Ministry of Higher Education and Scientific Research
Tikrit University
Engineering Collage –Al shirqat

FUNDAMENTALS OF ELECTRICAL ENGINEERING
LECTURE 2
OHM'S LAWS

الصباحي Classroom: xtofyek4

المسائي Classroom: cftcvpvp

PREPARED BY
TEACHING ASSISTANT

ABDULLAH AHMED ALWAN

General Objectives:

Understanding the Basic Principles of Electricity: Enhancing general comprehension of electrical concepts, including the relationship between current, voltage, and resistance (Ohm's Law).

Enhancing Efficiency in Handling Electrical Circuits: Enabling learners or professionals to analyze and design electrical circuits using resistance.

Introducing Students to Ohm's Law:

• Understanding the relationship between voltage, electric current, and resistance.

• Recognizing the importance of Ohm's in designing and analyzing electrical circuits.

Developing Scientific Thinking Skills:

• Analyzing the mathematical relationship between electrical components.

• Applying Ohm's to solve practical electrical problems.

Enhancing Scientific Understanding in Daily Life:

• Recognizing how voltage and current affect electrical devices.

Specific Objectives:

- **The student should explain:** The relationship between voltage (V), current (I), and resistance (R).
- **The student should state:** The mathematical formula of Ohm's Law: $V = I \times R$.
- **Reducing electric current:** Using resistance to limit the current in specific parts of the circuit.
- **Voltage distribution:** Dividing voltage in electrical circuits to achieve the desired functions.
- **Protecting electrical circuits:** Safeguarding electronic components from damage caused by high currents or voltages.
- **Heat generation:** Utilizing resistance as a heat source in applications such as electric heaters.

Introduction

The general and specific objectives help achieve a comprehensive understanding of Ohm's Law from both theoretical and practical perspectives, enabling students to use it effectively in various real-life situations and in the study of electrical sciences.

Resistance of Conductors

Circuit components (called resistors) are specifically designed to possess resistance and are used in almost all electronic and electrical circuits. Although the resistor is the most simple component in any circuit, its effect is very important in determining the operation of a circuit. **The resistance R** of an element denotes its ability to resist the flow of electric current; it is measured in ohms (Ω).

$1\ \Omega = 1\ V/A$

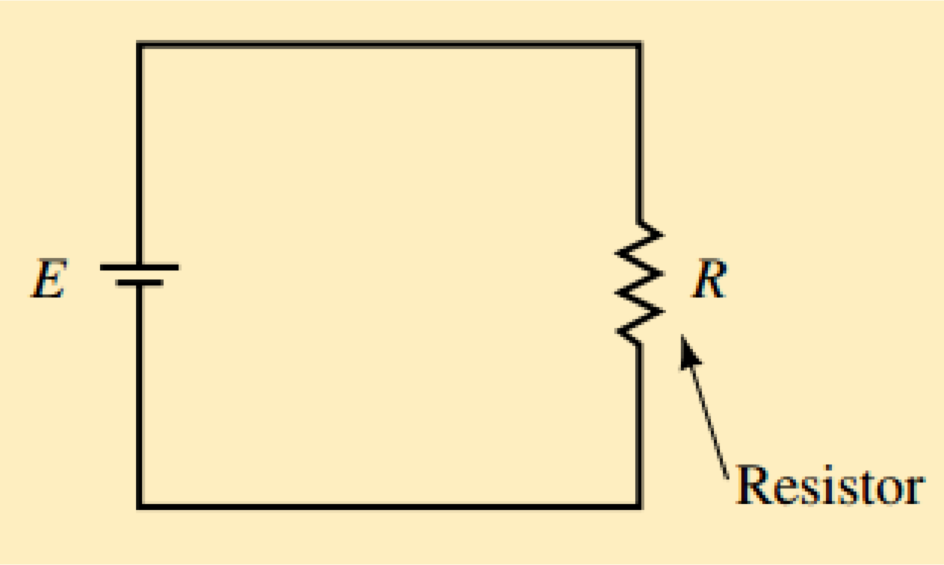


Figure 2-1 Basic circuit resistance

Resistance of Conductors

We may summarize this effect as follows: The resistance of a metallic conductor is inversely proportional to the cross-sectional area of the conductor. The factors governing the resistance of a conductor at a given temperature may be summarized mathematically as follows:

$$R = \frac{\rho \ell}{A} \quad [\text{ohms}, \Omega]$$

Where

ρ = resistivity, in ohm-meters (Ω-m)

ℓ = length, in meters (m)

A = cross-sectional area, in square meters (m^2).

Resistance of Conductors

Since most conductors are circular, as shown in Figure 2–2, we may determine the cross-sectional area from either the radius or the diameter as follows:

$$A = \pi r^2 = \pi\left(\frac{d}{2}\right)^2 = \frac{\pi d^2}{4}$$

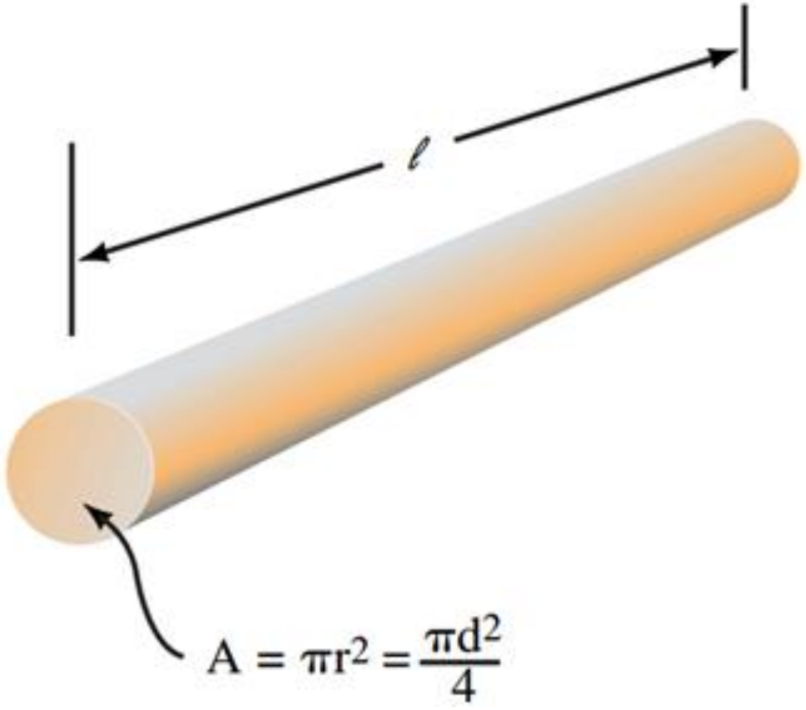


Figure 2-2Conductor with a circular cross-section

Resistance of Conductors

Table 2–1 lists the resistivities of various materials at a temperature of 20°C.

The resistivity r is also measured in ohms per mil-foot as shown in Table 2-2.

Material	Resistivity, ρ, at 20°C (Ω-m)
Silver	1.645×10^{-8}
Copper	1.723×10^{-8}
Gold	2.443×10^{-8}
Aluminum	2.825×10^{-8}
Tungsten	5.485×10^{-8}
Iron	12.30×10^{-8}
Lead	22×10^{-8}
Mercury	95.8×10^{-8}
Nichrome	99.72×10^{-8}
Carbon	3500×10^{-8}

Table 2-1 Resistivity of the materials (Ω-m)

Resistivity (ρ) of various materials.

Material	ρ @ 20°C $\frac{CM \cdot \Omega}{ft}$
Silver	9.9
Copper	**10.37**
Gold	14.7
Aluminum	17.0
Tungsten	33.0
Nickel	47.0
Iron	74.0
Constantan	295.0
Nichrome	600.0
Calorite	720.0
Carbon	21,000.0

Table 2-2 Resistivity of the materials $\frac{CM \cdot \Omega}{ft}$

Resistance of Conductors

EXAMPLE 3–1 Most homes use solid copper wire having a diameter of 1.63 mm to provide electrical distribution to outlets and light sockets. Determine the resistance of 75 meters of a solid copper wire having the above diameter.

Solution We will first calculate the cross-sectional area of the wire using equation 3–2.

$$A = \frac{\pi d^2}{4}$$

$$= \frac{\pi(1.63 \times 10^{-3}\ \text{m})^2}{4}$$

$$= 2.09 \times 10^{-6}\ \text{m}^2$$

Now, using Table 3–1, the resistance of the length of wire is found as

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

$$= \frac{(1.723 \times 10^{-8}\ \Omega\text{-m})(75\ \text{m})}{2.09 \times 10^{-6}\ \text{m}^2}$$

$$= 0.619\ \Omega$$

EXAMPLE 3–2 Bus bars are bare solid conductors (usually rectangular) used to carry large currents within buildings such as power generating stations, telephone exchanges, and large factories. Given a piece of aluminum bus bar as shown in Figure 3–3, determine the resistance between the ends of this bar at a temperature of 20°C.

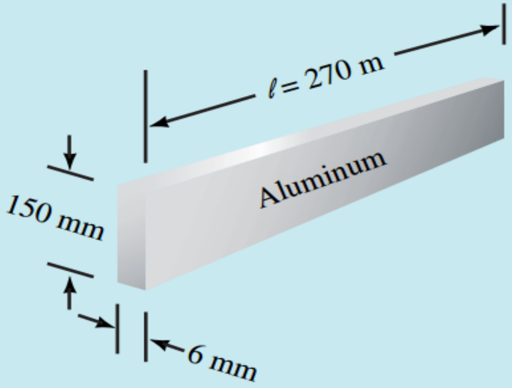


FIGURE 3–3 Conductor with a rectangular cross section.

Solution The cross-sectional area is

$$A = (150\ \text{mm})(6\ \text{mm})$$

$$= (0.15\ \text{m})(0.006\ \text{m})$$

$$= 0.0009\ \text{m}^2$$

$$= 9.00 \times 10^{-4}\ \text{m}^2$$

The resistance between the ends of the bus bar is determined as

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

$$= \frac{(2.825 \times 10^{-8}\ \Omega\text{-m})(270\ \text{m})}{9.00 \times 10^{-4}\ \text{m}^2}$$

$$= 8.48 \times 10^{-3}\ \Omega = 8.48\ \text{m}\Omega$$

Question: Does wire resistance change with temperature?

Resistance: Circular wires

For a circular wire, the quantities appearing in Eq. (3.1) are defined by Fig. 3.2.

$$R = \frac{\rho \ell}{A} \quad \frac{\mathrm{CM}\cdot\Omega}{\mathrm{ft}} \qquad \text{Eq.(3-1)}$$

ρ:	CM-ohms/ft at $T = 20°\mathrm{C}$
l:	feet
A:	circular mils (CM)

For two wires of the same physical size at the same temperature, as shown in Fig. 3.4(a),

The higher the resistivity, the more the resistance.

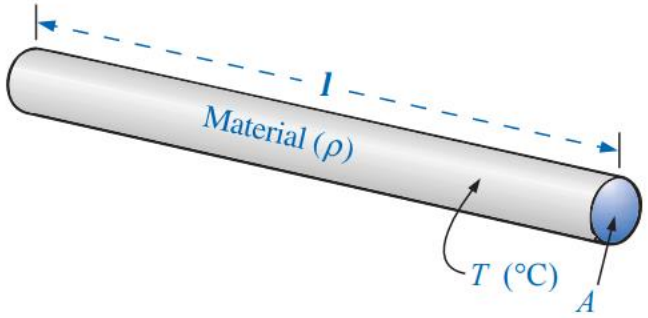


Figure 2.3 Factors affecting the resistance of a conductor.

As indicated in Fig. 3.4(b),

The longer the length of a conductor, the more the resistance.

Figure 3.4(c) reveals for the remaining similar determining variables that

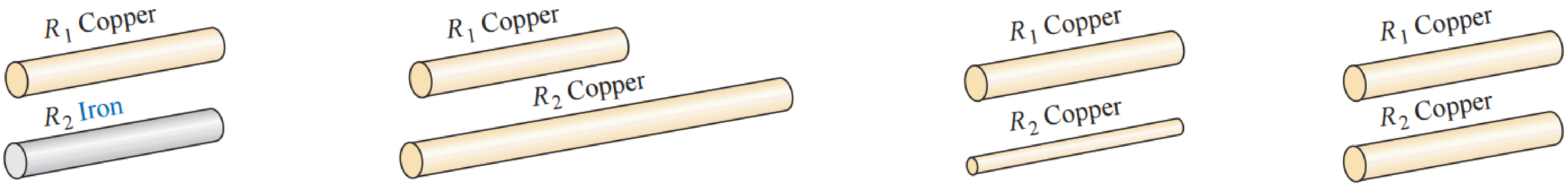
The smaller the area of a conductor, the more the resistance.

Finally, Figure 3.4(d) states that for metallic wires of identical construction and material,

The higher the temperature of a conductor, the more the resistance.

For circular wires, the quantities of Eq. (3.1) have the following units:

ρ:	CM-ohms/ft at $T = 20°C$
l:	feet
A:	circular mils (CM)



$\rho_2 > \rho_1$ (a) $l_2 > l_1$ (b) $A_2 < A_1$ (c) $T_2 > T_1$ (d)

Figure 3.4: Cases in which R2 > R1. For each case, all remaining parameters that control the resistance level are the same.

The conductors are measured in circular mils (CM) and not in square meters, inches, and so on, as determined by the equation:

$$\text{Area (circle)} = \pi r^2 = \frac{\pi d^2}{4}$$

r = radius
d = diameter

The mil is a unit of measurement for length and is related to the inch by

$$\mathbf{1\ mil = \frac{1}{1000}\ in.}$$

$$\mathbf{1\ meter = 3.281\ foot}$$

By definition,

$$\mathbf{1000\ mils = 1\ in.}$$

A wire with a diameter of 1 mil has an area of 1 circular mil (CM), as shown in Fig. 3.5.

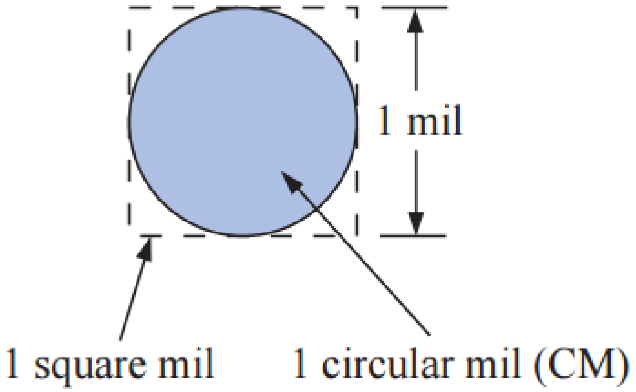


Figure 3.5 Defining the circular mil (CM).

The area in circular mils is simply equal to the diameter in mils square; that is:

$$\boxed{A_{CM} = (d_{mils})^2} \quad \text{Eq.(3.4)}$$

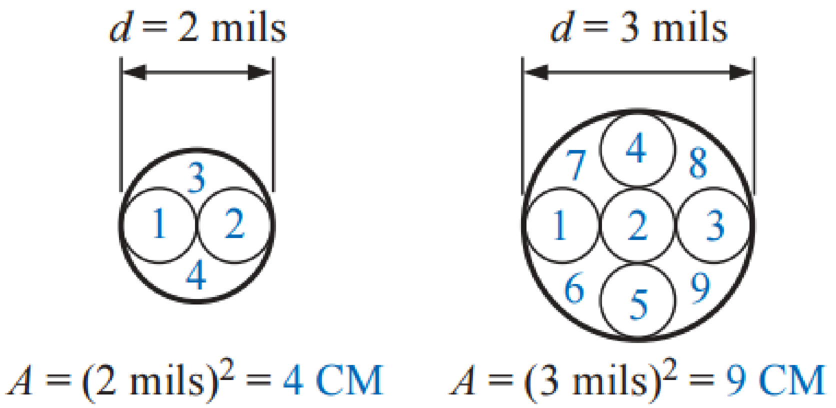


Figure 3.6 Verification of Eq. (3.4): ACM (dmils)2.

The constant ρ (resistivity) is different for every material. Its value is the resistance of a length of wire 1 ft by 1 mil in diameter, measured at 20°C (Fig. 3.7). The unit of measurement for ρ can be determined from Eq. (3.1) by first solving for ρ and then substituting the units of the other quantities. That is,

$$\rho = \frac{AR}{l}$$

$$\text{Units of } \rho = \frac{\mathbf{CM \cdot \Omega}}{\mathbf{ft}}$$

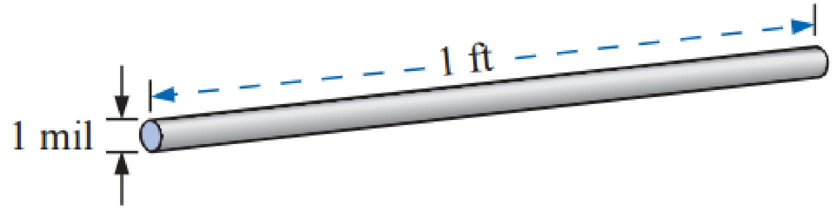


Figure 2.7 Factors affecting the resistance of a conductor.

EXAMPLE 3.1 What is the resistance of a 100-ft length of copper wire with a diameter of 0.020 in. at 20°C?

Material	**ρ @ 20°C**
Silver	9.9
Copper	**10.37**

Solution:

$$\rho = 10.37 \frac{\mathrm{CM} \cdot \Omega}{\mathrm{ft}} \qquad 0.020 \text{ in.} = 20 \text{ mils}$$

$$A_{\mathrm{CM}} = (d_{\mathrm{mils}})^2 = (20 \text{ mils})^2 = 400 \text{ CM}$$

$$R = \rho \frac{l}{A} = \frac{(10.37 \text{ CM} \cdot \Omega/\text{ft})(100 \text{ ft})}{400 \text{ CM}}$$

$$R = \mathbf{2.59\ \Omega}$$

EXAMPLE 3.3 What is the resistance of a copper bus-bar, as used in the power distribution panel of a high-rise office building, with the dimensions indicated in Fig. 3.8?

Solution:

$$A_{\mathrm{CM}}\begin{cases} 5.0 \text{ in.} = 5000 \text{ mils} \\ \dfrac{1}{2} \text{ in.} = 500 \text{ mils} \\ A = (5000 \text{ mils})(500 \text{ mils}) = 2.5 \times 10^6 \text{ sq mils} \\ \quad = 2.5 \times 10^6 \cancel{\text{sq mils}}\left(\dfrac{4/\pi \text{ CM}}{1 \cancel{\text{sq mil}}}\right) \\ A = 3.185 \times 10^6 \text{ CM} \end{cases}$$

$$R = \rho\frac{l}{A} = \frac{(10.37 \text{ CM}\cdot\Omega/\text{ft})(3 \text{ ft})}{3.185 \times 10^6 \text{ CM}} = \frac{31.110}{3.185 \times 10^6}$$

$$R = \mathbf{9.768 \times 10^{-6}\ \Omega}$$

(quite small, $0.000009768\ \Omega$)

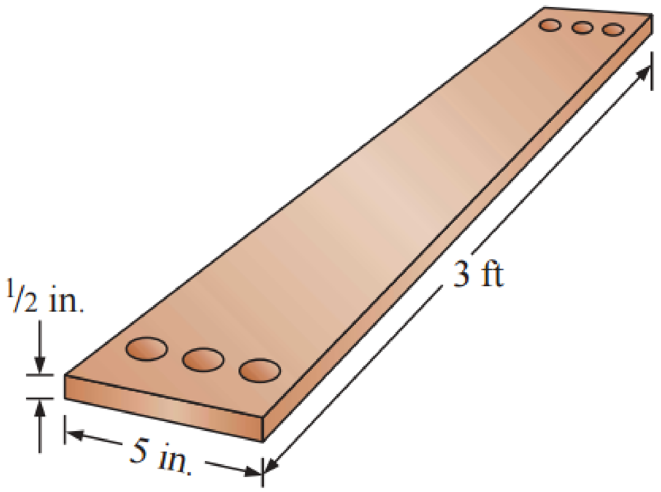


FIG. 3.8
Example 3.3.

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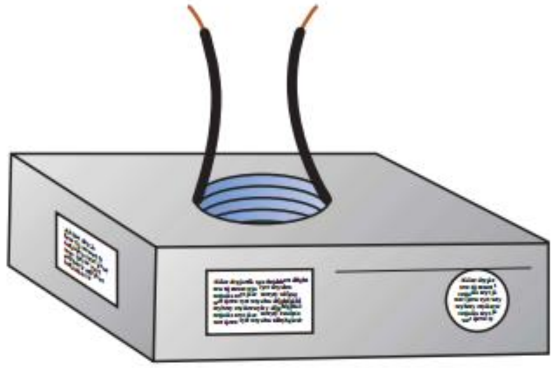
Homework:

An undetermined number of feet of wire have been used from the carton as shown in the figure below. Find the length of the remaining copper wire if it has a diameter of 1/16 in. and a resistance of 0.5Ω.



Temperature Effects

Temperature has a significant effect on the resistance of conductors, semiconductors, and insulators.

- For good conductors, an increase in temperature will result in an increase in the resistance level. Consequently, conductors have a positive temperature coefficient.
- For semiconductor materials, an increase in temperature will result in a decrease in the resistance level. Consequently, semiconductors have negative temperature coefficients.

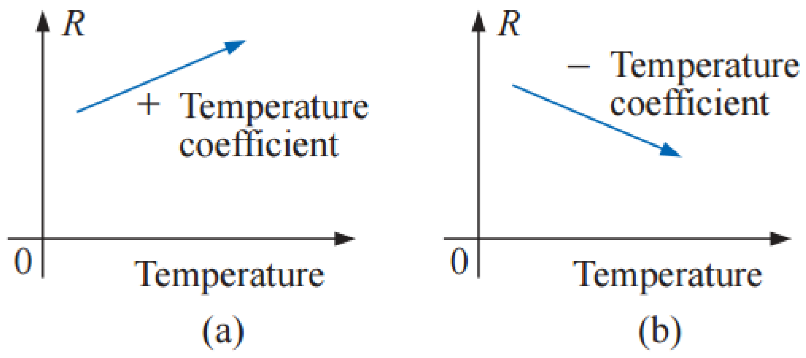
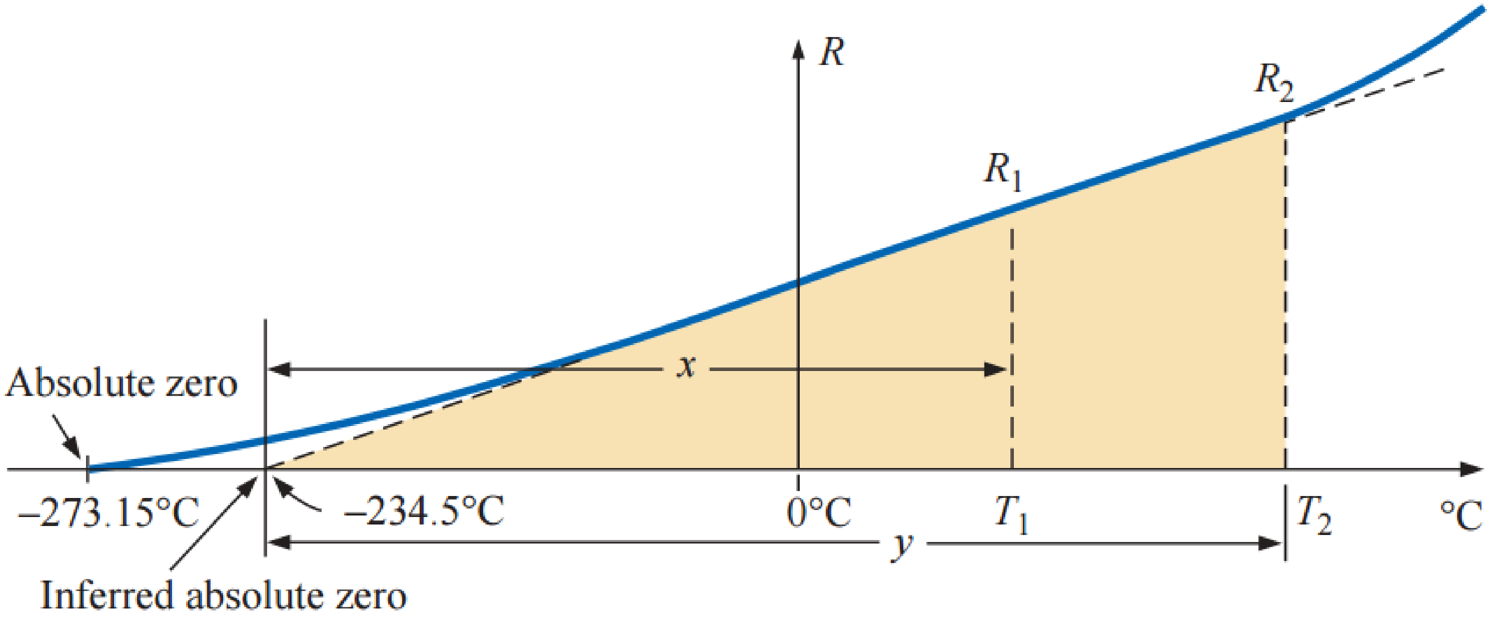


Figure 3.8 (a) Positive temperature coefficient—conductors; (b) negative temperature coefficient semiconductors.

- Insulators as with semiconductors, an increase in temperature will result in a decrease in the resistance of an insulator. The result is a negative temperature coefficient.

Temperature Effects

Section 3.1 indicated that the resistance of a conductor will not be constant at all temperatures. As temperature increases, more electrons will escape their orbits, causing additional collisions within the conductor. For most conducting materials, the increase in the number of collisions translates into a relatively linear increase in resistance, as shown in Figure 3–8.



$$\frac{x}{R_1} = \frac{y}{R_2}$$

$$\boxed{\frac{234.5 + T_1}{R_1} = \frac{234.5 + T_2}{R_2}}$$

$$\boxed{\frac{|T_1| + T_1}{R_1} = \frac{|T_1| + T_2}{R_2}}$$

Figure 3.9 Temperature effects on the resistance of a conductor.

Temperature Effects

EXAMPLE 3.9 If the resistance of a copper wire is 50 Ω at 20°C, what is its resistance at 100°C (boiling point of water)?

Solution: Eq. (3.5):

$$\frac{234.5°\text{C} + 20°\text{C}}{50\ \Omega} = \frac{234.5°\text{C} + 100°\text{C}}{R_2}$$

$$R_2 = \frac{(50\ \Omega)(334.5°\text{C})}{254.5°\text{C}} = \mathbf{65.72\ \Omega}$$

EXAMPLE 3.10 If the resistance of a copper wire at freezing (0°C) is 30 Ω, what is its resistance at −40°C?

Solution: Eq. (3.5):

$$\frac{234.5°\text{C} + 0}{30\ \Omega} = \frac{234.5°\text{C} - 40°\text{C}}{R_2}$$

$$R_2 = \frac{(30\ \Omega)(194.5°\text{C})}{234.5°\text{C}} = \mathbf{24.88\ \Omega}$$

EXAMPLE 3.11 If the resistance of an aluminum wire at room temperature (20°C) is 100 mΩ (measured by a milliohmmeter), at what temperature will its resistance increase to 120 mΩ?

Solution: Eq. (3.5):

$$\frac{236°\text{C} + 20°\text{C}}{100\ \text{m}\Omega} = \frac{236°\text{C} + T_2}{120\ \text{m}\Omega}$$

and

$$T_2 = 120\ \text{m}\Omega\left(\frac{256°\text{C}}{100\ \text{m}\Omega}\right) - 236°\text{C}$$

$$T_2 = \mathbf{71.2°C}$$

Temperature Coefficient of Resistance

the higher the temperature coefficient of resistance for a material, the more sensitive the resistance level to changes in temperature

$$\boxed{\alpha_{20} = \frac{1}{|T_1| + 20°\text{C}}} \qquad (\Omega/°\text{C}/\Omega)$$

$$\boxed{R_1 = R_{20}[1 + \alpha_{20}(T_1 - 20°\text{C})]}$$

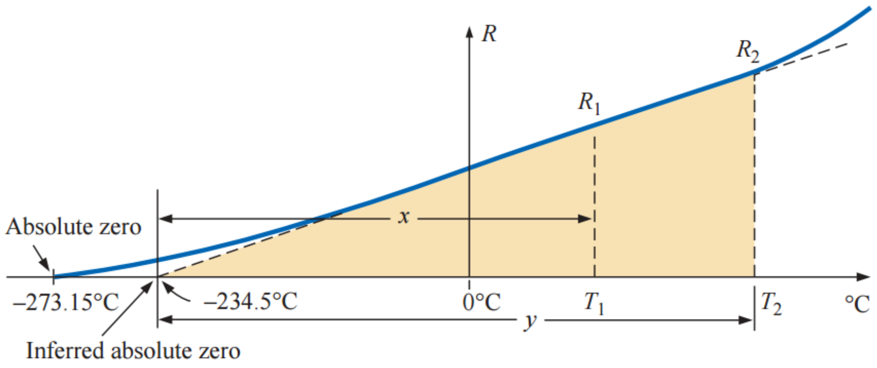


Figure 3.8 Temperature effects on the resistance of a conductor.

Ohm’s Law

Ohm determined experimentally that current in a resistive circuit is directly proportional to its applied voltage and inversely proportional to its resistance. In equation form, Ohm’s law states:

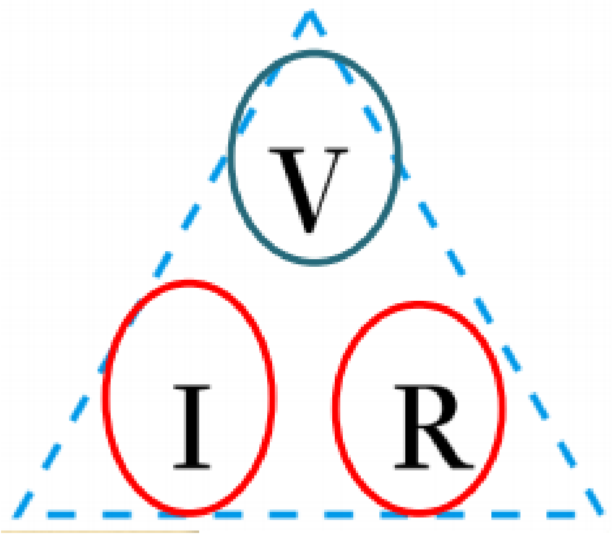
$I = \frac{E}{R}$ [amps, A] , $R = \frac{E}{I}$ [ohms, Ω] and $E = IR$ [volts, V]

Where

E is the voltage in volts,

R is the resistance in ohms,

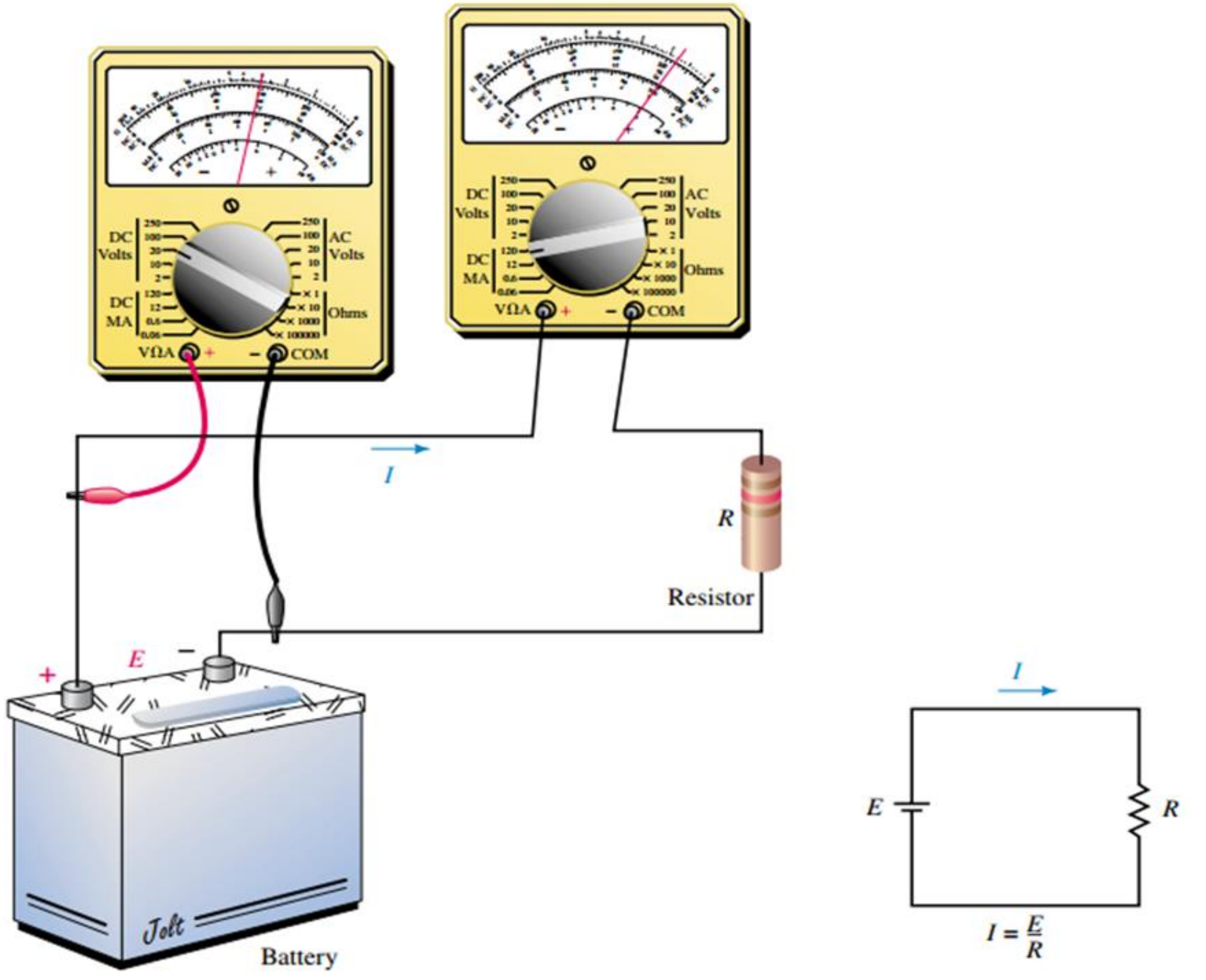
I is the current in amperes.



Ohm's Law

Consider the circuit of Figure 2–3. Using a circuit similar in concept to this

From this you can see that the larger the applied voltage, the larger the current, while the larger the resistance, the smaller the current.



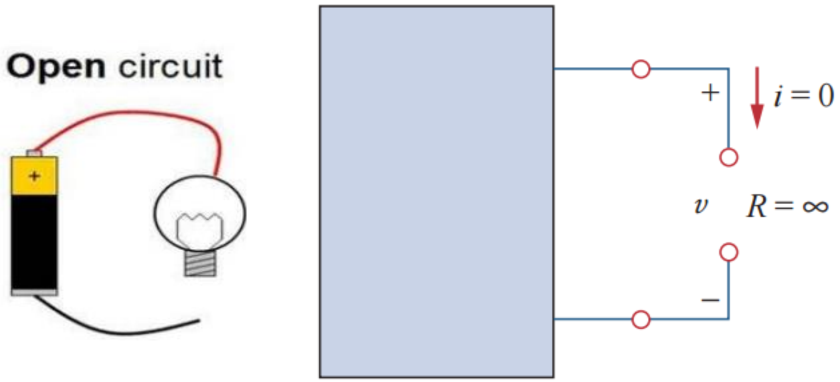
(a) Test circuit

(b) Schematic, meters not shown

Ohm's Law

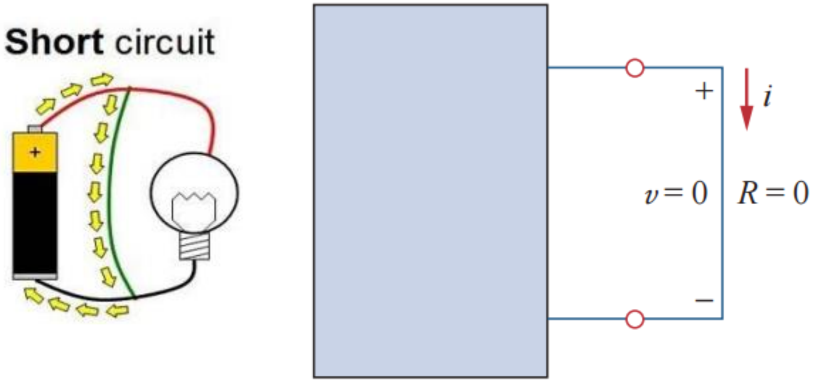
➢ Open Circuits: $R = \frac{v}{I} = \frac{v}{0} = \infty\ Ohms$

- An open circuit between A and B means i=0.
- Voltage across an open circuit: any value.
- An open circuit is equivalent to R = ∞ Ω.

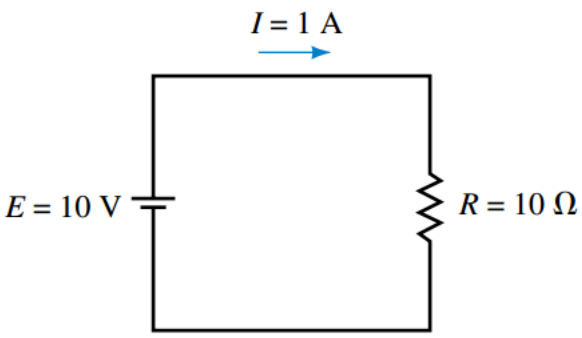


➢ Short Circuit: $R = \frac{v}{I} = \frac{0}{I} = 0\ Ohms$

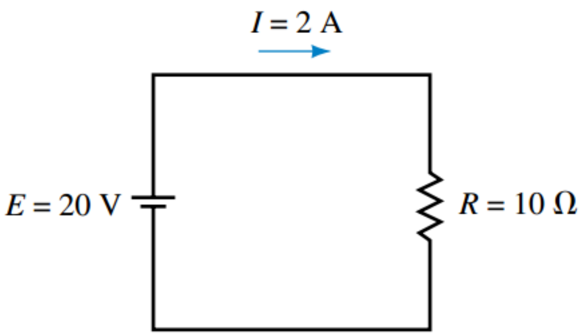
- A short circuit between A and B means v=0.
- Current through a short circuit: any value.
- A short circuit is equivalent to R = 0 Ω.



Ohm's Law



(a) $I = \frac{10\text{ V}}{10\ \Omega} = 1$ A



(b) $I = \frac{20\text{ V}}{10\ \Omega} = 2$ A

EXAMPLE 4–1 A 27-Ω resistor is connected to a 12-V battery. What is the current?

Solution Substituting the resistance and voltage values into Ohm's law yields

$$I = \frac{E}{R} = \frac{12\text{ V}}{27\ \Omega} = 0.444\text{ A}$$

EXAMPLE 4–2 The lamp of Figure 4–4 draws 25 mA when connected to a 6-V battery. What is its resistance?

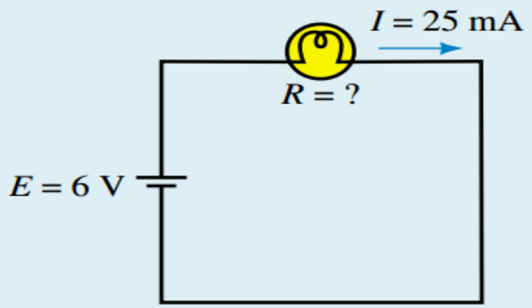


FIGURE 4–4

Solution Using Equation 4–3,

$$R = \frac{E}{I} = \frac{6\text{ V}}{25 \times 10^{-3}\text{ A}} = 240\ \Omega$$

Conductance

Conductance, G, is defined as the measure of a material's ability to allow the flow of charge and is assigned the SI unit the Siemens (S).

$$G = \frac{1}{R} \quad \text{[siemens, S]}$$

$1\ \mho = 1\ \text{S}$

$i = Gv$ and

$$P = vi = i^2R = \frac{v^2}{R}$$ (watt) or

$$P = vi = v^2G = \frac{i^2}{G}$$ (watt)

Conductance

Example: In the circuit shown in Fig. 2.10, calculate the current i, the conductance G, and the power p?

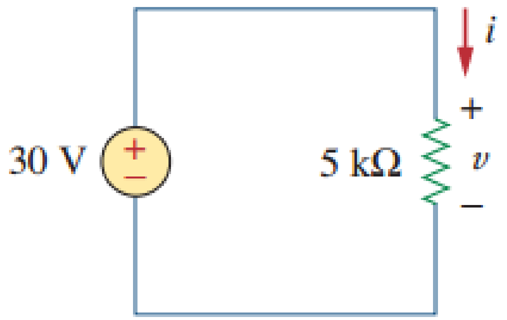


Figure 2-10 Basic circuit

Solution :

$$i = \frac{v}{R} = \frac{30}{5 \times 10^3} = 6 \text{ mA}$$

The conductance is

$$G = \frac{1}{R} = \frac{1}{5 \times 10^3} = 0.2 \text{ mS}$$

$$p = vi = 30(6 \times 10^{-3}) = 180 \text{ mW}$$

or

$$p = i^2R = (6 \times 10^{-3})^2 5 \times 10^3 = 180 \text{ mW}$$

or

$$p = v^2G = (30)^2 0.2 \times 10^{-3} = 180 \text{ mW}$$