Basic Electronics

- Ohm’s Law.

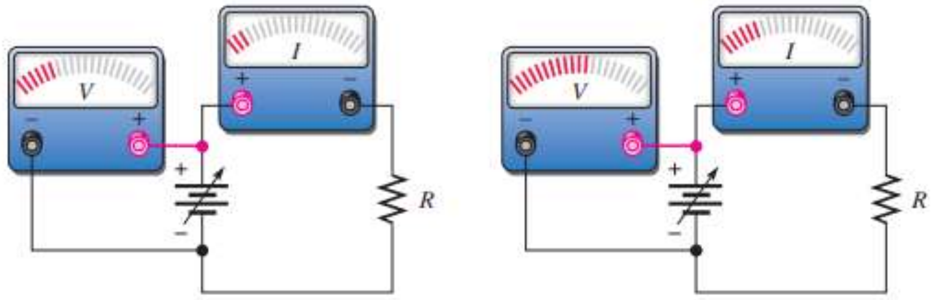
Ohm’s Law

- Ohm’s law is perhaps the single most important tool for the analysis of electric circuits, and you must know how to apply it.

- In 1826 Georg Simon Ohm found that current, voltage, and resistance are related in a specific and predictable way. Ohm expressed this relations with a formula that is known today as Ohm’s law

Ohm's Experiments

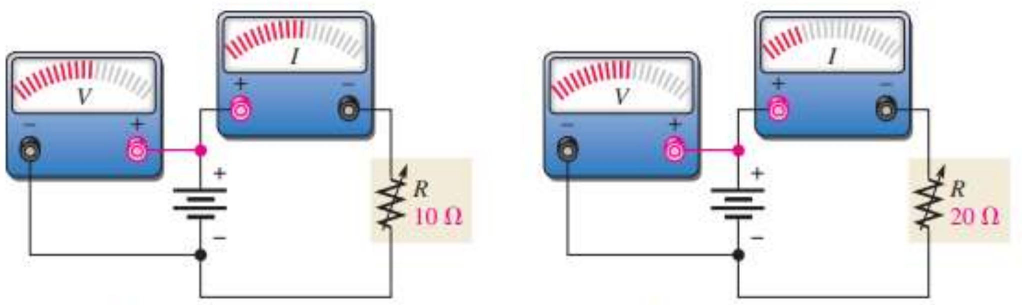
- Ohm determined experimentally that if the voltage across a resistor is increased, the current through the resistor will also increase; and, likewise, if the voltage is decreased, the current will decrease.
- For example, if the voltage is doubled, the current will double. If the voltage is halved, the current will also be halved.



(a) Less V, less I (b) More V, more I

Ohm’s Experiments

- Ohm also determined that if the voltage is held constant, less resistance results in more current, and, also, more resistance results in less current.
- For example, if the resistance is halved, the current doubles. If the resistance is doubled, the current is halved.



(a) Less *R*, more *I* (b) More *R*, less *I*

Ohm's Law

- Ohm's law states that current is directly proportional to voltage and inversely proportional to resistance

$$I= V/R$$

- where I is current in amperes (A), V is voltage in volts (V), and R is resistance in ohms
- For a constant value of R, if the value of V is increased, the value of I increases; if V is decreased, I decreases. If V is constant and R is increased, I decreases. Similarly, if V is constant and R is decreased, I increases

$$V=IR$$

$$R=V/R$$

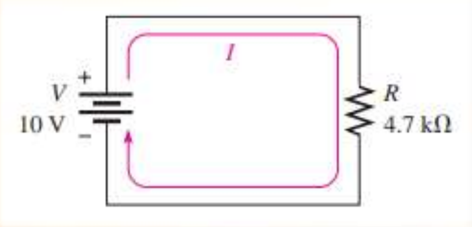
The Linear Relationship of Current and Voltage

- In resistive circuits, current and voltage are linearly proportional.
- Linear means that if one of the quantities is increased or decreased by a certain percentage, the other will increase or decrease by the same percentage, assuming that the resistance is constant in value.

The Linear Relationship of Current and Voltage

EXAMPLE 1 Show that if the voltage in the circuit of Figure 3 is increased to three times its present value, the current will triple in value.

▶ **FIGURE 3**



Solution With 10 V, the current is

$$I = \frac{V}{R} = \frac{10\text{ V}}{4.7\text{ k}\Omega} = \mathbf{2.13\text{ mA}}$$

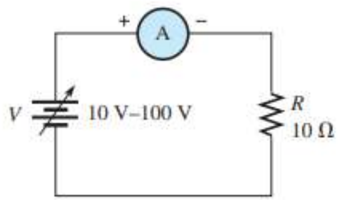
If the voltage is increased to 30 V, the current will be

$$I = \frac{V}{R} = \frac{30\text{ V}}{4.7\text{ k}\Omega} = \mathbf{6.38\text{ mA}}$$

The current went from 2.13 mA to 6.38 mA when the voltage was tripled to 30 V.

*Related Problem** If the voltage in Figure 3 is quadrupled, will the current also quadruple?

The Linear Relationship of Current and Voltage

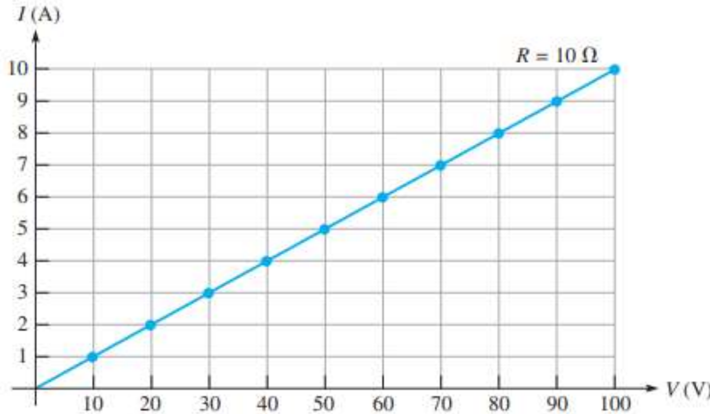


(a)

V	I
10 V	1 A
20 V	2 A
30 V	3 A
40 V	4 A
50 V	5 A
60 V	6 A
70 V	7 A
80 V	8 A
90 V	9 A
100 V	10 A

$$I = \frac{V}{10\ \Omega}$$

(b)



(c)

The Linear Relationship of Current and Voltage

EXAMPLE 2

Assume that you are measuring the current in a circuit that is operating with 25 V. The ammeter reads 50 mA. Later, you notice that the current has dropped to 40 mA. Assuming that the resistance did not change, you must conclude that the voltage source has changed. How much has the voltage changed, and what is its new value?

Solution The current has dropped from 50 mA to 40 mA, which is a decrease of 20%. Since the voltage is linearly proportional to the current, the voltage has decreased by the same percentage that the current did. Taking 20% of 25 V, you get

$$\text{Change in voltage} = (0.2)(25\text{ V}) = \mathbf{5\text{ V}}$$

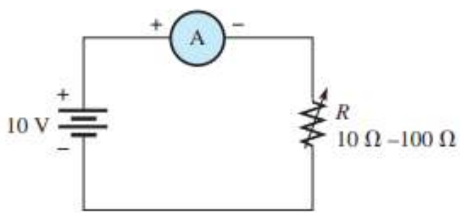
Subtract this change from the original voltage to get the new voltage.

$$\text{New voltage} = 25\text{ V} - 5\text{ V} = \mathbf{20\text{ V}}$$

Notice that you did not need the resistance value in order to find the new voltage.

Related Problem If the current drops to 0 A under the same conditions stated in the example, what is the voltage?

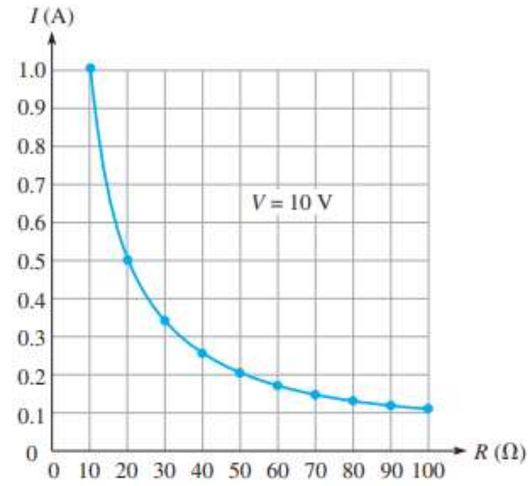
The Inverse Relationship of Current and Resistance



(a)

R (Ω)	I (A)
10	1.000
20	0.500
30	0.333
40	0.250
50	0.200
60	0.167
70	0.143
80	0.125
90	0.111
100	0.100

(b)

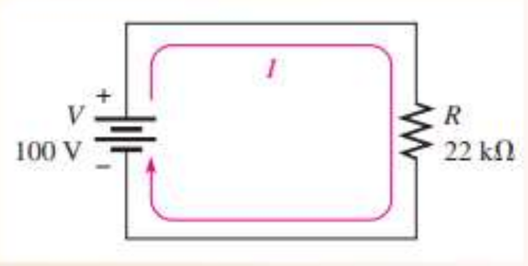


(c)

Current Calculations

EXAMPLE 3 How many amperes of current are in the circuit of Figure 6?

▶ FIGURE 6



Solution Use the formula $I = V/R$, and substitute 100 V for V and 22 kΩ for R.

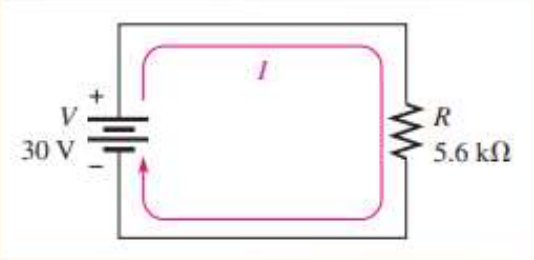
$$I = \frac{V}{R} = \frac{100\text{ V}}{22\text{ k}\Omega} = \mathbf{4.55\text{ mA}}$$

Related Problem If R is changed to 33 kΩ in Figure 6, what is the current?

Current Calculations

EXAMPLE 6 How many milliamperes are in the circuit of Figure 8?

▶ FIGURE 8



Solution When you divide volts by kilohms, you get current in milliamperes.

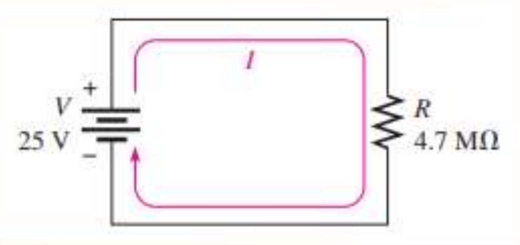
$$I = \frac{V}{R} = \frac{30\text{ V}}{5.6\text{ k}\Omega} = \mathbf{5.36\text{ mA}}$$

Related Problem What is the current in milliamperes if R is changed to 2.2 kΩ?

Current Calculations

EXAMPLE 7 Determine the amount of current in the circuit of Figure 9.

► FIGURE 9



Solution Recall that 4.7 MΩ equals $4.7 \times 10^6\ \Omega$. Substitute 25 V for V and $4.7 \times 10^6\ \Omega$ for R.

$$I = \frac{V}{R} = \frac{25\text{ V}}{4.7\text{ M}\Omega} = \frac{25\text{ V}}{4.7 \times 10^6\ \Omega} = 5.32 \times 10^{-6}\text{ A} = \mathbf{5.32\ \mu A}$$

Related Problem What is the current if V is increased to 100 V in Figure 6?

Current Calculations

EXAMPLE 10 How much current is there through a 100 MΩ resistor when 50 kV are applied?

Solution In this case, divide 50 kV by 100 MΩ to get the current. Substitute 50×10^3 V for 50 kV and $100 \times 10^6\ \Omega$ for 100 MΩ.

$$I = \frac{V}{R} = \frac{50\,\text{kV}}{100\,\text{M}\Omega} = \frac{50 \times 10^3\,\text{V}}{100 \times 10^6\,\Omega} = 0.5 \times 10^{-3}\,\text{A} = \mathbf{0.5\,mA}$$

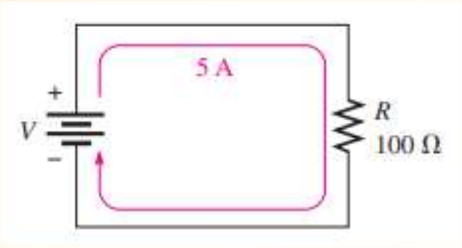
Remember that the power of ten in the denominator is subtracted from the power of ten in the numerator. So 50 was divided by 100, giving 0.5, and 6 was subtracted from 3, giving 10^{-3}.

Related Problem How much current is there through a 6.8 MΩ resistor when 10 kV are applied?

Voltage Calculations

EXAMPLE 11 In the circuit of Figure 10, how much voltage is needed to produce 5 A of current?

▶ FIGURE 10



Solution Substitute 5 A for I and 100 Ω for R into the formula $V = IR$.

$$V = IR = (5\text{ A})(100\ \Omega) = \mathbf{500\ V}$$

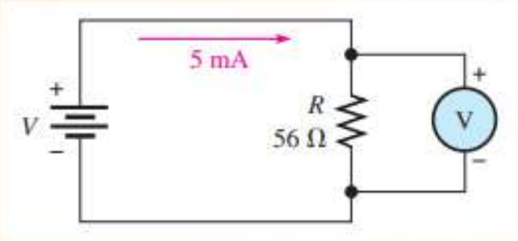
Thus, 500 V are required to produce 5 A of current through a 100 Ω resistor.

Related Problem In Figure 10, how much voltage is required to produce 12 A of current?

Voltage Calculations

EXAMPLE 12 How much voltage will be measured across the resistor in Figure 11?

▶ FIGURE 11



Solution Five milliamperes equals 5×10^{-3} A. Substitute the values for I and R into the formula $V = IR$.

$$V = IR = (5\text{ mA})(56\ \Omega) = (5 \times 10^{-3}\text{ A})(56\ \Omega) = 280 \times 10^{-3}\text{ V} = \mathbf{280\ mV}$$

Voltage Calculations

EXAMPLE 13 Suppose that a solar cell produces a current of 180 μA through a 100 Ω resistor. How much voltage is across the resistor?

Solution 180 microamperes equals 180×10^{-6} A. Substitute the values for I and R into the formula $V = IR$.

$$V = IR = (180\ \mu\text{A})(100\ \Omega) = (180 \times 10^{-6}\ \text{A})(100\ \Omega) = 18 \times 10^{-3}\ \text{V} = \mathbf{18\ mV}$$

Related Problem If there are 3.2 μA through a 47 Ω resistor, what is the voltage across the resistor?

Voltage Calculations

EXAMPLE 15 If there is a current of 50 μA through a 4.7 MΩ resistor, what is the voltage?

Solution Fifty microamperes equals 50×10^{-6} A and 4.7 MΩ is $4.7 \times 10^{6}\ \Omega$. Substitute these values into the formula $V = IR$.

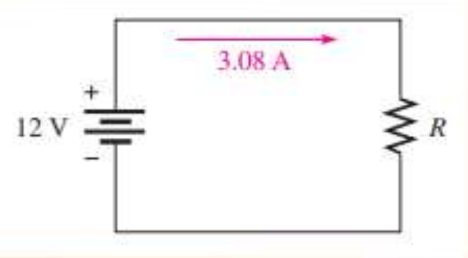
$$V = IR = (50\ \mu\text{A})(4.7\ \text{M}\Omega) = (50 \times 10^{-6}\ \text{A})(4.7 \times 10^{6}\ \Omega) = \mathbf{235\ V}$$

Resistance Calculations

EXAMPLE 16

In the circuit of Figure 13, how much resistance is needed to draw 3.08 A of current from the battery?

FIGURE 13



Solution Substitute 12 V for V and 3.08 A for I into the formula $R = V/I$.

$$R = \frac{V}{I} = \frac{12\text{ V}}{3.08\text{ A}} = \mathbf{3.90\ \Omega}$$

Related Problem In Figure 13, to what value must R be changed for a current of 5.45 A?

Resistance Calculations

EXAMPLE 17 Use Ohm's law to calculate the resistance of a rear window defroster grid in a certain vehicle. When it is connected to 12.6 V, it draws 15.0 A from the battery. What is the resistance of the defroster grid?

Solution

$$R = \frac{V}{I} = \frac{12.6\text{ V}}{15.0\text{ A}} = \mathbf{0.84\ \Omega}$$

Related Problem If one of the grid wires opens, the current drops to 13.0 A. What is the new resistance?

Basic Electronics

- Power & Energy.

Introduction

- When there is current through a resistance, electrical energy is converted to heat or other form of energy, such as light. A common example of this is a light bulb that becomes too hot to touch.
- The current through the filament that produces light also produces unwanted heat because the filament has resistance.
- Electrical components must be able to dissipate a certain amount of energy in a given period of time

Energy & Power

- Energy is the ability to do work, and power is the rate at which energy is used.
- Power (P) is a certain amount of energy (W) used in a certain length of time (t), expressed as follows:

$$P = W/t$$

where P is power in watts (W), W is energy in joules (J), and t is time in seconds (s). Note that an italic W is used to represent energy in the form of work and a nonitalic W is used for watts, the unit of power. The joule (J) is the SI unit of energy

Watt

- One watt (W) is the amount of power when one joule of energy is used in one second.
- Thus, the number of joules used in one second is always equal to the number of watts.
- For example, if 75 J are used in 1 s, the power is

$$P = W/t = 75\ J/1\ s = 75\ W$$

- 1 hp = 746 W

Energy in terms of Power

- power utilized over a period of time represents energy consumption. If you multiply power in watts and time in seconds, you have energy in joules, symbolized by W.

$$W = Pt$$

Energy & Power

EXAMPLE 1 An amount of energy equal to 100 J is used in 5 s. What is the power in watts?

Solution

$$P = \frac{\text{energy}}{\text{time}} = \frac{W}{t} = \frac{100\text{ J}}{5\text{ s}} = \mathbf{20\ W}$$

*Related Problem** If 100 W of power occurs for 30 s, how much energy, in joules, is used?

*Answers are at the end of the chapter.

EXAMPLE 2 Express the following values of electrical power using appropriate metric prefixes:

(a) 0.045 W **(b)** 0.000012 W **(c)** 3500 W **(d)** 10,000,000 W

Solution

(a) 0.045 W = **45 mW** **(b)** 0.000012 W = **12 μW**

(c) 3500 W = **3.5 kW** **(d)** 10,000,000 W = **10 MW**

Related Problem Express the following amounts of power in watts without metric prefixes:

(a) 1 mW **(b)** 1800 μW **(c)** 1000 mW **(d)** 1 μW

The Kilowatt-hour Unit of Energy

- The joule has been defined as a unit of energy. However, there is another way to express energy.
- Since power is expressed in watts and time in seconds, units of energy called the watt-second (Ws), watt-hour (Wh), and kilowatt-hour (kWh) can be used.
- When you pay your electric bill, you are charged on the basis of the amount of energy you use, not the power.
- Because power companies deal in huge amounts of energy, the most
- practical unit is the kilowatt-hour.
- You use a kilowatt-hour of energy when you use one thousand watts of power for one hour.
- For example, a 100 W light bulb burning for 10 h uses 1 kWh of energy

The Kilowatt-hour Unit of Energy

EXAMPLE 3 Determine the number of kilowatt-hours (kWh) for each of the following energy consumptions:

(a) 1400 W for 1 h **(b)** 2500 W for 2 h **(c)** 100,000 W for 5 h

Solution

(a) $1400\text{ W} = 1.4\text{ kW}$

$W = Pt = (1.4\text{ kW})(1\text{ h}) = \mathbf{1.4\text{ kWh}}$

(b) $2500\text{ W} = 2.5\text{ kW}$

$W = (2.5\text{ kW})(2\text{ h}) = \mathbf{5\text{ kWh}}$

(c) $100{,}000\text{ W} = 100\text{ kW}$

$W = (100\text{ kW})(5\text{ h}) = \mathbf{500\text{ kWh}}$

Related Problem How many kilowatt-hours are used by a 250 W bulb burning for 8 h?

Power in an Electric Circuit

- The generation of heat, which occurs when electrical energy is converted to heat energy, in an electric circuit is often an unwanted by-product of current through the resistance in the circuit.
- In some cases, however, the generation of heat is the primary purpose of a circuit as, for example, in an electric resistive heater. In any case, you must frequently deal with power in electrical and electronic circuits

Power in an Electric Circuit

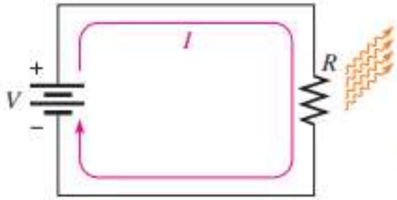
- When there is current through resistance, the collisions of the electrons produce heat as a result of the conversion of electrical energy.
- The amount of power dissipated in an electric circuit is dependent on the amount of resistance and on the amount of current, expressed as follows:

$$P = I^2R$$

where P is power in watts (W), I is current in amperes (A), and R is resistance in ohms (Ω). You can get an equivalent expression for power in terms of voltage and current by substituting V for IR (I^2 is $I \times I$).

$$P = I^2R = (I \times I)R = I(IR) = (IR)I$$

$$P = VI$$



Heat produced by current through resistance is a result of energy conversion.

Power in an Electric Circuit

where P is in watts when V is in volts and I is in amperes. You can obtain another equivalent expression by substituting V/R for I (Ohm's law).

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

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

The relationships between power and current, voltage, and resistance expressed in the preceding formulas are known as Watt's law. In each case, I must be in amps, V in volts, and R in ohms

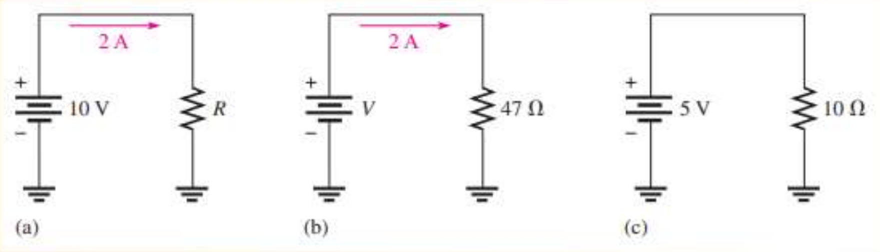
To calculate the power in a resistance, you can use any one of the three power formulas, depending on what information you have. For example, assume that you know the values of current and voltage

In this case calculate the power with the formula, If you know I and R, use the formula If you know V and R, use the formula P = V2/R

Power in an Electric Circuit

EXAMPLE 4 Calculate the power in each of the three circuits of Figure 2.

FIGURE 2



Solution In circuit (a), you know V and I. Therefore, use Equation 3.

$$P = VI = (10\text{ V})(2\text{ A}) = \mathbf{20\ W}$$

In circuit (b), you know I and R. Therefore, use Equation 2.

$$P = I^2R = (2\text{ A})^2(47\ \Omega) = \mathbf{188\ W}$$

In circuit (c), you know V and R. Therefore, use Equation 4.

$$P = \frac{V^2}{R} = \frac{(5\text{ V})^2}{10\ \Omega} = \mathbf{2.5\ W}$$

Related Problem Determine P in each circuit of Figure 2 for the following changes:

Circuit (a): I doubled and V remains the same

Circuit (b): R doubled and I remains the same

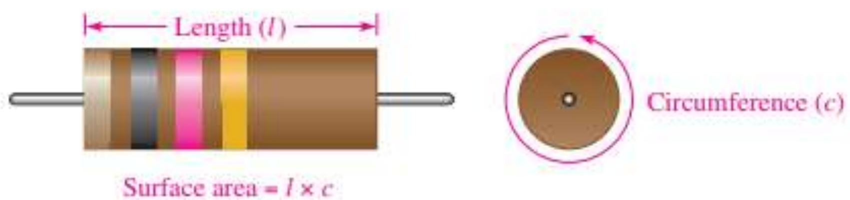
Circuit (c): V halved and R remains the same

Resistors Power Ratings

- The limit to the amount of heat that a resistor can give off is specified by its power rating.
- The power rating is the maximum amount of power that a resistor can dissipate without being damaged by excessive heat buildup.
- The power rating is not related to the ohmic value (resistance) but rather is determined mainly by the physical composition, size, and shape of the resistor
- All else being equal, the larger the surface area of a resistor, the more power it can dissipate

Resistors Power Ratings

- The surface area of a cylindrically shaped resistor is equal to the length (l) times the circumference (c)



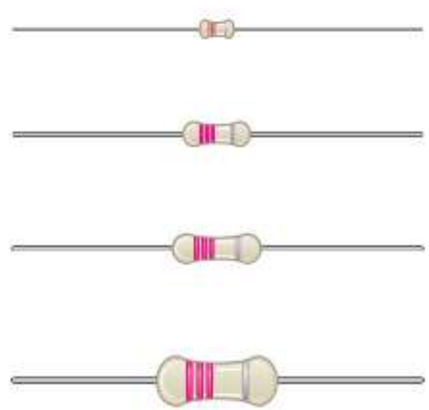


FIGURE 5

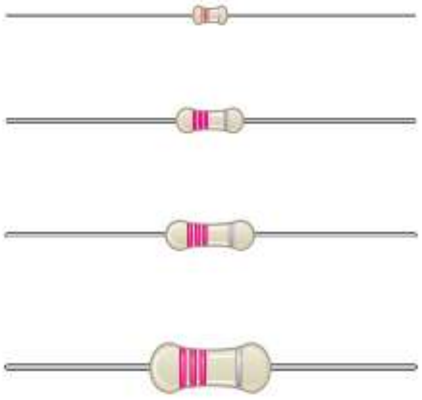
Relative sizes of metal-film resistors with standard power ratings of ⅛ W, ¼ W, ½ W, and 1 W.

Resistors Power Ratings

- When a resistor is used in a circuit, its power rating must be greater than the maximum power that it will have to handle. For example, if a resistor is to dissipate 0.75 W in a circuit application, its rating should be at least the next higher standard value which is 1 W. A rating larger than the actual power should be used when possible as a safety margin

▶ **FIGURE 5**

Relative sizes of metal-film resistors with standard power ratings of $\frac{1}{8}$ W, $\frac{1}{4}$ W, $\frac{1}{2}$ W, and 1 W.

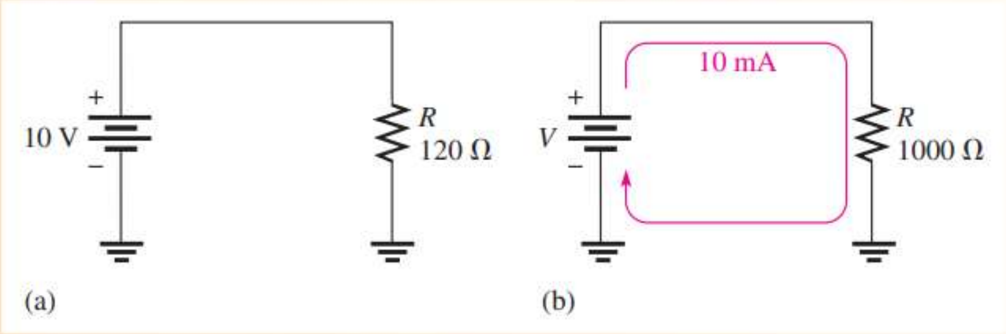


Resistors Power Ratings

EXAMPLE 6

Choose an adequate power rating for each of the metal-film resistors in Figure 7 ($\frac{1}{8}$ W, $\frac{1}{4}$ W, $\frac{1}{2}$ W, or 1 W).

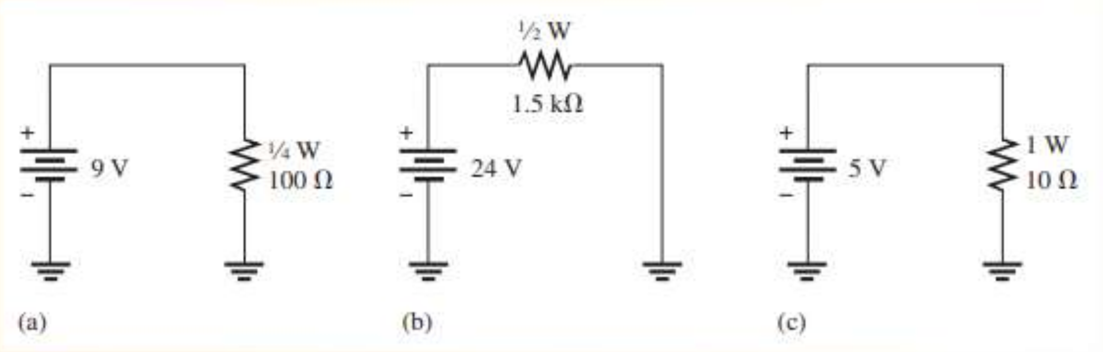
FIGURE 7



Resistors Power Ratings

EXAMPLE 7

Determine whether the resistor in each circuit of Figure 9 has possibly been damaged by overheating.



Energy Conversion and Voltage Drop in Resistance