Electricity and Magnetism

TOPIC 4

How Scientists Study Electricity and Magnetism

Is a 60-watt incandescent light bulb always more powerful than a 30-watt incandescent light bulb?

At normal operating temperatures, a 60-watt lamp has half the resistance of a 30-watt lamp, which has a thinner filament. When operated in parallel, the potential difference across each lamp is the same, but the current through the 60-watt lamp is twice that through the 30-watt lamp. Because power is the product of potential difference and current, the 60-watt lamp is twice as powerful as the 30-watt lamp, when connected in parallel.

When the lamps are connected in series, the current is the same through each lamp, but the potential difference across the 60-watt lamp is less than that across the 30-watt lamp, because the 30-watt lamp has more resistance. Because power equals VI, and I is the same for both lamps, VI is greater for the 30-watt lamp, making it more powerful than the 60-watt lamp.

The lamps consume 60 watts and 30 watts, respectively, only when operated, as designated, in parallel at 120 volts in a household circuit.

TOPIC 4

Electricity and Magnetism

Vocabulary

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

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 explained in the next section, neutral objects and charged objects can also be attracted to each other.

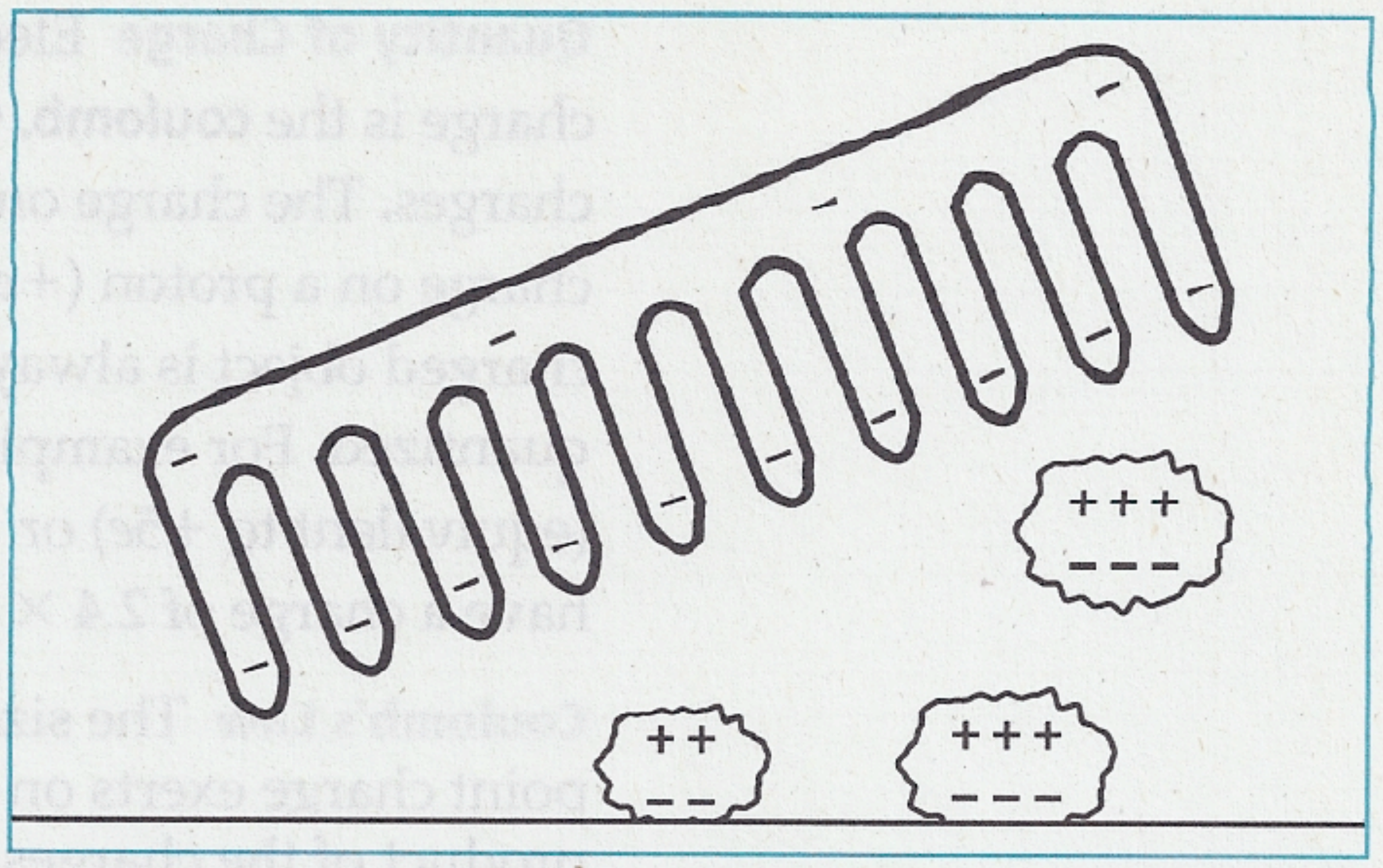


Figure 4-1. Opposite charges attract: The tiny pieces of paper are attracted to the comb. The magnitude of the electrostatic force is greater than the magnitude of Earth's gravitational force acting on the piece of paper being lifted.

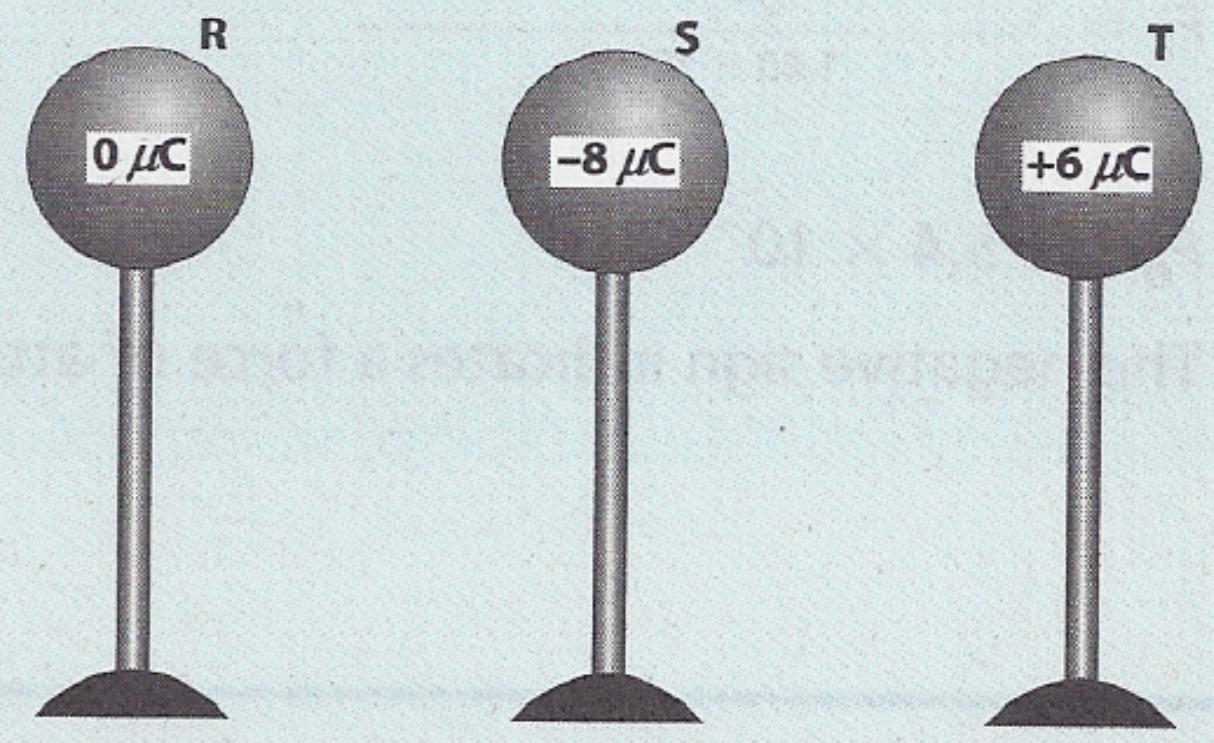
Transfer of Charge If a system consists only of neutral objects, it has a total net charge of zero. If objects in the system are rubbed together, electrons may be transferred between the objects. This, however, does not change the overall charge on the system—the system as a whole remains neutral. If 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.

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

$$\frac{-4\ \mu C + 6\ \mu C}{2} = \frac{+2\ \mu C}{2} = +1\ \mu C$$

The final charge on sphere T is $+1\ \mu C$. Note also, that charge is conserved; the initial charge of the system equals the final charge of the system.

$$-8\ \mu C + 6\ \mu C = -4\ \mu C + 1\ \mu C + 1\ \mu C = -2\ \mu C$$

Quantity of Charge Electric charge, q, is a scalar quantity. 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** that one point charge exerts on another point charge 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 formula

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

The electrostatic force F_e is 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 formula is valid for charged objects whose dimensions are small compared to the distance separating the objects.

SAMPLE PROBLEM

Calculate the electrostatic force that a small sphere, A, possessing a net charge of +2 microcoulombs exerts on another small sphere, B, possessing a net charge of −3.0 microcoulombs when the distance between their centers is 10.0 meters.

SOLUTION: Identify the known and unknown values.

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

Unknown
$F_e = ?$ N

1. Write the formula for Coulomb's law.

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

2. Substitute the known values and solve.

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

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

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

The negative sign indicates a force of attraction.

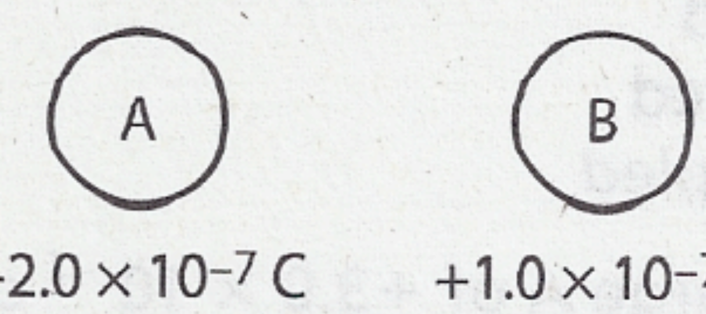
Review Questions

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. State *both* the sign and magnitude of the charge on a proton, an electron, and a neutron in terms of *e*, the elementary charge.

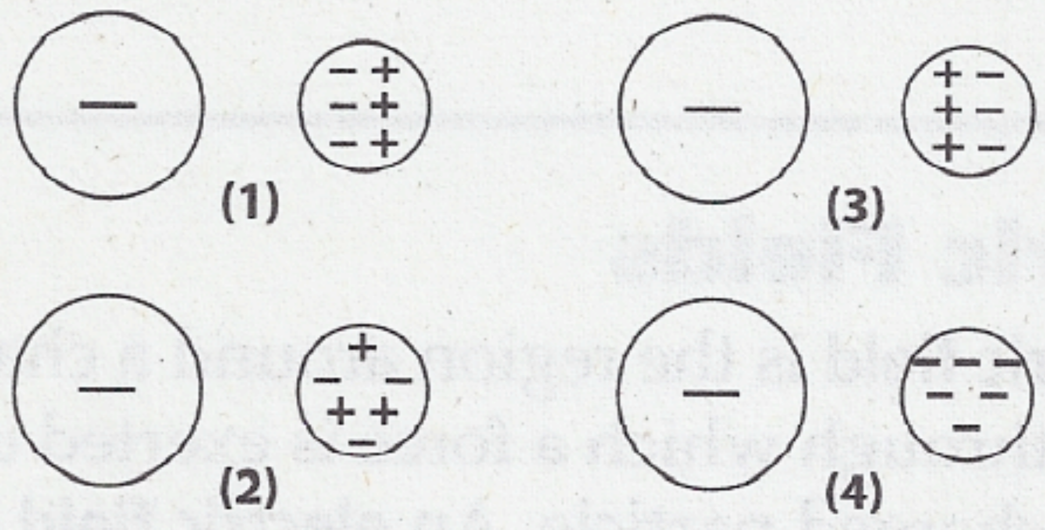
4. The diagram below represents two electrically charged identical-sized metal spheres, *A* and *B*.



If the spheres are brought into contact, which sphere will have a net gain of electrons?

(1) *A*, only
(2) *B*, only
(3) both *A* and *B*
(4) neither *A* nor *B*

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. A positively charged glass rod attracts object *X*. The net charge of object *X*

(1) may be zero or negative
(2) may be zero or positive
(3) must be negative
(4) must be positive

8. After two neutral solids, A and B, were rubbed together, Solid A acquired a net negative charge. Solid B, therefore, experienced a net

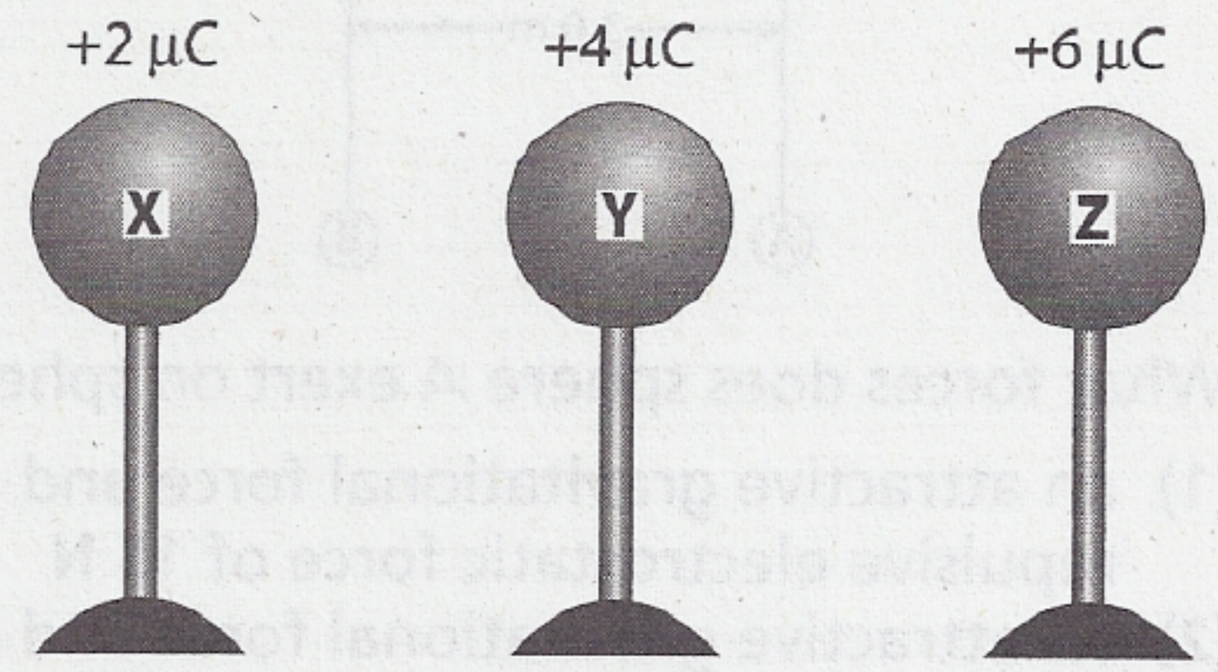
(1) loss of electrons
(2) increase of electrons
(3) loss of protons
(4) increase of protons

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?

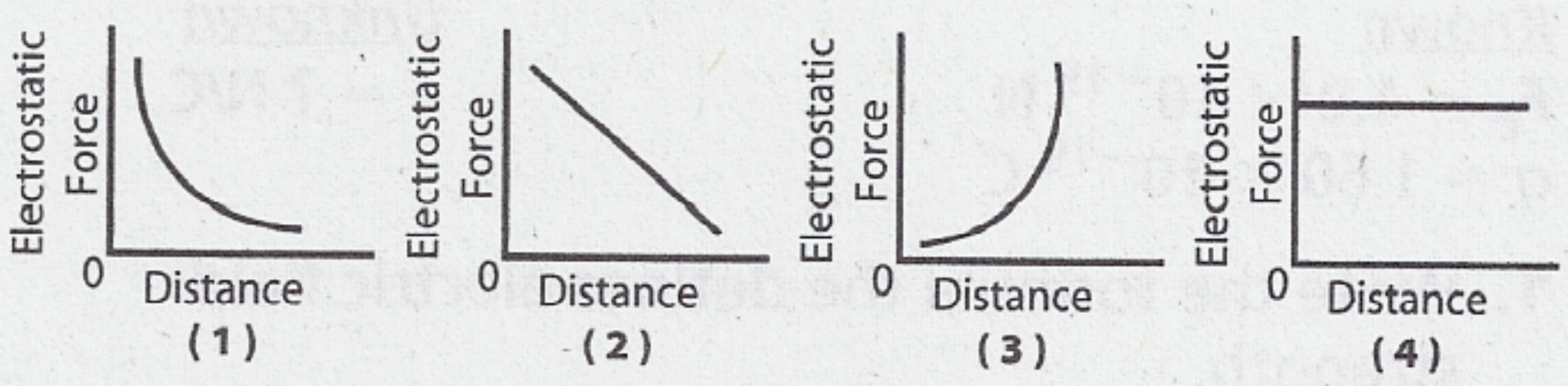
11. The diagram below shows the initial charges and positions of three identical metal spheres, X, Y, and Z, which have been placed on insulating stands. All three spheres are simultaneously brought into contact with each other and then returned to their original positions.



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 $+4\ \mu$C.
(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 electrostatic force one sphere exerts on the other sphere and the distance between their centers?



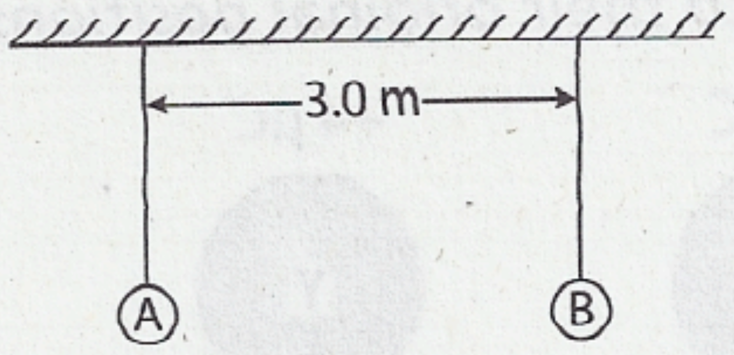
13. The electrostatic force of attraction between two small spheres that are 1.0 meter apart is *F*. If the distance between the spheres is decreased to 0.5 meter, the electrostatic force will be

(1) $\frac{F}{2}$
(2) 2*F*
(3) $\frac{F}{4}$
(4) 4*F*

14. 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 magnitude of the electrostatic force that one sphere exerts on the other?

(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

15. 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.



What forces does sphere *A* exert on sphere *B*?

(1) an attractive gravitational force and a repulsive electrostatic force of 15 N
(2) an attractive gravitational force and a repulsive electrostatic force of 45 N
(3) a repulsive gravitational force and an attractive electrostatic force of 15 N
(4) a repulsive gravitational force and an attractive electrostatic force of 45 N

16. If the charge is doubled on each of two small spheres having a fixed distance between their centers, the magnitude of the electrostatic force that one sphere exerts on the other will be

(1) halved
(2) doubled
(3) quartered
(4) quadrupled

17. A point charge *A* of $+3.0 \times 10^{-7}$ coulomb is placed 2.0×10^{-2} meter from a second point charge *B* of $+4.0 \times 10^{-7}$ coulomb. Calculate the magnitude of the electrostatic force that charge *A* exerts on charge *B*.

SAMPLE PROBLEM

Calculate the magnitude of the electric field strength at a point in a field where an electron experiences a force with a magnitude of 1.0×10^{-15} newton.

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
$F_e = 1.0 \times 10^{-15}$ N	$E = ?$ N/C
$q = 1.60 \times 10^{-19}$ C	

1. Write the formula the defines electric field strength.

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

2. Substitute the known values and solve.

$$E = \frac{1.0 \times 10^{-15}\ \text{N}}{1.60 \times 10^{-19}\ \text{C}} = 6.3 \times 10^{3}\ \text{N/C}$$

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 formula

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

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

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. Potential difference is a scalar quantity given by this formula.

(R)

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

The work W is in joules, the charge q is in coulombs, and the potential difference V is 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, $1.00 \text{ eV} = 1.60 \times 10^{-19}$ 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. Calculate the potential difference between these points.

SOLUTION: Identify the known and unknown values.

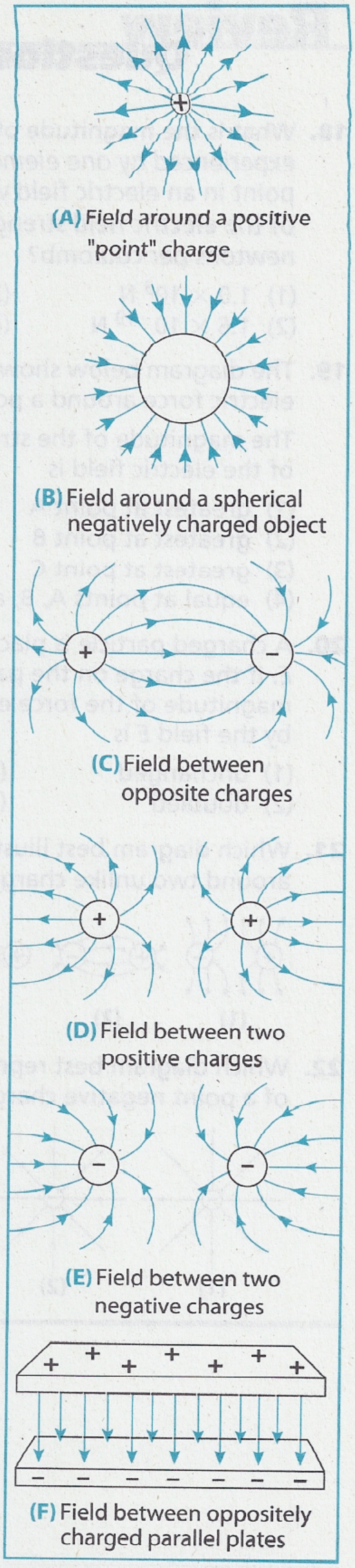
Known	*Unknown*
$q = 3.2 \times 10^{-19}$ C	$V = ?$ V
$W = 4.8 \times 10^{-18}$ J	

1. Write the formula that defines potential difference.

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

2. Substitute the known values and solve.

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



(A) Field around a positive "point" charge

(B) Field around a spherical negatively charged object

(C) Field between opposite charges

(D) Field between two positive charges

(E) Field between two negative charges

(F) Field between oppositely charged parallel plates

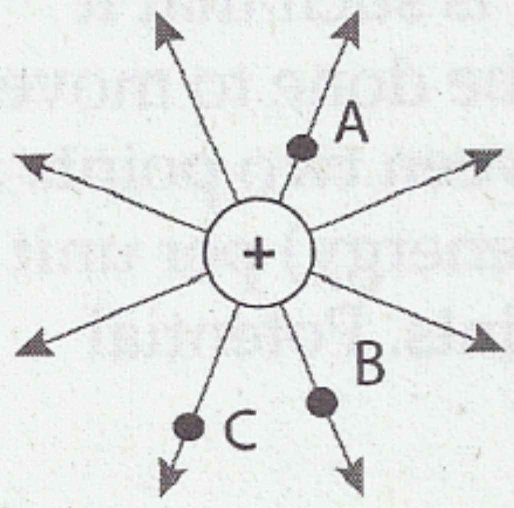
Figure 4-2. Fields surrounding charged objects

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 magnitude of 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.



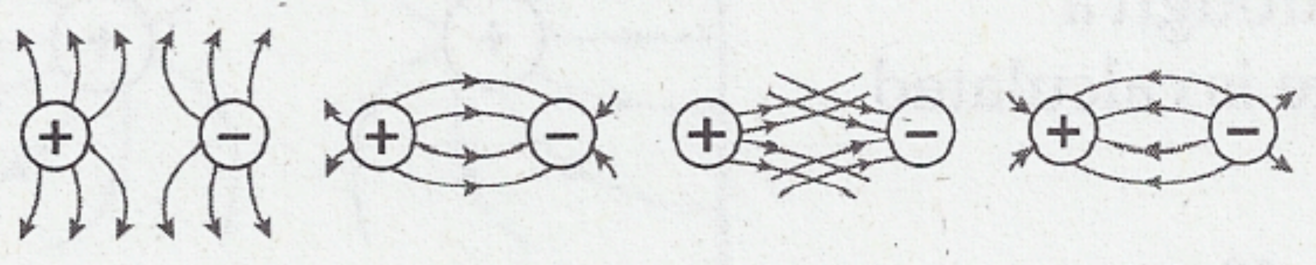
The magnitude of the strength of the electric field is

(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

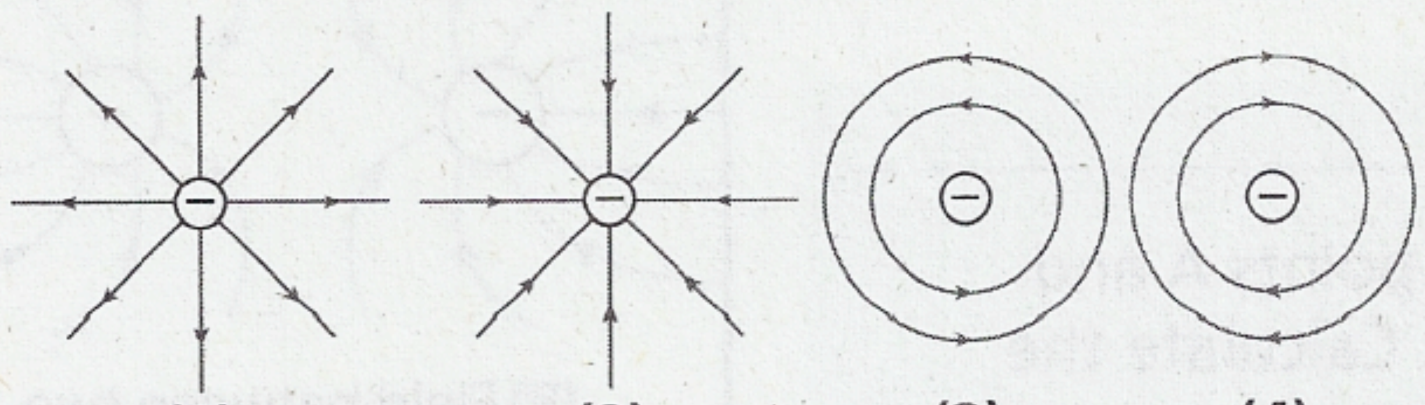
(1) unchanged
(2) doubled
(3) halved
(4) quadrupled

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?



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

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. In an electric field, 6.0 joules of work are done to move 2.0 coulombs of charge from point A to point B. Calculate the potential difference between points A and B.

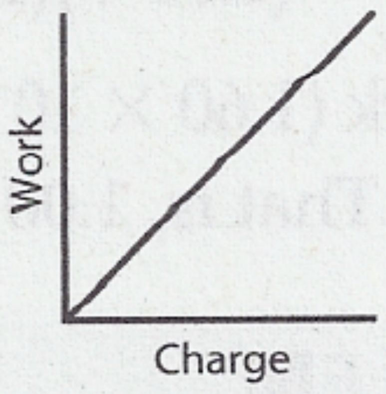
25. A helium ion with a charge of +2e is accelerated by a potential difference of 5.0×10^3 volts. What is the kinetic energy acquired by the ion?

(1) 3.2×10^{-19} eV
(2) 2.0 eV
(3) 5.0×10^3 eV
(4) 1.0×10^4 eV

26. Calculate the potential difference across a 6-ohm resistor if 4 joules of work are required to move 2 coulombs of charge through 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 electronvolts?

28. The uniform electric field between two oppositely charged parallel plates does work on a series of small positively charged spheres in moving them from one plate to the other. The graph below represents the relationship between the work done on the spheres and their respective charges.



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. Current is a scalar quantity. 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.

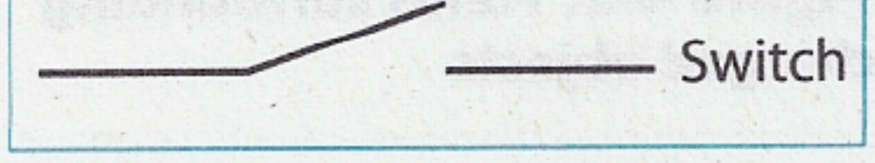


Figure 4-3. The symbol for a switch Ⓡ

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:

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

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

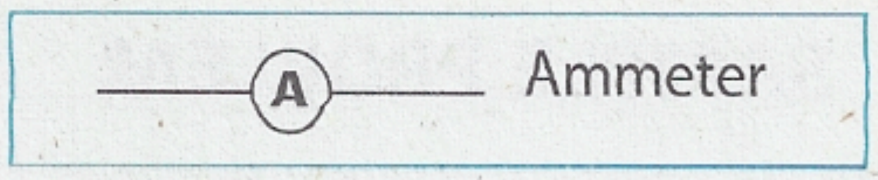


Figure 4-4. The symbol for an ammeter

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.

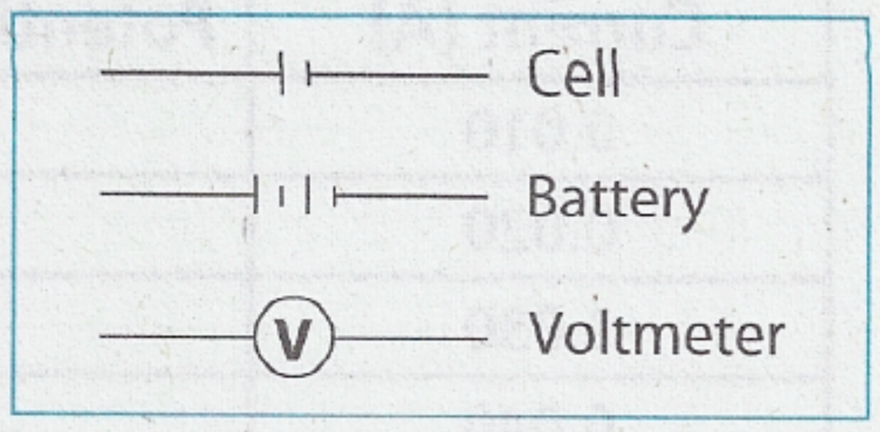


Figure 4-5. Symbols for sources of potential difference (voltage) and a voltmeter for measuring potential difference

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.

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

The potential difference V is in volts, current I is in amperes, and resistance R is 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 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*
$V = 12.0\ \text{V}$	$R = ?\ \Omega$
$I = 0.10\ \text{A}$	

1. Write the formula for Ohm's law.

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

2. Substitute the known values 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.

Data Table

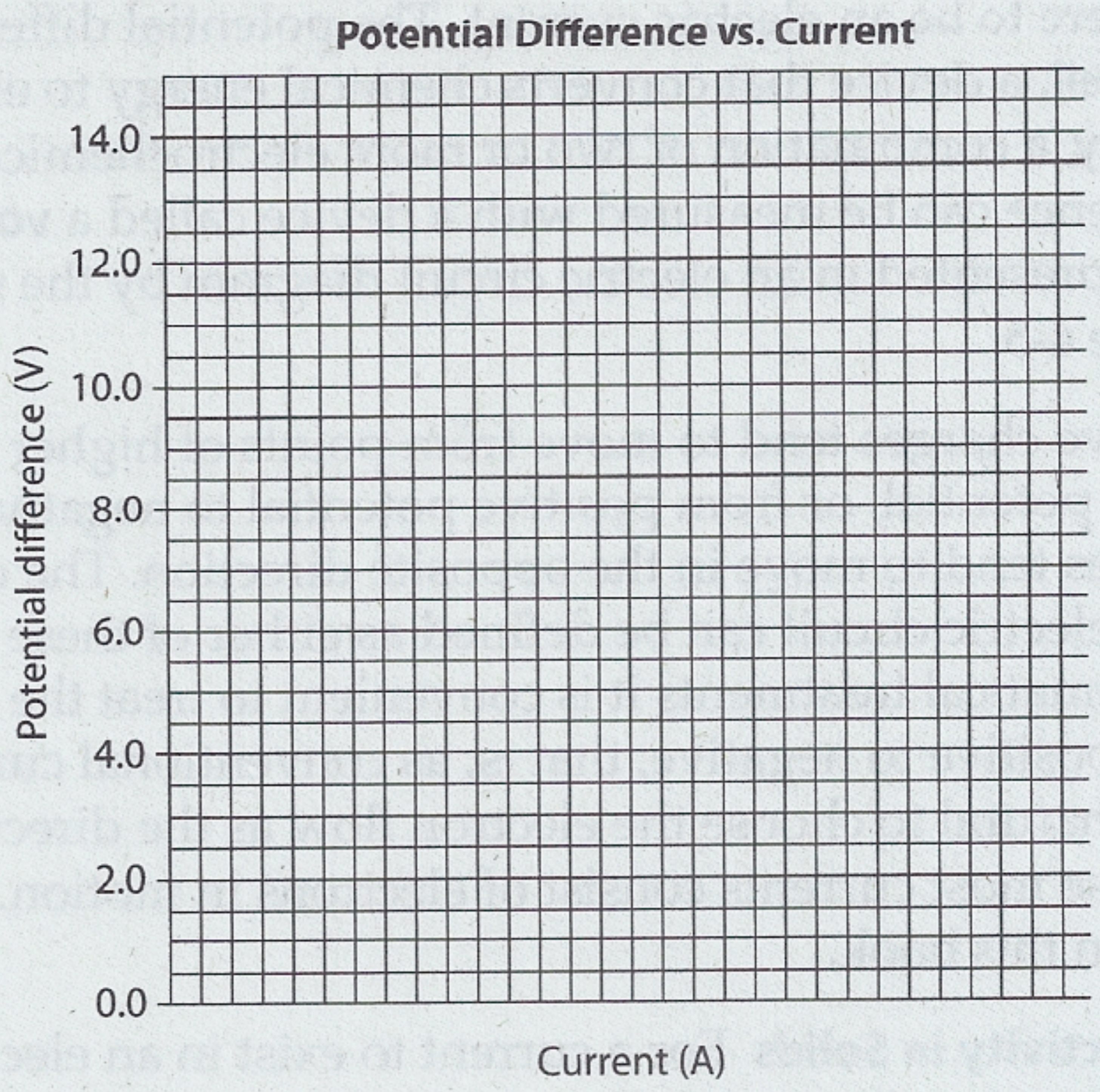
Current (A)	Potential Difference (V)
0.010	2.3
0.020	5.2
0.030	7.4
0.040	9.9
0.050	12.7

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

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

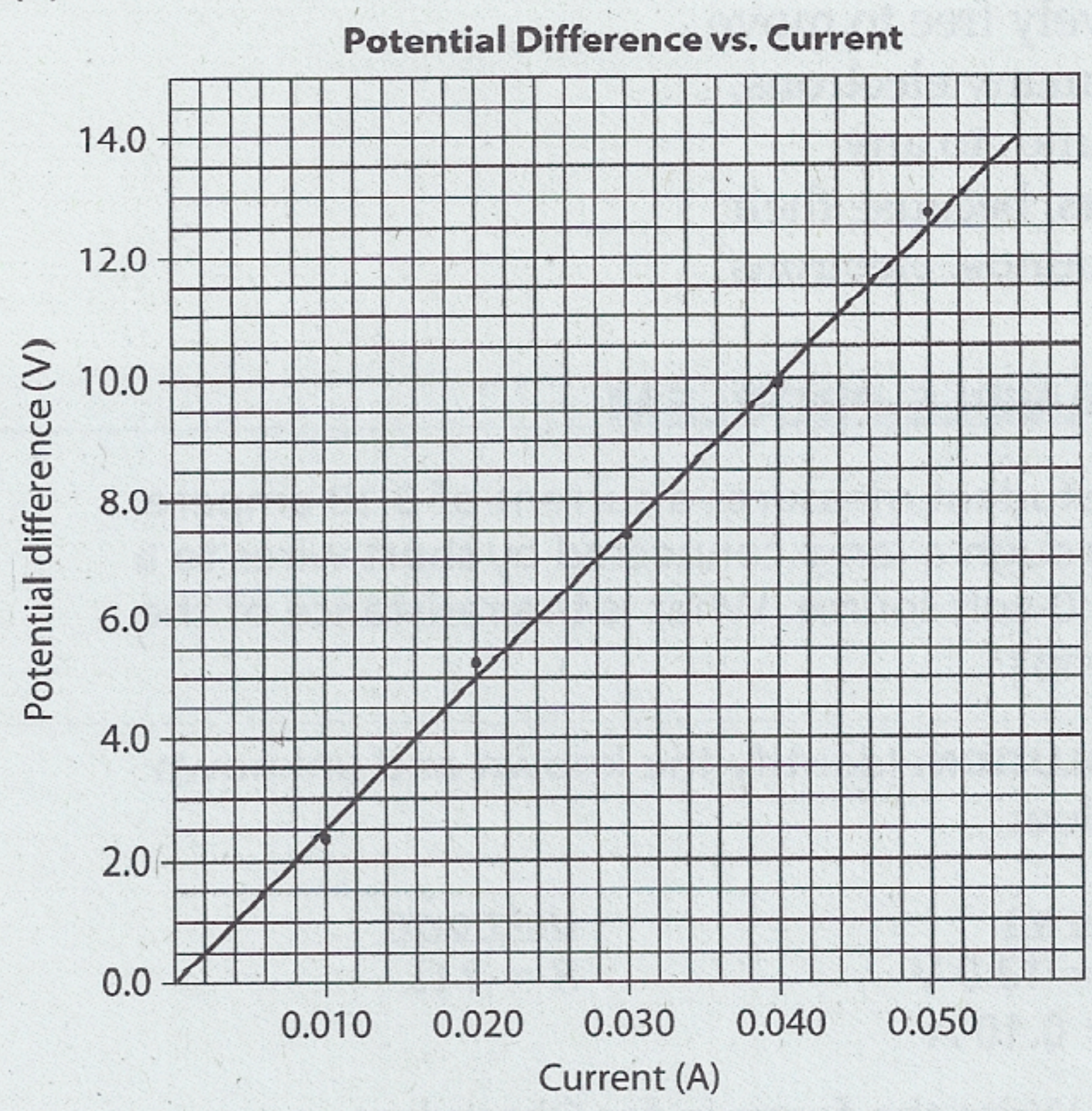
(b) Using your graph, find the slope of the best-fit line.

(c) Identify the physical quantity represented by the slope of the graph.



SOLUTION:

(a)



(b) Write the formula for slope.

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{\Delta V}{\Delta I}$$

Substitute values from places where the graphed line intersects the grid and solve. Points directly from the data table can be used only if those points lie on the line of best fit.

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

(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 $\Omega \cdot$ 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 formula for the resistance of a wire.

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

The resistivity ρ is in ohm · meters, length L is in meters, cross-sectional area A is in meters^2, and resistance R is in ohms.

SAMPLE PROBLEM

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

Unknown
$R = ?\ \Omega$

1. Write the formula that defines resistance.

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

2. Write the formula for the area of a circle given its radius. Recall that the radius equals one-half the diameter.

$$A = \pi r^2$$

3. Combine the equations.

$$R = \frac{\rho L}{\pi r^2}$$

4. Substitute the known values 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.

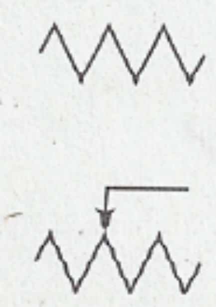


Figure 4-6. Symbols for a resistor and a variable resistor

Review Questions

29. A total of 20.0 coulombs of charge pass a given point in a conductor in 4.0 seconds. Calculate 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}

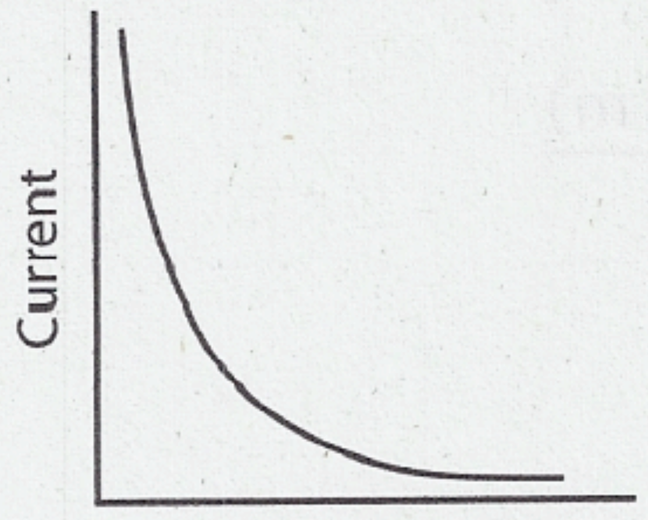
31. Which condition must exist between two points in a conductor in order to maintain a flow of charge?

(1) a potential difference
(2) a magnetic field
(3) a low resistance
(4) a high resistance

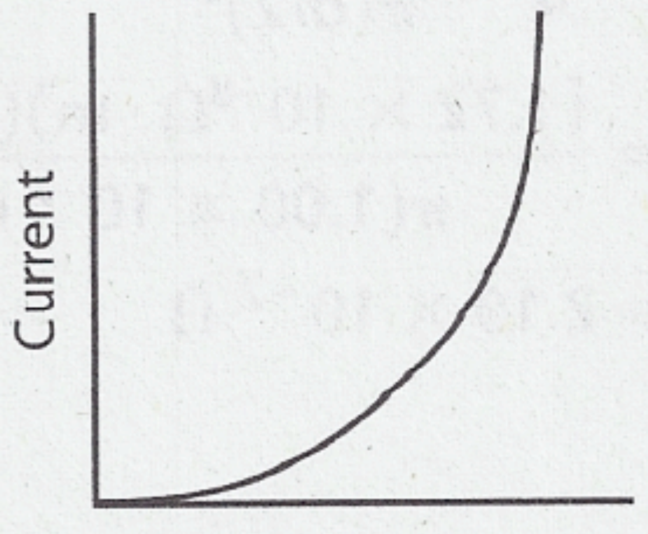
32. A simple circuit consists of a variable resistor connected to a battery. An ammeter and a voltmeter are connected properly in the circuit to measure the current through and potential drop across the variable resistor. What is the effect of increasing the resistance of the variable resistor from 10^3 ohms to 10^4 ohms ? [Assume constant temperature.]

(1) The ammeter reading decreases.
(2) The ammeter reading increases.
(3) The voltmeter reading decreases.
(4) The voltmeter reading increases.

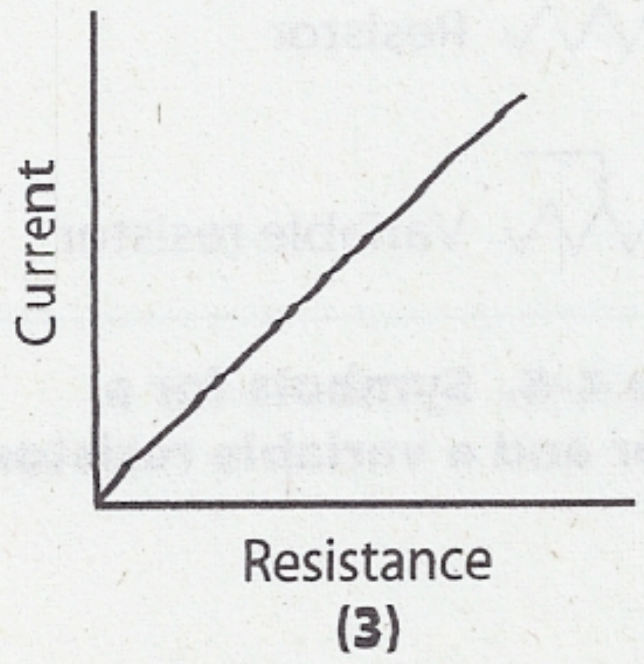
33. An electric circuit contains a variable resistor connected to a source of constant potential difference. Which graph best represents the relationship between current and resistance in this circuit?



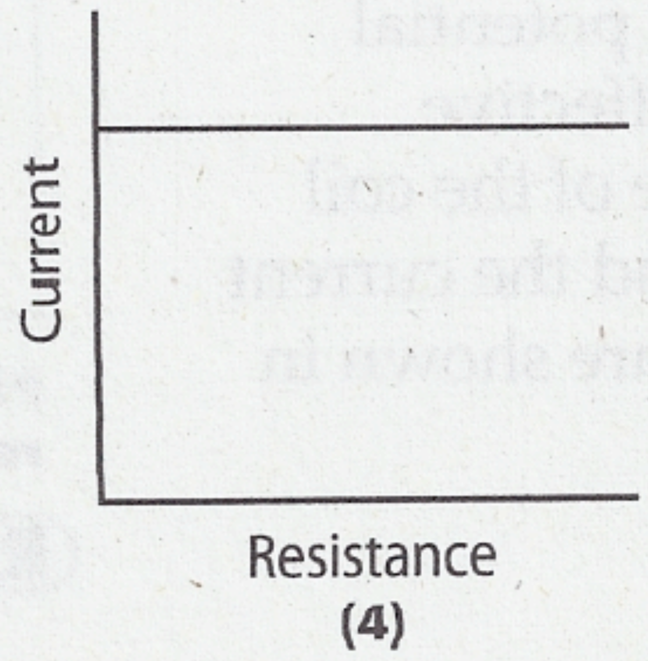
(1)



(2)

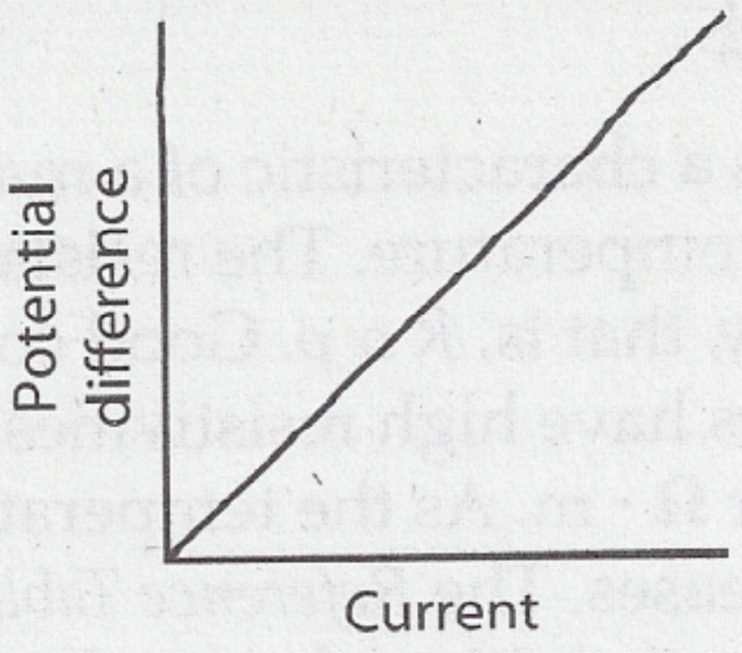


(3)



(4)

34. The graph below shows the relationship between potential difference and current in a simple circuit. [Assume constant temperature.]



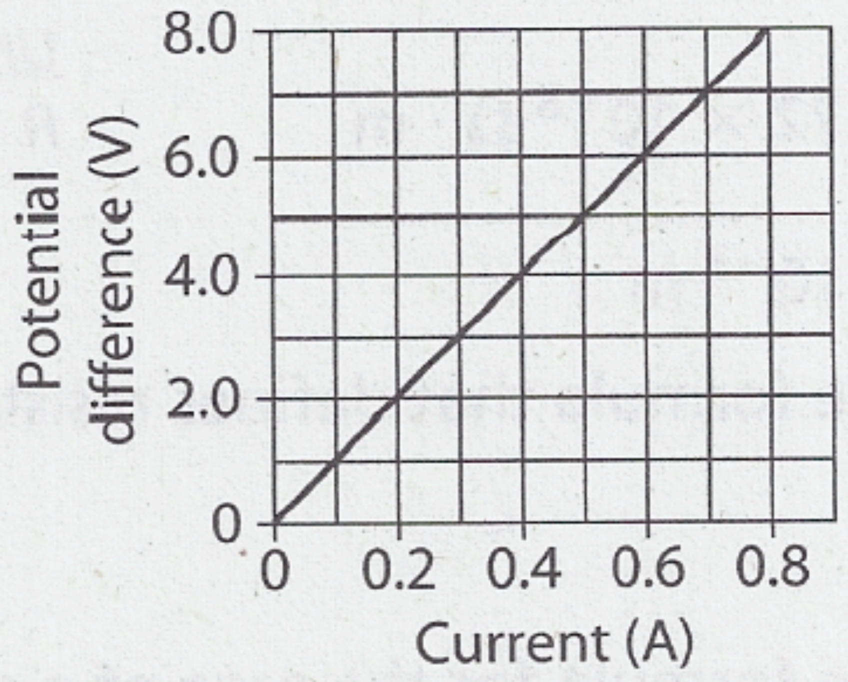
For any point on the line, what does the ratio of potential difference to current represent?

(1) resistivity in ohm·meters
(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. Calculate the potential difference across the resistor.

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

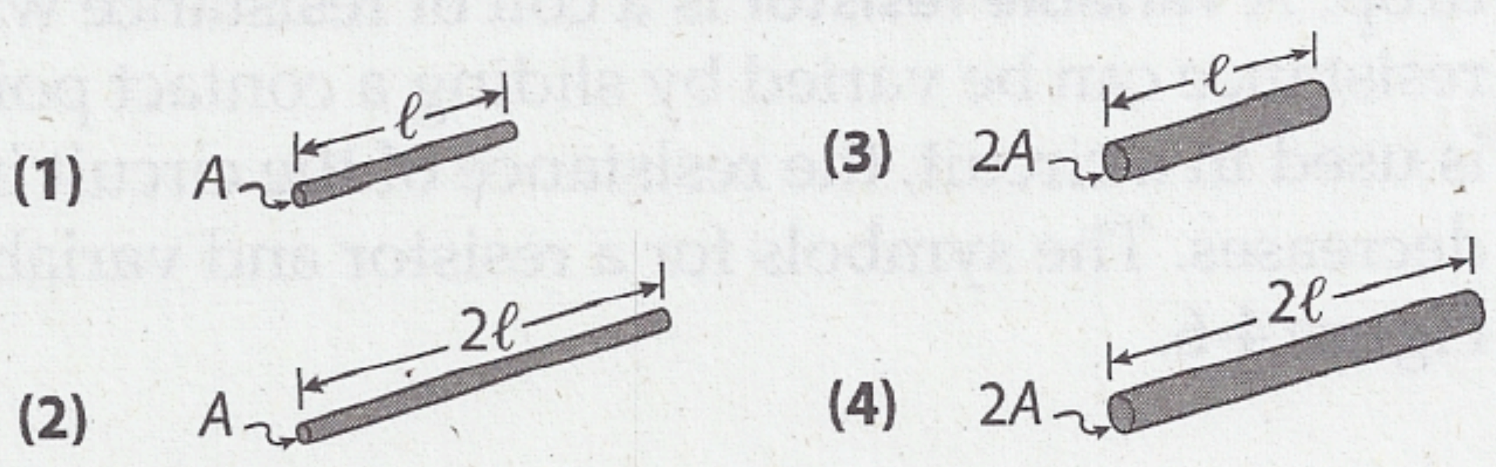
Potential Difference vs. Current



What is the resistance of the conductor?

37. A potential difference of 12 volts is applied across a circuit having a 4.0-ohm resistance. Calculate 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?



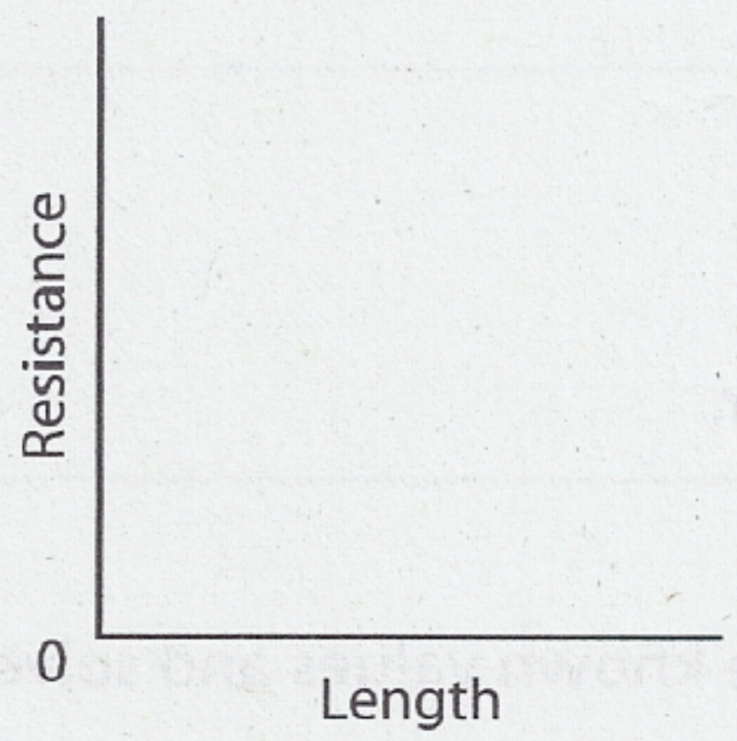
39. An incandescent lightbulb is supplied with a constant potential difference of 120 volts. As the filament of the bulb heats up, what happens to the resistance of the filament and the current through it?

(1) The resistance decreases, and the current decreases.
(2) The resistance decreases, and the current increases.
(3) The resistance increases, and the current decreases.
(4) The resistance increases, and the current increases.

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} meter^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} meter^2 and a resistance of 0.35 ohm. Calculate the resistivity of this tin wire.

46. At 20°C carbon has a resistivity of 3.5×10^{-5} ohm·meter. 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.

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

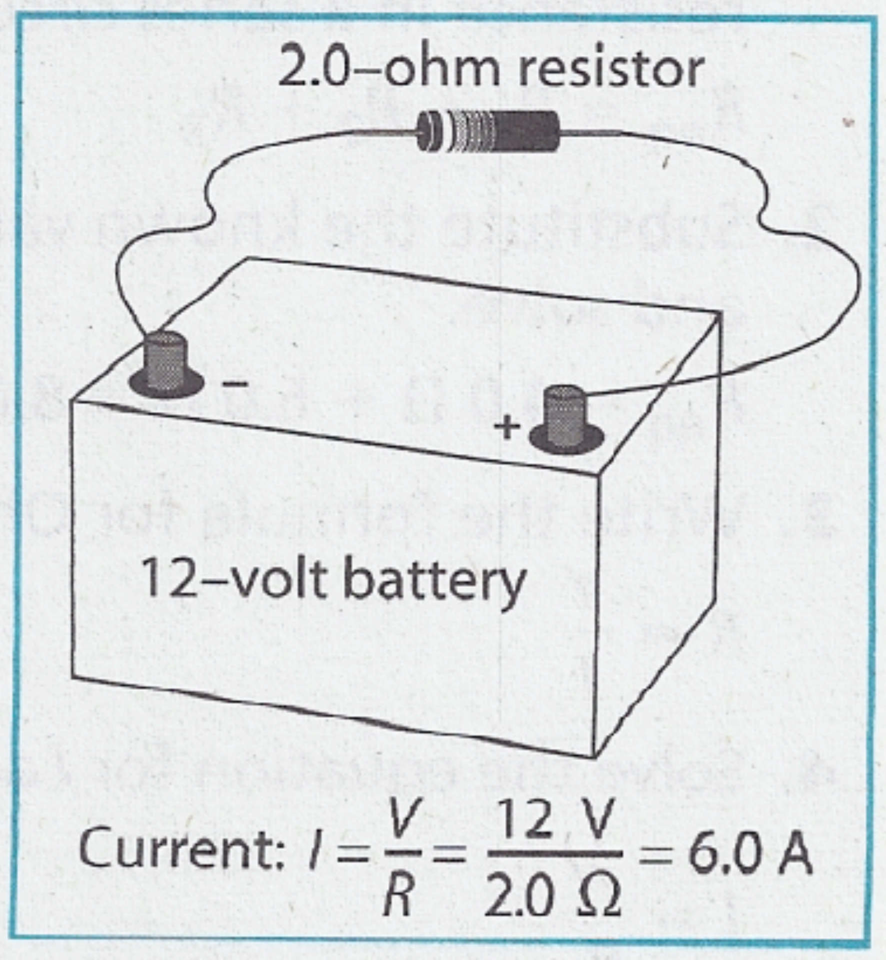


Figure 4-7. A simple circuit

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.

Since there is only one current path in a series circuit, the current is the same through each resistor. For resistors in series, the current is given by $I = I_1 = I_2 = I_3 = \ldots$. The applied potential difference at the terminals equals the sum of the potential differences across the individual resistors. That is, $V = V_1 + V_2 + V_3 + \ldots$ However, by Ohm's law $V = IR_{eq}$ where R_{eq} is the equivalent resistance of the entire circuit. **Equivalent resistance** is the single resistance that could replace the several resistors in a circuit. Substituting yields $IR_{eq} = I_1R_1 + I_2R_2 + I_3R_3 + \ldots$ However, because $I = I_1 = I_2 = I_3 = \ldots$, it follows that $IR_{eq} = IR_1 + IR_2 + IR_3 + \ldots$ Dividing each term in the equation by the common factor I yields $R_{eq} = R_1 + R_2 + R_3 + \ldots$

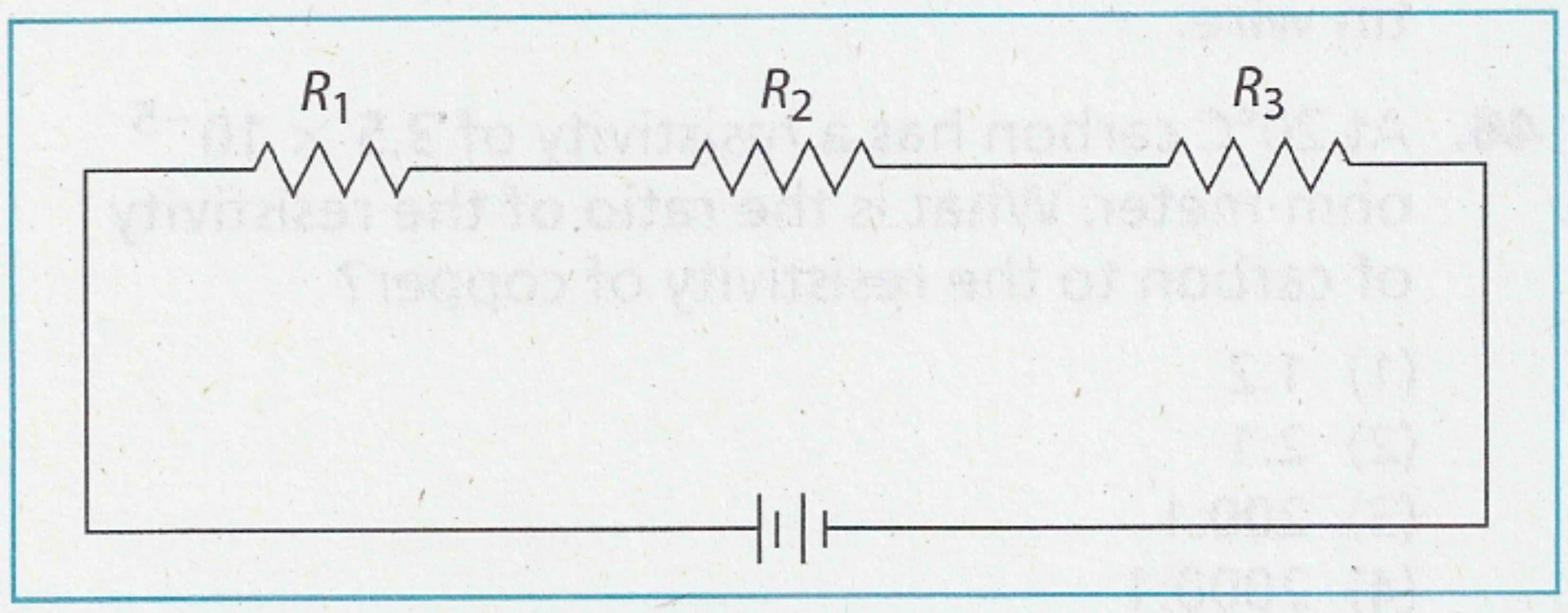


Figure 4-8. Resistors in a series circuit

To summarize for series circuits:

$$I = I_1 = I_2 = I_3 = \ldots$$
$$V = V_1 + V_2 + V_3 + \ldots$$
$$R_{eq} = R_1 + R_2 + R_3 + \ldots$$

SAMPLE PROBLEM

Three resistors, with resistances of 4.0 ohms, 6.0 ohms, and 8.0 ohms respectively, are connected in series to an applied potential difference of 36 volts. (a) Calculate the equivalent resistance. (b) Calculate the current through each resistor. (c) Calculate the potential drop across each resistor.

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
Series circuit	$R_{eq} = ?\ \Omega$
$R_1 = 4.0\ \Omega$	$I_1, I_2, I_3 = ?\ A$
$R_2 = 6.0\ \Omega$	$V_1 = ?\ V$
$R_3 = 8.0\ \Omega$	$V_2 = ?\ V$
$V = 36\ V$	$V_3 = ?\ V$

1. Write the formula for the equivalent resistance in a series circuit.

$$R_{eq} = R_1 + R_2 + R_3$$

2. Substitute the known values into the equation and solve.

$$R_{eq} = 4.0\ \Omega + 6.0\ \Omega + 8.0\ \Omega = 18.0\ \Omega$$

3. Write the formula for Ohm's law.

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

4. Solve the equation for I and substitute R_{eq} for R.

$$I = \frac{V}{R_{eq}}$$

5. Substitute the known values and solve.

$$I = \frac{36\ V}{18.0\ \Omega} = 2.0\ A$$

The current is the same throughout a series circuit.

$$I = I_1 = I_2 = I_3 = 2.0\ A$$

6. Use Ohm's law to calculate the potential difference across each resistor.

$$V_1 = I_1R_1 = (2.0\ A)(4.0\ \Omega) = 8.0\ V$$
$$V_2 = I_2R_2 = (2.0\ A)(6.0\ \Omega) = 12\ V$$
$$V_3 = I_3R_3 = (2.0\ A)(8.0\ \Omega) = 16\ V$$

Note that when resistors in a circuit are connected in series, the sum of the potential differences across the individual resistors is equal to the applied potential difference.

$$V = V_1 + V_2 + V_3 = 8.0\ V + 12\ V + 16\ V = 36\ V$$

Parallel Circuits A **parallel circuit** is a circuit in which the elements are connected between two points, with one of the two ends of each component connected to each point. Consequently, there are two or more paths for current flow. As shown in Figure 4-9, current is divided among the branches of the circuit.

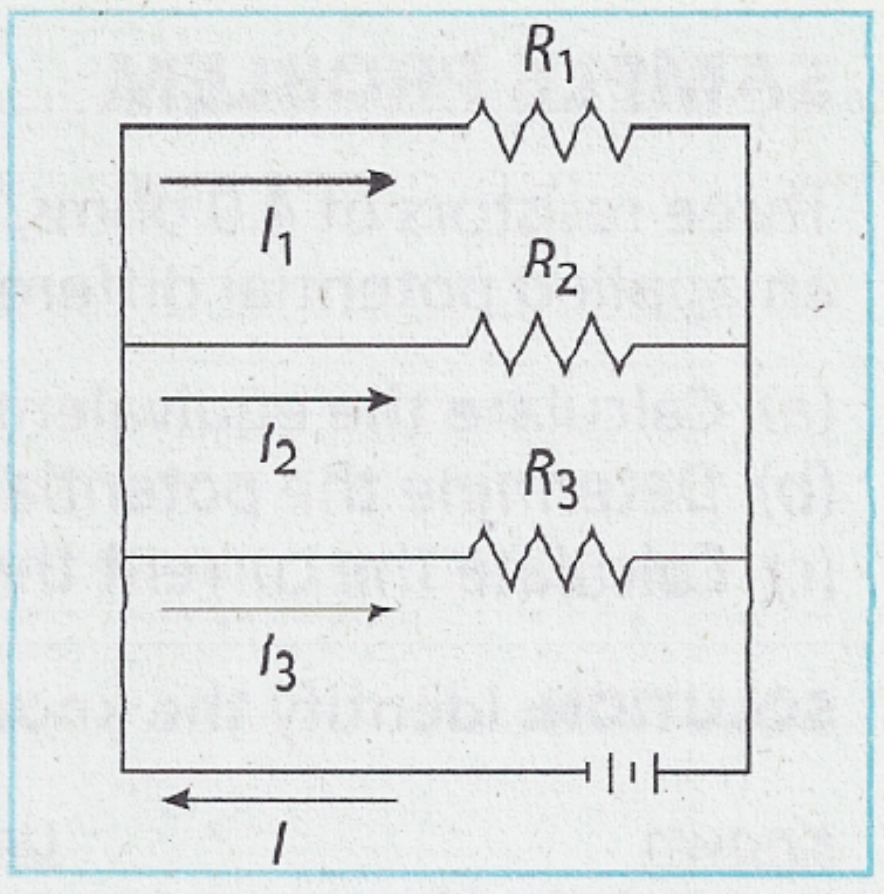


Figure 4-9. Currents in a parallel circuit: The total current *I* is divided among the three branches of the circuit.

In a parallel circuit, the sum of the currents in the branches is equal to the total current from the source. That is, $I = I_1 + I_2 + I_3 + \ldots$. The potential difference across each branch of the parallel circuit is the same as that of the potential difference supplied by the source, so $V = V_1 = V_2 = V_3 = \ldots$.

However, according to Ohm's law $I = \frac{V}{R}$ for each branch of the circuit. Substituting yields

$I = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \ldots$. By Ohm's law it is known that $I = \frac{V}{R_{eq}}$ for the circuit. Therefore,

$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + \ldots$. Dividing each term by V yields

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

To summarize for parallel circuits:

$$I = I_1 + I_2 + I_3 + \ldots$$
$$V = V_1 = V_2 = V_3 = \ldots$$
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

Note that in a parallel circuit the equivalent resistance R_{eq} is always less than the resistance of any branch. In addition, since V is the same for each branch, the current in each branch is inversely proportional to its resistance. As additional resistors or electrical devices are connected in parallel in a given circuit, the equivalent resistance of the circuit decreases. Consequently the total current in the circuit increases, perhaps to dangerous levels. A fuse or circuit breaker is inserted in the main line of each circuit in the home as a safety device. If the current becomes too large, the fuse or circuit breaker opens.

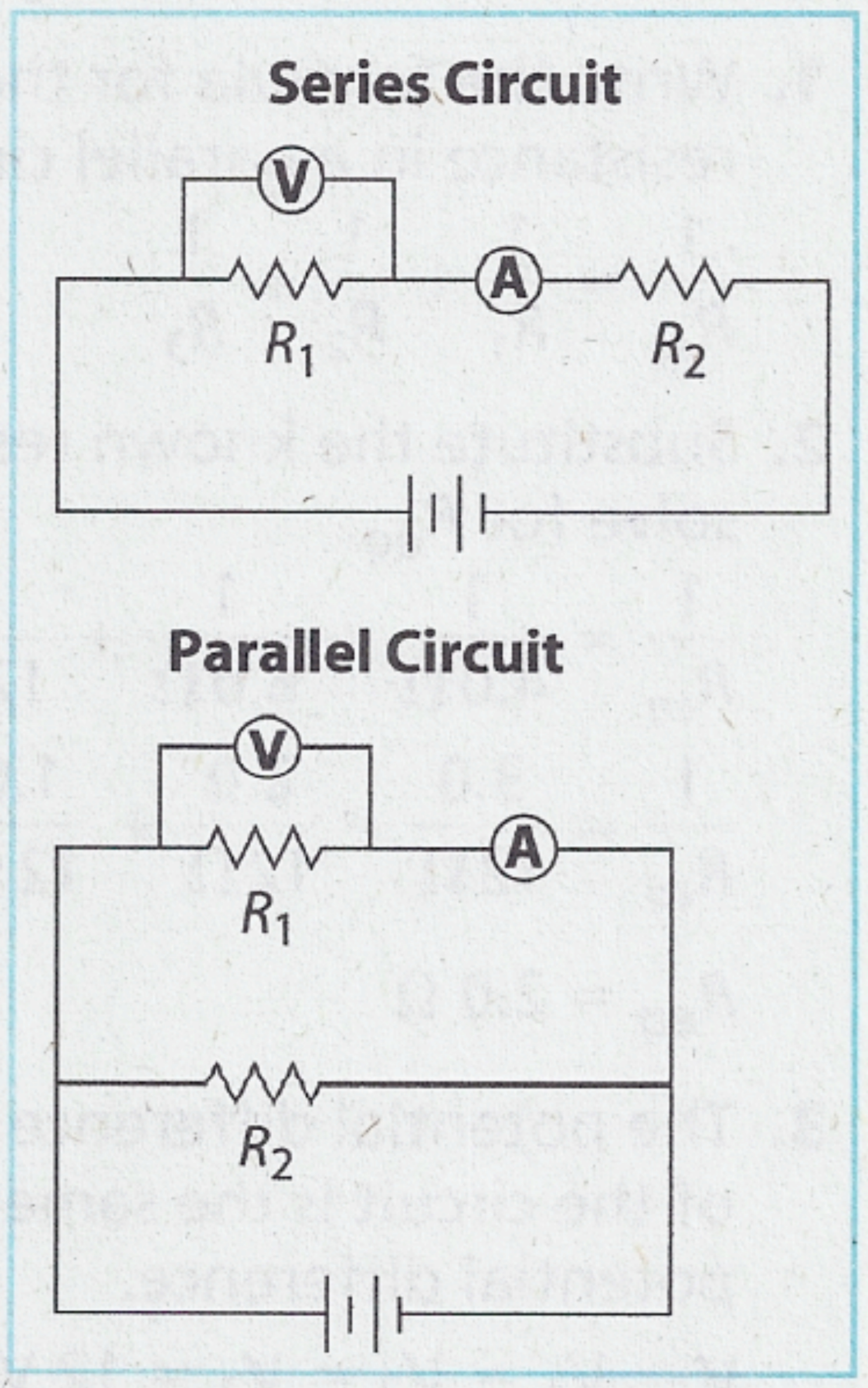


Figure 4-10. Connecting ammeters and voltmeters: The diagram shows how to use an ammeter and a voltmeter to measure the current through and the potential difference across the resistor R_1 in a series circuit and in a parallel circuit.

Meters in a Circuit As noted earlier, an ammeter is used to measure current and a voltmeter is used to measure potential difference. An ammeter is always connected in series with the circuit element being measured, whereas a voltmeter is always connected in parallel. The diagrams in Figure 4-10 show an ammeter and a voltmeter connected to determine the current through and potential difference across resistor R_1.

Conservation of Charge in Electric Circuits Charge in an electric circuit must be conserved. At any junction in a circuit, the sum of the currents entering the junction must equal the sum of the currents leaving it. Figure 4-11 illustrates the conservation of charge at a junction.

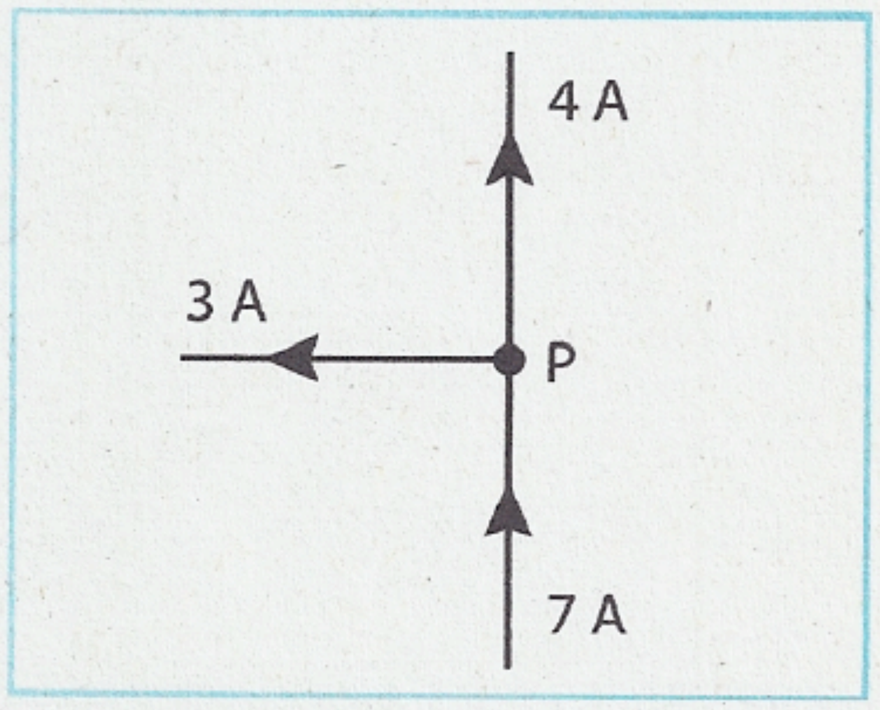


Figure 4-11. Current traveling near junction P in an electric circuit: Note that the sum of currents leaving the junction (3 A + 4 A) equals the current entering the junction (7 A).

Electric Power Recall that power is the time rate of doing work or expending energy. That is $P = \frac{W}{t}$ where work W is in joules, time t is in seconds, and power P is in watts. The derived SI unit for power is the

SAMPLE PROBLEM

Three resistors of 4.0 ohms, 6.0 ohms, and 12 ohms are connected in parallel to an applied potential difference of 12 volts.

(a) Calculate the equivalent resistance.
(b) Determine the potential difference across each resistor.
(c) Calculate the current through each resistor.

SOLUTION: Identify the known and unknown values.

Known	Unknown
Parallel circuit	$R_{eq} = ?\ \Omega$
$R_1 = 4.0\ \Omega$	$V_1, V_2, V_3 = ?\ V$
$R_2 = 6.0\ \Omega$	$I_1 = ?\ A$
$R_3 = 12.0\ \Omega$	$I_2 = ?\ A$
$V = 12\ V$	$I_3 = ?\ A$

1. Write the formula for the equivalent resistance in a parallel circuit.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

2. Substitute the known resistance values and solve for R_{eq}.

$$\frac{1}{R_{eq}} = \frac{1}{4.0\ \Omega} + \frac{1}{6.0\ \Omega} + \frac{1}{12\ \Omega}$$

$$\frac{1}{R_{eq}} = \frac{3.0}{12\ \Omega} + \frac{2.0}{12\ \Omega} + \frac{1.0}{12\ \Omega}$$

$$R_{eq} = 2.0\ \Omega$$

3. The potential difference across each branch of the circuit is the same as the applied potential difference.

$$V = V_1 = V_2 = V_3 = 12\ V$$

4. Write the formula for Ohm's law.

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

5. Solve the equation for I.

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

6. Substitute the known values for each individual resistor and solve.

$$I_1 = \frac{V_1}{R_1} = \frac{12\ V}{4.0\ \Omega} = 3.0\ A$$

$$I_2 = \frac{V_2}{R_2} = \frac{12\ V}{6.0\ \Omega} = 2.0\ A$$

$$I_3 = \frac{V_3}{R_3} = \frac{12\ V}{12\ \Omega} = 1.0\ A$$

Note that when resistors are connected in parallel in a circuit, the sum of the currents in the resistors is equal to the total current (the current leaving the source).

$$I = I_1 + I_2 + I_3$$

$$I = 3.0\ A + 2.0\ A + 1.0\ A = 6.0\ A$$

$$\text{Check: } I = \frac{V}{R_{eq}} = \frac{12\ V}{2.0\ \Omega} = 6.0\ A$$

watt, W. In fundamental units, one watt equals one $\frac{\text{kilogram} \cdot \text{meter}^2}{\text{second}^3}$. Power is a scalar quantity.

Electrical power is the product of potential difference and current. That is, $P = VI$ where power P is in watts, potential difference V is in volts, and current I is in amperes. It can be seen that this equation is valid by analyzing the units.

$$(1\ \text{volt})\ (1\ \text{ampere}) = \left(1 \frac{\text{joule}}{\text{coulomb}}\right)\left(1 \frac{\text{coulomb}}{\text{second}}\right)$$

$$= 1 \frac{\text{joule}}{\text{second}}$$

$$= 1\ \text{watt}$$

By Ohm's law $V = IR$, so IR can be substituted for V in the equation $P = VI$. This yields:

$$P = VI = (IR)I = I^2R$$

Because $I = \frac{V}{R}$, it follows by substitution that

$$P = VI = V\left(\frac{V}{R}\right) = \frac{V^2}{R}$$

These relationships are summarized below.

Ⓡ $$P = VI = I^2R = \frac{V^2}{R}$$

Electrical Energy Recall from Topic 3 that energy is the capacity for doing work. In an electric circuit the total **electrical energy** W is equal to the product of the power consumed P and the time t of charge flow. That is,

Ⓡ $$W = Pt = VIt = I^2Rt = \frac{V^2t}{R}$$

The SI derived unit for electrical energy is the **joule,** J. In fundamental units, one joule equals one $\frac{\text{kilogram} \cdot \text{meter}^2}{\text{second}^2}$. Electrical energy is a scalar quantity.

SAMPLE PROBLEM A

A potential difference of 60.0 volts is applied across a 15-ohm resistor. Calculate the power dissipated in the resistor.

SOLUTION: Identify the known and unknown values.

<u>Known</u>	<u>Unknown</u>
$V = 60.0$ V	$P = ?$ W
$R = 15\ \Omega$	

1. Write a formula for power in terms of potential difference and resistance.

$$P = \frac{V^2}{R}$$

2. Substitute the known values and solve.

$$P = \frac{(60.0\text{ V})^2}{15\ \Omega} = 240\text{ W}$$

SAMPLE PROBLEM B

A current of 0.40 ampere is measured in a 150-ohm resistor. Calculate the total energy expended by the resistor in 30. seconds.

SOLUTION: Identify the known and unknown values.

<u>Known</u>	<u>Unknown</u>
$I = 0.40$ A	$W = ?$ J
$R = 150\ \Omega$	
$t = 30.$ s	

1. Write a formula for electrical energy or work in terms of current, resistance, and time.

$$W = I^2Rt$$

2. Substitute the known values and solve.

$$W = (0.40\text{ A})^2(150\ \Omega)(30.\text{ s}) = 720\text{ J}$$

Review Questions

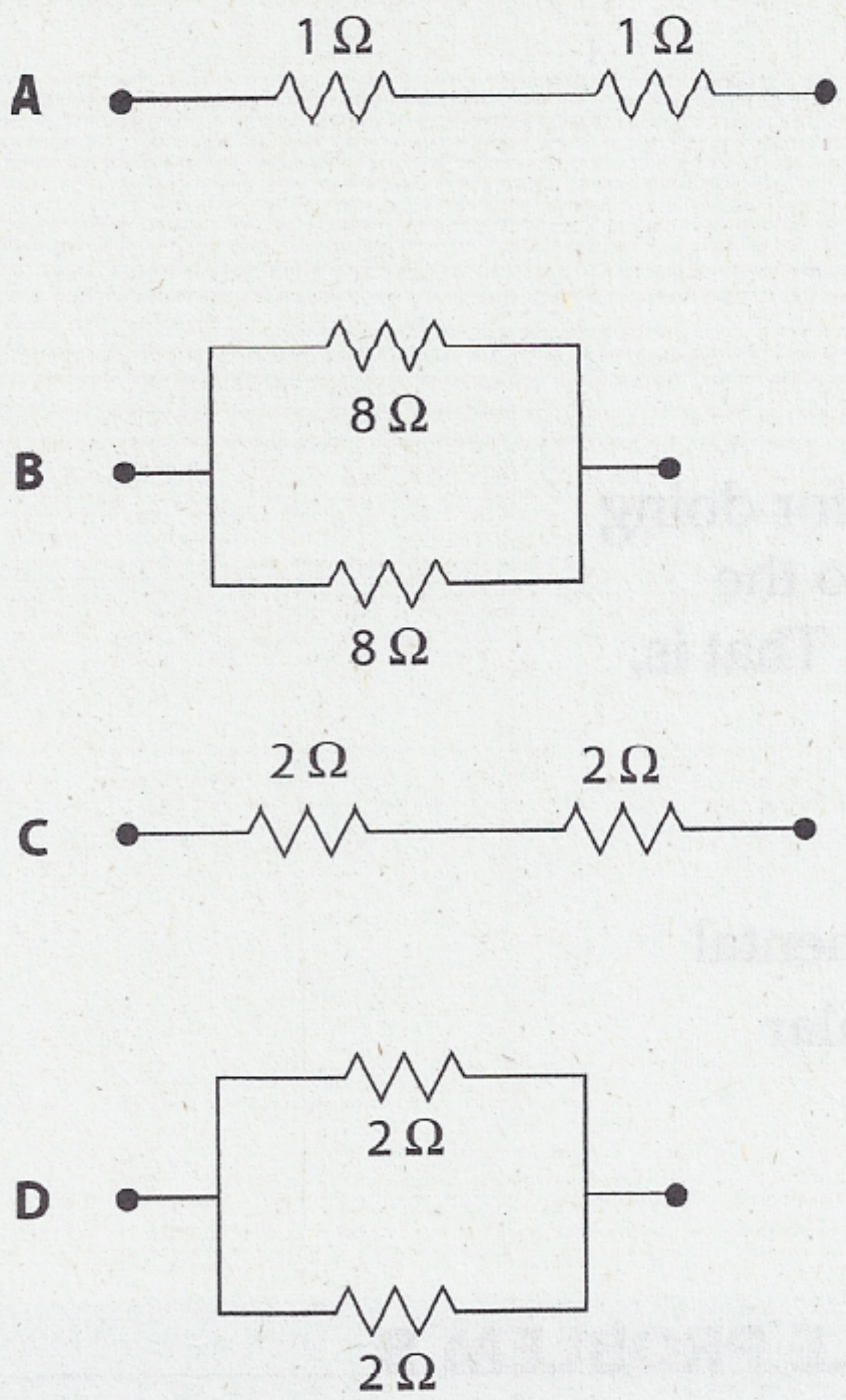
49. A 4-ohm resistor and an 8-ohm resistor are connected in series. If the current through the 4-ohm resistor is 2 amperes, the current through the 8-ohm resistor is

(1) 1 A (2) 2 A (3) 0.5 A (4) 4 A

50. If a 15-ohm resistor is connected in parallel with a 30.-ohm resistor, the equivalent resistance is

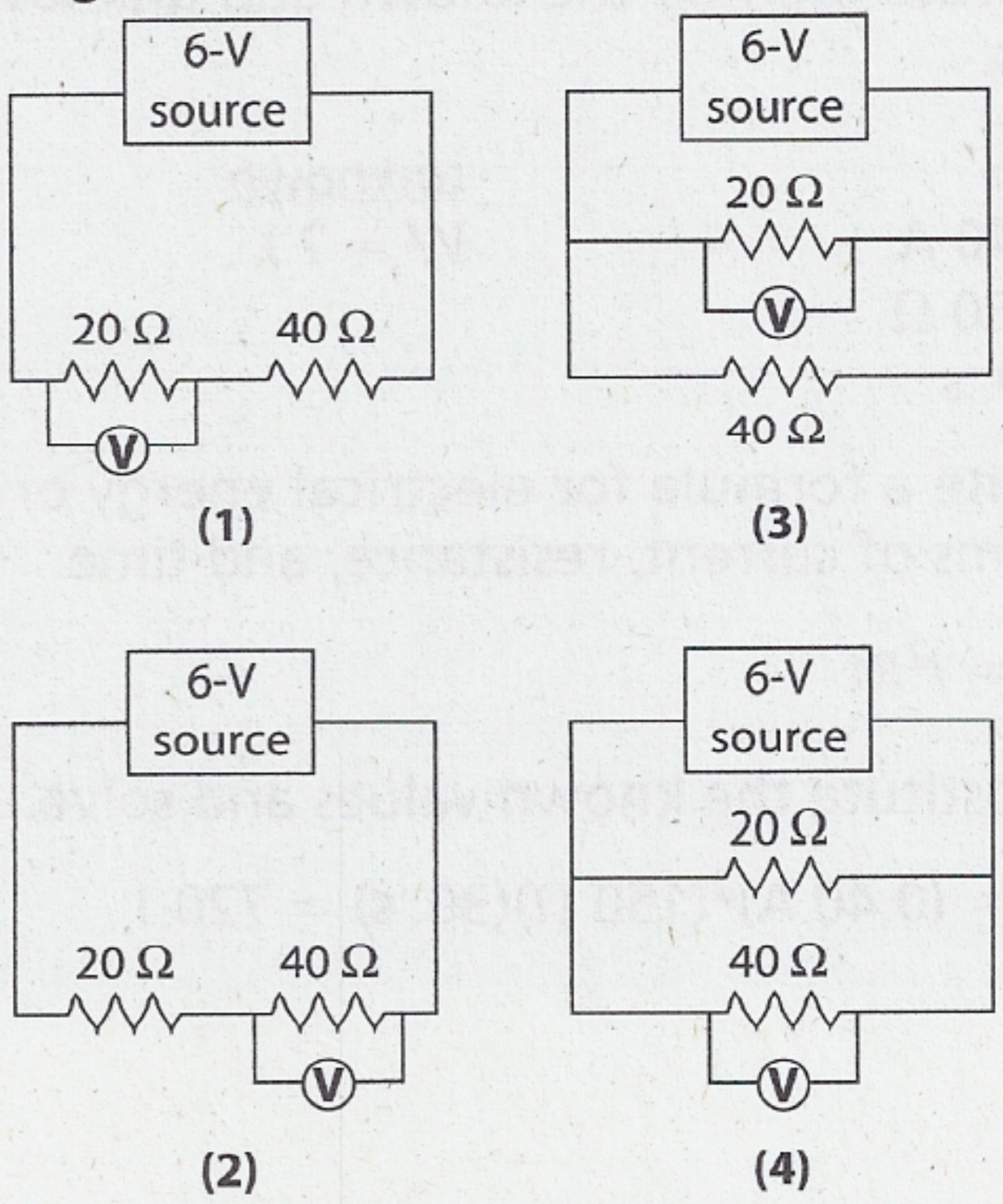
(1) 15 Ω (2) 2.0 Ω (3) 10. Ω (4) 45 Ω

51. Which two of the resistor arrangements below have the same equivalent resistance?

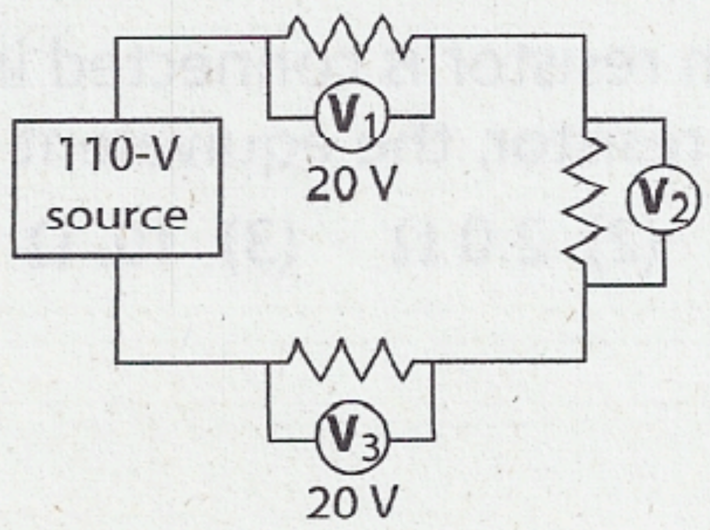


(1) A and B
(2) B and C
(3) C and D
(4) D and A

52. Which circuit would have the lowest voltmeter reading?

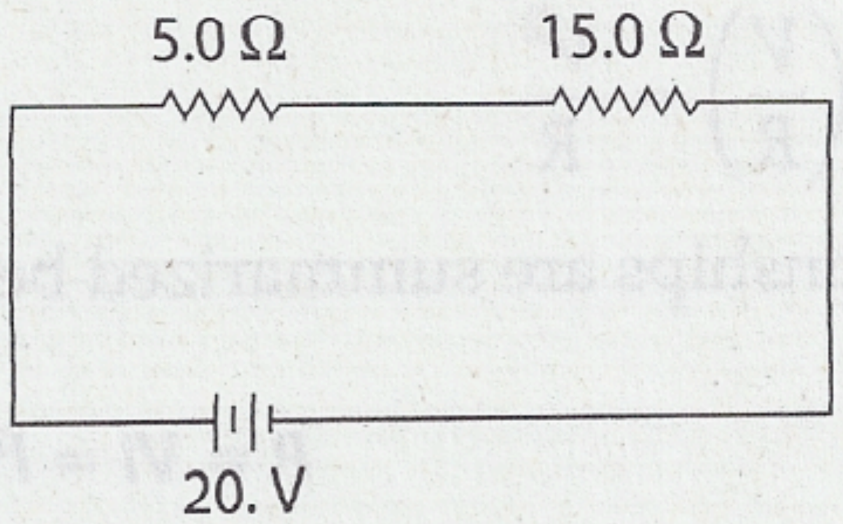


53. The circuit diagram below shows three voltmeters connected across resistors.



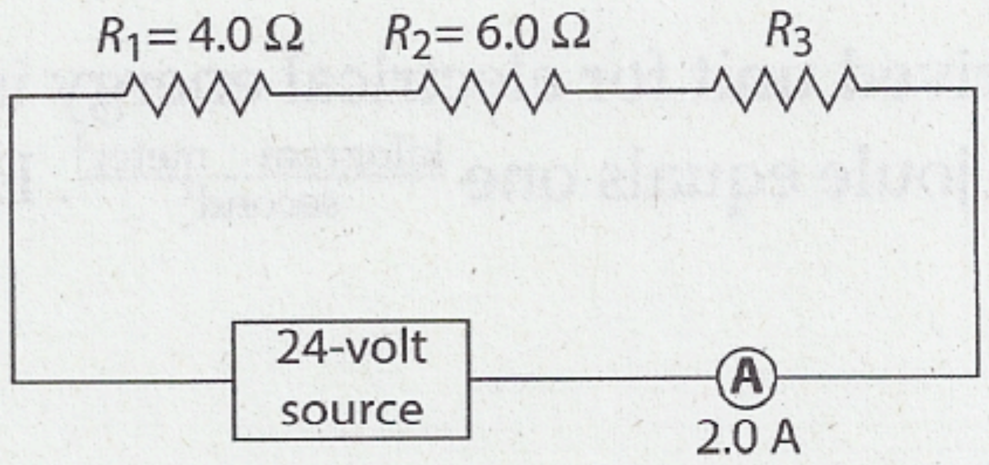
What is the reading of voltmeter V_2?

54. The diagram below shows two resistors connected to a 20.-volt battery.



If the current through the 5.0-ohm resistor is 1.0 ampere, what is the current through the 15.0-ohm resistor?

55. The diagram below shows a circuit with three resistors.



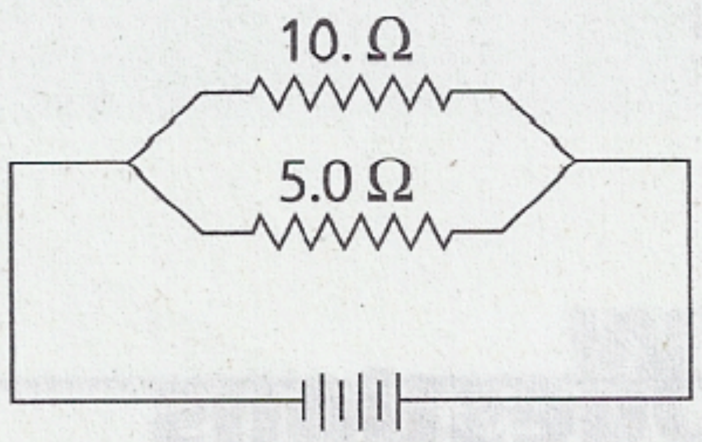
What is the resistance of resistor R_3?

(1) 6.0 Ω (2) 2.0 Ω (3) 12 Ω (4) 4.0 Ω

56. An electric circuit contains an operating heating element and a lit lamp. Which statement best explains why the lamp remains lit when the heating element is removed from the circuit?

(1) The lamp has less resistance than the heating element.
(2) The lamp has more resistance than the heating element.
(3) The lamp and heating element are connected in series.
(4) The lamp and heating element are connected in parallel.

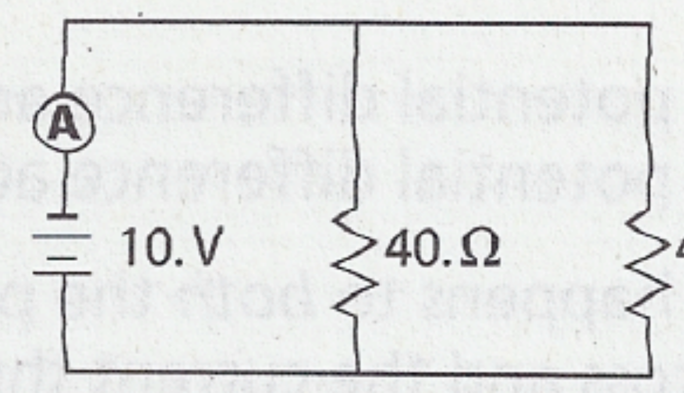
57. A 10.-ohm resistor and a 5.0-ohm resistor are connected as shown in the diagram below.



If the current through the 10.-ohm resistor is 1.0 ampere, then the current through the 5.0-ohm resistor is

(1) 15 A (2) 2.0 A (3) 0.50 A (4) 0.30 A

58. In the circuit diagram below, ammeter A measures the current supplied by a 10.-volt battery.



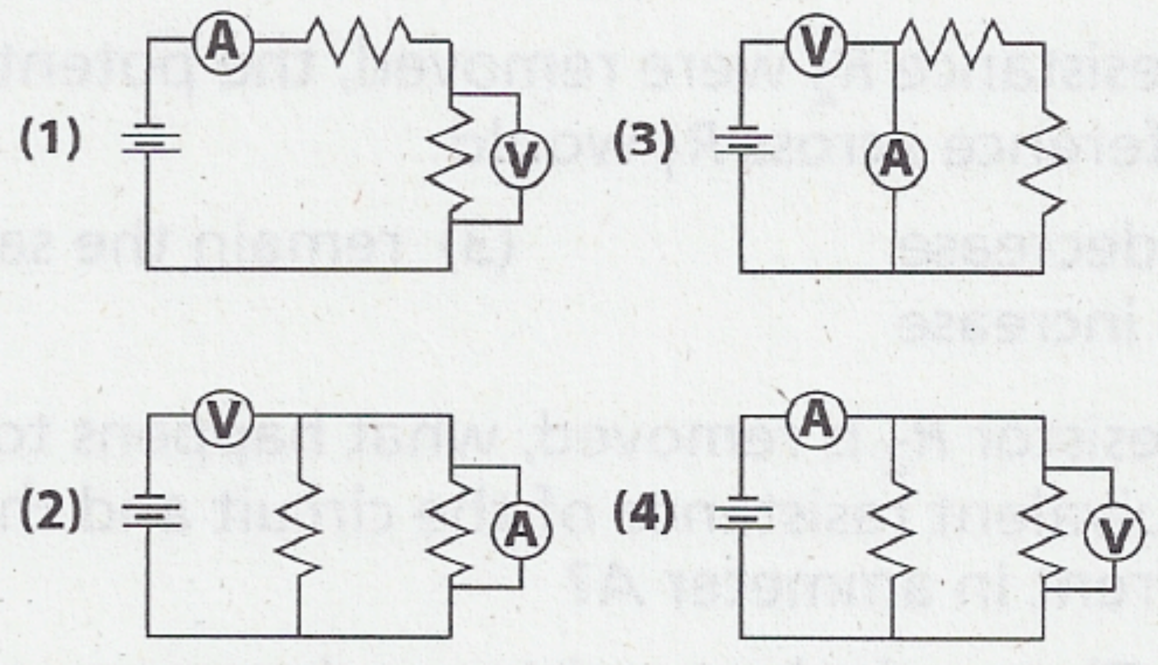
The current measured by ammeter A is

(1) 0.13 A (2) 2.0 A (3) 0.50 A (4) 4.0 A

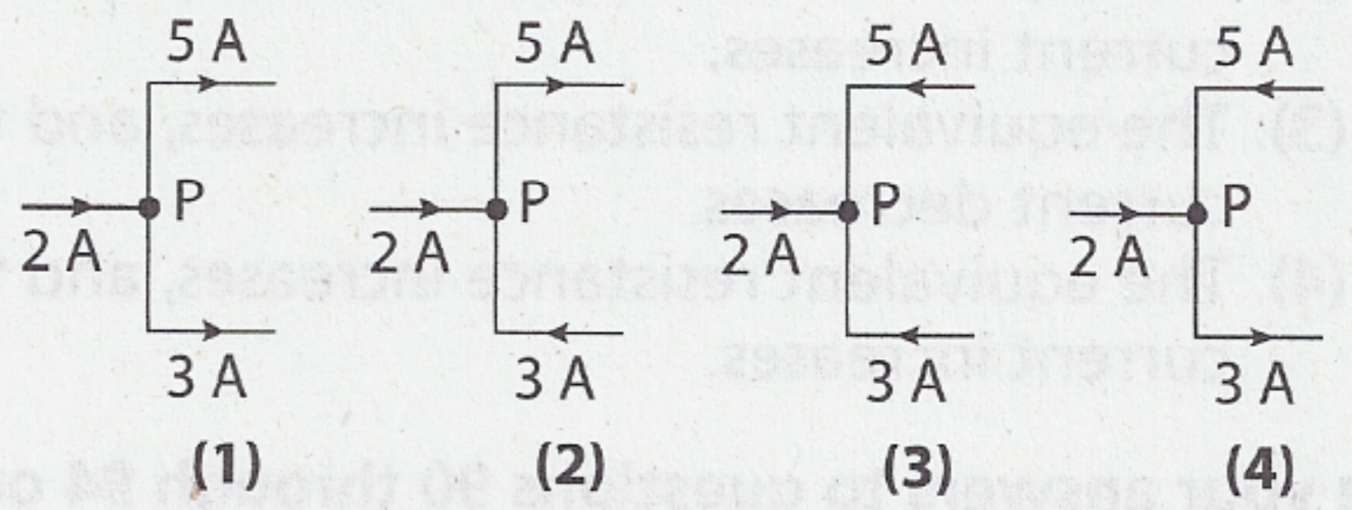
59. A physics student is given three 12-ohm resistors with instructions to create the circuit that would have the lowest possible resistance. The correct circuit would be a

(1) series circuit with an equivalent resistance of 36 Ω
(2) series circuit with an equivalent resistance of 4 Ω
(3) parallel circuit with an equivalent resistance of 36 Ω
(4) parallel circuit with an equivalent resistance of 4 Ω

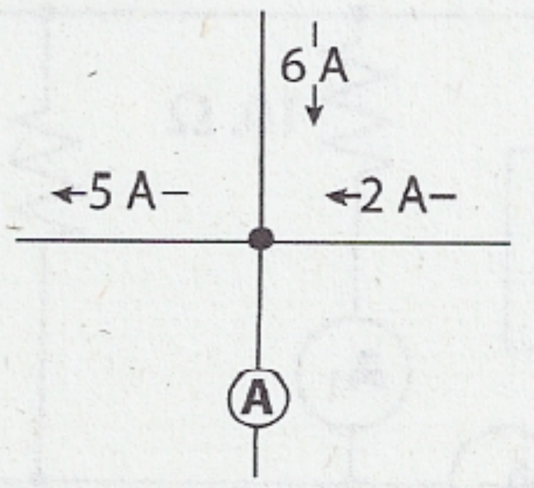
60. Which circuit could be used to determine the total current and potential difference of a parallel circuit?



61. Which diagram below shows correct current direction in a circuit segment?

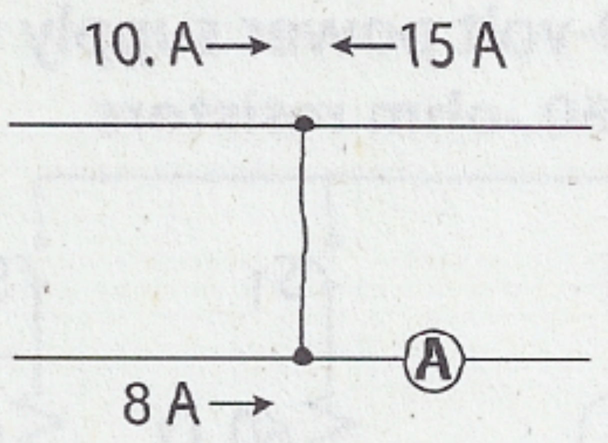


62. The diagram below shows currents in a segment of an electric circuit.



What is the reading of ammeter A?

63. The diagram below represents currents in branches of an electric circuit.



What is the reading on ammeter A?

64. An immersion heater has a resistance of 5.0 ohms while drawing a current of 3.0 amperes. What is the total electrical energy delivered to the heater during 4.0 minutes of operation?

(1) 1.8×10^2 J (3) 1.1×10^4 J
(2) 3.6×10^3 J (4) 5.4×10^4 J

65. In a simple circuit, two 3.0-ohm resistors are connected in series to a 12-volt battery. The rate at which electrical energy is expended in this circuit is

(1) 6.0 W (2) 12 W (3) 24 W (4) 36 W

66. Which combination of current and potential difference would use energy at the greatest rate?

(1) 7 A at 110 V (3) 3 A at 220 V
(2) 6 A at 110 V (4) 4 A at 220 V

67. How much time is required for an operating 100-watt incandescent lightbulb to dissipate 10 joules of electrical energy?

(1) 1 s (2) 0.1 s (3) 10 s (4) 1000 s

68. While operating at 120 volts, an electric toaster has a resistance of 15 ohms. The power used by the toaster is

(1) 8.0 W (2) 120 W (3) 960 W (4) 1800 W

69. An electric dryer consumes 6.0×10^6 joules of energy when operating at 220 volts for 30. minutes. During operation, the dryer draws a current of

(1) 10. A (2) 15 A (3) 20. A (4) 25 A

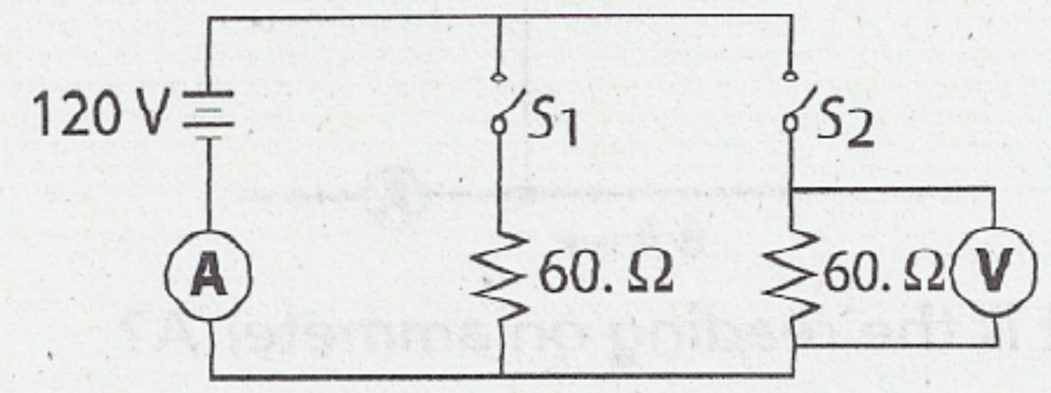
70. What is the total amount of electrical energy needed to operate a 1600-watt toaster for 60. seconds?

(1) 27 J (2) 1500 J (3) 1700 J (4) 96,000 J

71. To increase the brightness of a desk lamp, a student replaces a 60-watt incandescent lightbulb with a 100-watt incandescent lightbulb. Compared to the 60-watt lightbulb, the 100-watt lightbulb has

(1) less resistance and draws more current
(2) less resistance and draws less current
(3) more resistance and draws more current
(4) more resistance and draws less current

Base your answers to questions 72 through 75 on the diagram below, which represents a circuit containing a 120-volt power supply with switches S_1 and S_2 and two 60.-ohm resistors.



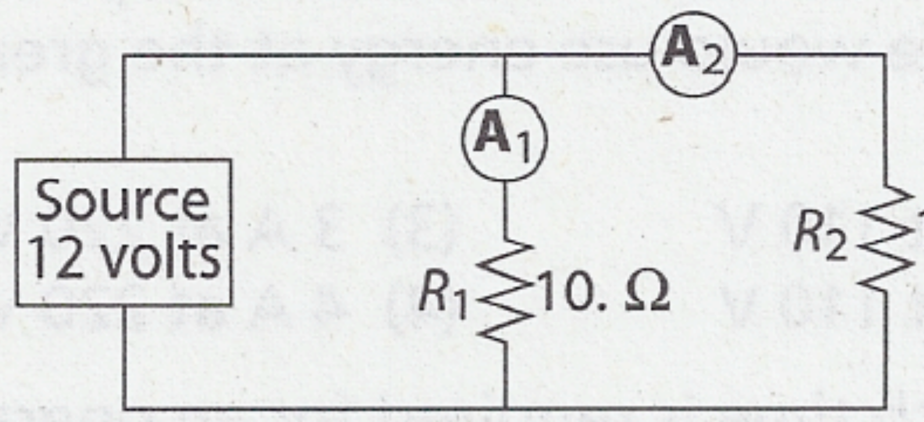
72. If switch S_1 is kept open and switch S_2 is closed, what is the circuit's resistance?

73. If switch S_2 is kept open and switch S_1 is closed, how much current will flow through the circuit?

74. When both switches are closed, what is the current in the ammeter?

75. When both switches are closed, what is the reading of the voltmeter?

Base your answers to questions 76 through 80 on the diagram below, which represents an electrical circuit.



76. Calculate the equivalent resistance of the circuit.

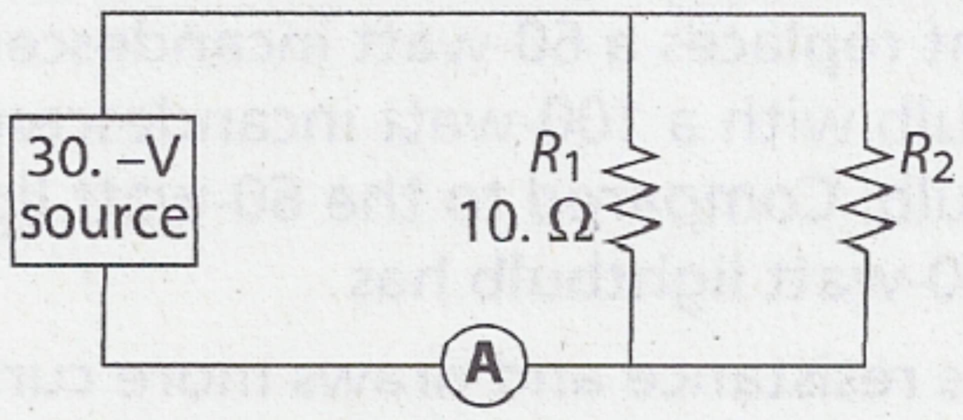
77. Determine the potential difference across resistor R_2.

78. Calculate the magnitude of the current through ammeter A_1.

79. Compare the current in ammeter A_1 to the current in ammeter A_2.

80. Explain what happens to *both* the equivalent resistance of the circuit and the total current in the circuit, if another resistor is added to the circuit in parallel.

Base your answers to questions 81 through 85 on the following information and diagram.
Two resistors, R_1 and R_2, and an ammeter are connected to a constant 30.-volt source.
The equivalent resistance of the circuit is 6.0 ohms.



81. Determine the resistance of R_2.

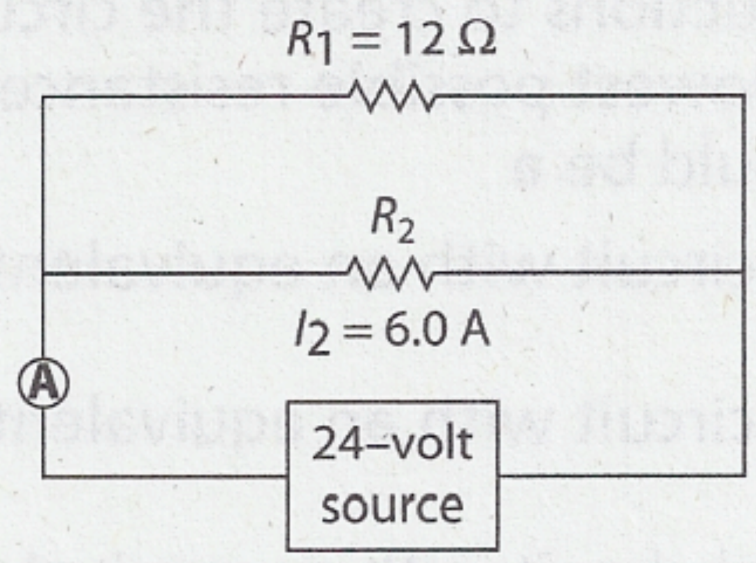
82. Calculate the current through ammeter A.

83. Calculate the power developed in resistor R_1 alone.

84. Compare the potential difference across the source to the potential difference across R_2.

85. Explain what happens to *both* the potential difference across and the current through R_2, if the resistance of R_2 is increased.

Base your answers to questions 86 through 89 on the circuit diagram below.



86. The current in ammeter A is

(1) 1.0 A (2) 2.0 A (3) 6.0 A (4) 8.0 A

87. What is the total energy used by the 12-ohm resistor in 30. minutes?

(1) 48 J
(2) 3.6×10^3 J
(3) 1.1×10^4 J
(4) 8.6×10^4 J

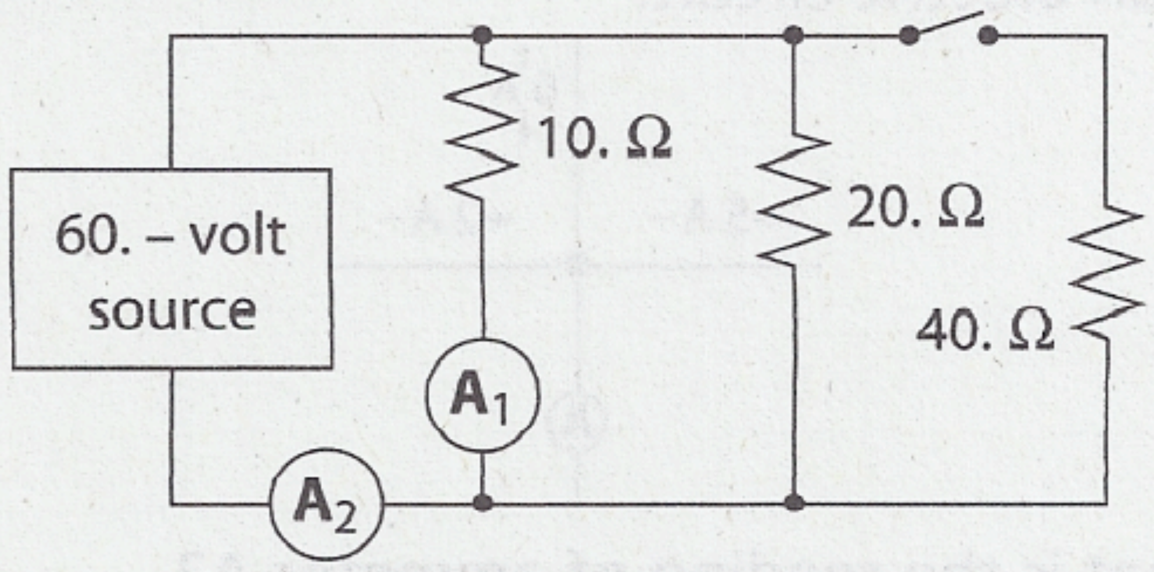
88. If resistance R_2 were removed, the potential difference across R_1 would

(1) decrease
(2) increase
(3) remain the same

89. If resistor R_2 is removed, what happens to the equivalent resistance of the circuit and the current in ammeter *A*?

(1) The equivalent resistance decreases, and the current decreases.
(2) The equivalent resistance decreases, and the current increases.
(3) The equivalent resistance increases, and the current decreases.
(4) The equivalent resistance increases, and the current increases.

Base your answers to questions 90 through 94 on the electric circuit below. Note that the switch is in the open position.



90. What is the reading of ammeter A_1?
(1) 0.16 A (2) 6.0 A (3) 60. A (4) 600 A

91. What is the reading of ammeter A_2?
(1) 9.0 A (2) 2.0 A (3) 12 A (4) 18 A

92. What is the power developed in the 10.-ohm resistor?
(1) 6.0 W (2) 36 W (3) 360 W (4) 600 W

93. Compared to the potential drop across the 10.-ohm resistor, the potential drop across the 20.-ohm resistor is
(1) less (2) greater (3) the same

94. When the switch is closed, what happens to the current through ammeters A_1 and A_2?
(1) The current through A_1 decreases, and the current through A_2 decreases.
(2) The current through A_1 decreases, and the current through A_2 increases.
(3) The current through A_1 remains the same, and the current through A_2 decreases.
(4) The current through A_1 remains the same, and the current through A_2 increases.

Base your answers to questions 95 and 96 on the following information. An electric heater rated at 4800 watts is operated at 120 volts.

95. Calculate the resistance of the heater.

96. Calculate the amount of energy used by the heater in 10.0 seconds.

97. A resistor develops 15 watts of power when connected to a 12-volt battery. Calculate the amount of charge passing through the resistor in 1.0 minute.

98. An electric circuit consists of a 3.0-ohm resistor, R_1, and a variable resistor, R_2, connected in series to a 12-volt battery. At what value must the variable resistor be set to produce a current of 1.0 ampere through R_1?
(1) 6.0 Ω (2) 9.0 Ω (3) 3.0 Ω (4) 12 Ω

99. An operating electric circuit consists of a lamp and a length of nichrome wire connected in series to a 12-volt battery. As the temperature of the nichrome is decreased, what happens to the equivalent resistance of the circuit and the power developed by the lamp?
(1) The equivalent resistance decreases, and the power developed by the lamp decreases.
(2) The equivalent resistance decreases, and the power developed by the lamp increases.
(3) The equivalent resistance increases, and the power developed by the lamp decreases.
(4) The equivalent resistance increases, and the power developed by the lamp increases.

Magnetism

A **magnet** is a material in which the spinning electrons of its atoms are aligned with one another. This motion of charges relative to each other produces a **magnetic force.** Even if two magnets are at rest relative to each other, they exert magnetic force because the electrons within them are in motion. Many permanent magnets are made of an alloy of aluminum, nickel, and cobalt.

A magnet has two ends called poles, where the magnetic force is strongest. One end is called the north-seeking **magnetic pole** (N-pole), and the other end is the south-seeking magnetic pole (S-pole). No matter how many times a magnet is broken, each piece always has a north pole and a south pole. Like magnetic poles repel each other and unlike poles attract each other. **Magnetism** is the force of attraction or repulsion between magnetic poles. Unmagnetized pieces of iron and steel are readily magnetized by pulling them across a pole of a strong magnet or by having them interact with a direct current.

Earth is like a large magnet with a S-pole near the geographic North Pole (the northern end of its axis of rotation) and an N-pole near the geographic South Pole. The N-pole of a compass, a device having a magnetized needle that can spin freely, is attracted toward Earth's S-pole (geographic North

Pole). Earth's magnetic field results from the motion of its molten iron and nickel core.

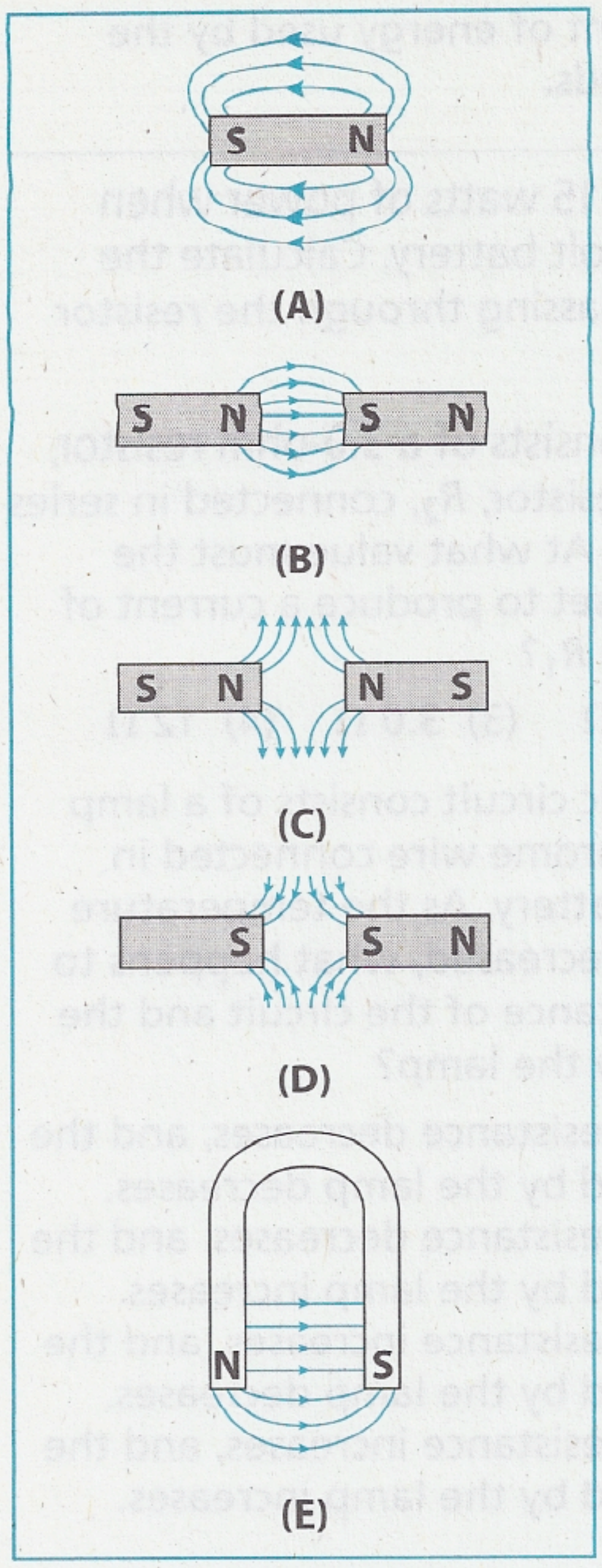


Figure 4-12. Magnetic field lines around some bar magnets and a horseshoe magnet

Magnetic Fields The region where magnetic force exists around a magnet or any moving charged object is called its **magnetic field.** Just as a gravitational or electric field allows objects to interact without coming into direct contact with each other, a magnetic field allows magnets to interact without touching. A magnetic field exerts a force on any moving charge and can be measured and detected by this effect.

Magnetic Flux Lines Imaginary lines that map out the magnetic field around a magnet are known as **magnetic field lines** or **magnetic flux lines.** Iron filings sprinkled on a card and held above a magnet are often used to map a magnetic field. The filings show the effects of magnetic force in the region surrounding a magnet and produce a pattern similar to the magnetic field lines. Magnetic flux lines always form closed loops and never intersect. Concentrated lines of flux emerge from the N-pole of a magnet, curve around the magnet, and then enter the S-pole of the magnet. The direction of a magnetic field is defined as the direction in which the N-pole of a compass would point in the field. When the field lines are curved, the direction of the field is determined by the direction of the N-pole of a compass placed along the tangent to the field at that point. Figure 4-12 shows the locations of the lines of magnetic flux around some bar magnets and around a horseshoe magnet.

Magnetic Field Strength The number of magnetic lines of flux per unit area passing through a plane perpendicular to the direction of the lines is called the **magnetic field strength,** B, or flux density. Magnetic field strength is a vector quantity, as are gravitational field strength and electric field strength.

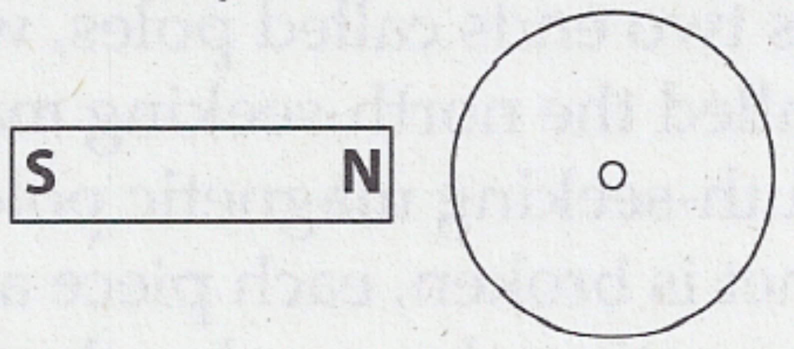
Review Questions

100. In order to produce a magnetic field, an electric charge must be
(1) stationary
(2) moving
(3) positive
(4) negative

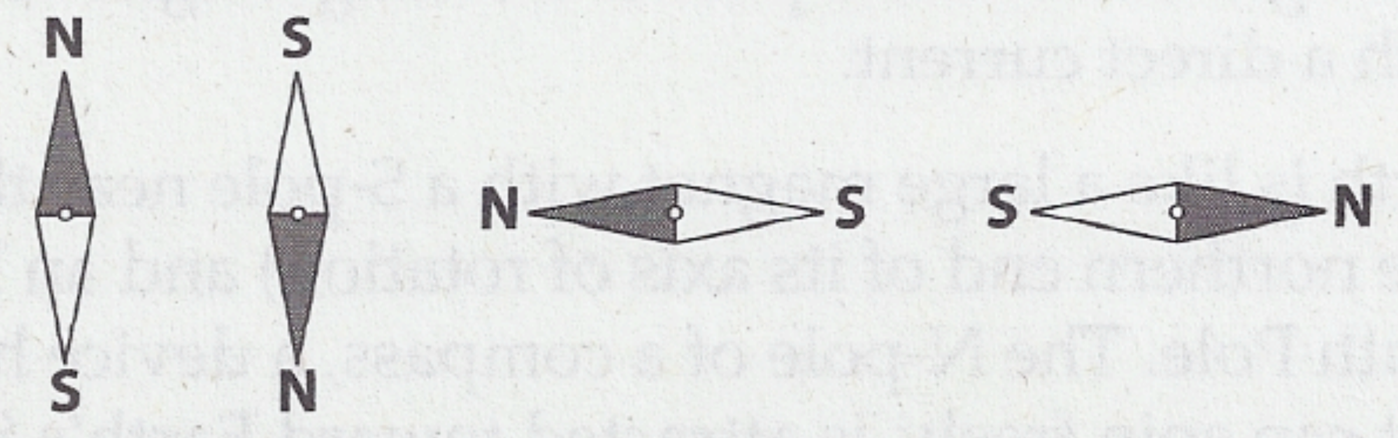
101. The presence of a uniform magnetic field may be detected by using a
(1) stationary charge
(2) small mass
(3) beam of neutrons
(4) magnetic compass

102. Which term does *not* identify a vector quantity?
(1) electric charge
(2) magnetic field strength
(3) velocity
(4) acceleration

103. The diagram below shows a compass placed near the north pole, N, of a bar magnet.

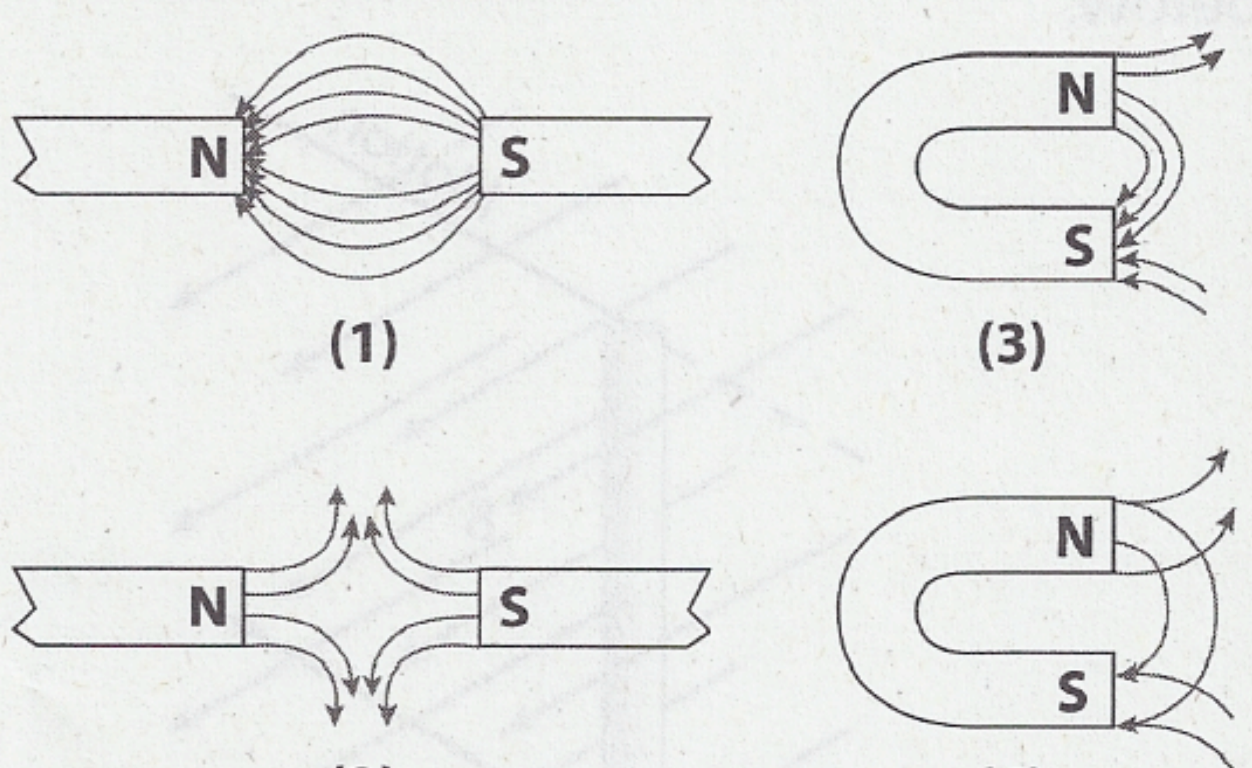


Which diagram best represents the position of the needle of a compass as it responds to the magnetic field of the bar magnet?

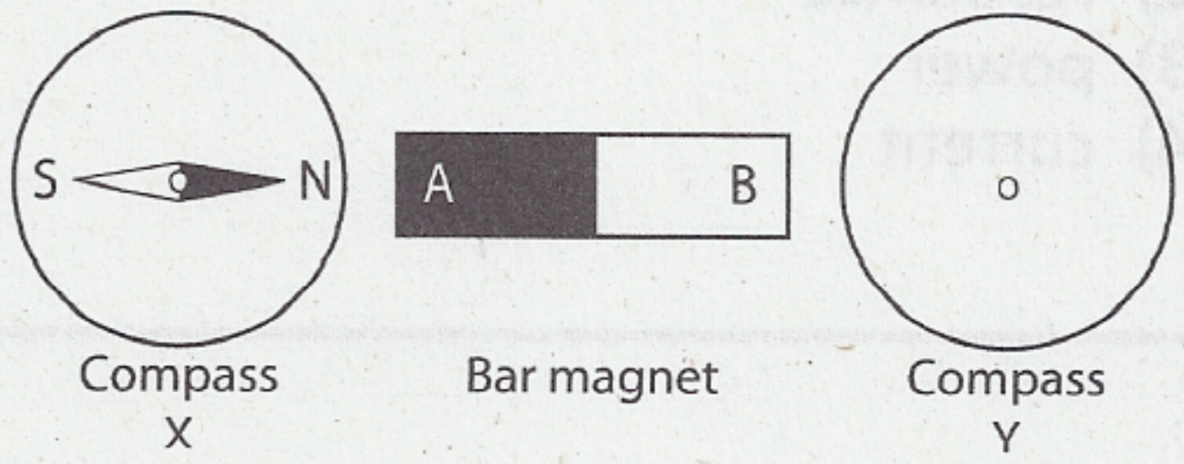


104. A student is given two pieces of iron and told to determine if one or both of the pieces are magnets. First, the student touches an end of one piece to one end of the other. The two pieces of iron attract. Next, the student reverses one of the pieces and again touches the ends together. The two pieces attract again. What does the student definitely know about the initial magnetic properties of the two pieces of iron? [1]

105. Which diagram correctly shows a magnetic field configuration?

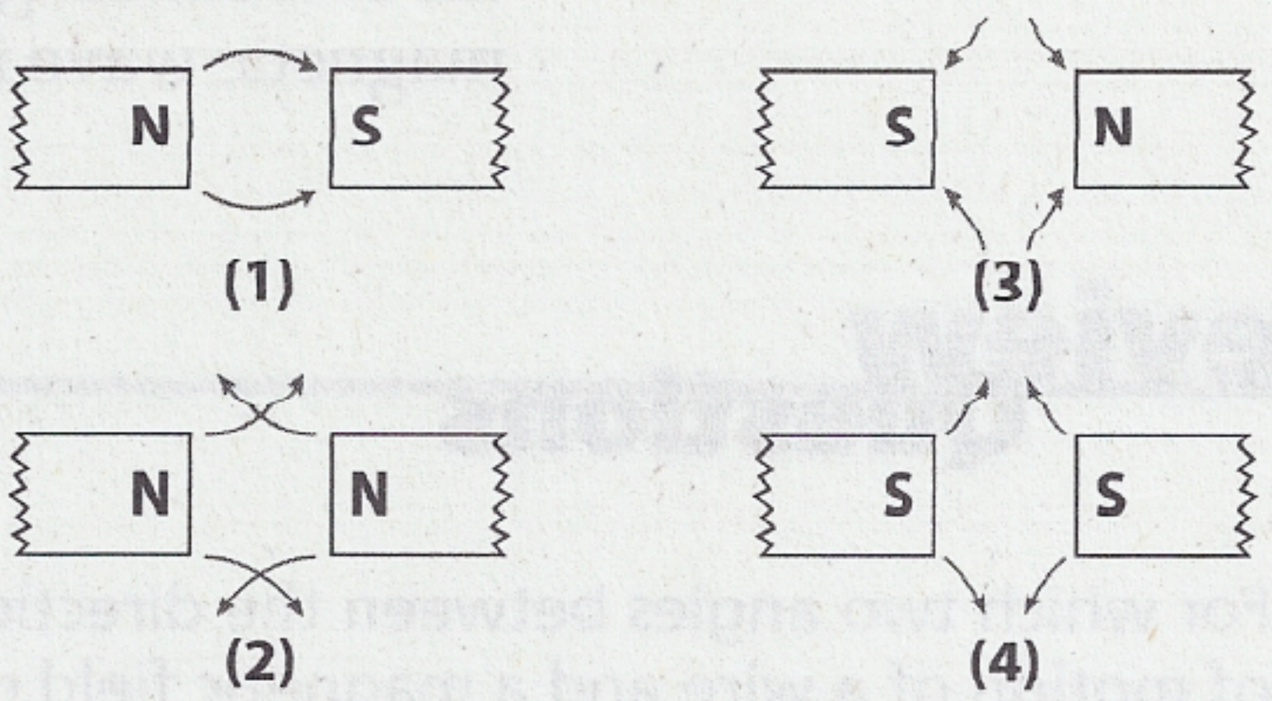


106. The diagram below shows two compasses located near the ends of a bar magnet. The north pole of compass *X* points toward end *A* of the magnet.

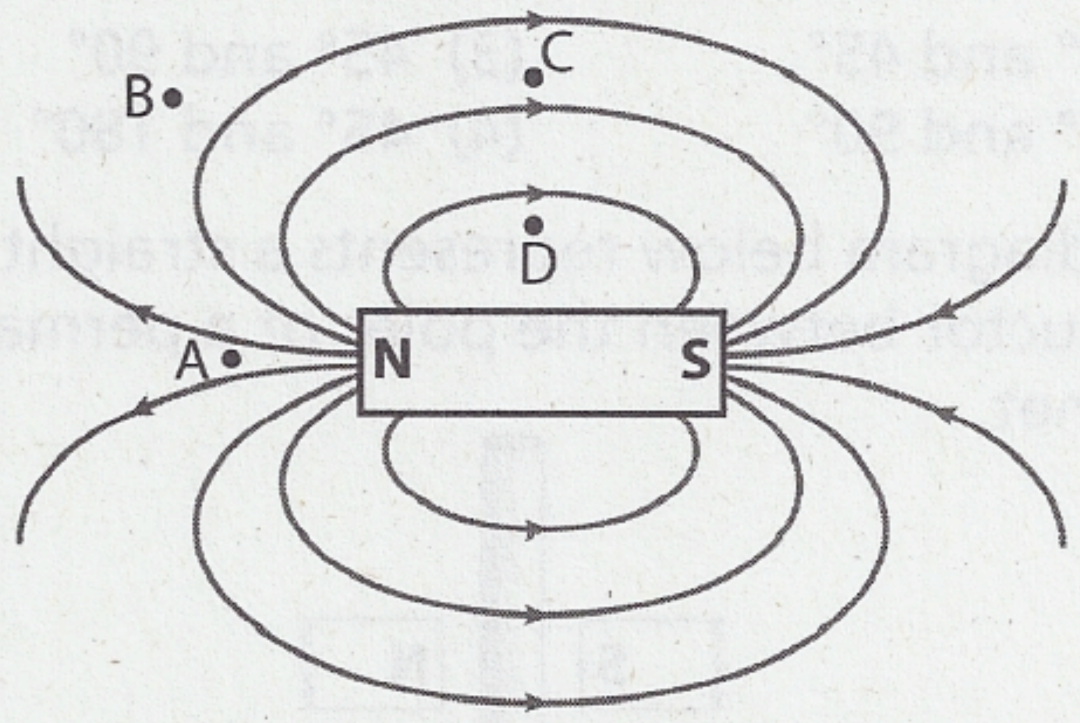


On the diagram draw the correct orientation of the needle of compass *Y* and label its polarity.

107. Which diagram best represents the lines of magnetic flux between the ends of two bar magnets?

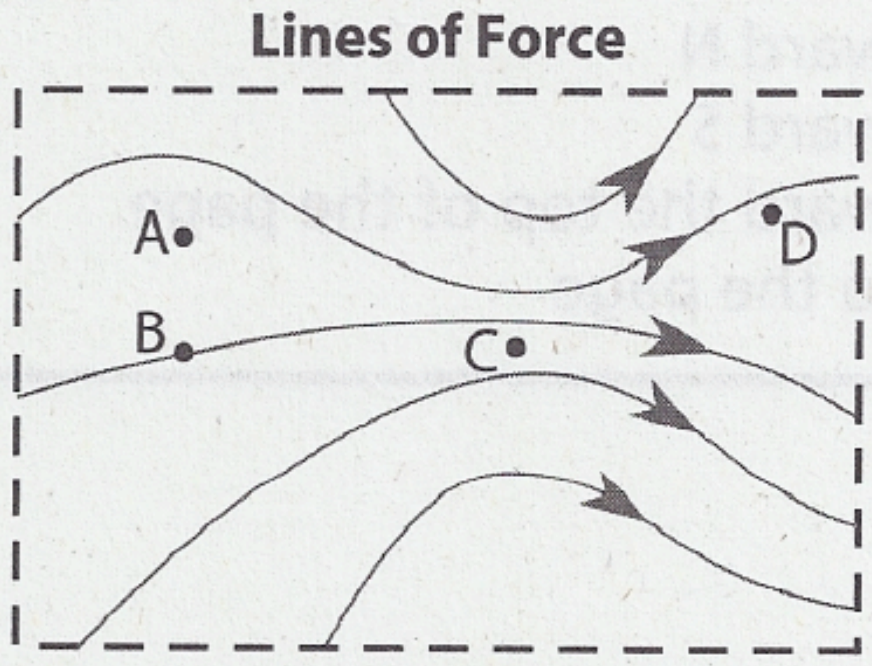


108. The diagram below represents the magnetic lines of force around a bar magnet.



At which point is the magnitude of the magnetic field strength of the bar magnet greatest?

109. The diagram below represents magnetic lines of force within a region of space.



At which point is the magnetic field strongest?

Electromagnetic Induction

Electromagnetic induction is the process of generating a potential difference in a conductor due to relative motion between the conductor and a magnetic field. If the conductor "cuts" across the magnetic flux lines, a magnetic force acts on the electrons in the conductor, causing them to move from one end toward the other. This results in a difference in the amount of negative charge at each end of the conductor, in other words, a potential difference. The difference in potential created in a conductor due to its relative motion in a magnetic field is called an **induced potential difference**. Figure 4-13 shows a potential difference being induced in a conductor.

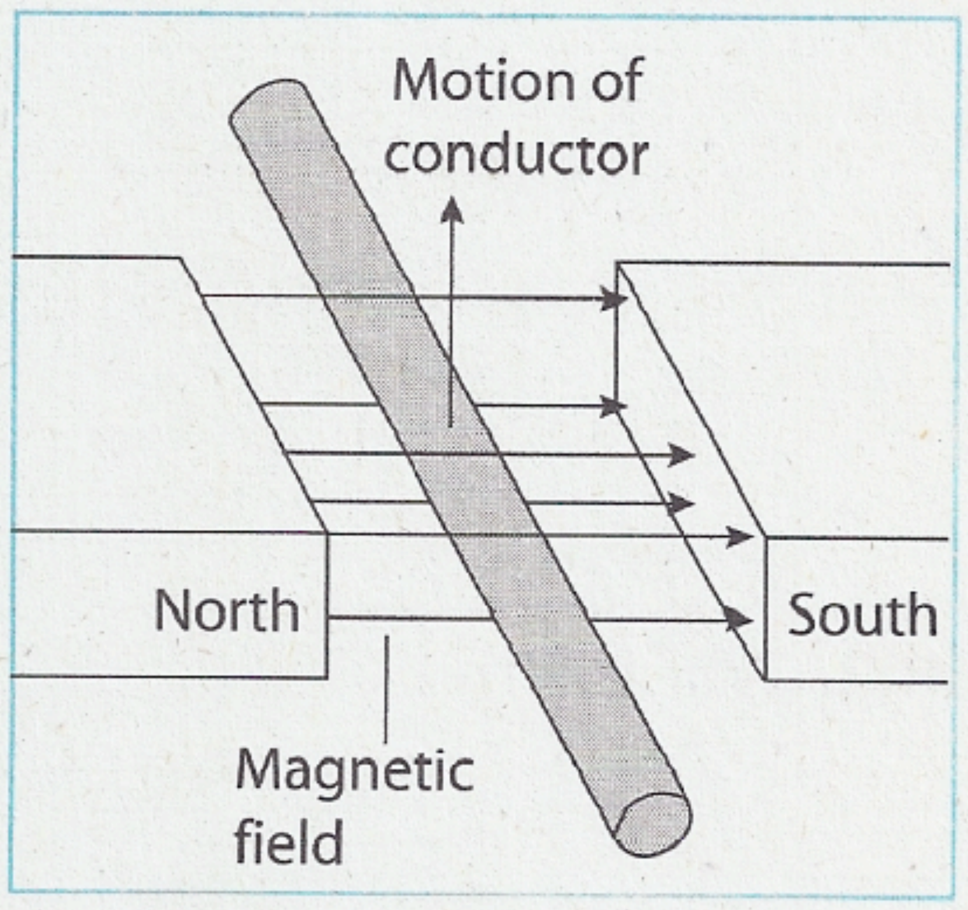


Figure 4-13. Electromagnetic induction: The diagram shows the direction of motion of a straight conductor relative to a magnetic field that produces a maximum induced potential difference in the conductor.

If the conductor is part of a complete circuit, an electric current is induced. If the conductor is moved parallel to the lines of flux (that is, it does not "cut" them) no potential difference is induced and there is no current, even if the conductor is part of a complete circuit.

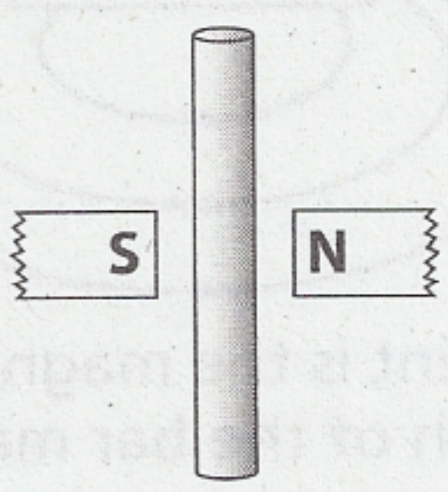
Electromagnetic Radiation Oscillating or accelerating electric charges produce changing electric and magnetic fields that radiate outward into the surrounding space in the form of waves. Such a combined electric and magnetic wave is called an **electromagnetic wave.**

Review Questions

110. For which two angles between the direction of motion of a wire and a magnetic field can a potential difference be induced across the wire?

(1) 0° and 45°
(2) 0° and 90°
(3) 45° and 90°
(4) 45° and 180°

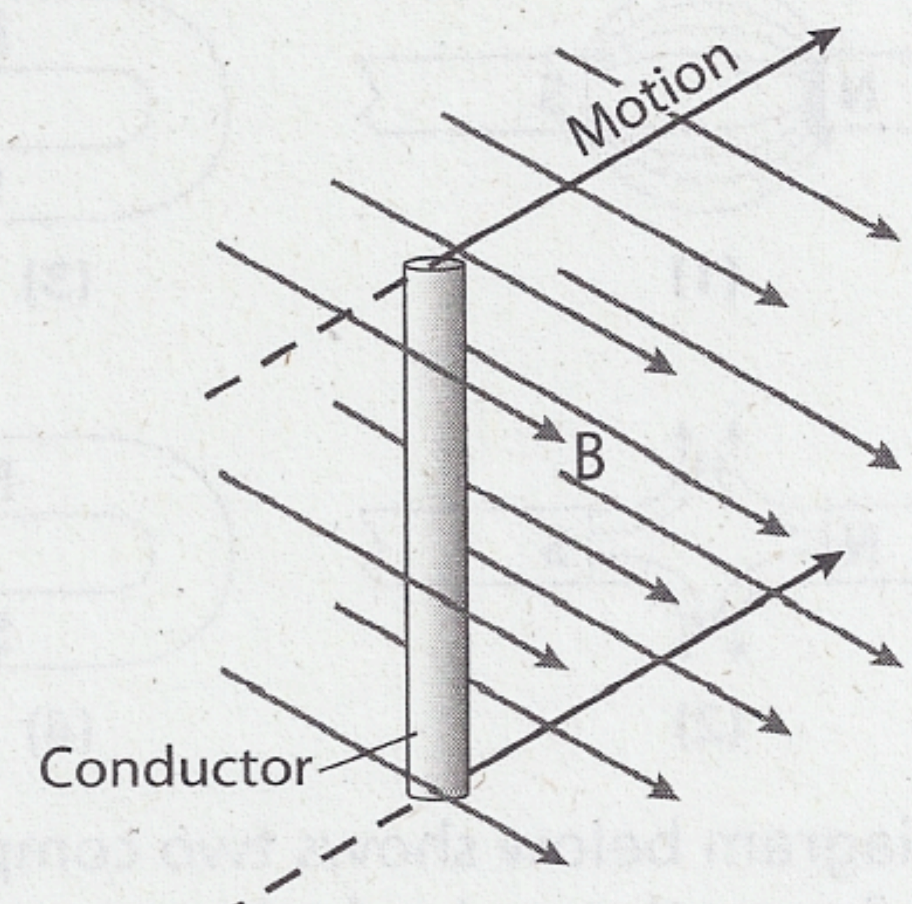
111. The diagram below represents a straight conductor between the poles of a permanent magnet.



In which direction should the wire be moved to induce a potential difference?

(1) toward N
(2) toward S
(3) toward the top of the page
(4) into the page

112. A conductor is moved perpendicularly through magnetic field B as represented in the diagram below.



What is being induced in the conductor?

(1) potential difference
(2) resistance
(3) power
(4) current

Practice Questions for the New York Regents Exam

TOPIC 4

Directions

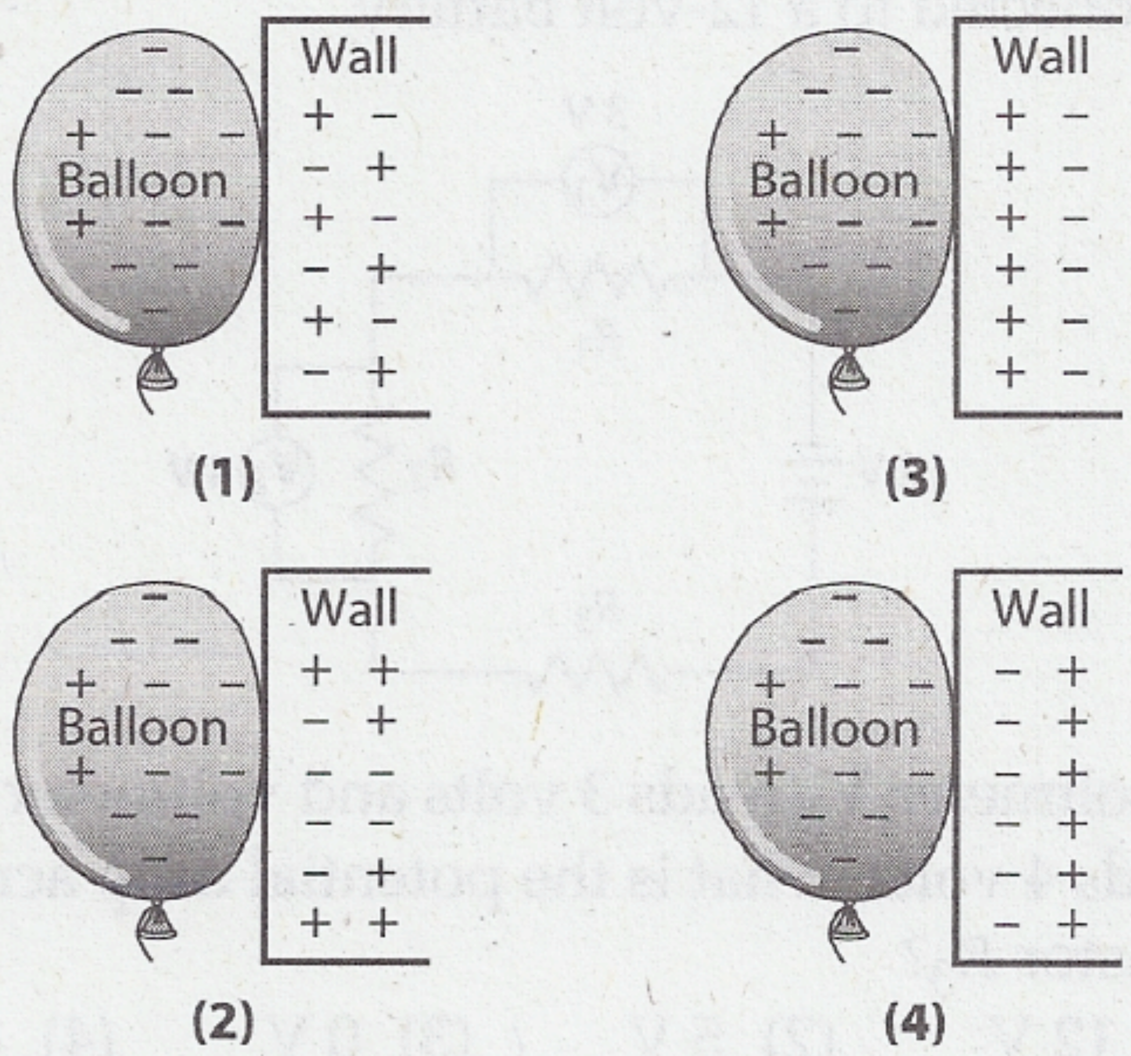
Review the Test-Taking Strategies section of this book. Then answer the following questions. Read each question carefully and answer with a correct choice or response.

Part A

1 A sphere has a charge of -6.40×10^{-7} coulomb. Approximately how many electrons must be removed to make the sphere neutral?

(1) 2.50×10^{-13} (3) 4.00×10^{12}
(2) 1.60×10^{12} (4) 7.03×10^{24}

2 An inflated balloon that has been rubbed against a person's hair is touched to a neutral wall and remains attracted to it. Which diagram best represents the charge distribution on the balloon and wall?



3 Which quantity of excess electric charge could be found on an object?

(1) 6.25×10^{-19} C
(2) 4.80×10^{-19} C
(3) 6.25 elementary charges
(4) 1.60 elementary charges

4 After a neutral object loses 2 electrons, it will have a net charge of

(1) $-2e$ (3) $-3.20 \times 10^{-19}\ e$
(2) $+2e$ (4) $+3.20 \times 10^{-19}\ e$

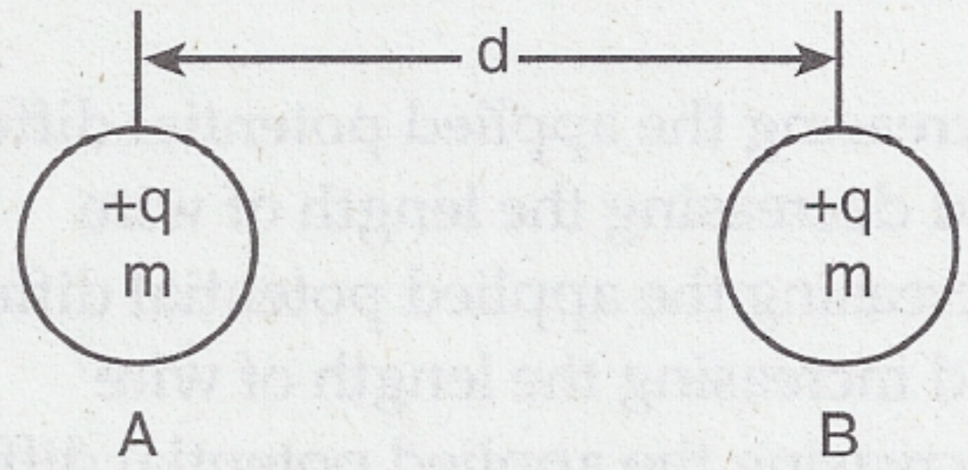
5 The electrostatic force between two positive point charges is F when the charges are 48 centimeters apart. When these point charges are placed 24 centimeters apart, the electrostatic force between them is

(1) $\frac{F}{4}$, and attracting (3) $\frac{F}{4}$, and repelling
(2) $4F$, and attracting (4) $4F$, and repelling

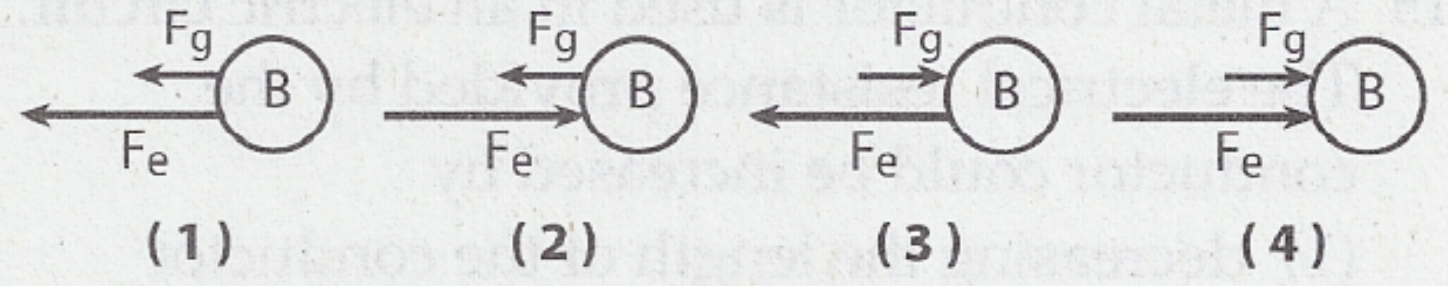
6 A repulsive electrostatic force of magnitude F exists between two metal spheres of identical charge q. The distance between the centers of the spheres is r. Which combination of changes would produce no change in the electrostatic force between the spheres?

(1) doubling q on one sphere while doubling r
(2) doubling q on both spheres while doubling r
(3) doubling q on one sphere while halving r
(4) doubling q on both spheres while halving r

7 The diagram below shows two identical metal spheres, A and B, separated by distance d. Each sphere has mass m and possesses charge $+q$.



Which diagram best represents the electrostatic force F_e and the gravitational force F_g acting on sphere B due to sphere A?



8 An electrostatic force of 20.0 newtons is exerted on a charge of 8.00×10^{-2} coulomb at point P in an electric field. The magnitude of the electric field strength at P is

(1) 4.00×10^{-3} C/N (3) 20.0 N/C
(2) 1.60 N · C (4) 2.50×10^{2} N/C

9 If 6.40×10^{-19} joule of work is required to move a proton between two points A and B in an electric field, what is the potential difference between points A and B?

(1) 6.40×10^{-19} V (3) 6.40 V
(2) 4.00×10^{-19} V (4) 4.00 V

10 How much energy is required to move 3.20×10^{-19} coulomb of charge through a potential difference of 5.0 volts?

(1) 5.0 eV (2) 2.0 eV (3) 10. eV (4) 16 eV

11 During a thunderstorm, a lightning strike transfers 12 coulombs of charge in 2.0×10^{-3} second. What is the average current produced in this strike?
(1) 1.7×10^{-4} A (3) 6.0×10^{3} A
(2) 2.4×10^{-2} A (4) 9.6×10^{3} A

12 A wire carries a current of 6.0 amperes. How much charge passes a point in the wire in 2.0 minutes?
(1) 720 C (2) 360 C (3) 3.0 C (4) 12 C

13 A simple circuit has a total resistance of 1.00×10^{2} ohms and an applied potential difference of 2.00×10^{2} volts. The amount of charge passing any point in the circuit in 2.00 seconds is
(1) 1.26×10^{19} C (3) 2.52×10^{19} C
(2) 2.00 C (4) 4.00 C

14 Which changes would cause the greatest increase in the rate of flow of charge through a conducting wire?
(1) increasing the applied potential difference and decreasing the length of wire
(2) increasing the applied potential difference and increasing the length of wire
(3) decreasing the applied potential difference and decreasing the length of wire
(4) decreasing the applied potential difference and increasing the length of wire

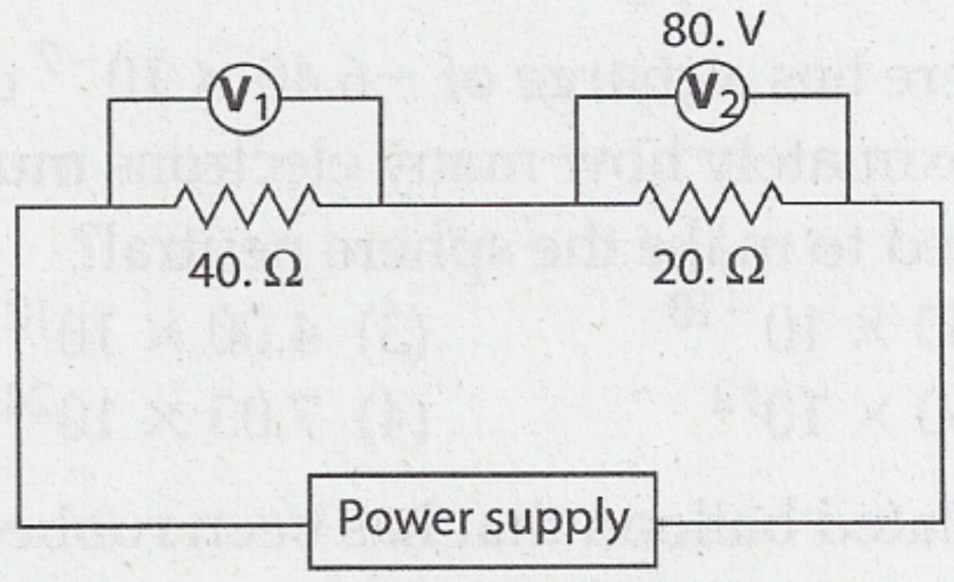
15 A metal conductor is used in an electric circuit. The electrical resistance provided by the conductor could be increased by
(1) decreasing the length of the conductor
(2) decreasing the applied voltage in the circuit
(3) increasing the temperature of the conductor
(4) increasing the cross-sectional area of the conductor

16 A uniform aluminum wire has a resistance of 100 ohms. If the wire is cut into 10 equal lengths, the resistance of each piece will be
(1) 1 Ω (2) 10 Ω (3) 100 Ω (4) 1000 Ω

17 A 6.50-meter-long copper wire at 20°C has a cross-sectional area of 3.0 millimeters^2. What is the resistance of the wire?
(1) 3.7×10^{-8} Ω (3) 3.7×10^{-2} Ω
(2) 3.73×10^{-8} Ω (4) 3.73×10^{-4} Ω

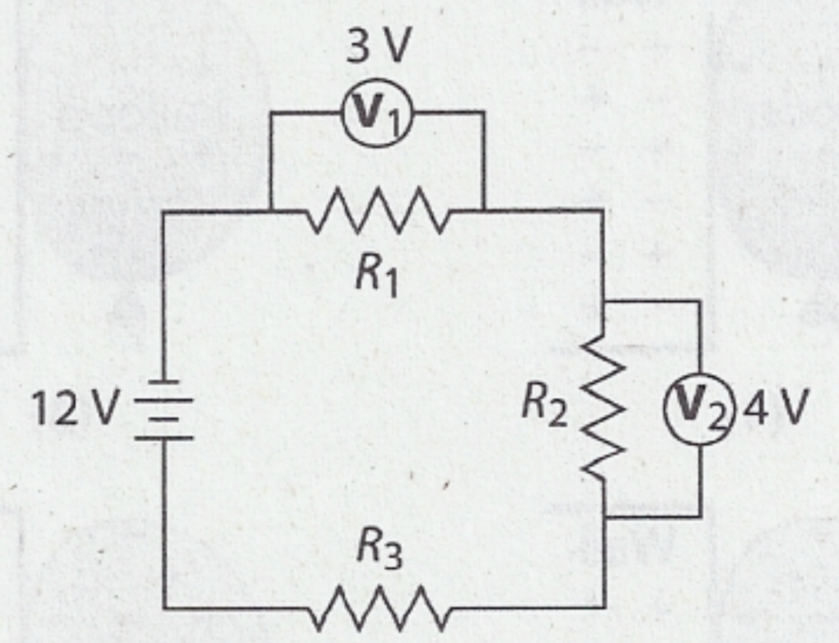
18 A 4.00-meter long aluminum wire at 20°C has a radius of 2.5×10^{-3} meter. What is the resistance of the wire?
(1) 1.4×10^{-5} Ω (3) 1.0×10^{-2} Ω
(2) 5.7×10^{-3} Ω (4) 5.7×10^{-1} Ω

19 In the circuit shown below, voltmeter V_2 reads 80. volts.



What is the reading of voltmeter V_1?
(1) 160 V (2) 80. V (3) 40. V (4) 20. V

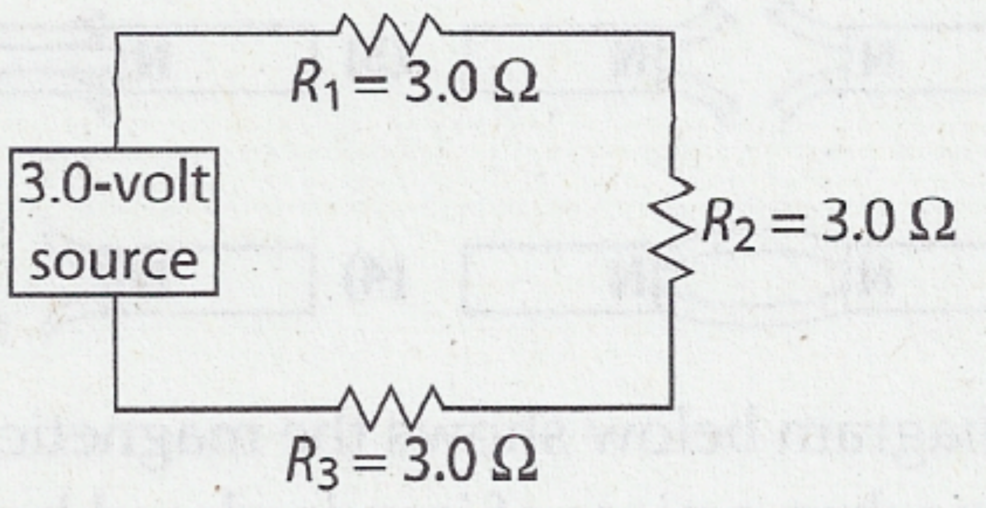
20 The diagram below shows three resistors connected to a 12-volt battery.



If voltmeter V_1 reads 3 volts and voltmeter V_2 reads 4 volts, what is the potential drop across resistor R_3?
(1) 12 V (2) 5 V (3) 0 V (4) 4 V

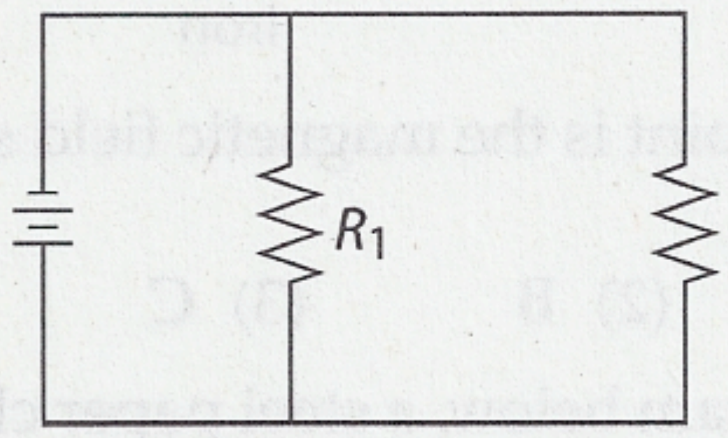
21 A 3.0-om resistor and 4.0-ohm resistor are connected in series to a battery. If a 5.0-ohm resistor is added to this circuit in series, what happens to the potential difference across and the current through the 3.0-ohm resistor?
(1) The potential difference decreases, and the current decreases.
(2) The potential difference decreases, and the current increases.
(3) The potential difference remains the same, and the current increases.
(4) The potential difference remains the same, and the current remains the same.

22 The diagram below represents a series circuit containing three resistors.



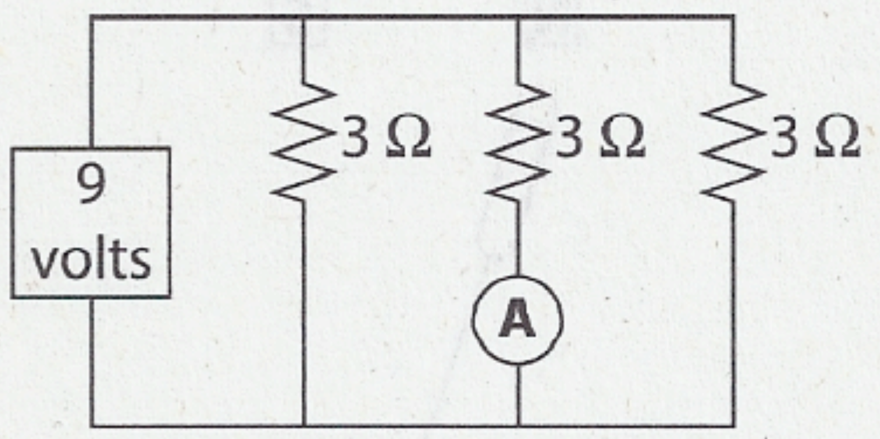
What is the current through resistor R_2?
(1) 1.0 A (2) 0.33 A (3) 3.0 A (4) 9.0 A

23 Resistors R_1 and R_2 have an equivalent resistance of 6 ohms when connected in the circuit shown below.



The resistance of R_1 could be
(1) 1 Ω (2) 5 Ω (3) 8 Ω (4) 4 Ω

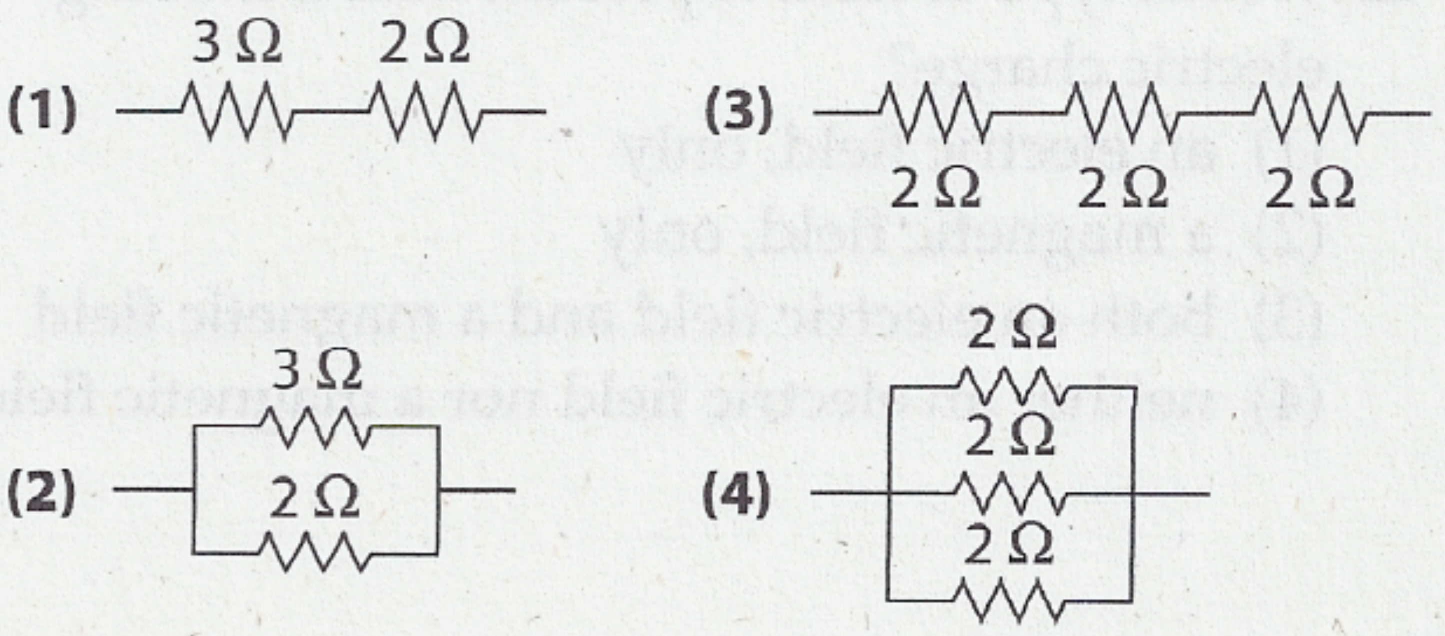
24 The diagram below shows three resistors connected to a 9-volt source.



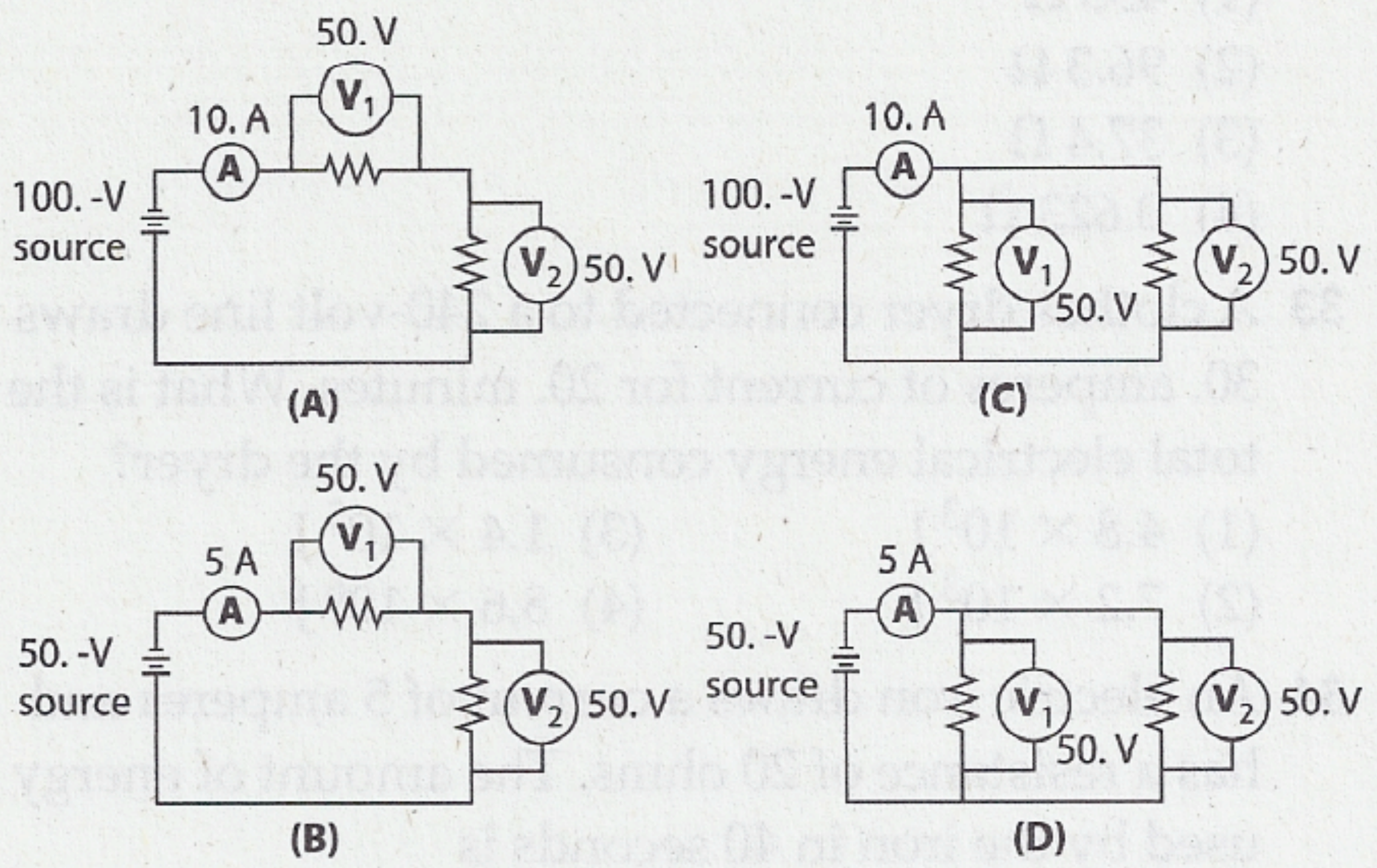
What is the current in ammeter A?
(1) 1 A (2) 0.3 A (3) 3 A (4) 9 A

25 A 10-ohm and a 20-ohm resistor are connected in parallel to a constant voltage source. If the current through the 10-ohm resistor is 4 amperes, the current through the 20-ohm resistor is
(1) 1 A (2) 2 A (3) 8 A (4) 4 A

26 Which circuit segment has an equivalent resistance of 6 ohms?

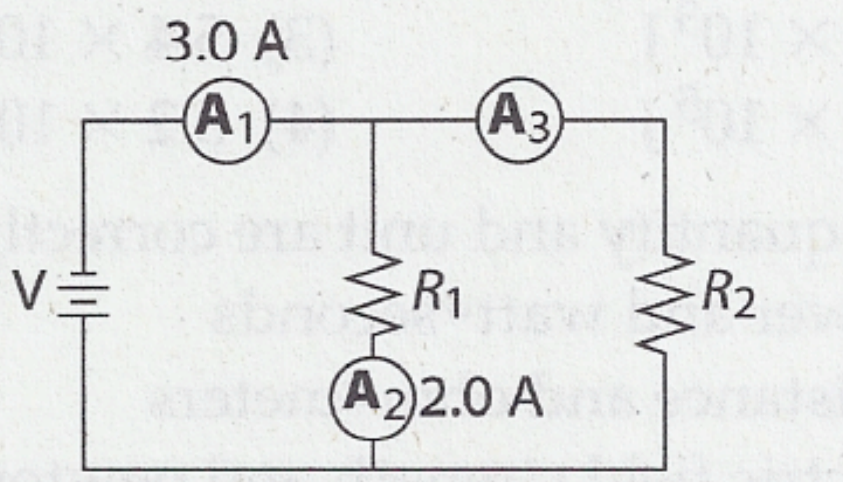


27 In which circuit shown below could the readings of voltmeters V_1 and V_2 and ammeter A be correct?



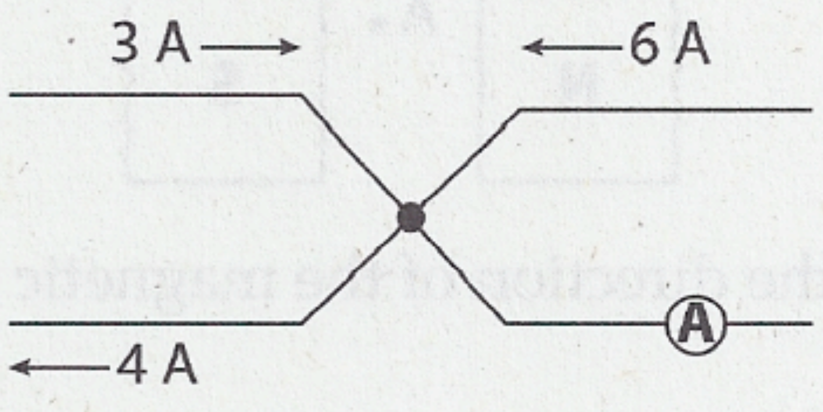
(1) A and B (3) C and D
(2) B and C (4) A and D

28 Ammeters A_1, A_2, and A_3 are placed in a circuit as shown below.



What is the reading of ammeter A_3?
(1) 1.0 A (2) 2.0 A (3) 3.0 A (4) 5.0 A

29 The diagram below shows the current in a segment of a direct current circuit.



What is the reading of ammeter A?
(1) 1 A (2) 5 A (3) 7 A (4) 8 A

30 An incandescent lightbulb operating at 120 volts draws a current of 0.50 ampere for 240 seconds. The power rating of the lightbulb is
(1) 30. W (2) 60. W (3) 75 W (4) 120 W

31 The heating element on an electric heater dissipates 4.0×10^2 watts of power when connected to a 120-volt source. What is the electrical resistance of this heating element?
(1) 0.028 Ω (2) 0.60 Ω (3) 3.3 Ω (4) 36 Ω

32 A 4.50-volt personal stereo uses 1950 joules of electrical energy in one hour. What is the electrical resistance of the personal stereo?
(1) 433 Ω
(2) 96.3 Ω
(3) 37.4 Ω
(4) 0.623 Ω

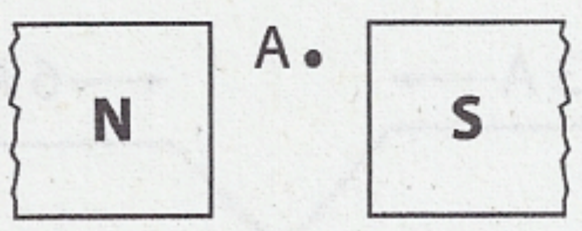
33 A clothes dryer connected to a 240-volt line draws 30. amperes of current for 20. minutes. What is the total electrical energy consumed by the dryer?
(1) 4.8×10^3 J
(2) 7.2×10^3 J
(3) 1.4×10^5 J
(4) 8.6×10^6 J

34 An electric iron draws a current of 5 amperes and has a resistance of 20 ohms. The amount of energy used by the iron in 40 seconds is
(1) 1×10^2 J
(2) 5×10^2 J
(3) 4×10^3 J
(4) 2×10^4 J

35 An operating 75-watt incandescent lamp is connected to a 120-volt outlet. How much electrical energy does the lamp use in 1.0 hour?
(1) 4.5×10^3 J
(2) 2.7×10^5 J
(3) 5.4×10^5 J
(4) 3.2×10^7 J

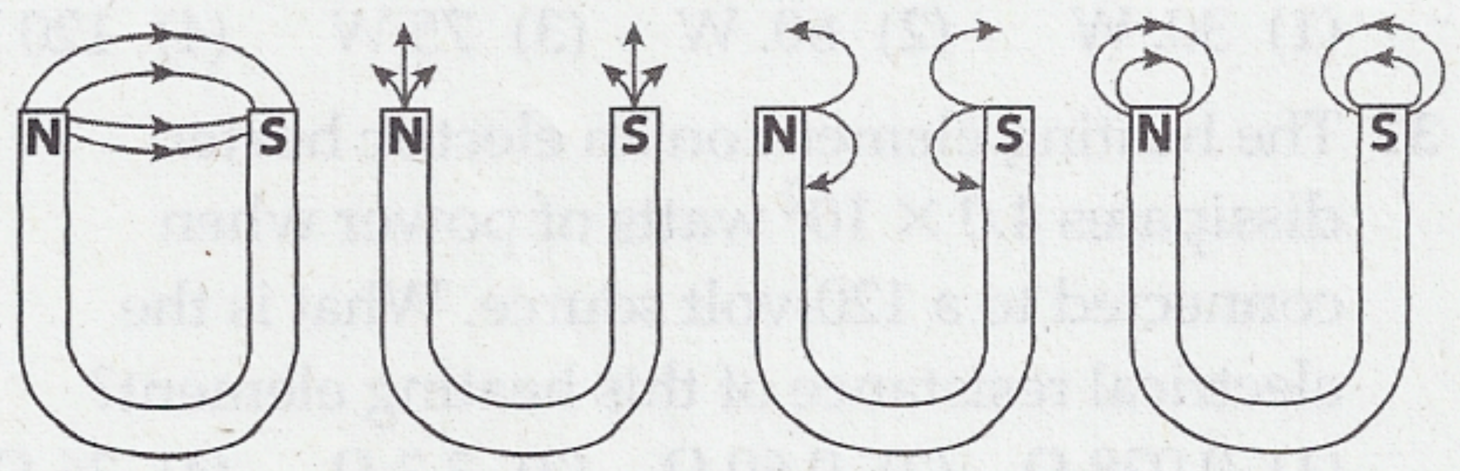
36 Which quantity and unit are correctly paired?
(1) power and watt•seconds
(2) resistance and ohm•meters
(3) electric field strength and newtons/ampere
(4) electric potential difference and joules/coulomb

37 The diagram below shows a point located between two magnetic poles.



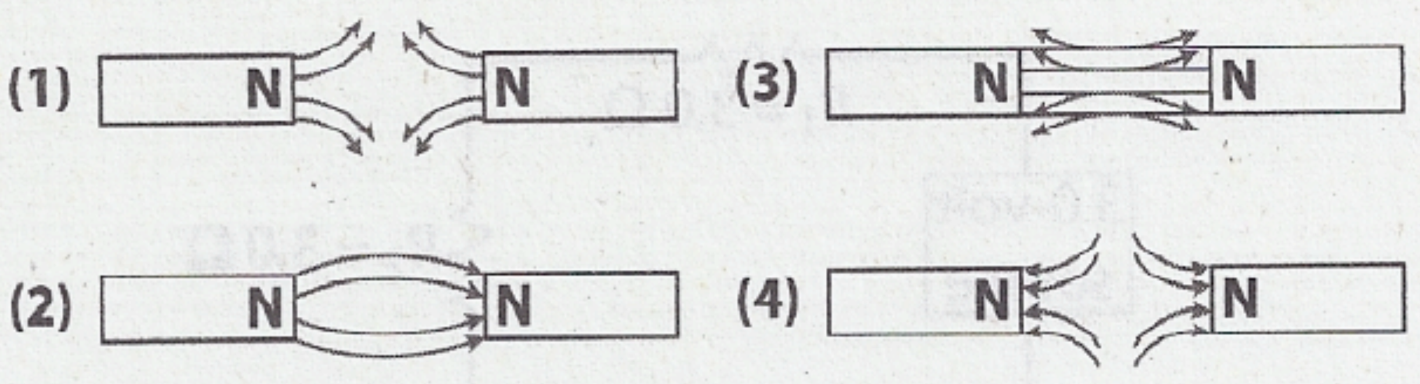
What is the direction of the magnetic field at point A?
(1) to the left
(2) to the right
(3) toward the top of the page
(4) toward the bottom of the page

38 Which diagram best represents the magnetic field near the poles of a horseshoe magnet?

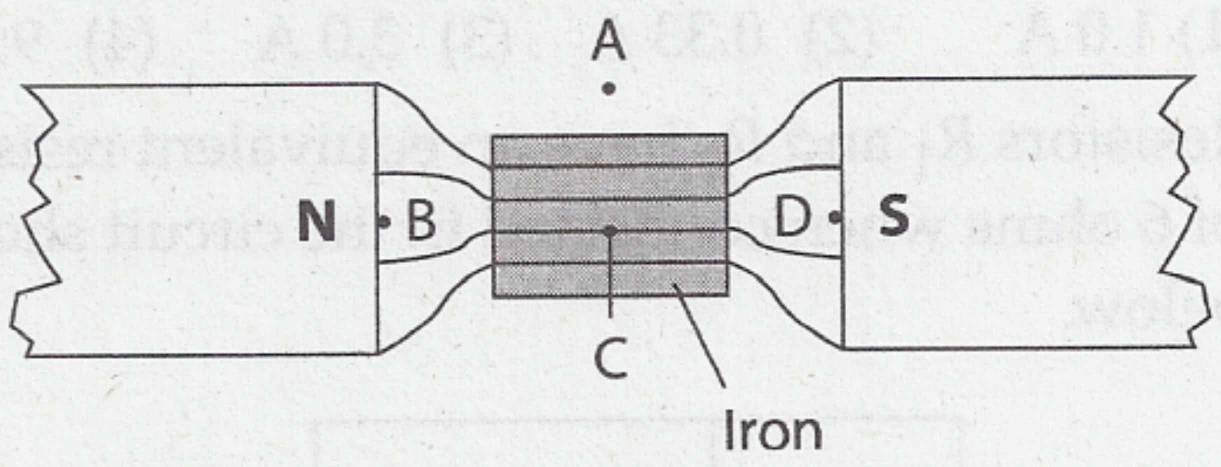


(1) (2) (3) (4)

39 Which diagram best represents the magnetic field between two magnetic north poles?

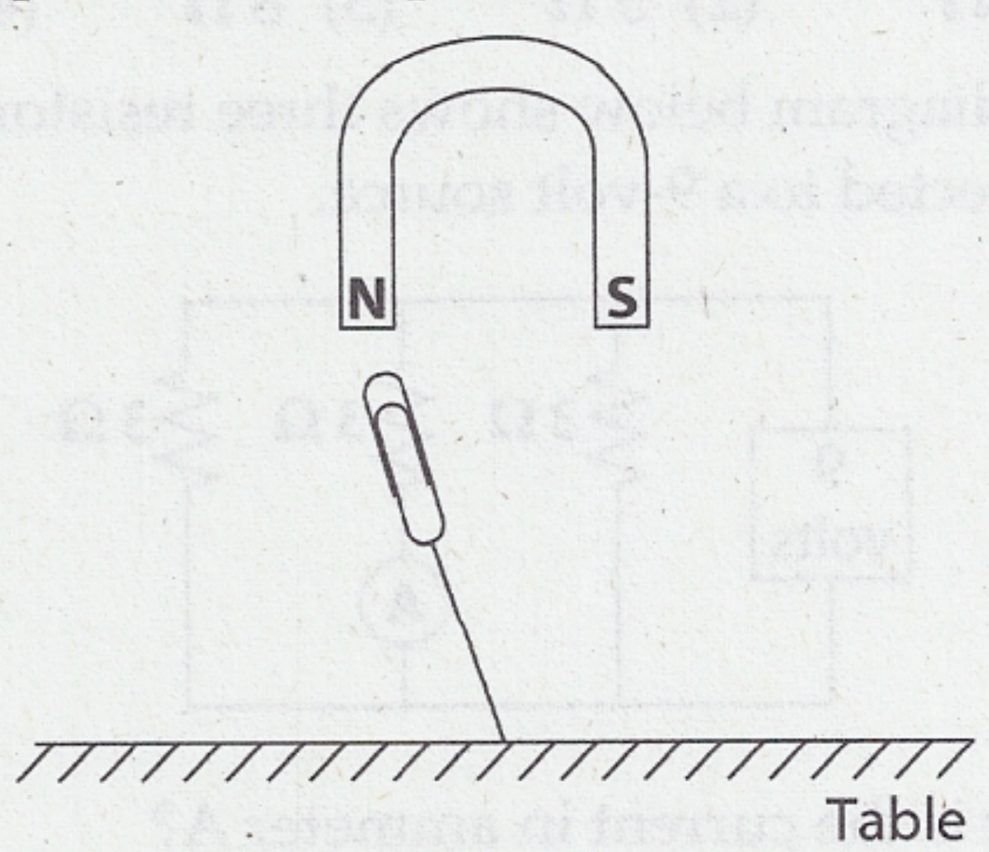


40 The diagram below shows the magnetic field that results when a piece of iron is placed between unlike magnetic poles.



At which point is the magnetic field strength greatest?
(1) A (2) B (3) C (4) D

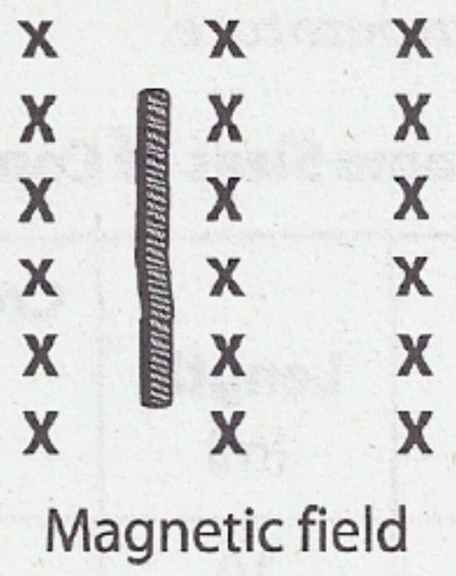
41 In the diagram below, a steel paper clip is attached to a string, which is attached to a table. The clip remains suspended beneath a magnet.



As the magnet is lifted, the paper clip begins to fall as a result of
(1) an increase in the potential energy of the clip
(2) an increase in the gravitational field strength near the magnet
(3) a decrease in the mass of the paper clip
(4) a decrease in the magnetic field strength near the clip

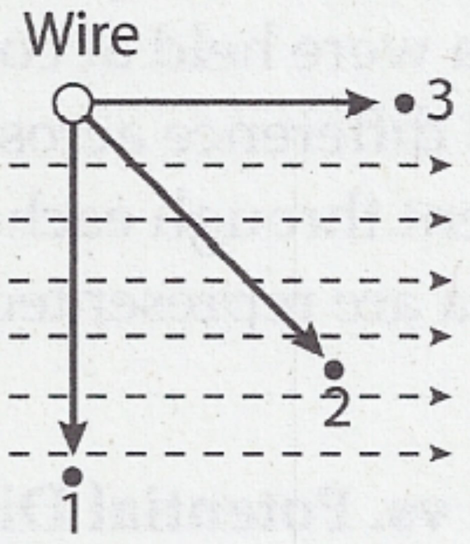
42 Which type of field is present near a moving electric charge?
(1) an electric field, only
(2) a magnetic field, only
(3) both an electric field and a magnetic field
(4) neither an electric field nor a magnetic field

43 In the diagram below a straight wire is at rest in a *uniform magnetic field directed into the page.*



A potential difference will be induced in the wire if it is moved
(1) toward the top of the page
(2) toward the right of the page
(3) into the page
(4) out of the page

44 The diagram below shows the cross section of a wire that is perpendicular to the page in a uniform magnetic field directed to the right.

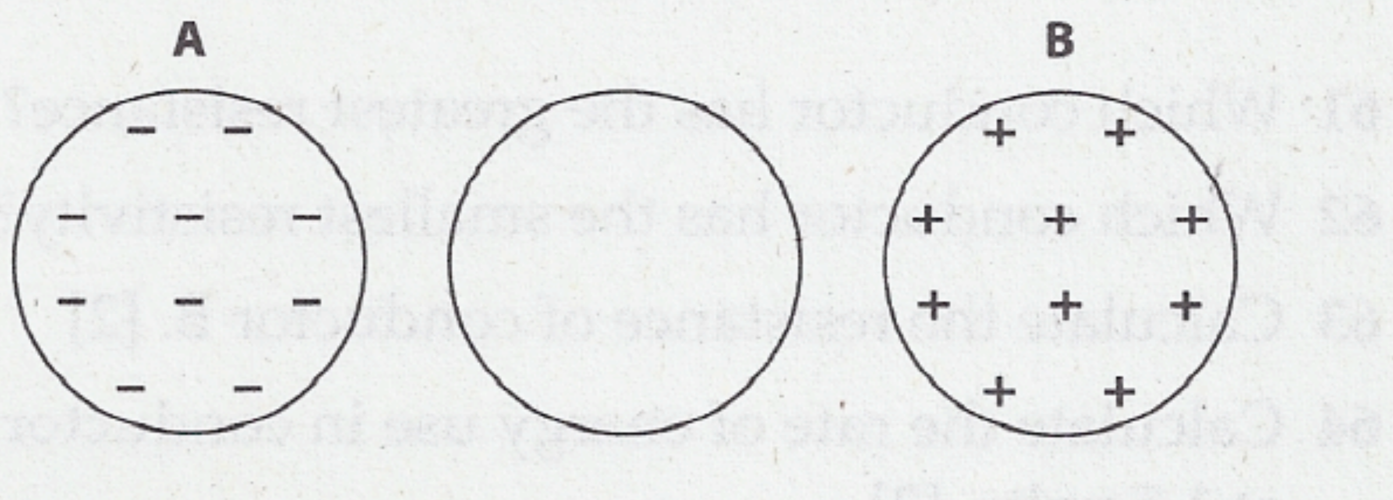


Toward which direction could the wire be moved to induce an electric potential?

(1) 1 only (3) 3 only
(2) both 1 and 2 (4) both 1 and 3

Part B

45 In the diagram below, the open circle represents an uncharged metal sphere located midway between two charged spheres, A and B. On the diagram, using + for positive and − for negative, mark at least six charges to represent the arrangement of charges on the uncharged sphere. [1]

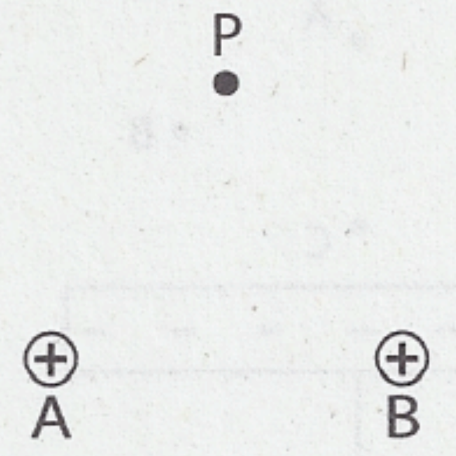


46 Charge A is +2.0 microcoulombs and charge B is +1.0 microcoulomb. If the magnitude of the electrostatic force that A exerts on B is 1.0×10^{-2} newton, what is the magnitude of the electrostatic force that B exerts on A? [1]

47 Calculate the charge to mass ratio ($\frac{e}{m}$) for an electron. [2]

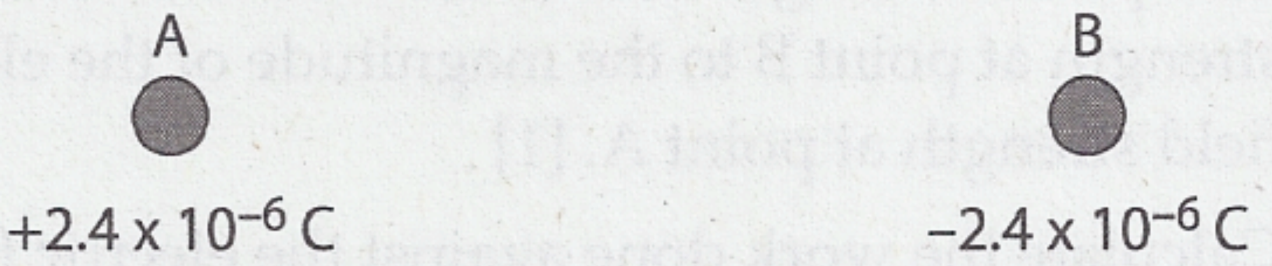
48 Three identical metal spheres are mounted on insulating stands. Initially, sphere A has a net charge of q and spheres B and C are uncharged. Sphere A is touched to sphere B and removed. Then sphere A is touched to sphere C and removed. What is the final charge on sphere A in terms of q? [1]

49 In the diagram below, two identical spheres A and B have equal net positive charges.



On the diagram, sketch an arrow that best represents the direction of the resultant electric field at point P. [1]

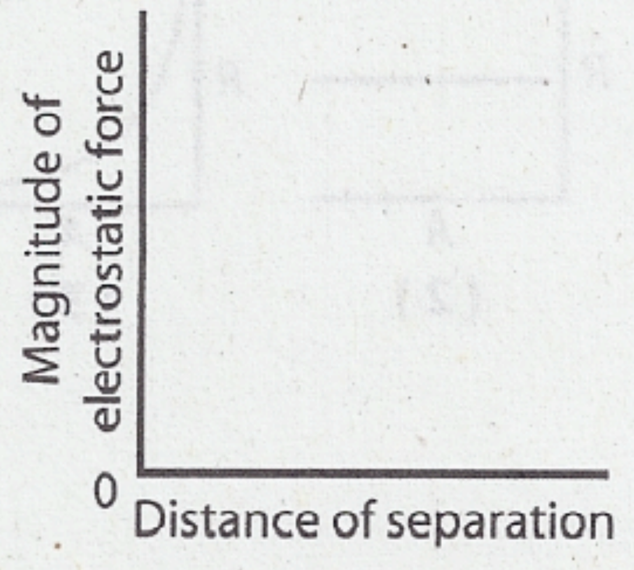
Base your answers to questions 50 through 53 on the following information and diagram. Two small spheres A and B are separated by a distance of 0.50 meter. The charge on sphere A is +2.4 microcoulombs and the charge on sphere B is −2.4 microcoulombs.



50 On the diagram sketch at least three electric field lines in the region between sphere A and sphere B. Draw an arrowhead on each field line to show the proper direction. [2]

51 Calculate the magnitude of the electrostatic force that sphere *A* exerts on sphere *B*. [2]

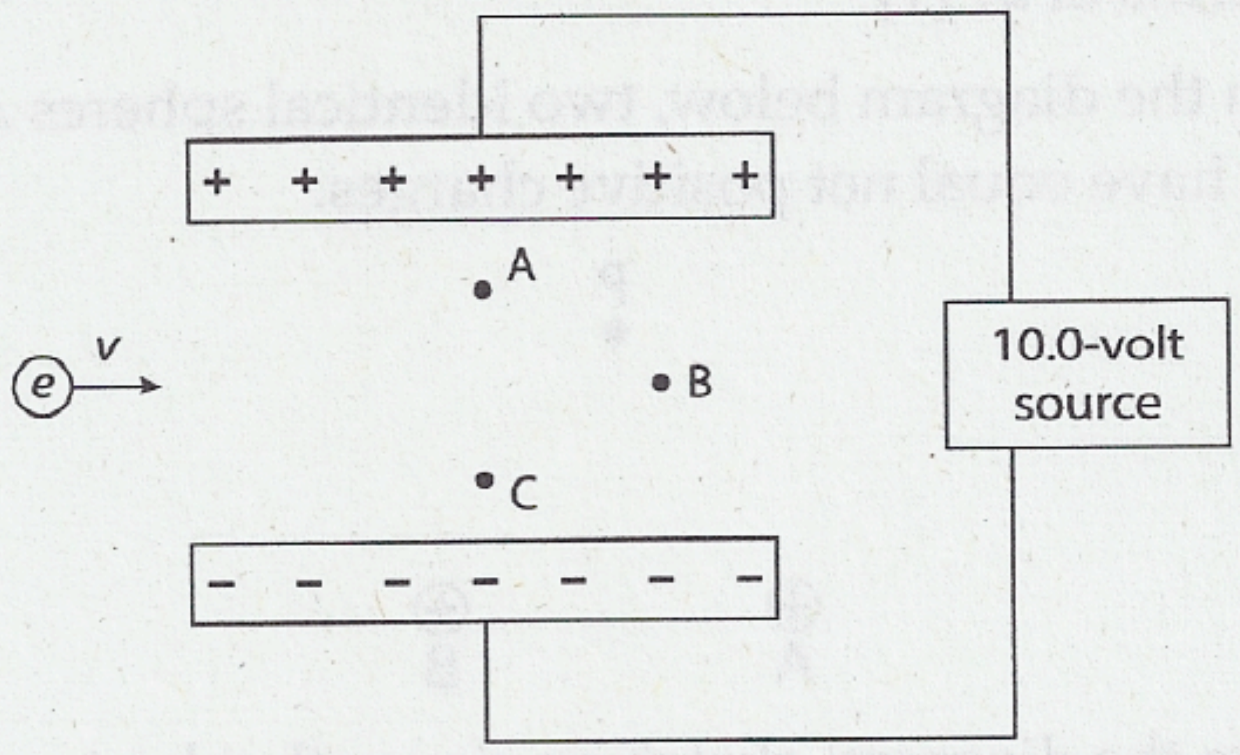
52 Using the axes below, draw the general shape of the graph representing the magnitude of the electrostatic force versus the distance separating the centers of the two oppositely charged spheres. [1]



53 The two spheres are brought into contact and then separated. After separation, what is the charge on each sphere? [1]

Base your answers to questions 54 through 58 on the following information and diagram.

Two parallel plates are charged to a potential difference of 10.0 volts. Points A, B, and C are located in the region between the plates.



54 Sketch at least three electric field lines to represent the field in the region between the oppositely charged parallel plates. Draw lines with arrowheads in the proper direction. [2]

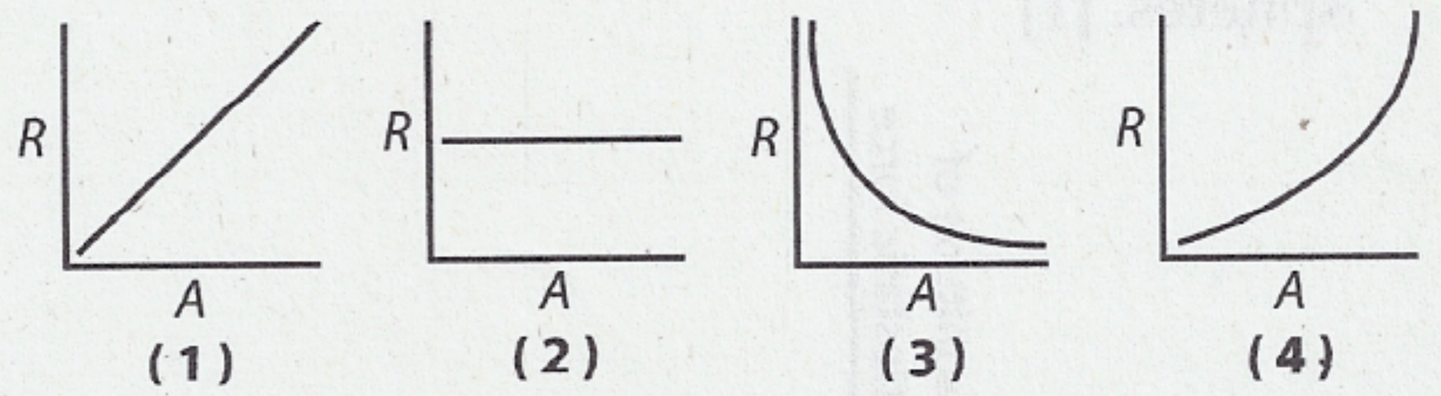
55 Describe the path an electron would travel if it were projected into the electric field with a velocity v, as shown. [1]

56 Compare the magnitude of the electric field strength at point B to the magnitude of the electric field strength at point A. [1]

57 Calculate the work done against the electric field in moving an electron from the positive plate to the negative plate. [2]

58 Determine the maximum speed of an electron that starts from rest at the negative plate and travels towards the positive plate. [1]

59 Which graph below best represents how the resistance R of a series of tungsten wires of uniform length and temperature varies with cross-sectional area A?



60 The table below shows the length and cross-sectional area of four pieces of copper wire at *the same temperature*.

Some Sizes of Copper Wire

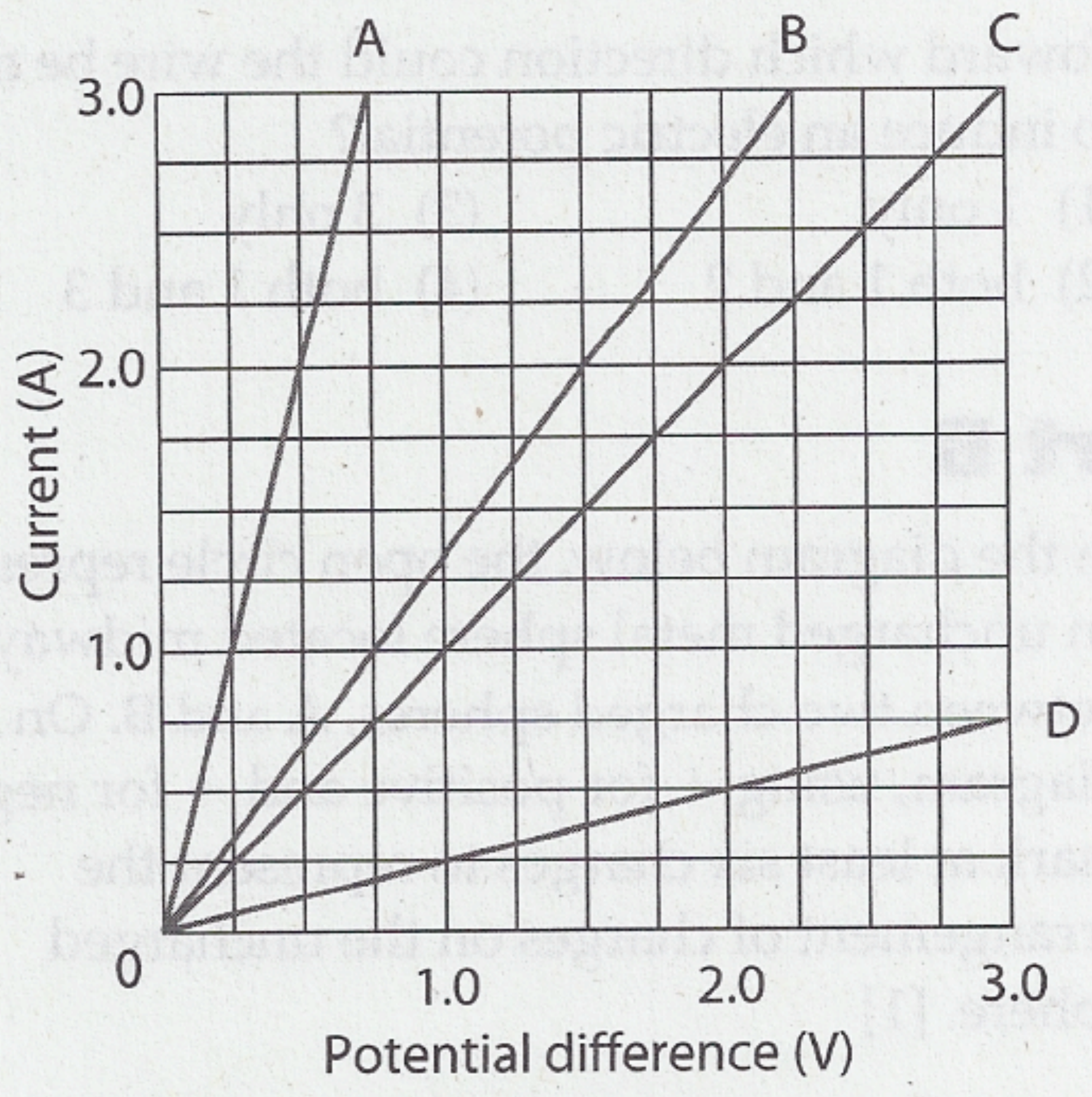
Wire	Length (m)	Cross-sectional Area (m^2)
A	10	2×10^{-6}
B	10	1×10^{-6}
C	1	2×10^{-6}
D	1	1×10^{-6}

Which wire has the highest resistance? [1]

Base your answers to questions 61 through 64 on the following information and graph.

Four different conductors of equal length and equal cross-sectional area were held at constant temperature while the potential difference across each was varied. The resulting current through each conductor was measured. The data are represented in the graph below.

Current vs. Potential Difference



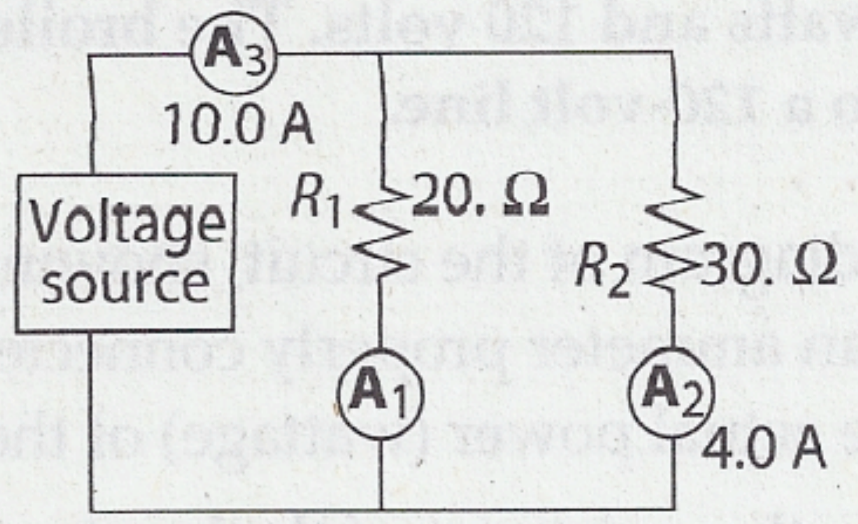
61 Which conductor has the greatest resistance? [1]

62 Which conductor has the smallest resistivity? [1]

63 Calculate the resistance of conductor B. [2]

64 Calculate the rate of energy use in conductor B at 1.5 volts. [2]

Base your answers to questions 65 through 67 on the circuit diagram below.

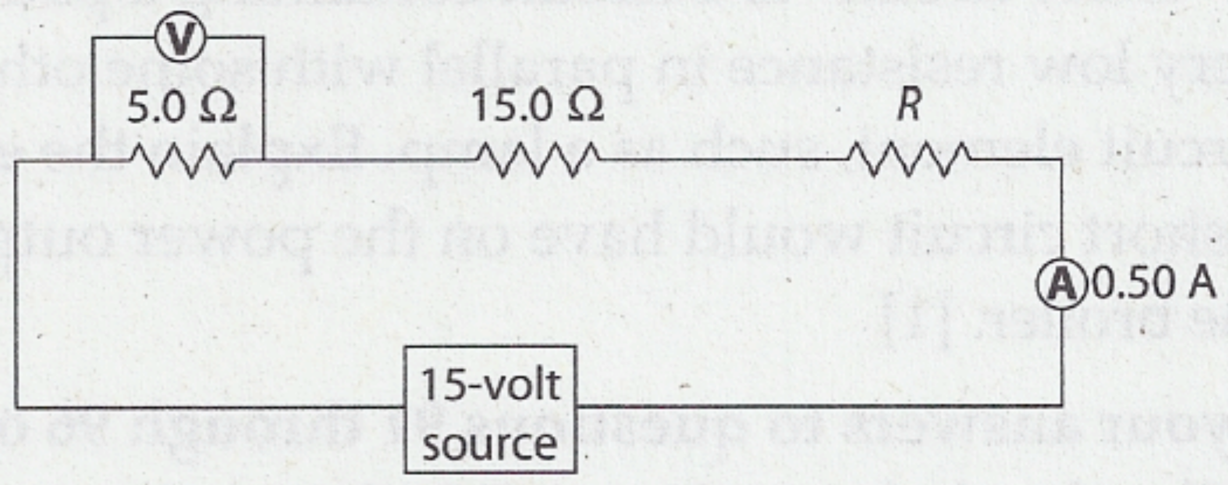


65 Determine the potential difference across the source. [1]

66 Calculate the current reading of ammeter A_1 [2].

67 Calculate the power dissipated by resistor R_2. [2]

Base your answers to questions 68 through 72 on the following information and diagram. A 5.0-ohm resistor, a 15.0-ohm resistor, and an unmarked resistor are connected as shown with a 15-volt source. The ammeter reads a current of 0.50 ampere.



68 Calculate the reading of the voltmeter across the 5.0-ohm resistor. [2]

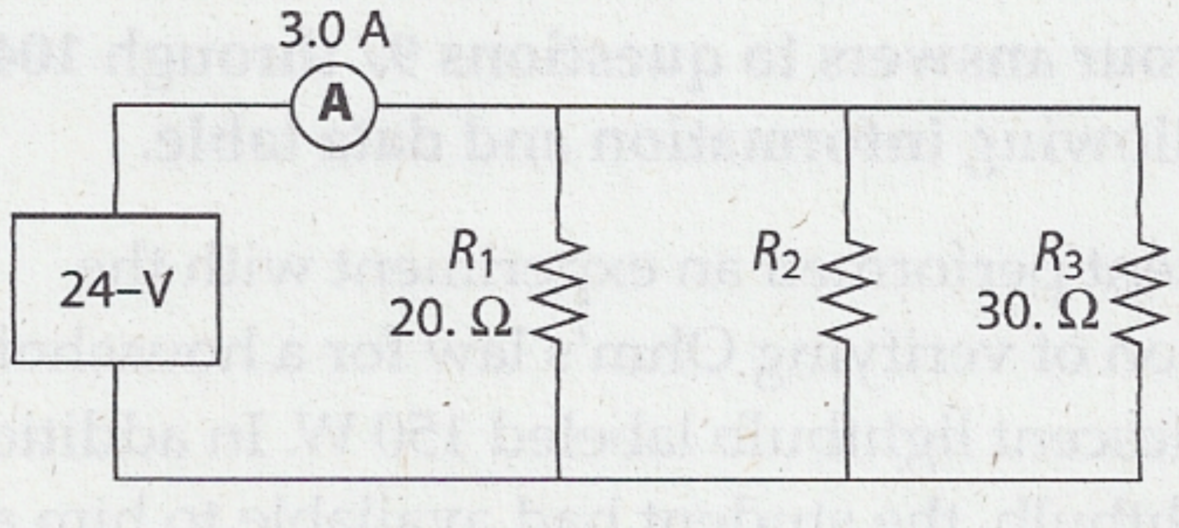
69 Calculate the total electrical energy used in the circuit in 10.0 minutes. [2]

70 Determine the value of the unmarked resistor. [1]

71 Compare the power dissipated by the 5.0-ohm resistor to the power dissipated by the 15.0-ohm resistor. [1]

72 The 5.0-ohm resistor is removed from the circuit and the remaining circuit elements reattached to the source in the same manner as in the original diagram. State the effect of this change on *both* the potential drop across resistor *R* and the current through the ammeter. [1]

Base your answers to questions 73 through 75 on the following information and diagram. Three resistors are connected in parallel across a 24-volt source. The ammeter reads 3.0 amperes.

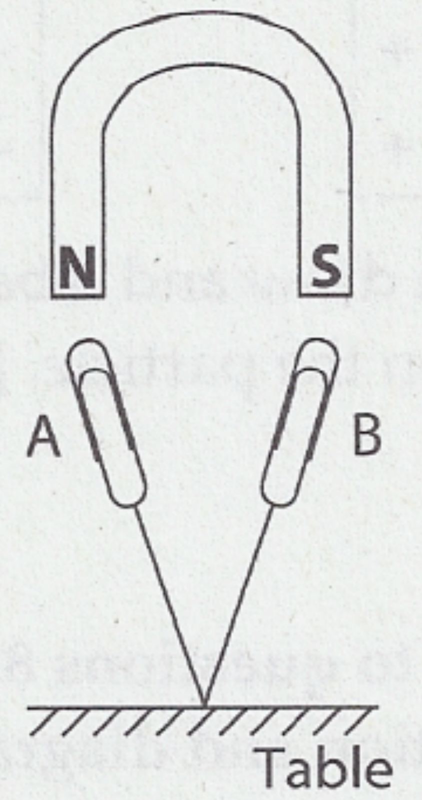


73 Determine the equivalent resistance of the circuit. [1]

74 Calculate the current in resistor R_1. [2]

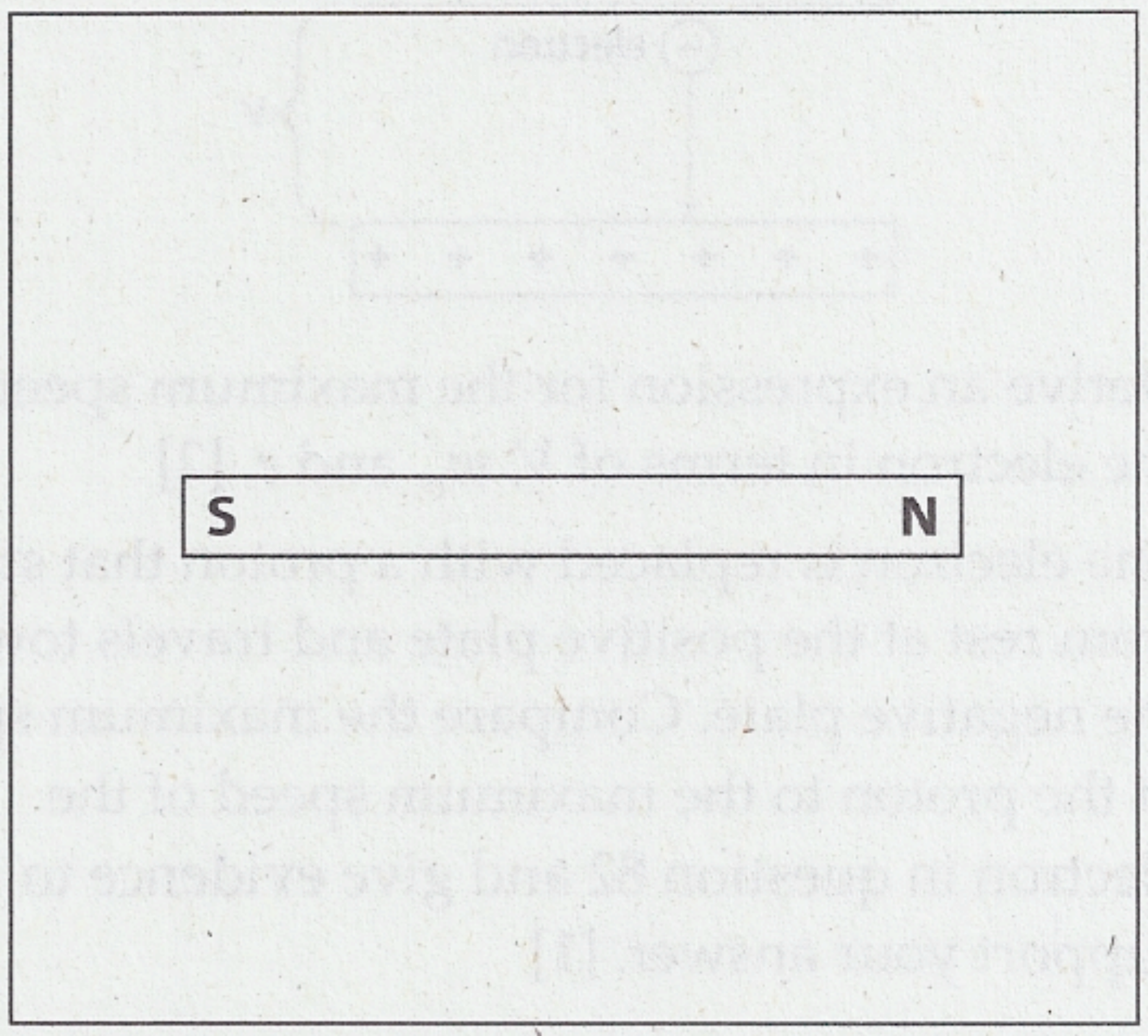
75 The ratio of the current in R_3 to the current in R_2 is 4 : 5. What is the resistance of R_2? [1]

76 In the diagram below steel paper clips A and B are attached to a string, which is attached to the table. The clips remain suspended beneath a magnet.



Label each of the paper clips in the diagram with its induced polarity. [1]

77 On the diagram of a bar magnet below, sketch at least four magnetic lines of flux with arrowheads to represent the magnetic field around the magnet. [2]



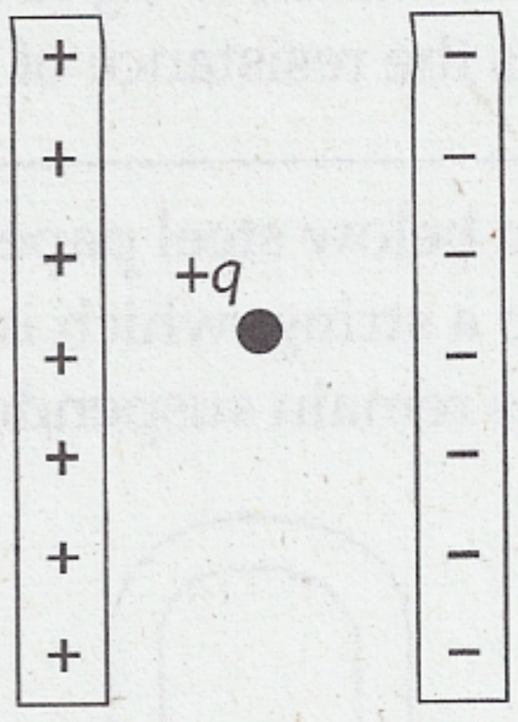
Base your answers to questions 78 through 80 on your knowledge of electricity.

78 Explain why it would be highly impractical to have household circuits wired in series. [1]

79 Explain why the tungsten filament of a 150-watt incandescent bulb is thicker and shorter than the filament of a 60-watt incandescent bulb. [1]

80 Explain why an electron appears to defy gravity as it accelerates upward between two oppositely charged parallel plates. [1]

81 The diagram below represents a particle of mass m and charge $+q$ located between two oppositely charged parallel plates. The electric field strength between the plates is E.

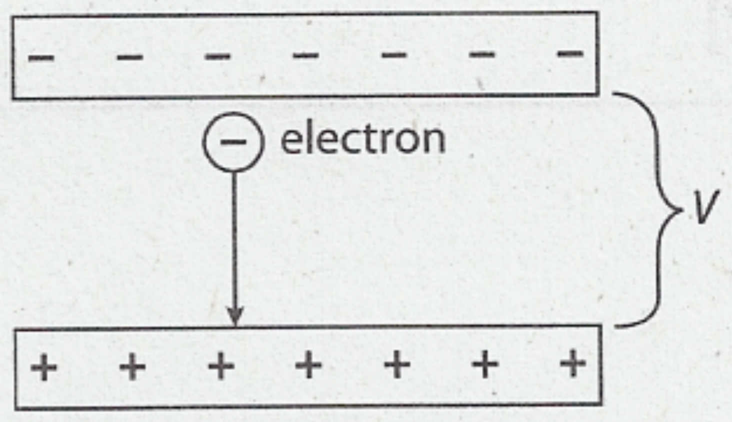


On the diagram draw and label all the force vectors acting on the particle. [2]

Part C

Base your answers to questions 82 and 83 on the following information and diagram.

Potential difference V exists between two oppositely charged parallel metal plates in a vacuum. An electron of mass m_e and charge e starts from rest at the negative plate and travels towards the positive plate. [Neglect the effect of gravity.]



82 Derive an expression for the maximum speed v of the electron in terms of V, m_e, and e. [2]

83 The electron is replaced with a proton that starts from rest at the positive plate and travels toward the negative plate. Compare the maximum speed of the proton to the maximum speed of the electron in question 82 and give evidence to support your answer. [1]

84 According to Ohm's law an ohm is equivalent to a volt per ampere. The ohm can be expressed in terms of the fundamental units kilogram, meter, second, and ampere. Show $1\frac{V}{A} = 1\frac{kg \cdot m^2}{A^2 \cdot s^3}$ [3]

85 Derive an expression for the radius r of a conductor in terms of its length ℓ, resistance R, and resistivity ρ. [2]

Base your answers to questions 86 through 90 on the following information. An electric broiler is rated 1440 watts and 120 volts. The broiler is connected to a 120-volt line.

86 Draw a diagram of the circuit, showing a voltmeter and an ammeter properly connected to determine the actual power (wattage) of the broiler. [2]

87 Calculate the resistance of the heating coil, if the broiler is operating at the rated power. [2]

88 Calculate the energy the broiler produces in 10.0 minutes. [Assume all of the electrical energy used is converted to heat energy.] [2]

89 A 15-ampere fuse protects the electrical power supply line. Calculate how much additional current can be drawn from the line before the fuse blows and opens the circuit. [2]

90 A "short circuit" is a circuit containing a path of very low resistance in parallel with some other circuit element, such as a lamp. Explain the effect a short circuit would have on the power output of the broiler. [1]

Base your answers to questions 91 through 96 on the following information. A 3.0-ohm resistor and a 6.0-ohm resistor are connected in parallel to an applied potential difference of 12 volts.

91 Using appropriate symbols from the *Reference Tables for Physical Setting/Physics*, draw a labeled circuit diagram. [1]

92 Calculate the current in the 6.0-ohm resistor. [2]

93 Determine the potential drop across the 3.0-ohm resistor. [1]

94 Calculate the power developed in the circuit. [3]

95 An additional 2.0-ohm resistor is connected in parallel in the circuit. Explain what effect, if any, this action has on the amount of current drawn by the 6.0-ohm resistor. [1]

96 Compare the equivalent resistance of the 3.0-ohm resistor and the 6.0-ohm resistor when connected in parallel to their equivalent resistance when connected in series. [1]

Base your answers to questions 97 through 104 on the following information and data table.

A student performed an experiment with the intention of verifying Ohm's law for a household incandescent lightbulb labeled 150 W. In addition to the lightbulb, the student had available to him a socket appropriate for a lamp, a variable source of potential difference, an ammeter, a voltmeter, and connecting wires of negligible resistance. After correctly connecting the ammeter and voltmeter in a circuit with the bulb and source, the student increased the applied potential difference in increments of 1.0 volt and recorded the reading of the ammeter each time. The student took only one reading of the ammeter for each potential difference value. The student's data are shown in the table below.

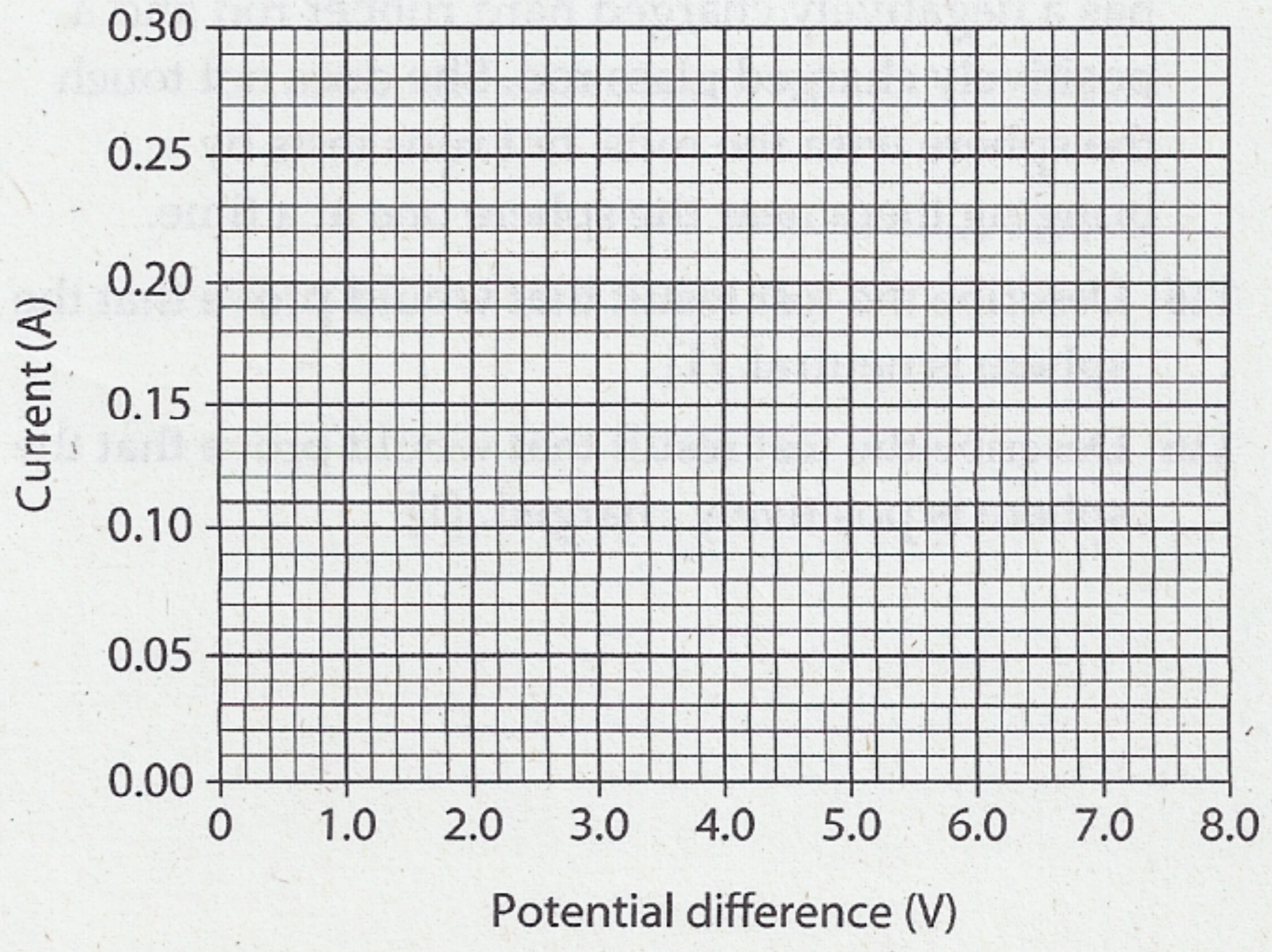
Meter Readings	
Potential Difference (V)	**Current (A)**
0.0	0.00
1.0	0.08
2.0	0.16
3.0	0.20
4.0	0.22
5.0	0.24
6.0	0.26
7.0	0.27

97 Using appropriate symbols from the *Reference Tables for Physical Setting/Physics* and a box labeled "power source," draw and label a complete circuit showing:

- the lamp connected to the power source [1]
- the ammeter connected to measure the current through the lamp [1]
- the voltmeter connected to measure the potential difference across the lamp [1]

98 Using the information in the data table, construct a graph using the grid below by:

- plotting the data points [1]
- drawing the line or curve of best fit [1]
- writing an appropriate title above the grid [1]



99 Calculate the slope of the graph at the 3.0-volt reading. [2]

100 What is the physical significance of the slope of the line at any point? [1]

101 The student concluded that the lamp does not obey Ohm's law. Based on your knowledge of physics and the graph, state the most likely reason why. [1]

102 On the same grid used in question 98, sketch a line representing a device that obeys Ohm's law. [1]

103 Calculate the maximum power developed by the lamp during the experiment. [2]

104 Explain why your answer to question 103 does *not* agree with the 150 W label on the bulb. [1]

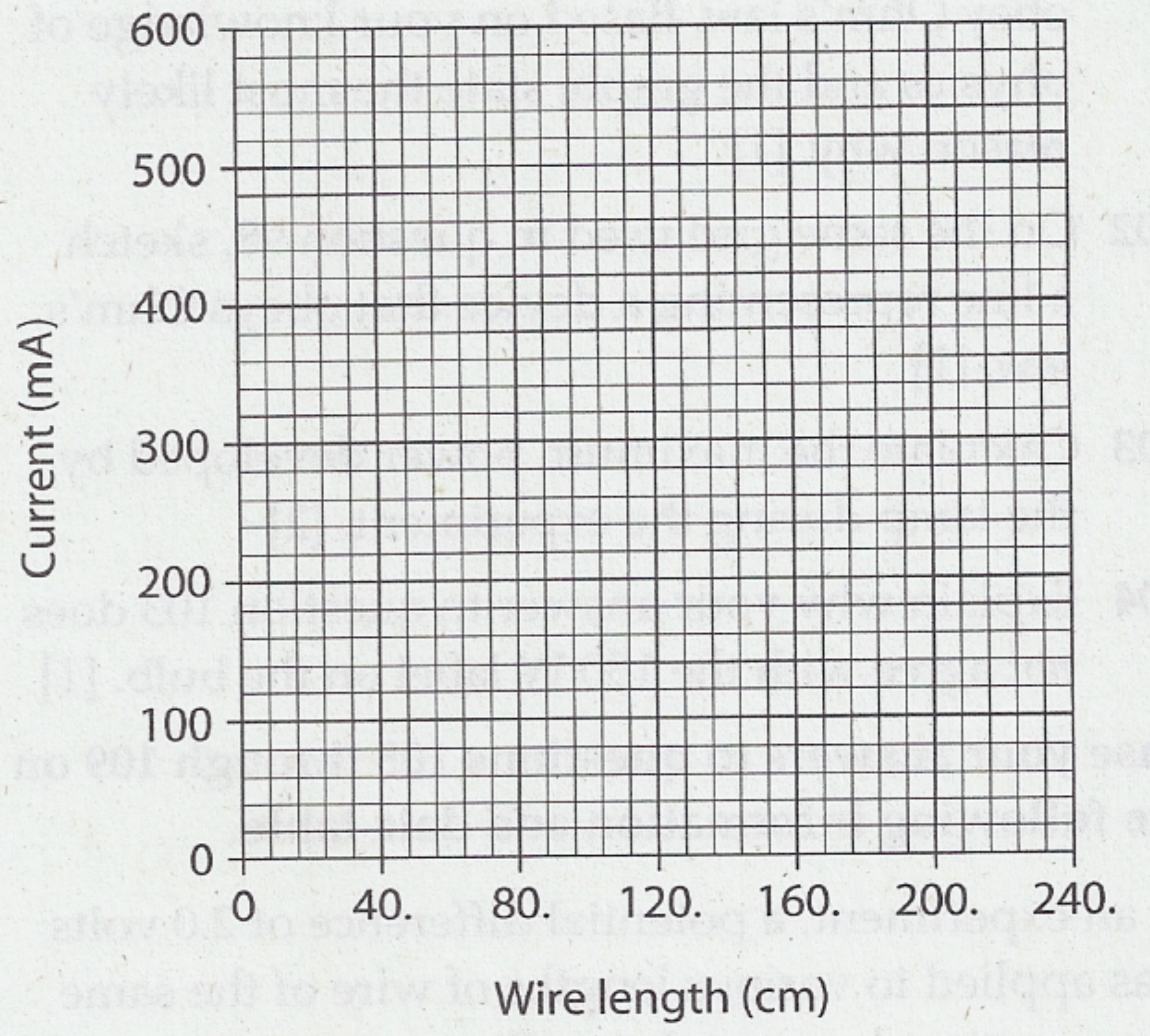
Base your answers to questions 105 through 109 on the following information and data table.

In an experiment, a potential difference of 2.0 volts was applied to various lengths of wire of the same cross-sectional area and metallic composition at a temperature of 20°C. The resulting current was measured and the data recorded in the table below. The student calculated the resistance for each length of wire and recorded that in the table as well.

Results of Varying Wire Length			
Length (cm)	**Potential Difference (V)**	**Current (mA)**	**Resistance**
40.	2.0	500	4.0
80.	2.0	240	8.3
120.	2.0	170	12
160.	2.0	120	17
200.	2.0	100	20.

105 Using the information in the data table, construct a graph on the grid below by:

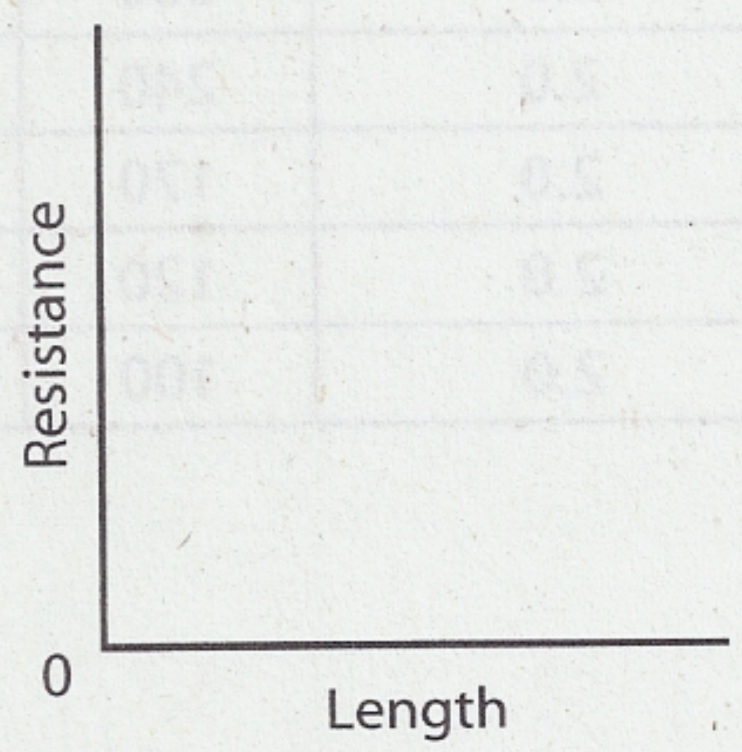
- plotting the data points [1]
- drawing the line or curve of best fit [1]
- writing an appropriate title above the grid [1]



106 Based on your graph, state the relationship between current and wire length. [1]

107 What unit should be written on the data table for resistance? [1]

108 On the axes below sketch the general shape of the graph that shows the relationship between resistance and wire length based on information in the data table. [1]



109 The diameter of the wire is 3.18×10^{-4} meter. Calculate the resistivity of the 200.-centimeter-long wire at 20°C. [3]

Base your answers to questions 110 through 114 on the following information and data table.

Three lamps were connected in a circuit with a battery of constant potential. The current, potential difference, and resistance for each lamp are listed in the data table below. [There is negligible resistance in the wires and the battery.]

	Current (A)	Potential Difference (V)	Resistance (Ω)
lamp 1	0.45	40.1	89
lamp 2	0.11	40.1	365
lamp 3	0.28	40.1	143

110 Using the circuit symbols found in the *Reference Tables for Physical Setting/Physics*, draw a circuit showing how the lamps and batter diagram are connected. [2]

111 What is the potential difference supplied by the battery? [1]

112 Calculate the equivalent resistance of the circuit. [2]

113 If lamp 3 is removed from the circuit, what would be the value of the potential difference across lamp 1 after lamp 3 is removed? [1]

114 If lamp 3 is removed from the circuit, what would be the value of the current in lamp 2 after lamp 3 is removed? [1]

Base your answers to questions 115 and 116 on the information below.

A lightweight sphere hangs by an insulating thread. A student wishes to determine if the sphere is neutral or electrostatically charged. She has a negatively charged hard rubber rod and a positively charged glass rod. She does not touch the sphere with the rods, but runs tests by bringing them near the sphere one at a time.

115 Describe the test result that would prove that the sphere is neutral. [1]

116 Describe the test result that would prove that the sphere is positively charged. [1]