Answer: A

Assessment Questions

5. The magnetic field lines about a current-carrying wire form
   a. circles.
   b. radial lines.
   c. eddy currents.
   d. spirals.

Assessment Questions

5. The magnetic field lines about a current-carrying wire form
   a. circles.
   b. radial lines.
   c. eddy currents.
   d. spirals.

Answer: A

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Assessment Questions

6. A magnetic force cannot act on an electron when it moves
   a. perpendicular to the magnetic field lines.
   b. at an angle between 90° and 180° to the magnetic field lines.
   c. at an angle between 45° and 90° to the magnetic field lines.
   d. parallel to the magnetic field lines.

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Assessment Questions

6. A magnetic force cannot act on an electron when it moves
   a. perpendicular to the magnetic field lines.
   b. at an angle between 90° and 180° to the magnetic field lines.
   c. at an angle between 45° and 90° to the magnetic field lines.
   d. parallel to the magnetic field lines.

Answer: D

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Assessment Questions

7. A magnetic force acts most strongly on a current-carrying wire when it is
   a. parallel to the magnetic field.
   b. perpendicular to the magnetic field.
   c. at an angle to the magnetic field that is less than 90°.
   d. at an angle to the magnetic field that is more than 90°.

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Assessment Questions

7. A magnetic force acts most strongly on a current-carrying wire when it is
   a. parallel to the magnetic field.
   b. perpendicular to the magnetic field.
   c. at an angle to the magnetic field that is less than 90°.
   d. at an angle to the magnetic field that is more than 90°.

Answer: B

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Assessment Questions

8. Your teacher gives you two electrical machines and asks you to identify which is a galvanometer and which is an electric motor. How can you tell the difference between the two?
   a. In a galvanometer, the current changes direction every time the coil makes a half revolution.
   b. In an electric motor, the current changes direction every time the coil makes a half revolution.
   c. In a galvanometer, the current changes direction every time the coil makes a whole revolution.
   d. In an electric motor, the current changes direction every time the coil makes a whole revolution.

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Assessment Questions

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   a. In a galvanometer, the current changes direction every time the coil makes a half revolution.
   b. In an electric motor, the current changes direction every time the coil makes a half revolution.
   c. In a galvanometer, the current changes direction every time the coil makes a whole revolution.
   d. In an electric motor, the current changes direction every time the coil makes a whole revolution.

Answer: B

Assessment Questions

9. The magnetic field surrounding Earth
    a. is caused by magnetized chunks of iron in Earth's crust.
    b. is likely caused by magnetic declination.
    c. never changes.
    d. is likely caused by electric currents in its interior.

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Assessment Questions

9. The magnetic field surrounding Earth
    a. is caused by magnetized chunks of iron in Earth's crust.
    b. is likely caused by magnetic declination.
    c. never changes.
    d. is likely caused by electric currents in its interior.

Answer: D