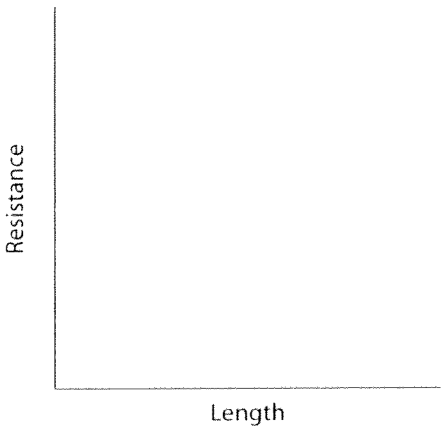
39. If the temperature of a metal conductor is reduced, its resistance will usually (1) decrease (2) increase (3) remain the same

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

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



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

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

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

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

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

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

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

Electric Circuits

The simplest electric circuit consists of a source of electrical energy, such as a battery; connecting wires; and a circuit element, such as a lamp or a resistor, that converts electrical energy to light or heat. The current in the circuit is dependent on the potential difference V provided by the battery at the ends of the circuit element, and the resistance R of the circuit element. These quantities are related to each other by Ohm's Law, $I = \frac{V}{R}$. Figure 4-7 shows a simple electric circuit.

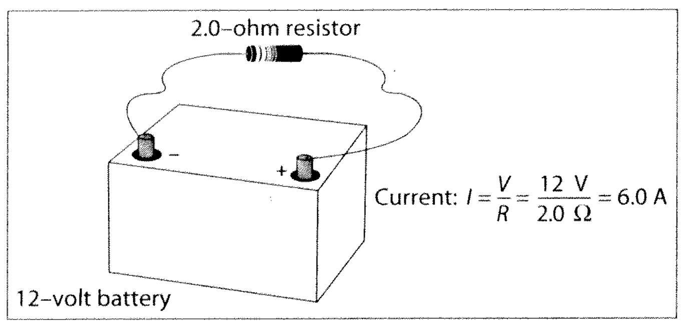


Figure 4-7. A simple circuit

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

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

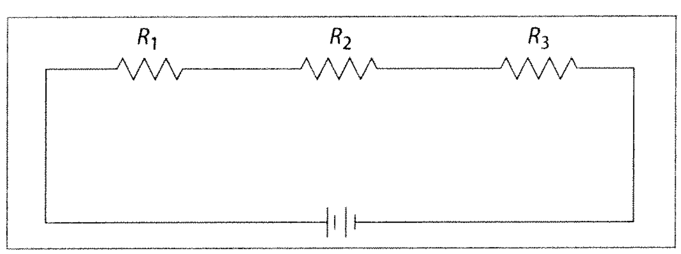


Figure 4-8. Resistors in a series circuit

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

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. Determine (a) the equivalent resistance, (b) the current through each resistor, and (c) the potential drop across each resistor.

Solution: Identify the known and unknown values.

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

(a) Substitute the known resistance values into the equation for equivalent resistance of a series circuit and solve for R_{eq}.

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

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

(b) Substitute the known values for V and R_{eq} into the equation for Ohm's law and solve for I.

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

The current is the same throughout a series circuit.

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

(c) Ohm's law is used to calculate the voltage drop 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.

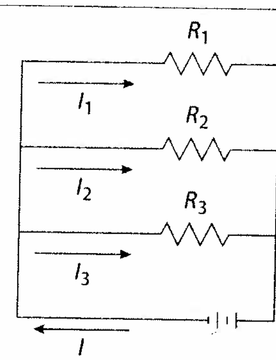


Figure 4-9. Currents in a parallel circuit: The total current I is divided among the three branches of the circuit.

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 $I = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \ldots$ You know by Ohm's law 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 total 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.

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

Solution: Identify the known and unknown values.

Known	*Unknown*
$R_1 = 4.0\ \Omega$	$R_{eq} = ?\ \Omega$
$R_2 = 6.0\ \Omega$	$V = ?\ V$
$R_3 = 12.0\ \Omega$	$I_1 = ?\ A$
	$I_2 = ?\ A$
	$I_3 = ?\ A$

(a) Substitute the known resistance values into the equation for equivalent resistance of a parallel circuit and solve for R_{eq}.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
$$\frac{1}{R_{eq}} = \frac{1}{4.0\ \Omega} + \frac{1}{6.0\ \Omega} + \frac{1}{12\ \Omega}$$
$$\frac{1}{R_{eq}} = \frac{3.0}{12\ \Omega} + \frac{2.0}{12\ \Omega} + \frac{1.0}{12\ \Omega}$$
$$R_{eq} = 2.0\ \Omega$$

(b) The potential difference across each branch of the circuit is the same as the applied potential difference.

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

(c) Ohm's law is used to calculate the current through each resistor.

$$I_1 = \frac{V_1}{R_1} = \frac{12\ V}{4.0\ \Omega} = 3.0\ A$$
$$I_2 = \frac{V_2}{R_2} = \frac{12\ V}{6.0\ \Omega} = 2.0\ A$$
$$I_3 = \frac{V_3}{R_3} = \frac{12\ V}{12\ \Omega} = 1.0\ A$$

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).

$$I = I_1 + I_2 + I_3$$
$$I = 3.0\ A + 2.0\ A + 1.0\ A = 6.0\ A$$
$$\text{Check: } I = \frac{V}{R_{eq}} = \frac{12\ V}{2.0\ \Omega} = 6.0\ A$$

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.

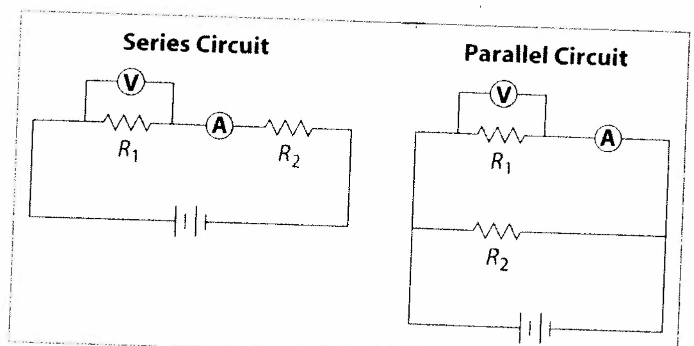


Figure 4-10. Connecting ammeters and voltmeters: The diagram shows how to use an ammeter and a voltmeter to measure the current through and the potential difference across the resistor R_1 in a series circuit and in a parallel circuit.

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 on the next page illustrates the conservation of charge at a junction.

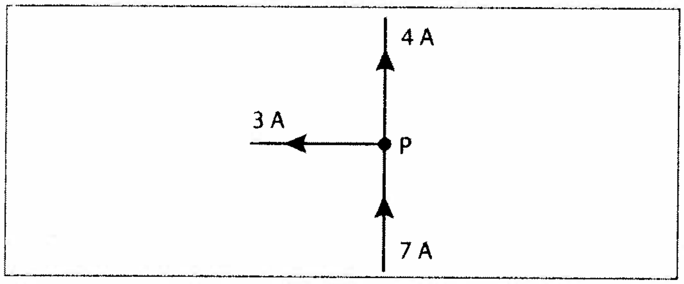


Figure 4-11. Current traveling near junction P in an electric circuit: Note that the sum of currents leaving the junction (3 A + 4 A) equals the current entering the junction (7 A).

ELECTRIC POWER Recall from Topic 3 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 **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.

$$\begin{aligned}(1\ \text{volt})(1\ \text{ampere}) &= \left(1\frac{\text{joule}}{\cancel{\text{coulomb}}}\right)\left(1\frac{\cancel{\text{coulomb}}}{\text{second}}\right)\\ &= 1\,\frac{\text{joule}}{\text{second}}\\ &= 1\ \text{watt}\end{aligned}$$

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.

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

SAMPLE PROBLEM

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

Solution: Identify the known and unknown values.

Known	*Unknown*
$V = 60.0\ \text{V}$	$P = ?\ \text{W}$
$R = 15\ \Omega$	

Substitute the known values into the equation for power and solve.

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

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 current of 0.40 ampere is measured in a 150-ohm resistor. How much energy is expended by the resistor in 30. seconds?

Solution: Identify the known and unknown values.

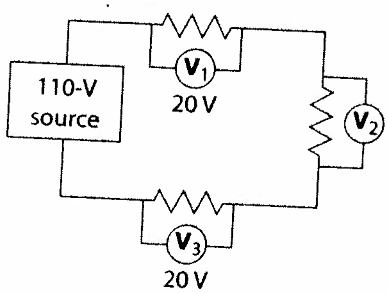
Known	*Unknown*
$I = 0.40\ \text{A}$	$W = ?\ \text{J}$
$R = 150\ \Omega$	
$t = 30.\ \text{s}$	

Substitute the known values into the equation for electrical energy and solve.

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

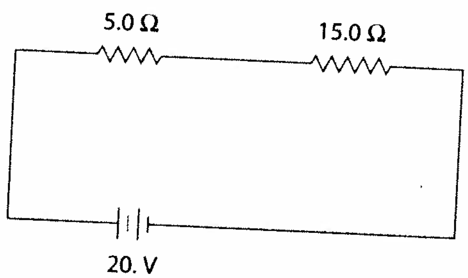
Review Questions

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



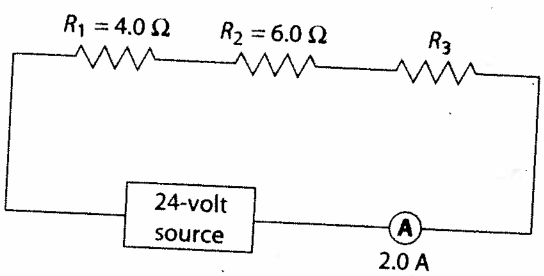
What is the reading of voltmeter V_2?

50. 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?

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

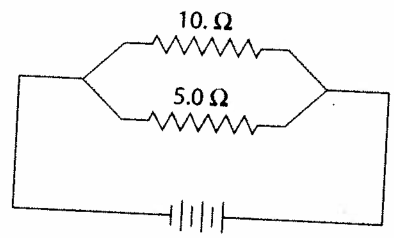


What is the resistance of resistor R_3? (1) 6.0 Ω (2) 2.0 Ω (3) 12 Ω (4) 4.0 Ω

52. 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.

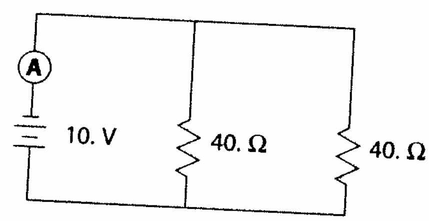
53. A 4-ohm resistor and an 8-ohm resistor are connected in series. If the current through the 4-ohm resistor is 2 amperes, the current through the 8-ohm resistor is (1) 1 A (2) 2 A (3) 0.5 A (4) 4 A

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



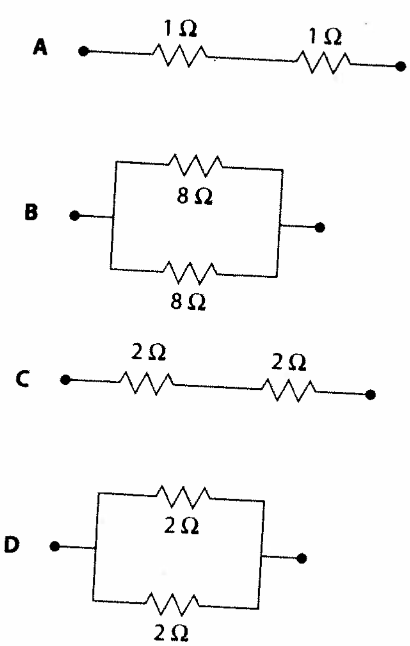
If the current through the 10.-ohm resistor is 1.0 ampere, then the current through the 5.0-ohm resistor is (1) 15 A (2) 2.0 A (3) 0.50 A (4) 0.30 A

55. 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

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

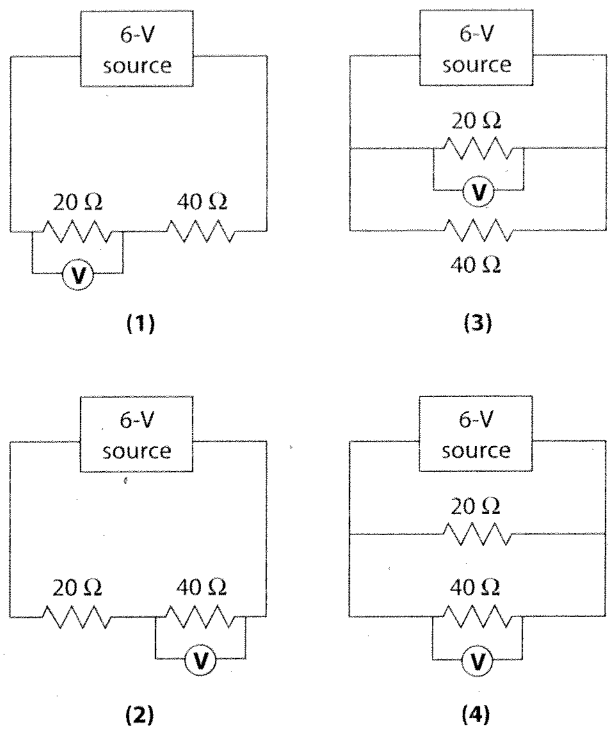


(1) A and B (2) B and C (3) C and D (4) D and A

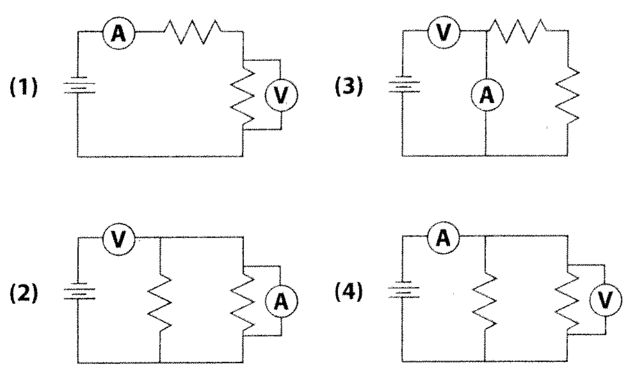
57. A physics student is given three 12-ohm resistors with instructions to create the circuit that would have the lowest possible resistance. The correct circuit would be a (1) series circuit with an equivalent resistance of 36 Ω (2) series circuit with an equivalent resistance of 4 Ω (3) parallel circuit with an equivalent resistance of 36 Ω (4) parallel circuit with an equivalent resistance of 4 Ω

58. 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

59. Which circuit below would have the lowest voltmeter reading?



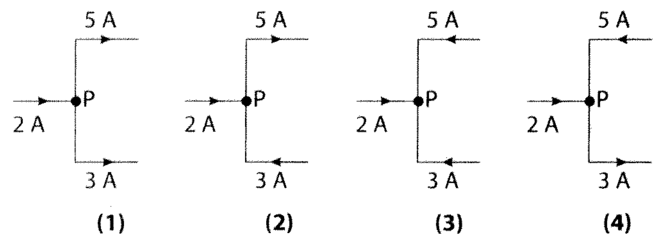
60. Which circuit below could be used to determine the total current and potential difference of a parallel circuit?



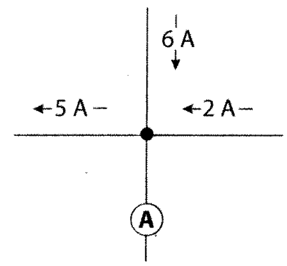
61. A simple electrical circuit contains a battery, a light bulb, and a properly connected ammeter. The ammeter has a very low internal resistance because it is connected in (1) parallel with the bulb to have little effect on the current through the bulb (2) parallel with the bulb to prevent current flow through the bulb (3) series with the bulb to have little effect on the current through the bulb (4) series with the bulb to prevent current through the bulb

62. Compared to the resistance being measured, the internal resistance of a voltmeter is designed to be very high so that the meter will draw (1) no current from the circuit (2) little current from the circuit (3) most of the current from the circuit (4) all the current from the circuit

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

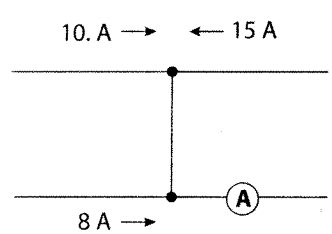


64. The diagram below shows currents in a segment of an electric circuit.



What is the reading of ammeter A?

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



What is the reading on ammeter A? (1) 13 A (2) 17 A (3) 3 A (4) 33 A

66.

67.

68.

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Base
diag
a 12
two

72.

73.

74.

75.

66. Which combination of current and potential difference would use energy at the greatest rate? (1) 7 A at 110 V (2) 6 A at 110 V (3) 3 A at 220 V (4) 4 A at 220 V

67. How much time is required for an operating 100-watt light bulb to dissipate 10 joules of electrical energy? (1) 1 s (2) 0.1 s (3) 10 s (4) 1000 s

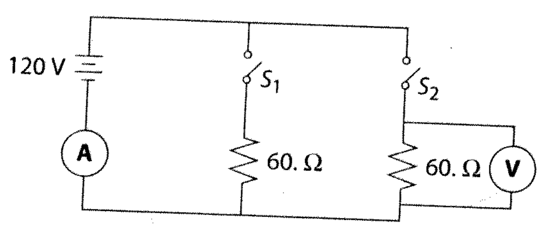
68. While operating at 120 volts, an electric toaster has a resistance of 15 ohms. The power used by the toaster is (1) 8.0 W (2) 120 W (3) 960 W (4) 1800 W

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

70. What is the approximate 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 light bulb with a 100-watt light bulb. Compared to the 60-watt light bulb, the 100-watt light bulb 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.



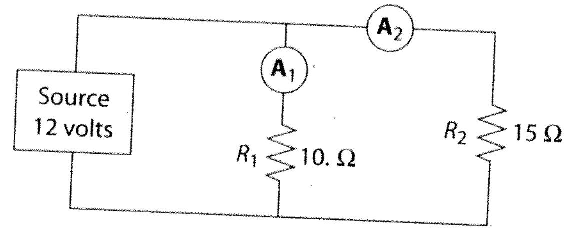
72. If switch S_1 is kept open and switch S_2 is closed, what is the circuit's resistance?

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. The equivalent resistance of the circuit is (1) 25 Ω (2) 6.0 Ω (3) 5.0 Ω (4) 0.17 Ω

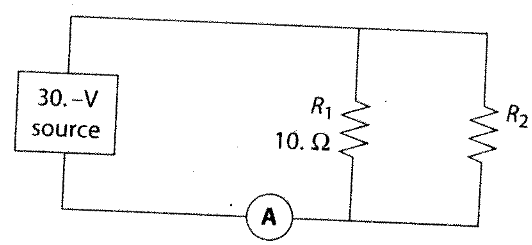
77. Determine the potential difference across resistor R_2.

78. Determine the magnitude of the current flowing through ammeter A_1.

79. Compared to the current in ammeter A_1, the current in ammeter A_2 is (1) less (2) greater (3) the same

80. If another resistor is added to the circuit in parallel, the equivalent resistance of the circuit would (1) decrease (2) increase (3) remain the same

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. The resistance of R_2 is equal to (1) 6.0 Ω (2) 2.0 Ω (3) 15 Ω (4) 4.0 Ω

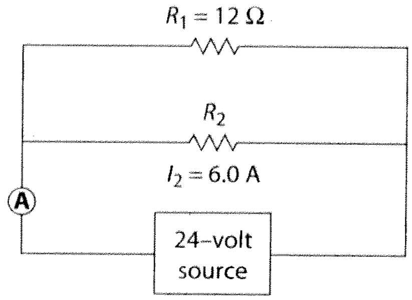
82. Determine the current read by ammeter A.

83. Determine the power developed in resistor R_1 alone.

84. Compared to the potential difference across the source, the potential difference across R_2 is (1) less (2) greater (3) the same

85. If the resistance of R_2 were increased, the current through R_2 would (1) decrease (2) increase (3) remain the same

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



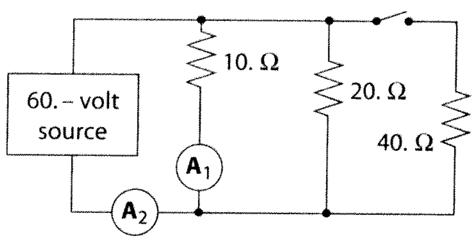
86. The current in ammeter A is (1) 1.0 A (2) 2.0 A (3) 6.0 A (4) 8.0 A

87. How much energy is 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 resistance R_2 were removed, the current in ammeter A would (1) decrease (2) increase (3) remain the same

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. Determine the power developed in the 10.-ohm resistor.

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. Compared to the current through ammeter A_1 when the switch is open, the current passing through ammeter A_1 when the switch is closed is (1) less (2) greater (3) the same

Base your answers to questions 95 through 99 on the following information. An electric heater rated at 4800 watts is operated at 120 volts.

95. Determine the resistance of the heater.

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

97. If the heater is replaced with one having a greater resistance, the amount of heat energy produced each second will (1) decrease (2) increase (3) remain the same

98. If another heater is connected in parallel with the first one and both operate at 120 volts, the current in the first heater will (1) decrease (2) increase (3) remain the same

99. If the original heater is operated at less than 120 volts, the amount of heat produced will (1) decrease (2) increase (3) remain the same

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.