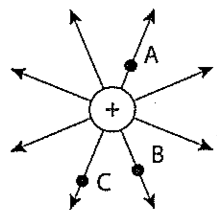
Review Questions

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 (3) 3.0×10^3 N
(2) 1.6×10^{-19} N (4) 4.8×10^{-16} N

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



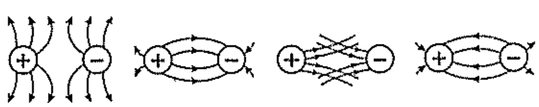
The magnitude of the strength of the electric field is

(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

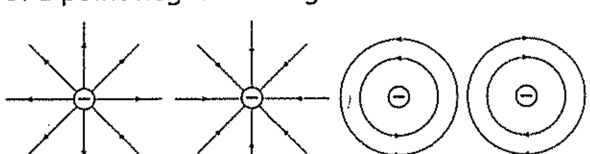
(1) unchanged (3) halved
(2) doubled (4) quadrupled

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 (3) 1.6×10^{-17} J
(2) 1.0×10^2 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.

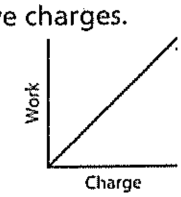
25. A helium ion with a charge of +2e is accelerated by a potential difference of 5.0×10^3 volts. What is the kinetic energy acquired by the ion?

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

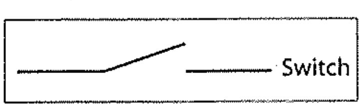


Figure 4-3. The symbol for a switch (R)

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.

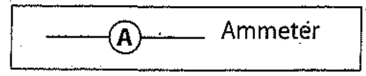


Figure 4-4. The symbol for an ammeter

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.

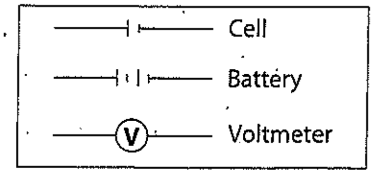


Figure 4-5. Symbols for sources of potential difference (voltage) and a voltmeter for measuring potential difference

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.

<u>Known</u>	<u>Unknown</u>
$V = 12.0\ \text{V}$	$R = ?\ \Omega$
$I = 0.10\ \text{A}$	

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.

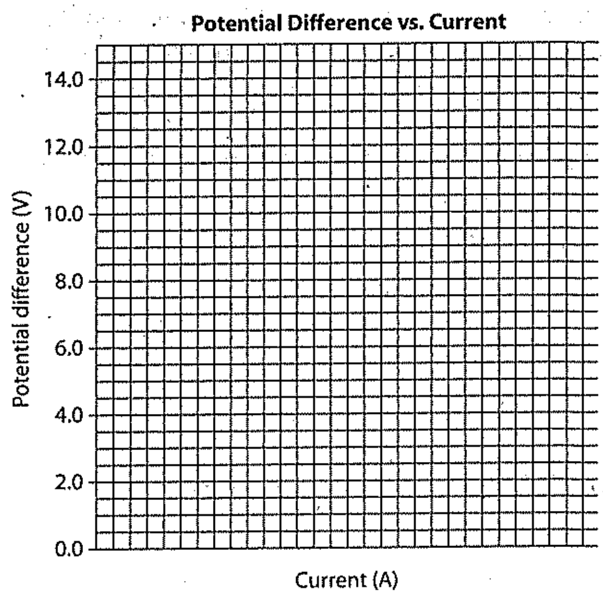
Data Table	
Current (A)	Potential Difference (V)
0.010	2.3
0.020	5.2
0.030	7.4
0.040	9.9
0.050	12.7

(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.

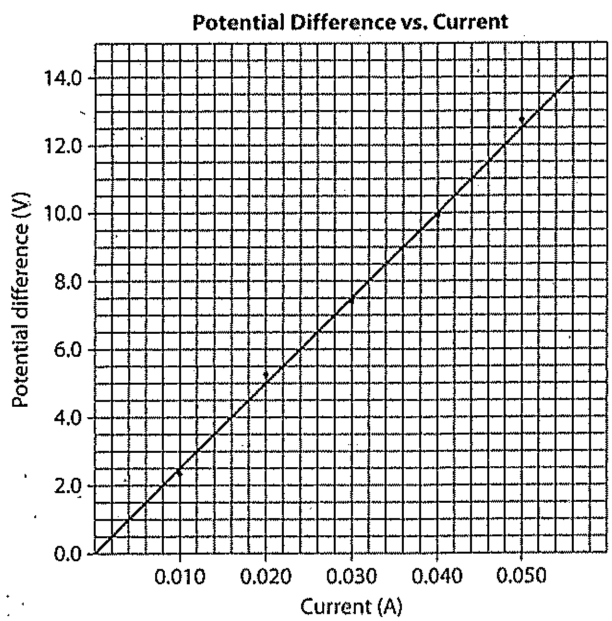
(b) Using your graph, find the slope of the best-fit line.

(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	Unknown
$\rho_{copper} = 1.72 \times 10^{-8}\ \Omega \cdot m$	$R = ?\ \Omega$
$L = 4.00$ m	
$d = 2.00 \times 10^{-3}$ m	

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.

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

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

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

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.

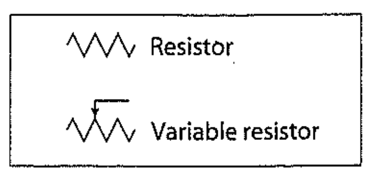


Figure 4-6. Symbols for a resistor and a variable resistor

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} (3) 1.3×10^{19}
(2) 2.0×10^{18} (4) 2.0×10^{19}

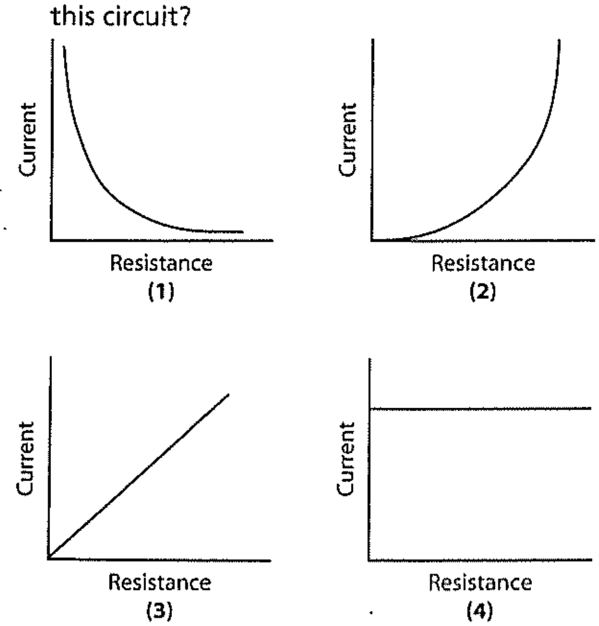
31. Which condition must exist between two points in a conductor in order to maintain a flow of charge?

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

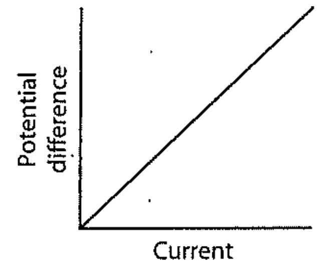
32. A simple circuit consists of a variable resistor connected to a battery. An ammeter and a voltmeter are connected properly in the circuit to measure the current through and potential drop across the variable resistor. What is the effect of increasing the resistance of the variable resistor from 10^3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



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



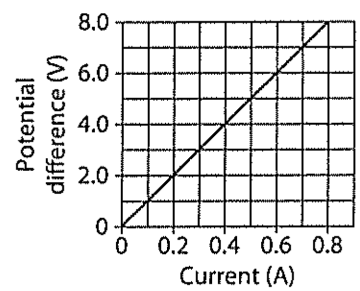
For any point on the line, what does the ratio of potential difference to current represent?

(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.

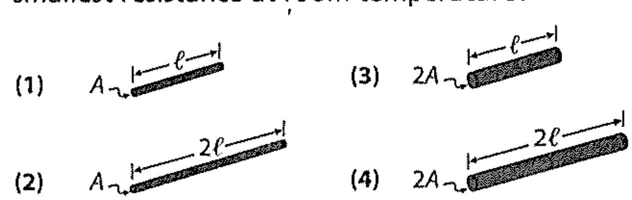
Potential Difference vs. Current



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?



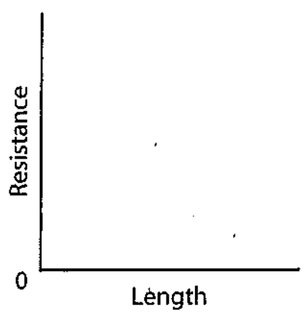
39. An incandescent lightbulb is supplied with a constant potential difference of 120 volts. As the filament of the bulb heats up, what happens to the resistance of the filament and the current through it?

(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.

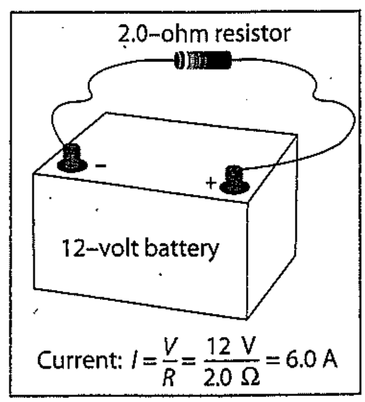


Figure 4-7. A simple circuit

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

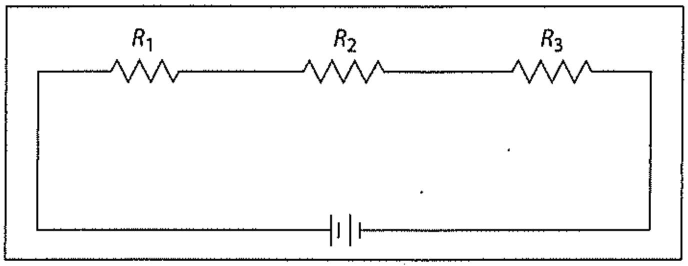


Figure 4-8. Resistors in a series circuit

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.

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

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.

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

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.

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

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.

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.

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.

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

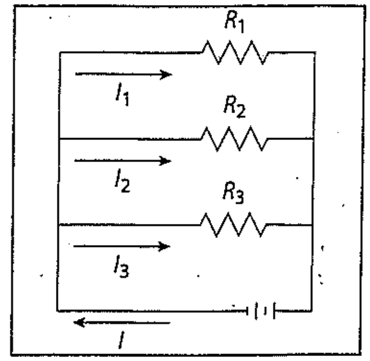


Figure 4-9. Currents in a parallel circuit: The total current I is divided among the three branches of the circuit.

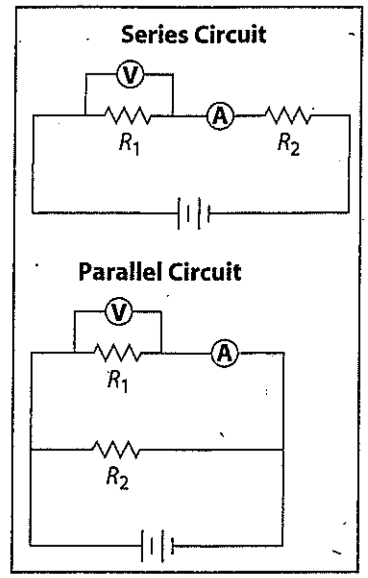


Figure 4-10. Connecting ammeters and voltmeters: The diagram shows how to use an ammeter and a voltmeter to measure the current through and the potential difference across the resistor R_1 in a series circuit and in a parallel circuit.

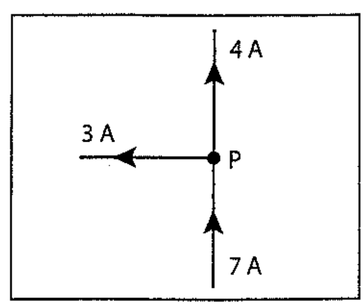


Figure 4-11. Current traveling near junction P in an electric circuit: Note that the sum of currents leaving the junction (3 A + 4 A) equals the current entering the junction (7 A).

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

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.

$$V = V_1 = V_2 = V_3 = 12\ \text{V}$$

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.

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

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

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

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).

$$I = I_1 + I_2 + I_3$$

$$I = 3.0\ \text{A} + 2.0\ \text{A} + 1.0\ \text{A} = 6.0\ \text{A}$$

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

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.

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

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:

Known	*Unknown*
$V = 60.0$ 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.

Known	*Unknown*
$I = 0.40$ 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

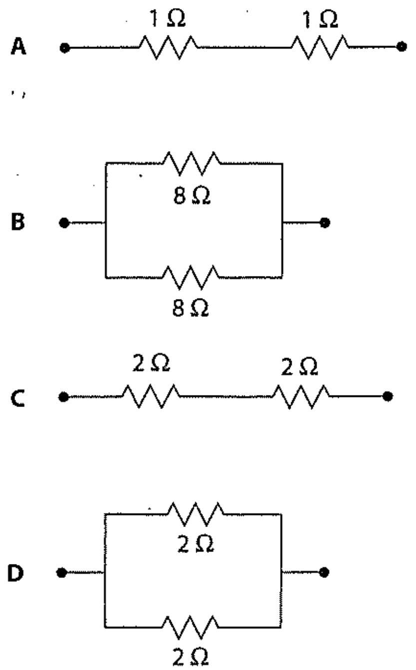
49. A 4-ohm resistor and an 8-ohm resistor are connected in series. If the current through the 4-ohm resistor is 2 amperes, the current through the 8-ohm resistor is

(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

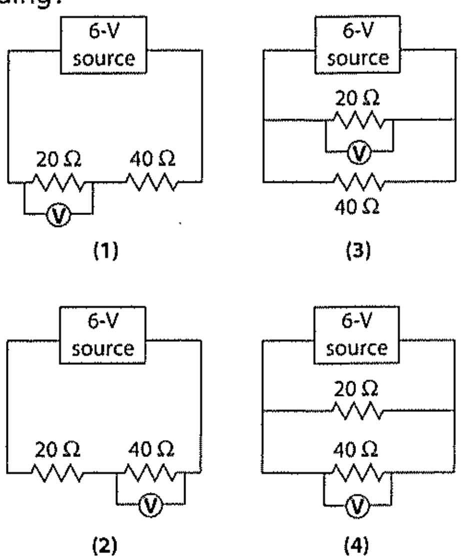
(1) 15 Ω (2) 2.0 Ω (3) 10. Ω (4) 45 Ω

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

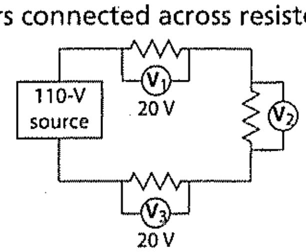


(1) A and B
(2) B and C
(3) C and D
(4) D and A

52. Which circuit would have the lowest voltmeter reading?

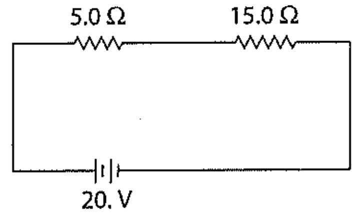


53. The circuit diagram below shows three voltmeters connected across resistors.



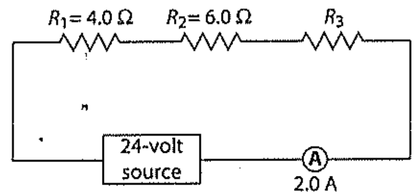
What is the reading of voltmeter V_2?

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.



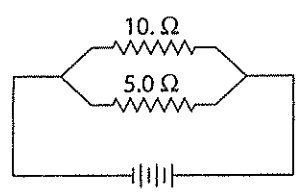
What is the resistance of resistor R_3?

(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.

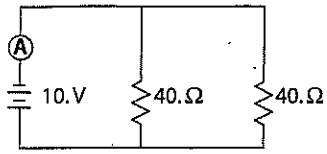
57. A 10.-ohm resistor and a 5.0-ohm resistor are connected as shown in the diagram below.



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.



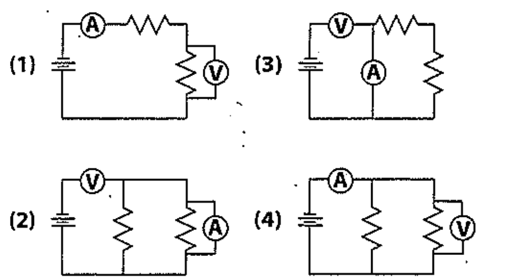
The current measured by ammeter A is

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

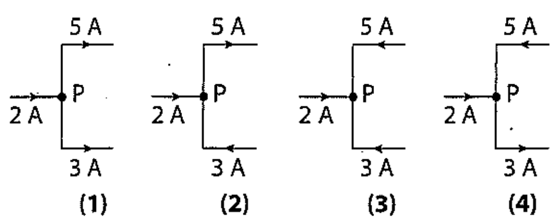
59. A physics student is given three 12-ohm resistors with instructions to create the circuit that would have the lowest possible resistance. The correct circuit would be a

(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

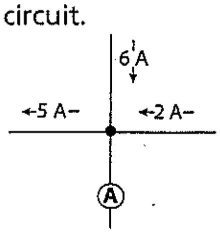
60. Which circuit could be used to determine the total current and potential difference of a parallel circuit?



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

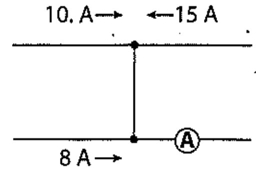


62. The diagram below shows currents in a segment of an electric circuit.



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

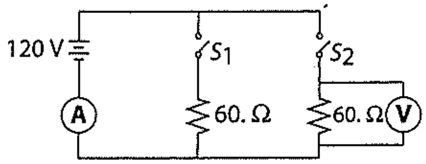
70. What is the total amount of electrical energy needed to operate a 1600-watt toaster for 60. seconds?

(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.



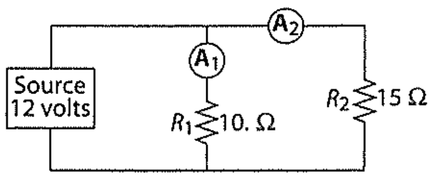
72. If switch S_1 is kept open and switch S_2 is closed, what is the circuit's resistance?

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.

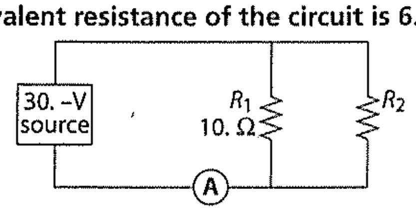
77. Determine the potential difference across resistor R_2.

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.

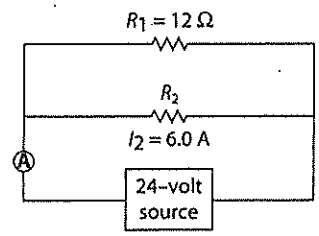
82. Calculate the current through ammeter A.

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.