Electricity and Magnetism

VOCABULARY

- ammeter
- ampere
- battery
- cell
- conductivity
- conductor
- coulomb
- Coulomb's law
- current
- electric circuit
- electric field
- electric field line
- electric field strength
- electrical energy
- electrical power
- electromagnetic induction
- electromagnetic wave
- electron
- electronvolt
- electrostatic force
- elementary charge
- equivalent resistance
- induced potential difference
- joule
- law of conservation of charge
- magnet
- magnetic field
- magnetic field strength
- magnetic field (flux) lines
- magnetic force
- magnetism
- neutron
- north magnetic pole
- ohm
- ohm · meter
- Ohm's law
- parallel circuit
- potential difference
- proton
- resistance
- resistivity
- resistor
- series circuit
- switch
- tesla
- variable resistor
- volt
- voltmeter
- watt
- weber

Electrostatics

The study of electric charges at rest, and their electric fields and potentials, is called electrostatics. Charges are said to be "at rest" if there is no net transfer of charge.

MICROSTRUCTURE OF MATTER The smallest unit of an element is the atom. Atoms are composed of several different subatomic particles—electrons, protons, and neutrons. A typical atom consists of a cloud of electrons surrounding a central dense core known as the nucleus. The nucleus always contains protons and usually contains neutrons. The **electron** is the fundamental negatively charged (−) particle of matter. The **proton** is the fundamental positively charged (+) particle of matter. The **elementary charge,** e, is equal in magnitude to the charge on an electron ($-e$) or the charge on a proton ($+e$). Although the charge on the proton is equal in magnitude to the charge on the electron, the mass of the proton is much greater than the mass of the electron. **Neutrons,** which are found in the nucleus, are neutral (no charge) subatomic particles that have nearly the same mass as protons. Because they contain equal numbers of protons and electrons, all atoms are electrically neutral.

CHARGED OBJECTS Protons and neutrons cannot be removed from an atom by ordinary means. Because of this, electrically charged objects are usually formed when neutral objects lose or gain electrons. Electrons are often removed from an atom when energy is imparted to the atom by friction, heat, or light. When an atom gains or loses electrons, it becomes a charged particle known as an ion. An object with an excess of electrons is negatively charged, and an object with a deficiency of electrons is positively charged.

Two objects with the same sign of charge (both positive or both negative) that are located near each other are repelled by an electrical force. A negatively charged object and a positively charged object that are near each other are attracted by an electrical force. As you'll learn in the next section, neutral objects and charged objects can also be attracted to each other.

TRANSFER OF CHARGE If a system consists only of neutral objects, it has a total net charge of zero. If objects in the system are rubbed together, electrons may be transferred between the objects. This, however, does not change the overall charge on the system—the system as a whole remains neutral. If one of the objects loses electrons and becomes positively charged, the object in contact with it acquires the electrons and becomes negatively charged.

If you run a plastic comb through your hair, electrons are transferred from your hair to the comb. Your hair becomes positively charged and the comb becomes negatively charged. If you then bring the comb near neutral pieces of paper on a tabletop, the charges within the paper are rearranged, as shown in Figure 4-1.

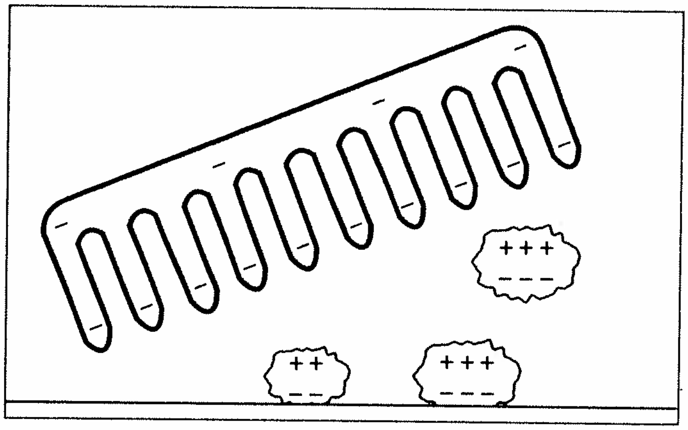
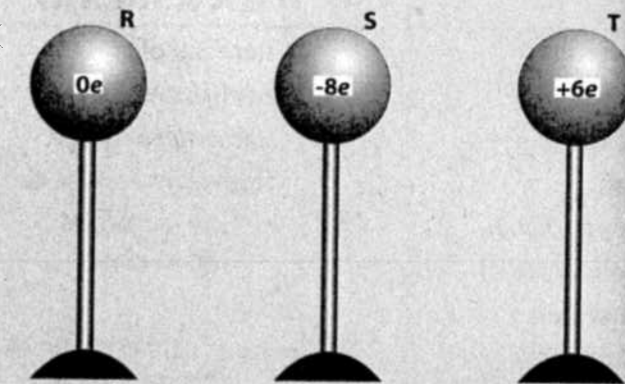


Figure 4-1. Opposite charges attract: The tiny pieces of paper are attracted to the comb by an electric force that is greater than Earth's gravitational force.

LAW OF CONSERVATION OF CHARGE The statement that in a closed, isolated system, the total charge of the system remains constant is known as the **law of conservation of charge**. Charges within the system may be transferred from one object to another, but charge is neither created nor destroyed.

SAMPLE PROBLEM

The diagram below shows the initial charges and positions of three metal spheres, R, S, and T, on insulating stands.



Sphere R is brought into contact with sphere S and then removed. Then sphere S is brought into contact with sphere T and removed. What is the charge on sphere T after this procedure is completed?

Solution: When spheres R and S are brought into contact, they share the $-8e$ charge equally. Thus each sphere possesses $-4e$ when they are separated. When spheres S and T are brought into contact, they also share the charge evenly.

$$\frac{-4e + 6e}{2} = \frac{+2e}{2} = +e$$

The final charge on sphere T is $+e$. Note also that charge is conserved; the initial charge of the system equals the final charge of the system.

$$-8e + 6e = -4e + e + e = -2e$$

QUANTITY OF CHARGE The SI unit of charge is the **coulomb,** C. One coulomb is equal to 6.25×10^{18} elementary charges. The charge on an electron ($-e$) is -1.6×10^{-19} coulomb, and the charge on a proton ($+e$) is $+1.6 \times 10^{-19}$ coulomb. The net charge on a charged object is always an integral multiple of e, that is, charge is quantized. For example, an object may have a net charge of 8.0×10^{-19} C (equivalent to $+5e$) or -1.6×10^{-18} C (equivalent to $-10e$), but it cannot have a charge of 2.4×10^{-19} C (equivalent to $\frac{3}{2}e$).

COULOMB'S LAW The size or magnitude of the **electrostatic force** between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them. This relationship, called **Coulomb's law,** is given by this equation.

$$F_e = \frac{kq_1q_2}{r^2}$$

F_e is the electrostatic force in newtons, q_1 and q_2 are the charges in coulombs, and r is the distance of separation in meters. The electrostatic constant, k, is equal to $8.99 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$. The electrostatic force is directed along the line joining the charges. The force that q_1 exerts on q_2 is equal in magnitude but opposite in direction to the force that q_2 exerts on q_1. The Coulomb's law equation is valid for charged objects whose dimensions are small compared with the distance separating the objects.

SAMPLE PROBLEM

What is the electrostatic force between two small spheres possessing net charges of +2.0 microcoulombs and −3.0 microcoulombs, respectively, if the distance between them is 10.0 meters?

Solution: Identify the known and unknown values.

Known	*Unknown*
$k = 8.99 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$	$F_e = ?\ \text{N}$
$q_1 = +2.0 \times 10^{-6}\ \text{C}$	
$q_2 = -3.0 \times 10^{-6}\ \text{C}$	
$r = 10.0\ \text{m}$	

Substitute the known values into the Coulomb's law equation and solve.

$$F_e = \frac{kq_1q_2}{r^2}$$

$$F_e = \frac{\left(8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(+2.0 \times 10^{-6}\ \text{C})(-3.0 \times 10^{-6}\ \text{C})}{(1.00 \times 10^1\ \text{m})^2}$$

$$F_e = \frac{\left(8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(-6.0 \times 10^{-12}\ \text{C}^2)}{1.00 \times 10^2\ \text{m}^2}$$

$$F_e = -5.4 \times 10^{-4}\ \text{N}$$

The negative sign indicates a force of attraction.

Review Questions

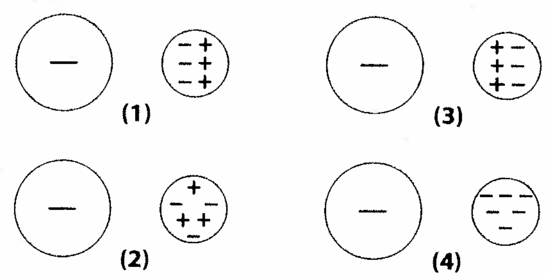
1. What is the charge of a proton? (1) 9.11×10^{-31} C (2) 1.67×10^{-27} C (3) 1.60×10^{-19} C (4) 6.25×10^{18} C

2. A charge of 100 elementary charges is equivalent to (1) 1.60×10^{-21} C (2) 1.60×10^{-17} C (3) 6.25×10^{16} C (4) 6.25×10^{20} C

3. Compare the sign and magnitude of the charge on a proton to the sign and magnitude of the charge on an electron.

4. Which particle has no charge? (1) neutron (2) proton (3) electron (4) ion

5. A small, uncharged metal sphere is placed near a large, negatively charged sphere. Which diagram best represents the charge distribution of the smaller sphere?



6. Which net charge could be found on an object? (1) 8.00×10^{-20} C (2) 2.40×10^{-19} C (3) 3.20×10^{-19} C (4) 6.25×10^{-18} C

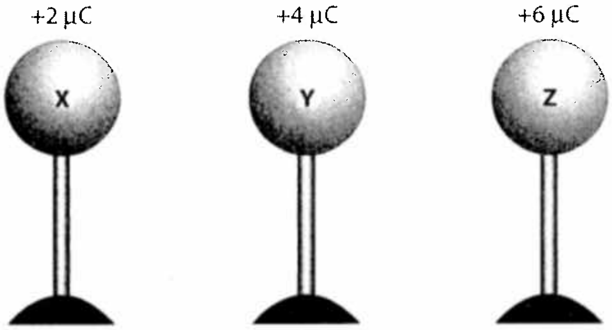
7. One of two identical metal spheres has a charge of $+q$ and the other sphere has a charge of $-q$. The spheres are brought together and then separated. Compared to the total charge on the two spheres before contact, the total charge on the spheres after contact is (1) less (2) greater (3) the same

8. After two neutral solids, A and B, were rubbed together, Solid A acquired a net negative charge. Solid B, therefore, experienced a net (1) loss of electrons (2) increase of electrons (3) loss of protons (4) increase of protons

9. A rod and a piece of cloth are rubbed together. If the rod acquires a charge of $+1 \times 10^{-6}$ coulomb, the cloth acquires a charge of (1) 0 C (2) $+1 \times 10^{-6}$ C (3) -1×10^{-6} C (4) $+1 \times 10^{+6}$ C

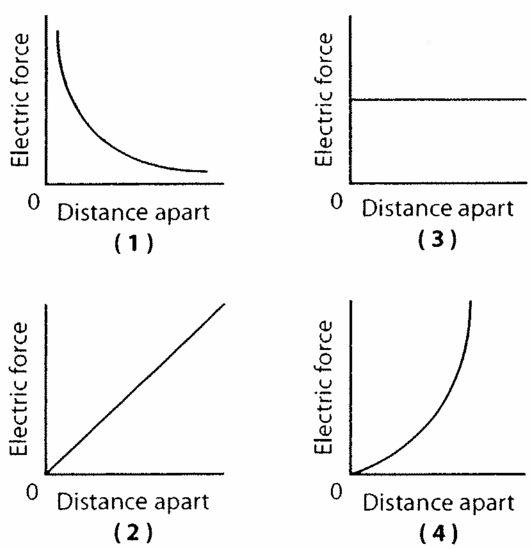
10. Two identical spheres, A and B, carry charges of +6 microcoulombs and −2 microcoulombs; respectively. If these spheres touch, what will be the resulting charge on sphere A?

11. The diagram below shows the initial charges and positions of three identical metal spheres, X, Y, and Z, which have been placed on insulating stands.



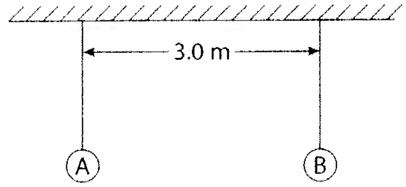
All three spheres are simultaneously brought into contact with each other and then returned to their original positions. Which statement best describes the charge of the spheres after this procedure is completed? (1) All the spheres are neutral. (2) Each sphere has a net charge of +4 μC. (3) Each sphere retains the same charge that it had originally. (4) Sphere Y has a greater charge than sphere X or sphere Z.

12. Two oppositely charged metal spheres are brought toward each other. Which graph best represents the relationship between the magnitude of the electric force between the spheres and the distance between them?



13. The electrostatic force of attraction between two small spheres that are 1.0 meter apart is F. If the distance between the spheres is decreased to 0.5 meter, the electrostatic force will be (1) $\frac{F}{2}$ (2) $2F$ (3) $\frac{F}{4}$ (4) $4F$

14. The diagram below shows two metal spheres suspended by strings and separated by a distance of 3.0 meters. The charge on sphere A is $+5.0 \times 10^{-4}$ coulomb, and the charge on sphere B is $+3.0 \times 10^{-5}$ coulomb.



Which statement best describes the electrical force between the spheres? (1) It has a magnitude of 15 N and is repulsive. (2) It has a magnitude of 45 N and is repulsive. (3) It has a magnitude of 15 N and is attractive. (4) It has a magnitude of 45 N and is attractive.

15. Two identical small spheres possessing charges q_1 and q_2 are separated by distance r. Which change would produce the greatest increase in the electrical force between the two spheres? (1) doubling charge q_1 (2) doubling r (3) doubling r and charge q_1 (4) doubling r and charges q_1 and q_2

16. If the charge on each of two small spheres a fixed distance apart is doubled, the electrostatic force between the spheres will be (1) halved (2) doubled (3) quartered (4) quadrupled

17. A point charge of $+3.0 \times 10^{-7}$ coulomb is placed 2.0×10^{-2} meter from a second point charge of $+4.0 \times 10^{-7}$ coulomb. What is the magnitude of the electrostatic force between the charges?

Electric Fields

An **electric field** is the region around a charged particle through which a force is exerted on another charged particle. An **electric field line** is the imaginary line along which a positive test charge would move in an electric field. The direction of an electric field is the direction of the force on a stationary positive test charge located at any point on a field line. On a curved field line, the direction of the field at any point is the tangent drawn to the field line at that point. Electric field lines begin on positive charges (or at infinity) and end on negative charges (or infinity). Field lines never intersect.

Electric field strength, E, is the force on a stationary positive test charge per unit charge in an electric field. It is given by this equation.

$$E = \frac{F_e}{q}$$

F_e is the electrostatic force in newtons, q is the charge in coulombs, and E is the electric field strength in newtons per coulomb. Because it has both magnitude and direction, electric field strength is a vector quantity.

SAMPLE PROBLEM

What is the magnitude of the electric field strength at a point in a field where an electron experiences a 1.0-newton force?

Solution: Identify the known and unknown values.

Known	*Unknown*
$F_e = 1.0\ \text{N}$	$E = ?\ \text{N/C}$
$q = 1.60 \times 10^{-19}\ \text{C}$	

Substitute the known values into the electric field strength equation and solve.

$$E = \frac{F_e}{q} = \frac{1.0\ \text{N}}{1.60 \times 10^{-19}\ \text{C}} = 6.3 \times 10^{18}\ \text{N/C}$$

FIELD AROUND A POINT CHARGE OR SPHERE Field lines extend radially outward from a positive point charge and radially inward toward a negative point charge. On a sphere, charge is distributed uniformly, and electric field lines are normal (perpendicular) to the surface. According to Coulomb's law, the electric field strength around a point charge or charged sphere varies inversely with the square of the distance from the point charge or sphere. The electric field strength within a hollow, charged conducting sphere is zero.

FIELD BETWEEN TWO OPPOSITELY CHARGED PARALLEL PLATES If the distance separating two oppositely charged parallel plates is small compared to their area, the electric field between the plates is uniform. The electric field lines are parallel to each other, so the field strength is the same at every point between the plates. Figure 4-2 shows the electric fields surrounding charged objects.

The magnitude of the electric force on an electron or a proton located at any point between two given oppositely charged parallel plates is the same. The electric force acting on either of these charged particles causes it to accelerate toward the plate of opposite sign. That is, the particle's speed increases as it approaches the plate of opposite sign.

POTENTIAL DIFFERENCE If the direction of an electric field is such that it opposes the motion of a charged particle, work must be done to move the particle in that direction. The **potential difference** between two points in an electric field is the work done (or change in potential energy) per unit charge as a charged particle is moved between the points. The potential difference is given by this formula.

$$V = \frac{W}{q}$$

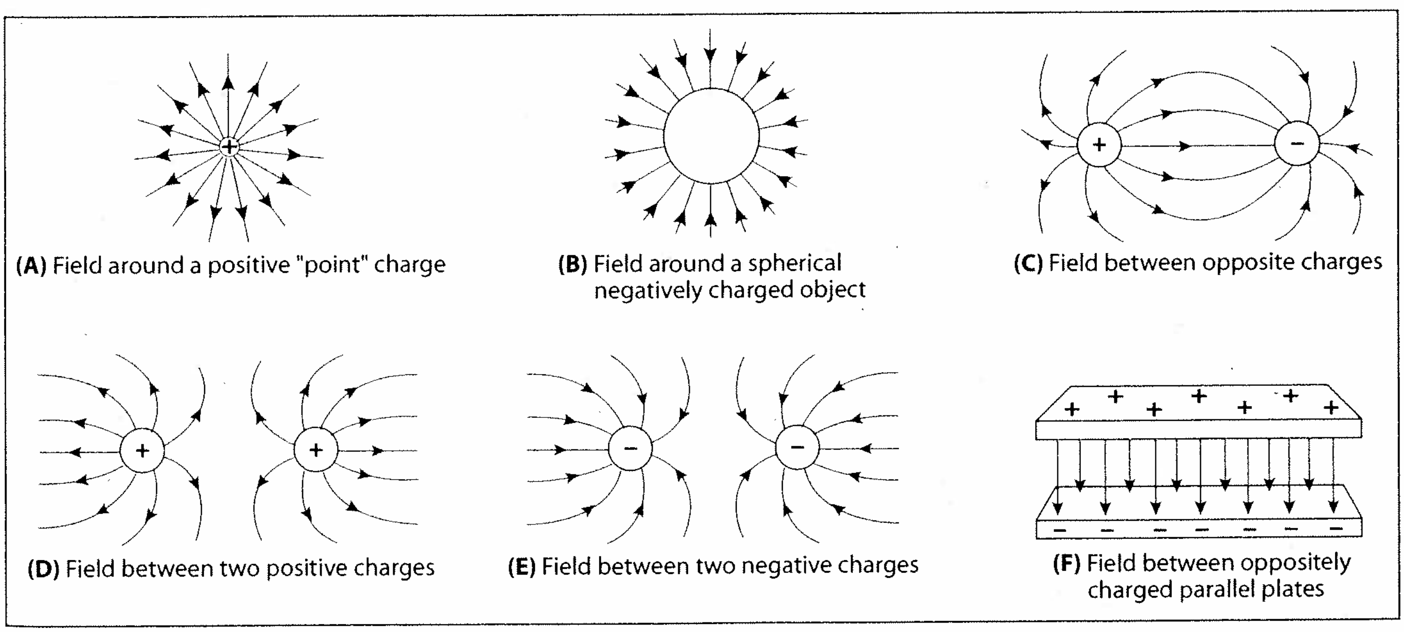


Figure 4-2. Fields surrounding charged objects

W is the work in joules, q is the charge in coulombs, and V is the potential difference in joules per coulomb. If one joule of work is done to move one coulomb of charge between two points in an electric field, a potential difference of one **volt** is said to exist between the two points. That is, 1 joule/coulomb = 1 volt. The volt, V, is the derived SI unit for potential difference.

If an elementary charge is moved against an electric field through a potential difference of one volt, the work done on the charge is calculated as shown below.

$$W = Vq = (1.00\text{ V})(1.60 \times 10^{-19}\text{ C}) = 1.60 \times 10^{-19}\text{ J}$$

This amount of work (1.60×10^{-19} J), or gain in potential energy, is called the **electronvolt,** eV. That is, 1.00 eV = 1.60×10^{-19} J.

SAMPLE PROBLEM

Moving a point charge of 3.2×10^{-19} coulomb between points A and B in an electric field requires 4.8×10^{-18} joule of energy. What is the potential difference between these points?

Solution: Identify the known and unknown values.

Known	*Unknown*
$q = 3.2 \times 10^{-19}$ C	$V = ?$ V
$W = 4.8 \times 10^{-18}$ J	

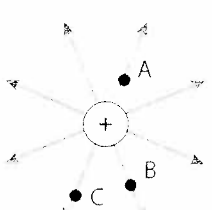
Substitute the known values into the equation for potential difference and solve.

$$V = \frac{W}{q} = \frac{4.8 \times 10^{-18}\text{ J}}{3.2 \times 10^{-19}\text{ C}} = 15\text{ V}$$

Review Questions

18. What is the magnitude of the electrostatic force experienced by one elementary charge at a point in an electric field where the electric field strength is 3.0×10^3 newtons per coulomb? (1) 1.0×10^3 N (2) 1.6×10^{-19} N (3) 3.0×10^3 N (4) 4.8×10^{-16} N

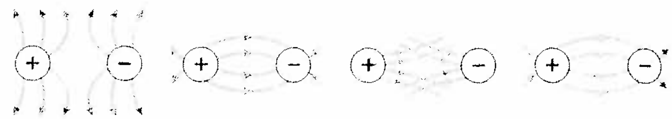
19. The diagram below shows some of the lines of electric force around a positive point charge.



The strength of the electric field is (1) greatest at point A (2) greatest at point B (3) greatest at point C (4) equal at points A, B, and C

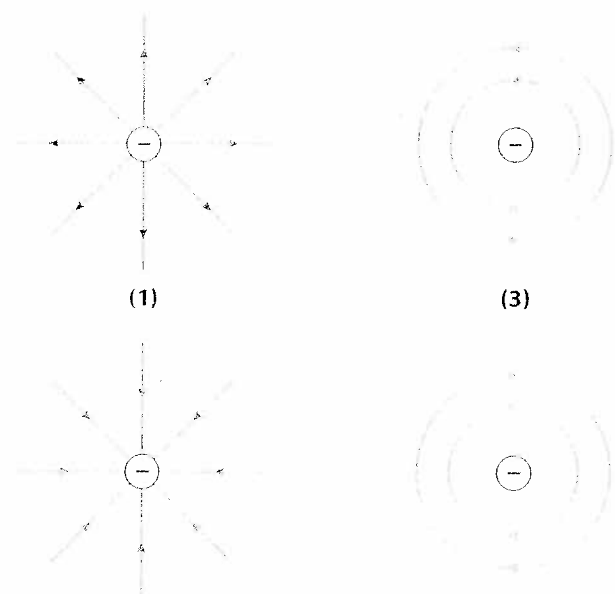
20. A charged particle is placed in an electric field E. If the charge on the particle is doubled, the magnitude of the force exerted on the particle by the field E is (1) unchanged (2) doubled (3) halved (4) quadrupled

21. Which diagram best illustrates the electric field around two unlike charges?



(1) (2) (3) (4)

22. Which diagram best represents the electric field of a point negative charge?



23. How much energy is needed to move one electron through a potential difference of 1.0×10^2 volts? (1) 1.0 J (2) 1.0×10^2 J (3) 1.6×10^{-17} J (4) 1.6×10^{-19} J

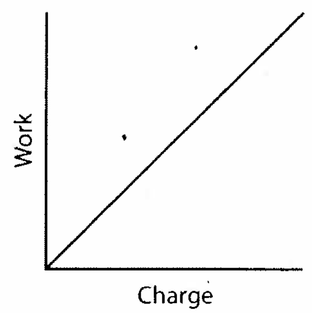
24. 6.0 joules of work are done to move 2.0 coulombs of charge from point A to point B. Determine the potential difference between points A and B.

25. A helium ion with a charge of $+2e$ is accelerated by a potential difference of 5.0×10^3 volts. What is the kinetic energy acquired by the ion? (1) 3.2×10^{-19} eV (2) 2.0 eV (3) 5.0×10^3 eV (4) 1.0×10^4 eV

26. If 4 joules of work are required to move 2 coulombs of charge through a 6-ohm resistor, what is the potential difference across the resistor?

27. An electron is accelerated from rest through a potential difference of 200. volts. What is the work done on the electron in electron volts?

28. The graph below shows the relationship between the work done on a charged body in an electric field and the net charge on the body.



What does the slope of the graph represent?

Electric Current

Electric **current** is the rate at which charge passes a given point in a circuit. An **electric circuit** is a closed path along which charged particles move. A **switch** is a device for making, breaking, or changing the connections in an electric circuit. Figure 4-3 shows the symbol for a switch.

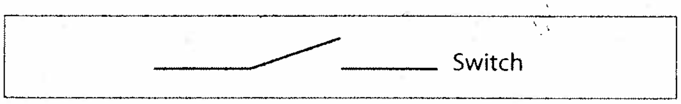


Figure 4-3. The symbol for a switch

UNIT OF CURRENT The SI unit of electric current, I, is the **ampere,** A. It is a fundamental unit. The coulomb, C, the unit of charge, is a derived unit defined to be the amount of charge that passes a point when a current of one ampere flows for one second. This relationship can be expressed as follows:

$$I = \frac{\Delta q}{t}$$

I is current in amperes, q is charge in coulombs, and t is time in seconds. An **ammeter** is a device used to measure current. The symbol for an ammeter is shown in Figure 4-4.

Figure 4-4. The symbol for an ammeter

CONDITIONS NECESSARY FOR AN ELECTRIC CURRENT In addition to a complete circuit, a difference in potential between two points in the circuit must exist for there to be an electric current. The potential difference may be supplied by a **cell,** a device that converts chemical energy to electrical energy, or a **battery,** a combination of two or more electrochemical cells. The potential difference can be measured with a device called a **voltmeter.** These devices are represented in an electric circuit diagram by the symbols shown in Figure 4-5.

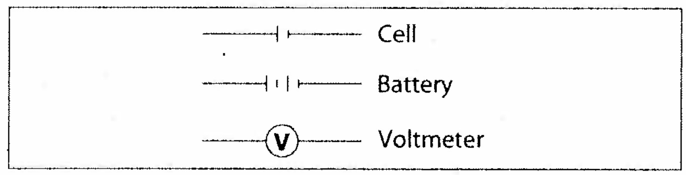


Figure 4-5. Symbols for sources of potential difference (voltage) and a voltmeter for measuring potential difference

Positive charges tend to move from points of higher potential to points of lower potential, or from positive potential to negative potential. Negative charges tend to move in the opposite direction. The direction of a current in an electric circuit can be defined as either of these directions. In some mathematical treatments it is convenient to treat the current as flowing from positive to negative, that is, as conventional current. However, it is more natural to choose the electron flow as the direction of current, because most currents consist of electrons in motion. This is the definition used in this book.

CONDUCTIVITY IN SOLIDS For a current to exist in an electric circuit, the circuit must consist of materials through which charge can move. The ability of a material to conduct electricity depends on the number of free charges per unit volume and on their mobility. **Conductivity** is a property of a material that depends on the availability of charges that are relatively free to move under the influence of an electric field. Pure metals have many electrons, and these electrons are not bound, or are only loosely bound, to any particular atom. Consequently, metals are good **conductors,**

because their electrons move readily. In nonmetallic elements or compounds, electrons are tightly bound and few are free to move. These types of materials are called insulators, because they are poor conductors.

RESISTANCE AND OHM'S LAW Electrical **resistance,** R, is the opposition that a device or conductor offers to the flow of electric current. The resistance of a conductor is the ratio of the potential difference applied to its ends and the current that flows through it. This relationship, called **Ohm's law,** is expressed as follows.

$$R = \frac{V}{I}$$

V is potential difference in volts, I is current in amperes, and R is resistance in volts per ampere. The **ohm,** Ω, is a derived SI unit equal to one volt per ampere. It should be noted that the equation is true for entire circuits or for any portion of a circuit, provided that the temperature does not change.

SAMPLE PROBLEM

A student measures a current of 0.10 ampere flowing through a lamp connected by short wires to a 12.0-volt source. What is the resistance of the lamp?

Solution: Identify the known and unknown values.

Known	*Unknown*
$V = 12.0\ \text{V}$	$R = ?\ \Omega$
$I = 0.10\ \text{A}$	

Substitute the known values into the equation for Ohm's law and solve.

$$R = \frac{V}{I} = \frac{12.0\ \text{V}}{0.10\ \text{A}} = 120\ \Omega$$

SAMPLE PROBLEM

A resistor was held at constant temperature in an operating electric circuit. A student measured the current through the resistor and the potential difference across it. The measurements are shown in the data table below.

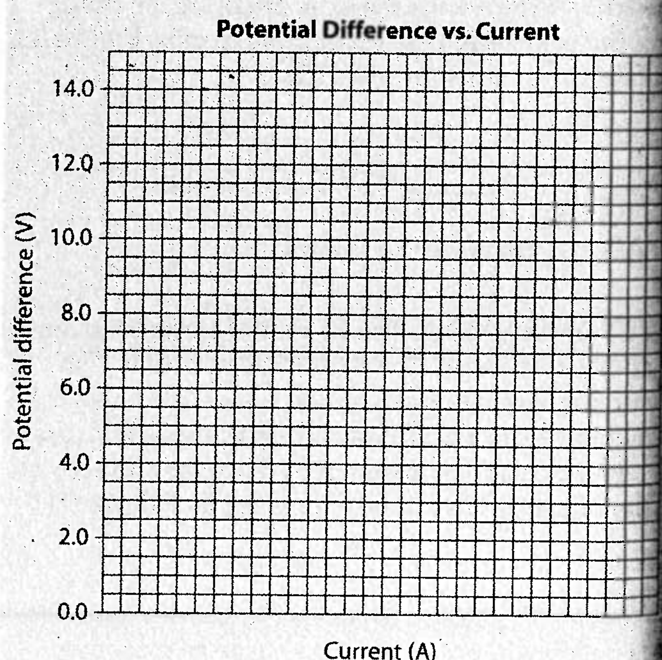
Current (A)	**Potential Difference** (V)
0.010	2.3
0.020	5.2
0.030	7.4
0.040	9.9
0.050	12.7

(a) Using the information in the data table, construct a graph on the grid below.

- Mark an appropriate scale on the axis labeled Current (A).
- Plot the data points.
- Draw the best-fit line.

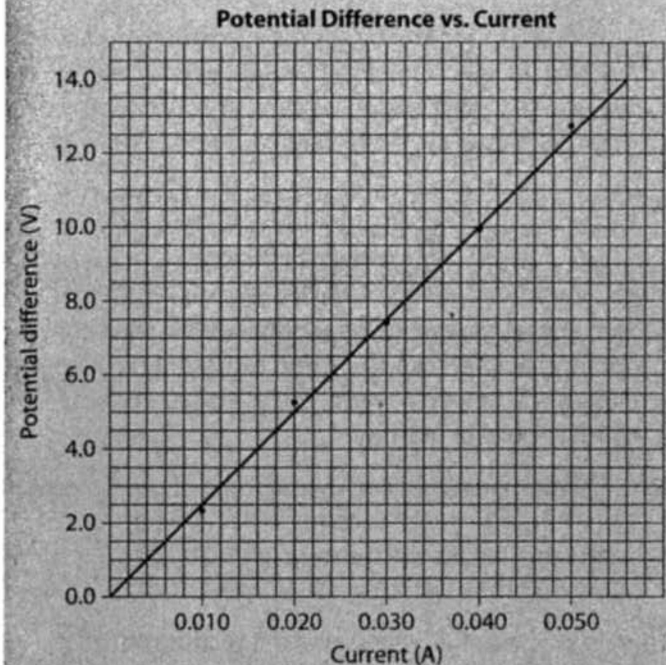
(b) Using your graph, find the slope of the best-fit line.

(c) What physical quantity does the slope represent?



Solution:

(a)



(b) slope = rise/run = $\Delta V / \Delta I$

$$\text{slope} = \frac{10.0\ \text{V} - 2.5\ \text{V}}{0.040\ \text{A} - 0.010\ \text{A}} = 250\ \Omega$$

(c) The slope of the line represents the resistance of the resistor.

FACTORS THAT AFFECT THE RESISTANCE OF A CONDUCTOR The resistance of a conducting wire increases with the increasing length of a wire because the current (electrons) encounter and collide with an increasing number of atoms. That is, the resistance R of a wire varies directly with its length L, or $R \propto L$. As the thickness of a wire decreases, there are fewer spaces between atoms in the cross-section through which electrons can travel in a given period of time. For example, if two wires have the same composition and length but one has half the diameter of the other, the thinner wire will have one-quarter the cross-sectional area, and therefore four times the resistance. That is, the resistance R of a wire varies inversely with its cross-sectional area A, or $R \propto \frac{1}{A}$.

Resistivity, ρ, is a characteristic of a material that depends on its electronic structure and temperature. The resistance of a wire is directly proportional to its resistivity, that is, $R \propto \rho$. Good conductors have low resistivities and good insulators have high resistivities. The SI unit for resistivity is the **ohm · meter**, or $\Omega \cdot \text{m}$. As the temperature of a conductor increases, its resistivity increases. The *Reference Tables for Physical Setting/Physics* contain a chart listing resistivities of several metals at 20°C.

Combining the factors yields the following equation for the resistance of a wire.

$$R = \frac{\rho L}{A}$$

ρ is the resistivity in ohm · meters, L is length in meters, A is cross-sectional area in square meters, and R is resistance in ohms.

SAMPLE PROBLEM

Determine the resistance of a 4.00-meter length of copper wire having a diameter of 2.00 millimeters. Assume a temperature of 20°C.

Solution: Identify the known and unknown values.

Known
$\rho_{copper} = 1.72 \times 10^{-8}\ \Omega \cdot \text{m}$
$L = 4.00\ \text{m}$
$d = 2.00 \times 10^{-3}\ \text{m}$

Unknown
$R = ?\ \Omega$

Substitute the known values into the resistance equations and solve.

$$R = \frac{\rho L}{A} = \frac{\rho L}{\pi (d/2)^2}$$

$$R = \frac{(1.72 \times 10^{-8}\ \Omega \cdot \text{m})(4.00\ \text{m})}{\pi (1.00 \times 10^{-3}\ \text{m})^2}$$

$$R = 2.19 \times 10^{-2}\ \Omega$$

A **resistor** is a device designed to have a definite amount of resistance. It can be used in a circuit to limit current flow or provide a potential drop. A **variable resistor** is a coil of resistance wire whose effective resistance can be varied by sliding a contact point. As more of the coil is used in a circuit, the resistance of the circuit increases, and the current decreases. The symbols for a resistor and variable resistor are shown in Figure 4-6.

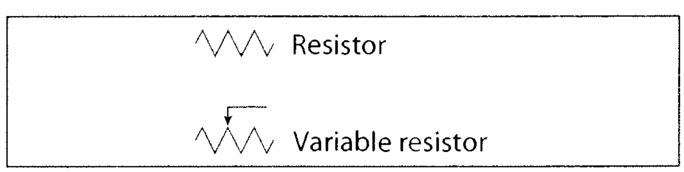


Figure 4-6. Symbols for a resistor and a variable resistor

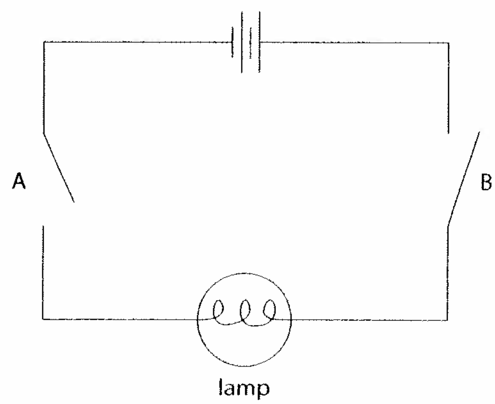
Review Questions

29. A total of 20.0 coulombs of charge pass a given point in a conductor in 4.0 seconds. Determine the current in the conductor.

30. A wire carries a current of 2.0 amperes. How many electrons pass a given point in this wire in 1.0 second?
(1) 1.3×10^{18} (2) 2.0×10^{18} (3) 1.3×10^{19}
(4) 2.0×10^{19}

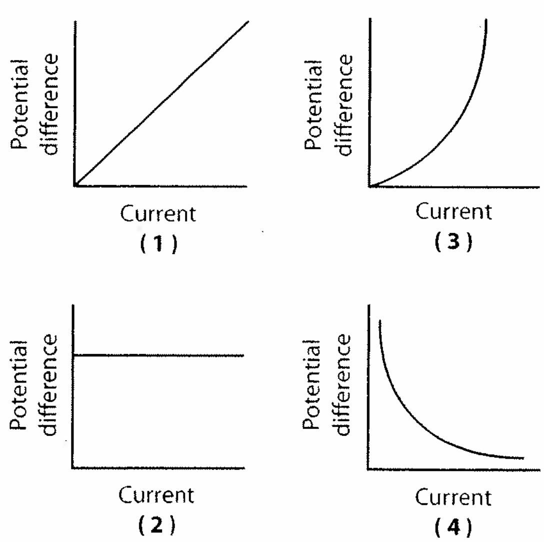
31. Which condition must exist between two points in a conductor in order to maintain a flow of charge?
(1) a potential difference (2) a magnetic field
(3) a low resistance (4) a high resistance

32. In the diagram below, which of the switches must be closed in order for the lamp to light?

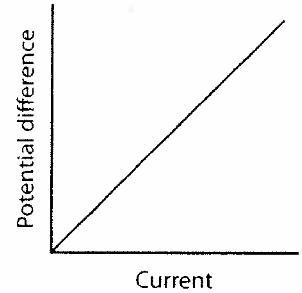


(1) A only (2) B only (3) both A and B

33. Which graph best represents the relationship between potential difference applied to a conductor and the resulting current through the conductor? (Assume constant temperature.)



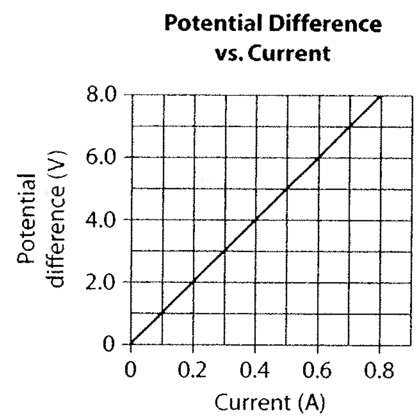
34. The graph below shows the relationship between potential difference and current in a simple circuit.



For any point on the line, what does the ratio of potential difference to current represent? (1) work in joules (2) power in watts (3) resistance in ohms
(4) charge in coulombs

35. A 20.-ohm resistor has 40. coulombs of charge passing through it in 5.0 seconds. What is the potential difference across the resistor? (1) 8.0 V (2) 1.0×10^2 V
(3) 1.6×10^2 V (4) 2.0×10^2 V

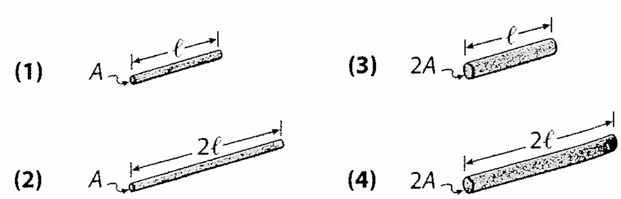
36. The graph below represents the relationship between the potential difference across a metal conductor and the current through the conductor at constant temperature.



What is the resistance of the conductor? (1) 1 Ω
(2) 0.01 Ω (3) 0.1 Ω (4) 10 Ω

37. A potential difference of 12 volts is applied across a circuit having a 4.0-ohm resistance. What is the current in the circuit?

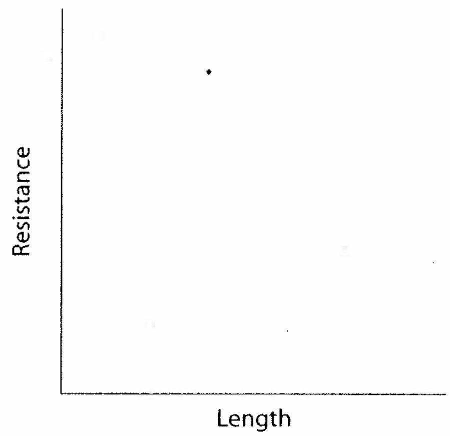
38. In the diagrams below, ℓ represents a unit length of copper wire and A represents a unit cross-sectional area. Which copper wire has the smallest resistance at room temperature?



39. If the temperature of a metal conductor is reduced, its resistance will usually (1) decrease (2) increase (3) remain the same

40. The resistance of a wire at constant temperature depends on the wire's (1) length only (2) type of metal only (3) length and cross-sectional area only (4) length, type of metal, and cross-sectional area

41. On the axes below, sketch the general shape of the graph that shows the relationship between the resistance of a copper wire of uniform cross-sectional area and the wire's length at constant temperature.



42. A piece of wire has a resistance of 8 ohms. What is the resistance of a second piece of wire of the same composition, same diameter, and at the same temperature, but with one half the length of the first wire?

43. An aluminum wire has a resistance of 48 ohms. A second aluminum wire of the same length and at the same temperature, but with twice the cross-sectional area, would have a resistance of (1) 12 Ω (2) 24 Ω (3) 48 Ω (4) 96 Ω

44. What is the resistance of a 10.0-meter long copper wire having a cross-sectional area of 1.50×10^{-6} m^2 at 20°C? (1) 1.15×10^{-1} Ω (2) 1.15×10^{-2} Ω (3) 1.15×10^{-13} Ω (4) 1.15×10^{-14} Ω

45. A 5.00-meter long tin wire has a cross-sectional area of 2.00×10^{-6} m^2 and a resistance of 0.35 ohm. Determine the resistivity of tin.

46. At 20°C carbon has a resistivity of 3.5×10^{-5} Ω·m. What is the ratio of the resistivity of carbon to the resistivity of copper? (1) 1:2 (2) 2:1 (3) 200:1 (4) 2000:1

47. Unlike most metals, the resistivity of carbon decreases with increasing temperature. As the temperature of carbon increases, its resistance (1) decreases (2) increases (3) remains the same

48. An aluminum wire and a tungsten wire have the same cross-sectional area and the same resistance at 20°C. If the aluminum wire is 4.0×10^{-2} meter long, what is the length of the tungsten wire?
(1) 1.0×10^{-2} m (2) 2.0×10^{-2} m
(3) 4.0×10^{-2} m (4) 8.0×10^{-2} m

Electric Circuits

The simplest electric circuit consists of a source of electrical energy, such as a battery; connecting wires; and a circuit element, such as a lamp or a resistor, that converts electrical energy to light or heat. The current in the circuit is dependent on the potential difference V provided by the battery at the ends of the circuit element, and the resistance R of the circuit element. These quantities are related to each other by

Ohm's Law, $I = \frac{V}{R}$. Figure 4-7 shows a simple electric circuit.

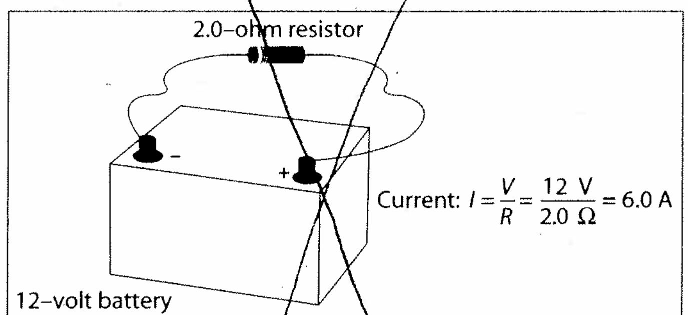


Figure 4-7. A simple circuit

When two or more resistors are present in a circuit, there are two basic methods of connecting them—in series or in parallel.

SERIES CIRCUITS A **series circuit** is a circuit in which all parts are connected end to end to provide a single path for the current. Figure 4-8 shows three resistors connected in series with a battery. The resistors are differentiated by the use of subscripts R_1, R_2, and R_3.

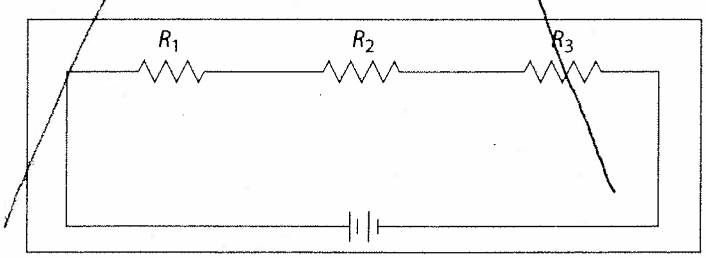


Figure 4-8. Resistors in a series circuit