IV. Electric Current, Voltage, Resistance and Conductance

This part of the course covers electrical terms, electrical materials, electrical quantities and units and deals with the factors affecting resistance of materials. Furthermore, calculation of equivalent conductance and equivalent resistance are also discussed. Moreover, electric current and Faraday's law of electrolysis are applied.

Learning Outcomes:

At the end of this unit, the learner will be able to:

- Identify electrical terms, parameters, units and electrical quantities, distinguish different types of electrical conductor materials, properties and analyze resistance of materials considering some factors affecting them.
- Calculate equivalent conductance and equivalent resistance: Series-connection, parallel connection and series-parallel connection.
- Describe current and apply Faraday's law of electrolysis

Pre-Test:

Instructions: Answer the each question/problem quietly and encircle the letter of the correct answer.

1. What are the big three in electricity?

   I. Elastance; II. Resistance; III. Current; IV. Electromotive Force

   (a) I, II & III (b) !, III & IV (c) II, III & IV (d) I, III & IV

2. Is the property of an electric circuit tending to prevent the flow of electric current at the same time causing electric energy to be converted into heat energy?

   (a) Inductance (b) Capacitance
   (c) Resistance (d) Conductance

3. Production of AC Emf by mechanical vibration of quarts or Rochelle salt crystals

   (a) Magnetic
   (b) Magneto hydrodynamics
   (c) Chemical
   (d) Piezoelectric

4. A ______ is a device used to measure voltage. It is connected _____ two points where voltage is to be measured.

   (a) Voltmeter, in series between (b) Ammeter, in series between
   (c) Voltmeter, across (d) Ammeter, across

5. A type of conductor where conduction is accompanied by a movement of material through the conductor and usually by chemical action.

   (a) metallic (b) electrolytic
   (c) gaseous (d) ionic

6. Factor/s affecting the resistance of materials?

   I. Length; II. Cross-section; III. Temperature; IV. strength

   (a) II & III (b) !, II & IV (c) I, II & III (d) I, III & IV

7. The resistance of a certain conductor is 46 Ohm @ 25 ^{o}C. The temperature coefficient of resistance is 0.00454545 per C^{o} @ 20 ^{o}C. At what temperature will its resistance be 92 Ohms? Ans.

   (a) 269.98 ^{o}C (b) 249.98 ^{o}C (c) 289.98 ^{o}C (d) 294.98 ^{o}C

8. The resistance of a particular conductor is 0.08 Ohm. By successive passes through drawing dies its length has increase to three times its original value. Find the new resistance of the conductor when the volume is fixed.

   (a) 0.72 Ω (b) 5.11 Ω (c) 2.11 Ω (d) 0.69 Ω

9. A kilometer of wire having a diameter of 11.7 mm and a resistance of 0.0231-Ohm is drawn down so that its diameter is 5.0 mm. What does its resistance become?

   (a) 0.01 Ω (b) 5.11 Ω (c) 2.11 Ω (d) 0.69 Ω

10. The resistance of a cylindrical brass conductor, 0.50 cm diameter and 3 m long, is 0.0108 Ohm. Determine the resistance of a cylindrical conductor of the same material at the same temperature and having a diameter of 0.25 cm and a length of 8.0 m.

    (a) 0.515 Ω (b) 0.5211 Ω (c) 0.1152 Ω (d) 0.2511 Ω

Content:

Definition of Terms

Electronic - Infers circuits including either first electronic devices-vacuum tubes or the never solid-state devices such as diodes and transistors, as well as integrated circuits (IC's).

Electric of Electrical - applied to systems or circuits in which electron flow through wires, but many modern electric systems are now using electronic devices to control the electronic current that flows in them.

Big Three in Electricity

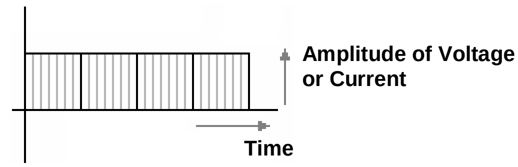
Current - progressive movement of free electrons along a wire or other conductor produced by electrostatic line of force.

Electromotive Force - electron moving force in a circuit that pushes and pulls electrons (current) through the circuit.

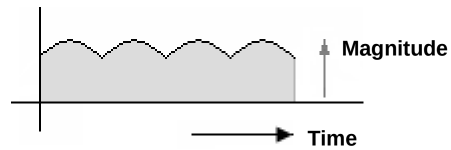
Resistance - any opposing effect that hinders free-electrons progress through wires when an electromotive force is attempting to produce a current in a circuit.

Type of Voltage or Current

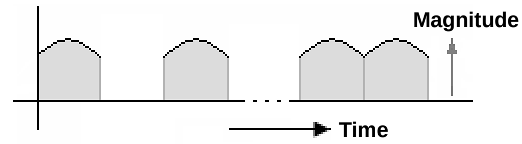
Direct Current (DC) – No variation of amplitude (strength) of the current and voltage obtained from batteries, DC Generators and power supply.



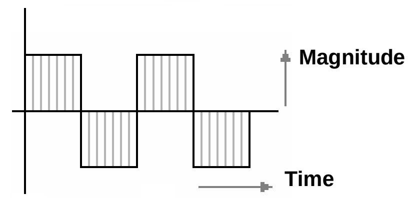
Varying Direct Current (Vdc) – Amplitude of the current or voltage varies but never falls to zero. Found in many transistors and vacuum circuits.



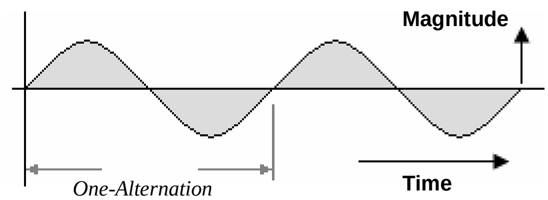
Pulsating Direct Current (Pdc) – The amplitude drops to zero periodically. Produced in rectifier circuits.



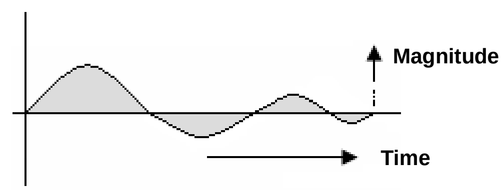
Interrupted Direct Current (Idc) – Current or voltage starts and stops abruptly ("Square wave"). Produced by vibrations, choppers, and special circuits.



Alternating Current (AC) – Electron flow reverses (alternates) periodically and usually changes amplitude in a more or less regular manner. Produced in AC generators, oscillators, some microphones and radio in general. This is the usual house current.



Damped AC – Alternating current which dies out in amplitude, produced by sparks-type oscillators and in advertently in many circuits as they make and break.



Methods of Producing Emf

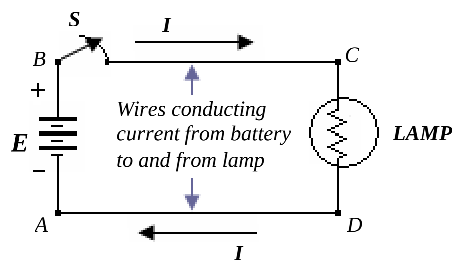
Production of unidirectional pressure:

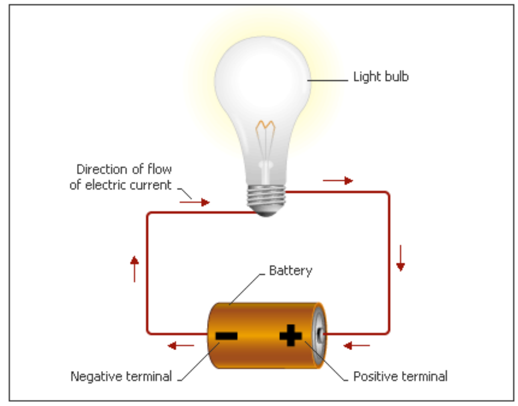
- Chemical (batteries)
- Magnetic (DC generators)
- Thermal (heated thermocouple junction)
- Photoelectric (conversion of light energy into movement of electrons)
- Frictions (produced by rubbing two substances together, as an automobile in motion, walking across wool rugs, or stroking a cat)
- Magnetohydrodynamics (MHD) – converting heat energy in hot gasses directly into electric energy.

Production of Alternating Current:

- Magnetic (mechanical motion) – a wire alternate direction of magnetic lines induces alternating emf.
- Magnetostrictive – A mechanical vibration of ferromagnetic materials induces an alternating Emf in a wire coiled around the material.
- Piezoelectric – Mechanical vibration of quarts or Rochelle salt crystals produces an alternating Emf between two metal plates on opposite sides of the crystal.

Simple Electric Circuit:





Electric Circuit
An electric circuit is the path of an electric current. In a closed circuit, the path is continuous and moves in only one direction.

Figure 4.1 Simple electric circuit

Alternate diagrams of Figure 4.1

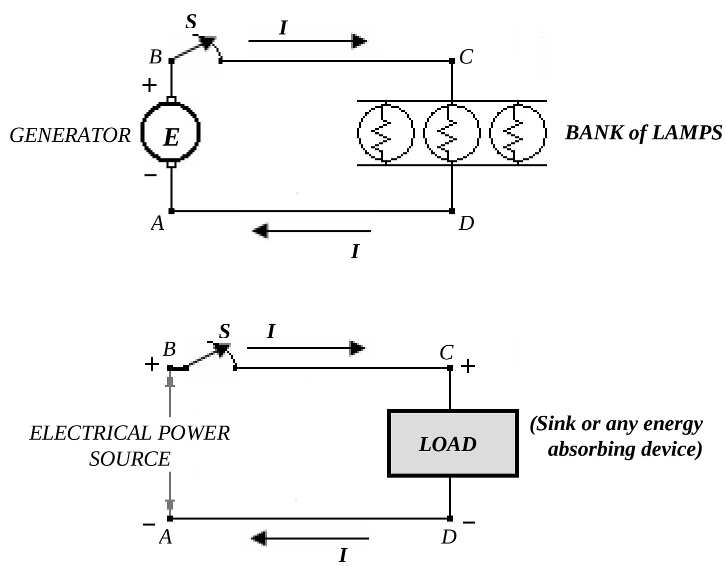


Figure 4.2 Alternate diagrams of Figure 1.1

Types of Circuits

Complete or closed Circuit - conduction of current from the battery and lamp, and back.

Open Circuit – one of the wires is disconnected or a switch inserted is opened. Current (*I*) output is zero; no transfer of energy.

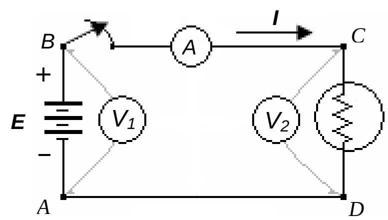
Short Circuit – by mistake a wire is connected between points C and D around the lamp, or A and B around the battery, or insulation in the base of the lamp broke down and become conductive. Current (*I*) output is high; no effective transfer of energy.

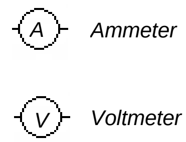
Measurement of Emf, Potential Difference and Current

Instruments:

Ammeter – A device used to measure current. It is connected in series.

Voltmeter – A device used to measure voltage. It is connected across two points where voltage is to be measured.





A - Reads line current

V_1 - Reads voltage across the battery, called battery terminal voltage

V_2 - Reads voltage across the lamp (load voltage)

Figure 4.3 Simple electric circuit showing connections of ammeter and voltmeters.

Summary of Electrical Quantities

SUMMARY OF ELECTRICAL QUANTITIES:					
Electrical Quantity	***Symbol***	***Unit (mks)***	***Related Equation***	***Mechanical Analogy***	***Hydraulic Analogy***
Charge	q, Q	Coulomb (C)	…	Position	Volume
Current	i, I	Ampere (A)	$I = \frac{dq}{dt}$	Velocity	Flow
Potential Difference or Volt	e, E or v, V	Volt (V)	$E = \frac{dw}{dq}$	force	Head or pressure
Power	p, P	Watt (W)	$P = ei$	Power	Power
Energy or Work	w, W	Joule or Watt-second (J or W-sec)	$W = \int e\, dq$ $W = \int e\, i\, dt$	Energy or Work	Energy or work

Prefixes Used with Electrical Quantities

Prefixes used with Electrical Quantities	
Larger Quantities	**Smaller Quantities**
Kilo (K) = 10^3 Units	*milli (m) = 10^{-3} Unit*
Mega (M) = 10^6 Units	*micro (μ) = 10^{-6} Unit*
Giga (G) = 10^9 Units	*nano (n) = 10^{-9} Unit*
Tera (T) = 10^{12} Units	*pico (p) = 10^{-12} Unit*

Conductors and Insulators

- In some substances, electrons are able to pass readily from atom to atom, and such substances are called *conductors*. On the other hand, with other substances, electrons can be removed from the atom only with difficulty, and such substances are called *insulators*.

Conductor – A substance that possesses free electrons.

Free electrons – electrons that are loosely bound by the nucleus.

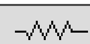
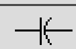
General Classes of Conductors:

Metallic – Conduction is due to the inter-atomic movement of the electrons within the conductor. Ex. Copper, silver and alloys, etc.

Electrolytic – conduction is accompanied by a movement of material through the conductor and usually by chemical action.

Gaseous – conduction is due to the movement of free positive ions and free negative ions of electrons into which the atoms of the gas become divided when it becomes ionized

Type of Circuit Parameters:

Parameter	*Symbol*	*Unit (Abbreviation)*
Resistance		*Ohm* (Ω)
Inductance		*Henry* (H)
Capacitance		*Farad* (F)

Electrical Resistance - Is the property of an electric circuit tending to prevent the flow of electric current at the same time causing electric energy to be converted into heat energy.

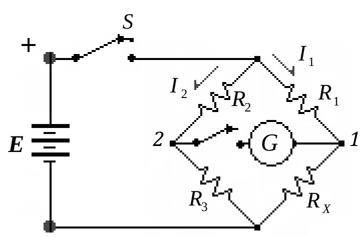
Unit of Resistance - The *OHM* is the practical unit of resistance and is defined as that resistance which will allow One-Ampere to flow if One-Volt is impressed across its terminals.

Measurement of Resistance

(1) Voltmeter-Ammeter Method
(2) Ohm-meter – an instrument used to measure resistance
(3) The Wheatstone Bridge – one of the most precise and widely used instrument to measure resistance
(4) Others

The Wheatstone Bridge

FIGURE: Conventional diagram of a Wheatstone bridge



R_X *- is the unknown resistance*

$I_G = 0$

When the bridge is balanced so that,

$$V_1 = V_2 \; ; \; I_G = 0$$

Thus,

$$I_1 R_1 = I_2 R_2 \qquad (1)$$

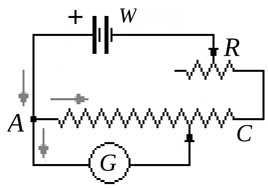
Also,

$$I_1 R_X = I_2 R_3 \qquad (2)$$

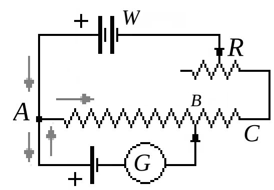
Dividing Eq. (2) by Eq. (1) to solve R_X,

$$R_X = \frac{R_1 R_3}{R_2} \quad \Omega$$

<u>The Potentiometer</u>



(a) A Potential divider



(b) a simple slide-wire

Factors Determining the Resistance of Material

1. *Kind of material*
   - *Conductor* – a good conductor has less resistance ex. Copper, silver, aluminum
   - *Insulator* – (valence electrons more than four) ex. Rubber, plastic, glass, etc.
   - *Semi- conductor* – (valence electron exactly four) ex. Silicon, Germanium
2. *Length* – the longer the material has greater resistance
3. *Cross sectional area* – the greater cross sectional area has lesser resistance.
4. *<u>Temperature</u>* – hotter material has greater resistance

Variation of Resistance of Material with Respect to its Length and Cross-sectional Area

- The resistance of a homogenous body of uniform cross section varies directly as its length and inversely as its cross section.

$$R \;\alpha\; \frac{L}{A}$$

$$R = \rho \frac{L}{A} \quad Ohms\,(\Omega) \qquad \text{Eq. 4.1}$$

Where:
- L - length of conductor along the path of I
- A - Its cross section at right angle of I
- ρ - Resistivity of the conductor

UNITS FOR RESISTIVITIES OF MATERIAL			
	Resistivity ρ	**Length** L	**Cross-Sectional Area** A
ENGLISH SYSTEM (British System)	$\frac{\Omega \cdot CM}{Ft}$	Ft	CM
	$\Omega \cdot Ft$	Ft	Ft^2
	$\Omega \cdot in$	$in.$	$in.^2$
SYSTEMS INTERNATIONAL (S.I.)	$\Omega \cdot mm$	mm	mm^2
	$\Omega \cdot cm$	cm	cm^2
	$\Omega \cdot m$	m	m^2

***Note**: CM – Stands for Circular mils*

Circular Mil (CM)

- *A mil is one-thousandth of an inch (1 mil = 1/1000 inch).*
- *A square mil is the area of a square, each side of which is one mil (0.001 inch).*
- *A circular mil is the area of a circle whose diameter is one-mil (0.001 inch).*

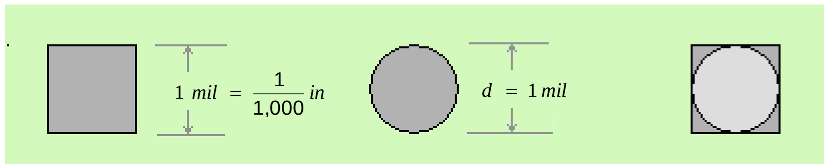


Figure 4.4 Comparison of square mil and circular mil

Note: -To obtain the number of circular mils (CM) in solid cylindrical wire of a given diameter, express the diameter in mils, and then square it.

Area in Circular Mils:

$$CM = d^2 \qquad \text{Eq. 4.2}$$

- To obtain the diameter of a solid cylindrical wire having a given number of circular mils (CM) take the square-root of the circular mils, and the result will be the diameter of the wire in *mils*.

$$d = \sqrt{CM} \quad \text{mils} \qquad \text{Eq. 4.3}$$

Illustrative Problem 4.1

No. 00 AWG has a diameter of 0.3648 inch; determine its cross section in circular mils.

Note: AWG – American Wire Gauge (Size of conductor in English Unit)

Solution:

Given Data:

Conductor:

No. 00 (AWG)

diameter = 0.3648 inch = 0.3648 x 1000 = 364.8 mils

Required: Area in CM

From Eq. 4.2

Area in Circular – Mils

$$CM = d^2 = (364.8)^2 = 133{,}079 \text{ CM}$$

Illustrative Problem 4.2

A certain wire has a cross section of 52.640 circular mils. Determine diameter.

Solution:

Given Data:

Conductor:

Area in CM = 52,640 CM

Required: Diameter

From Eq. 4.3

Diameter in Mils:

$$d = \sqrt{CM} = \sqrt{52{,}640} = 229.434 \text{ mils}$$

$$= 229.434 \text{mils} \times \left(\frac{1\text{-inch}}{1000\text{mils}}\right) = 0.23 \text{ inch}$$

Illustrative Problem 4.3

The diameter of No. 17 (*AWG*) solid conductor is 0.045 in. Determine cross section in (a) square mils; (b) circular mils.

Solution:

Given Data:

Conductor:
No. 17 (AWG)
diameter = 0.045 in = 0.045 x 1000 = 45 mils

Required: Area in square-mils and in CM

Area in sq.mils: Recall area of a circle with diameter d

$$\text{Area in sq.mils}$$

$$A = \frac{\pi \cdot d^2}{4} = \frac{\pi \cdot (45)^2}{4} = 1{,}590.43 \text{ sq.mils}$$

From Eq. 4.2

$$\text{Area in Circular-Mils}$$

$$CM = d^2 = (45)^2 = 2{,}025 \text{ CM}$$

Circular-Mil-Foot;

- This unit is the resistance of a wire having a cross section of 1 *CM* and a length of one-foot.

Illustrative Problem 4.4

Determine the resistance of 750,000 CM copper cable, 2500 ft. long at 20^{o}C. Resistivity of copper is 1.724 microhm-cm at 20^{o}C

Solution:

Given Data:

Conductor:
A = 750,000 CM
L = 2,500 ft
ρ = 10.371 Ohm-CM-ft

Required: Resistance

From Eq. 4.1 the resistance is

$$R = \rho \frac{L}{A} = 10.371 \cdot \left(\frac{2{,}500}{750{,}000}\right) = 0.035 \text{ Ohms}(\Omega)$$

Table 4.1 Resistivities and Temperature Coefficients of Some Materials

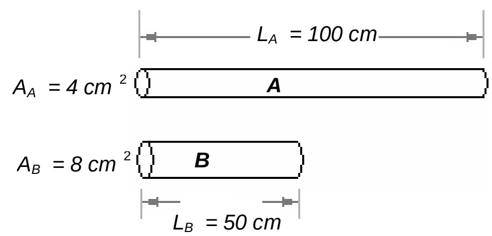
MATERIAL	$\rho \ (at\ 20°C)$		Temperature coefficient of resistance (based upon resistance at 20 °C), per C°
	$\mu\Omega \cdot cm$	$\Omega \cdot CM / ft$	
Copper, commercial	1.72	10.5	0.00393
Silver	1.63	9.85	0.00377
Aluminum	2.83	17.1	0.00393
Iron, annealed	9.5	57.4	0.0052
Tungsten (wolfram)	5.5	33.2	0.0045
German Silver (Cu, Zn, Ni)	20-23	122-201	0.0004
Manganin	44	266	0.00000
Carbon, arc lamp	3,500		-0.0003
Paraffin	3×10^{24}		

Table 4.2 Resistivities for Copper and Aluminum Conductors

Resistivity of Copper - The resistivity at 20 °C of the International Annealed Copper Standard		*Resistivity of Aluminum* - The resistivity at 20 °C
0.15328 *Ohm* (meter-gram)		0.0764 *Ohm* (meter-gram)
875 *Ohm* (mile-pound)		436 *Ohm* (mile-pound)
1.7241 *microhm-cm*		2.828 *microhm-cm*
0.67879 *microhm-inch*		1.113 *microhm-inch*
10.371 *Ohm-CM-ft*		17.01 *Ohm-CM-ft*
0.017241 *Ohm* (mm^2-meter)		
Density of Copper at 20 °C is 8.89 g/cm^3, or 0.3212 lb/in.^{3}		Density of Aluminum at 20 °C is 2.703 g/cm^3, or 0.0975 lb/in.^{3}

<u>Illustrative Problem 4.5</u>

Determine the resistances of the two brass rods A and B, the resistivity of the brass being 11.4 microhm-cm. Rod A is 100 cm long and has a circular cross section of 4 sq.cm; rod B is 50 cm long and has a circular cross section of 8 sq.cm.



Solution:

Given Data:

Conductor A:
A = 4 sq.cm
L = 100 cm
ρ = 11.4 μΩ-cm

Conductor B:
A = 8 sq.cm
L = 50 cm
ρ = 11.4 μΩ-cm

Required: Resistance rod A (R_A) and rod B (R_B)

From Eq. 4.1 the resistance:

$$R_A = \rho_A \frac{L_A}{A_A} = 11.4\,\mu\Omega\cdot\text{cm}\cdot\left(\frac{100\,\text{cm}}{4\,\text{cm}^2}\right) = 285\ \mu\Omega$$

$$R_B = \rho_B \frac{L_B}{A_B} = 11.4\,\mu\Omega\cdot\text{cm}\cdot\left(\frac{50\,\text{cm}}{8\,\text{cm}^2}\right) = 71.25\ \mu\Omega$$

Illustrative Problem 4.6

The resistance of a cylindrical brass conductor, 0.50 cm diameter and 3 m long, is 0.0108 Ohm. Determine the resistance of a cylindrical conductor of the same material at the same temperature and having a diameter of 0.25 cm and a length of 8.0 m.

Solution:

Given Data: Two conductors of same material ($\rho_1 = \rho_2 = \rho$)

Conductor 1:
$R_1 = 0.0108\ \Omega$
$d_1 = 0.50$ cm
$L_1 = 3$ m
$\rho_1 = \rho_2 = \rho$

Conductor 2:
$d_2 = 0.25$ cm
$L_2 = 8$ m
$\rho_2 = \rho_1 = \rho$
$R_2 = ?$

Required: Resistance of rod 2 (R_2)

From Eq. 4.1

For Conductor 1: Resistivity ρ_1 can be calculated

$$R_1 = \rho_1 \frac{L_1}{A_1}$$

$$0.0108\,\Omega = \rho_1 \cdot \left(\frac{3\text{ m } x \left(\frac{100\text{cm}}{\text{m}}\right)}{\pi \cdot \frac{(0.50\text{ cm})^2}{4}} \right)$$

Thus,

$$\rho_1 = \rho = 7.069\ x\,10^{-6}\ \ \Omega \cdot cm$$

For Conductor 2: (Note: $\rho_2 = \rho_1 = \rho$ =7.069 x 10-6 Ωcm)

$$R_2 = \rho_2 \cdot \frac{L_2}{A_2}$$

$$= 7.069\,x\,10^{-6}\ \Omega\cdot\text{cm}\cdot \left(\frac{8\text{ m } x \left(\frac{100\text{cm}}{\text{m}}\right)}{\pi \cdot \frac{(0.25\text{ cm})^2}{4}} \right)$$

$$= 0.1152\ \Omega$$

SUPPLEMENTARY PROBLEMS

1. The resistance of a 10 ft. length of resistor material having a cross section of 0.00204 in.^{2} is 4.1 ohms, the resistance of a 12 ft. length of the same material is 7.7 ohms. Determine its cross section in sq. inches. $A_2 = 0.0013035\ \ in.^2$

2. The resistivity of copper is 1.724 microhm-cm at 20^{o}C. Determine for copper, at the same temperature, the resistance (a) between opposite faces of an inch cube; (b) of a wire 1 foot long and 0.001 in. diameter (one-circular mil); (c) of a rod one-meter long having a diameter of 1 mm.

3. The resistivity of a ferric-chromium alloy is 51.0 microhm-in. A sheet of the material is 15 in. long, 6 in. wide, and 0.014 in thick. Determine the resistance between (a) opposite ends (b) opposite sides. $(a)\ R_e = 9.107\ x\,10^{-3}\ \ \Omega$ $(b)\ R_S = 1.46\ x\,10^{-3}\ \ \Omega$

Learning Activity 4.1	**Self-Assessment 4.1** **Identifying terms, units of Electrical Quantities and Resistance of Materials**

I. Direction. Answer the each question quietly and encircle the letter of the correct answer. (See Answer-Key to verify your answers)

1. Emf produced by friction, such as produced by rubbing two substances together, as an automobile in motion, walking across wool rugs, or stroking a cat.

   (a) Varying (b) Oscillatory (c) Direct Current (d) Alternating

2. General classes of conductors?
   I. metallic; II. magnetic; III. gaseous; IV. electrolytic

   (a) II & III (b) !, II & IV (c) I, III & IV (d) III & IV

3. Alternating current which dies out in amplitude, produced by sparks-type oscillators and in advertently in many circuits as they make and break.

   (a) Damp AC (b) Varying AC
   (c) Alternating Current (d) Harmonic

4. Amplitude of the current or voltage varies but never falls to zero. Found in many transistors and vacuum circuits.

   (a) Direct Current (b) Alternating Current
   (c) Varying Direct Current (d) Pulsating Direct Current

5.. Infers circuits including either first electronic devices-vacuum tubes or the never solid-state devices such as diodes and transistors, as well as integrated circuits (IC's).

   (a) Electric (b) Coupler
   (c) Magnetic (d) Electronic

II. Direction. Analyze and identify data given on the following problems and employ related equations to determine the corresponding required data for each problem. (See Answer-Key to verify your answers)

6. A certain circular solid conductor has a diameter of 1.25cm. Determine cross section in (a) square mils; (b) circular mils.

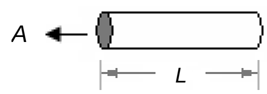
7. A mile of No. 00 (AWG) copper conductor has a diameter of 0.3648 inch; determine its cross section in circular mils and resistance. Refer to Table 1.1 for the resistivity of copper.

8. Determine the resistance of 1,500,000 CM copper cable, 10km long at 20^{o}C. Resistivity of copper is 1.724 microhm-cm at 20^{o}C

9. It is desired to obtain a resistance of 22.1 Ohms with a 120 in. length of nickel-chromium-alloy ribbon with has a resistivity of 640 CM-ft. Determine (a) cross section in CM (b) thickness in mils if the ribbon has a width of 1.50 inches.

Volume Resistivity:
Resistance of Conductor when Volume is Fixed (At constant temperature)

$$V = L\,A$$



Where:
L = Length
A = Uniform cross-section
V = Volume (Fixed)

From Equation 4.1:
$$R = \rho \frac{L}{A} \quad \text{Ohms}\,(\Omega)$$

Thus, in terms of length (L)

$$R = \rho \frac{L}{A} = \rho \cdot \frac{L}{V/L}$$

$$R = \rho \cdot \frac{L^2}{V}$$
- That is, the resistance of a conductor varies directly as the square of its length when the volume is fixed. Eq. 4.4

in terms of area (A)

$$R = \rho \frac{L}{A} = \rho \cdot \frac{V/A}{A}$$

$$R = \rho \cdot \frac{V}{A^2}$$
- That is, the resistance of a conductor varies inversely as the square of cross-section when the volume is fixed. Eq. 4.5

Illustrative Problem 4.7

The resistance of a particular conductor is 0.08 Ohm. By successive passes through drawing dies its length has increase to three times its original value. Find the new resistance of the conductor when the volume is fixed.

Solution:

Given Data:

Condition 1:
$R_1 = 0.08\ \Omega$
$L_1 = 0.50$ cm
$V = k$
$\rho_1 = \rho_2 = \rho$ *(same conductor)*

Condition 2: (After drawing process)
$R_2 = ?$
$L_2 = 3L_1$
$V = k$

Required: Resistance R_2 in the second condition

Note: Variation is in terms of length (V=k)
Using Eq. 4.4

For Condition 1:
$$R_1 = \rho \cdot \frac{L_1^2}{V} \quad \Rightarrow \quad \textit{Eq. 1}$$

For Condition 2:
$$R_2 = \rho \cdot \frac{L_2^2}{V} \quad \Rightarrow \quad \textit{Eq. 2}$$

Dividing Eq. 2 by Eq. 1 gives
$$\frac{R_2}{R_1} = \frac{\rho \cdot \frac{L_2^2}{V}}{\rho \cdot \frac{L_1^2}{V}} = \left(\frac{L_2}{L_1}\right)^2$$

Cross-multiplying to solve for R_2
$$R_2 = R_1 \cdot \left(\frac{L_2}{L_1}\right)^2 = 0.08 \cdot \left(\frac{3 \cdot L_1}{L_1}\right)^2 = 0.72\ \Omega$$

Illustrative Problem 4.8

A kilometer of wire having a diameter of 11.7 mm and a resistance of 0.0231-Ohm is drawn down so that its diameter is 5.0 mm. What does its resistance become?

Solution:

Given Data:

Condition 1:	*Condition 2: (After drawing process)*
$R_1 = 0.0231\ \Omega$	$R_2 = ?$
$d_1 = 11.7\ mm$	$d_2 = 5.0\ mm$
$V = k$	$V = k$
$\rho_1 = \rho_2 = \rho$ (same conductor)	

Required: Resistance R_2 in the second condition

Note: Variation is in terms of area, since diameters are given in both conditions

Using Eq. 4.4

For Condition 1:

$$R_1 = \rho \cdot \frac{V}{A_1^2} \quad \Rightarrow \quad \textit{Eq. 1}$$

For Condition 2:

$$R_2 = \rho \cdot \frac{V}{A_2^2} \quad \Rightarrow \quad \textit{Eq. 2}$$

Dividing Eq. 2 by Eq. 1 gives

$$\frac{R_2}{R_1} = \frac{\rho \cdot \frac{V}{A_2^2}}{\rho \cdot \frac{V}{A_1^2}} = \left(\frac{A_1}{A_2}\right)^2$$

Cross-multiplying to solve for R_2

$$R_2 = R_1 \cdot \left(\frac{A_1}{A_2}\right)^2 = 0.0231 \cdot \left(\frac{\pi \cdot \frac{(11.7)^2}{4}}{\pi \cdot \frac{(5)^2}{4}}\right)^2$$

$$R_2 = 0.69\ \Omega$$

SUPPLEMENTARY PROBLEMS

1. A kilometer of wire having a diameter of 11.7 mm and a resistance of 0.0231-Ohm is drawn down so that its diameter is 5.0 mm. What does its resistance become? $R_2 = 0.69\ \Omega$

2. A cylindrical copper rod having a diameter of 0.40 in. has resistance of 0.00264-Ohm. Taking the resistivity of copper as 1.745 microhm-cm at 20°C, determine (a) length of rod in feet; (b) resistance of rod when it is drawn down to one-third the initial diameter, the volume remaining unchanged. $(a)\ L = 40.24\ Ft. = 1276.\_\_\ cm$ $(b)\ R_S = 0.2138\ \Omega$

3. The resistance of a particular conductor is 0.08-Ohm. By successive passes through drawing dies its length has increased to three times its original value. Find the new resistance of the conductor when the volume is fixed. $R_2 = 0.72\ \Omega$

Learning Activity 4.2	Self-Assessment 4.2 Calculation of Resistance of Material: When Volume is Fixed

Direction. Analyze and identify data given on the following problems and employ related equations to determine the corresponding required data for each problem. (See Answer-Key to verify your answers)

1. A cylindrical copper rod having a diameter of 0.40 in. has resistance of 0.00264-Ohm. Taking the resistivity of copper as 1.745 microhm-cm at 20^oC, determine (a) length of rod in feet; (b) resistance of rod when it is drawn down to one-third the initial diameter, the volume remaining unchanged.

2. The density of copper is 8.89 g/cm^3, and the resistivity is 1.724 micro-ohm-cm. Determine length in meters and resistance of 12 kg copper, the cross section of which is 2.09 mm^2.

Variation of Resistance with Temperature
Temperature Coefficient of Resistance: Inferred Zero Resistance

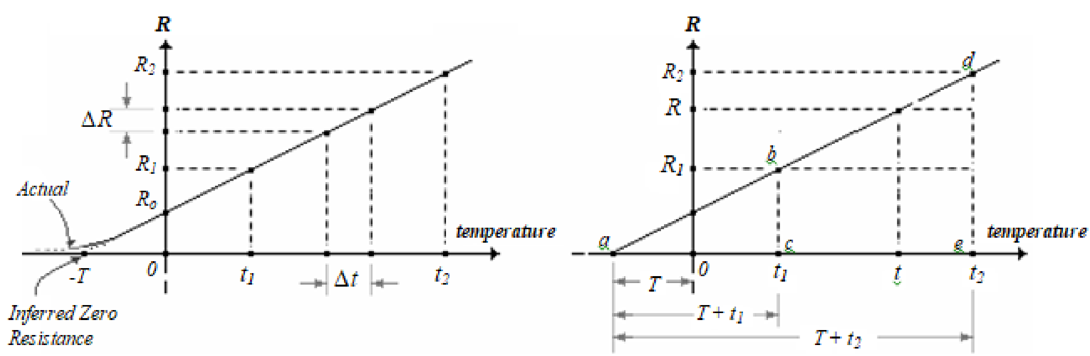


Figure 4.5 Variation of resistance with temperature

<u>Let</u>: R_2 and R_1 be the resistances at temperatures t_2 and t_1, respectively
By similar triangle: *abc* and *ade*

$$\frac{R_2}{T+t_2} = \frac{R_1}{T+t_1}$$

$$R_2 = R_1\left[\frac{T+t_2}{T+t_1}\right] = R_1\left[\frac{T}{T+t_1} + \frac{t_2}{T+t_1} + \frac{t_1}{T+t_1} - \frac{t_1}{T+t_1}\right]$$

$$R_2 = R_1\left[\frac{T+t_1}{T+t_1} + \frac{t_2-t_1}{T+t_1}\right] = R_1\left[1+\left(\frac{1}{T+t_1}\right)(t_2-t_1)\right]$$

Where: $\frac{1}{T+t_1} = \alpha_1 \Rightarrow$ *the temperature coefficient resistance @ temperature* t_1.
- defined as the change in resistance per Ohm per degree centigrade from temperature t_1. *(If Centigrade is used).*

Hence,@ temperature t_2 *the resistance is*

$$R_2 = R_1\left[1+\alpha_1(t_2-t_1)\right] \quad \text{Ohm} \qquad \text{Eq. 4.6}$$

<u>for copper</u>: $T = -234.5\ ^oC$
$/T/ = 234.5\ ^oC$

Illustrative Problem 4.9

The resistance of an electro-magnet winding of copper wire at 20 ^{0}C is 30 Ohms. Determine its resistance at 80 ^{o}C.

Solution:

Given Data:

Condition 1:	Condition 2:
$R_1 = 30\ \Omega$	$R_2 = ?$
$t_1 = 20\ ^{0}C$	$T_2 = 80\ ^{0}C$

Required: Resistance R_2 in the second condition

Using Eq. 4.6

$$R_2 = R_1\left[1 + \alpha_1 \cdot (t_2 - t_1)\right]$$

$$R_2 = 30\left[1 + \left(\frac{1}{234.5 + 20}\right)\cdot(80 - 20)\right]$$

$$R_2 = 37.073\ \Omega$$

Illustrative Problem 4.10

The temperature coefficient of resistance of copper at 0 degrees Celsius is 0.00427/C^{o}, the resistance of a coil of copper wire is 8.820 ohms at 24 ^{o}C, determine resistance (a) at 0 ^{o}C; (b) at 42 ^{o}C.

Solution:

Given Data:

Condition 1: At $0^{0}C$	Condition 2: At $24^{0}C$	Condition 3: At $42^{0}C$
$t_1 = 0^{0}C$	$t_2 = 24\ ^{0}C$	$t_3 = 42\ ^{0}C$
$\alpha_1 = 0.00427/C^{0}$	$R_2 = 8.820\ \Omega$	$R_3 = ?$

Required: Resistance R_2 in the second condition

Using Eq. 4.6

$$R_2 = R_1\left[1 + \alpha_1 \cdot (t_2 - t_1)\right]$$

(a) Resistance @ $0^{0}C$ (R_1):

$$R_2 = R_1\left[1 + \alpha_1 \cdot (t_2 - t_1)\right]$$

$$8.820 = R_1\left[1 + (0.00427)\cdot(24 - 0)\right] = 1.342 \cdot R_1$$

Hence,

$$R_1 = 8.0\ \Omega$$

(B) Resistance @ $42^{0}C$ (R_3):

$$R_3 = R_1\left[1 + \alpha_1 \cdot (t_3 - t_1)\right]$$

$$R_3 = 8.0\left[1 + (0.00427)\cdot(42 - 0)\right]$$

Hence,

$$R_3 = 9.435\ \Omega$$

SUPPLEMENTARY PROBLEMS

1. Tungsten wire has a temperature coefficient of resistance of 0.0045 at 20 ^oC. The hot resistance of a 100-watt 115-volt lamp is 132 Ohms at its operating temperature of 2580 ^oC. Determine its cold resistance at a room temperature of 25 ^oC.

2. The resistance of the field coil of a 400 kW, 230-Volt shunt generator is measured after the machine has been standing for sometime in a room temperature of which is 21 ^oC and is found to be 14.6 Ohms. After the generator has been in operation for three hours, the resistance is again measured and found out to be 16.2 Ohms. Determine (a) average temperature of field coils after 3-hours; (b) temperature rise.

3. The resistance of the armature (*copper conductor*) of a dc-generator is 0.0846 Ohm at a room temperature of 21 ^oC. Determine its resistance (a) at 0 ^oC; (b) at its allowable operating temperature, which is 40 ^oC above room temperature. $(a)\ R_0 = 0.078\ \Omega$ $(b)\ R_{40>} = 0.098\ \Omega$

4. The resistance of the armature (*copper conductor*) of a dc-generator is 0.0846 Ohm at a room temperature of 21 ^oC. Determine its resistance (a) at 0 ^oC; (b) at its allowable operating temperature, which is 40 ^oC above room temperature. $(a)\ R_0 = 0.078\ \Omega$ $(b)\ R_{40>} = 0.098\ \Omega$

5. The resistance of a coil of copper wire at 20 ^oC is 2.21 Ohms. After a current of 10 amperes has been flowing in the wire for 2 hours, the resistance of the coil is found to be 2.59 Ohms. What is the temperature rise? $t_2 = 60.32\ ^oC$ $(a)\ \Delta t = 40.32\ ^oC$

Learning Activity 4.3	**Self-Assessment 4.3** **Calculation of Resistance of Material: Variation of Resistance with Respect to Temperature**

Direction. Analyze and identify data given on the following problems and employ related equations to determine the corresponding required data for each problem. (See Answer-Key to verify your answers)

1. The resistance of the armature (*copper conductor*) of a dc-generator is 0.0846 Ohm at a room temperature of 21 ^oC. Determine its resistance (a) at 0 ^oC; (b) at its allowable operating temperature, which is 40 ^oC above room temperature.

2. The resistance of a coil of copper wire at 20 ^oC is 2.21 Ohms. After a current of 10 amperes has been flowing in the wire for 2 hours, the resistance of the coil is found to be 2.59 Ohms. What is the temperature rise?.

Conductance - *Conductance is the reciprocal of resistance and may be defined as being that property of a circuit or of a material which tends to permit the flow of electricity. The unit of conductance is mho or Siemens (S).*

$$G = \frac{1}{R} \qquad \text{Eq. 4.7}$$

$$G = \frac{1}{R} = \frac{1}{\rho \cdot \frac{L}{A}} = \frac{1}{\rho} \cdot \frac{A}{L} \qquad \Rightarrow \text{Where: } \frac{1}{\rho} = \partial = \textit{Conductivty of material}$$

Hence,

$$G = \partial \cdot \frac{A}{L} \qquad \Rightarrow \text{Mhos or Siemens (S)} \qquad \text{Eq. 4.8}$$

Illustrative Problem 4.11

The conductivity of aluminum is 353,600 mho-cm^{-1} @ 20^{o}C. Determine (a) conductance and resistance @ 20^{o}C of an aluminum bus-bar 6 by ½ in. and 42 ft. long; (b) weight in in grams and in pounds. The density aluminum is 2.70 g/cm^{3}.

Solution:

Given Data:

Conductivity:

$$\partial = 353{,}600 \text{ mho} \cdot \text{cm}^{-1}$$

Conductor: Aluminum Bus-bar:
6 by ½ in., 42-ft long

Required:

(a) Conductance and resistance of bus-bar:
Using Eq. 4.8 for conductance:

$$G = \partial \cdot \frac{A}{L} = (353{,}600 \text{mho/cm}) \frac{\left(6 \text{ in. x } 0.50 \text{ in.} \left[\frac{2.54 \text{ cm}}{\text{in.}}\right]^2\right)}{42 \text{ ft x } \left[\frac{12 \text{ in.}}{\text{ft}} \text{x} \frac{2.54 \text{ cm}}{\text{in}}\right]}$$

$$G = 5{,}346.10 \text{ Mhos or Siemens (S)}$$

Using Eq. 4.7 for resistance:

$$G = \frac{1}{R}$$

$$5{,}346.10 = \frac{1}{R}$$

Thus,

$$R = 187.05 \ \mu \cdot \Omega$$

(b) Weight in pounds

$$\text{Weight} = \text{Volume x Density}$$

Where:

$$\text{Volume} = \left[6 \text{ in. x } 0.50 \text{ in. x } 42 \cdot \text{ft} \left(\frac{12 \text{ in.}}{\text{ft}}\right) \text{x} \left(\frac{2.54 \text{ cm}}{\text{in.}}\right)^3\right]$$

$$= 24{,}777.20 \text{ cm}^3$$

Thus,

$$\text{Weight} = (24{,}777.20 \text{cm}^3) \text{ x } \left(2.70 \frac{\text{gm}}{\text{cm}^3}\right)$$

$$= 66{,}898.60 \text{ gm}$$

$$= (66{,}898.60 \text{ gm}) \text{ x } \left(\frac{1\text{kg}}{1000 \text{gm}} \text{x} \frac{2.2 \text{lbs}}{\text{kg}}\right) = 147.18 \text{ Lbs}$$

Illustrative Problem 4.12

The cross section of no.6 AWG copper wire is 0.02062 in.^{2}, and the resistivity at 25^{o}C is 0.6794 microhm-in. Determine the conductance of one-mile of such wire.

Solution:

Given Data:

Conductor: No. 6 AWG copper wire
A = 0.02062 in.^{2}
L = 1 mile

Resistivity: $\rho \;=\; 0.6794\ \mu\cdot\Omega\cdot\text{in.}$ $\left(\text{Note}:\ \partial \;=\; \dfrac{1}{\rho}\right)$

Required:

(a) Conductance
Using Eq. 4.8 for conductance:

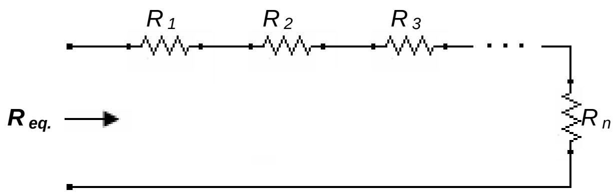
$$G \;=\; \partial\cdot\frac{A}{L}$$

$$=\;\left(\frac{1}{0.6794\ \mu\Omega\cdot\text{in}}\right)\frac{\left(0.02062\ \text{in.}^2\right)}{42\,\text{ft}\ \ x\ \left[1\,\text{mi.}\ x\,\dfrac{5280\,\text{ft}}{\text{mi}}\ x\ \dfrac{12\,\text{in.}}{\text{ft}}\right]}$$

$$=\;0.01141\ \ \text{Mho or Siemen (S)}$$

Connection of Resistors:

Resistor in Series Connection - In a series circuit the total resistance is the sum of the resistances.



Where;

$R_{eq.}$ = the equivalent resistance of the combination or the total resistance of the combination.

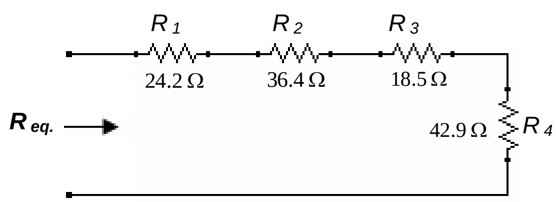
$$R_{eq.} = R_1 + R_2 + R_3 + \ldots + R_n \qquad \text{Eq. 4.9}$$

Illustrative Problem 4.13

Four resistors having resistance R_1 = 24.2 Ohms; R_2 = 36.4 Ohms; R_3 = 18.5 Ohms; R_4 = 42.9 Ohms. Determine the value of a single resistance R, which is equivalent to these four in series.

Solution:

Given Data: (Four resistors connected in series)



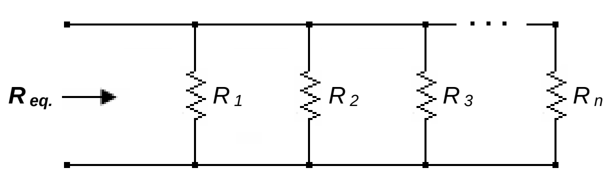
Using Eq. 1.9 for equivalent resistance for resistors connected in series

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

$$R_{eq.} = 24.2 + 36.4 + 18.5 + 42.9$$

$$= 122\ \Omega$$

Resistors in Parallel Connection - In a parallel circuit, the reciprocal of the equivalent resistance is equal to the sum of the reciprocals of the individual resistance, see Equation 4.10.

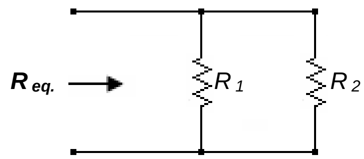


$$\frac{1}{R_{eq.}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n} \qquad \text{Eq. 4.10}$$

- I*n parallel circuit, the reciprocal of the equivalent resistance is equal to the sum of the conductances, that is*

$$G_{eq.} = G_1 + G_2 + G_3 + \ldots + G_n \qquad \text{Eq. 4.11}$$

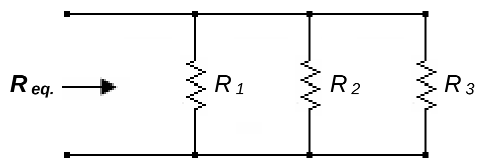
<u>For a Two-Branch Circuit</u>:



$$\frac{1}{R_{eq.}} = \frac{1}{R_1} + \frac{1}{R_2} \qquad \text{Eq. 4.12}$$

$$R_{eq.} = \frac{R_1 R_2}{R_1 + R_2}$$

<u>For a Three-Branch Circuit</u>:



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

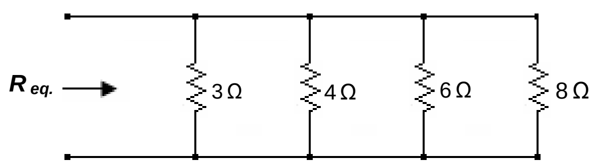
$$R_{eq.} = \frac{R_1 R_2 R_3}{R_1 R_2 + R_2 R_3 + R_3 R_1} \qquad \text{Eq. 4.13}$$

<u>Illustrative Problem 4.14</u>

Determine the equivalent resistance of a circuit having four resistors in parallel the individual resistance of which are 3,4,6,8 Ohms.

Solution:

Given Data: (Four resistors connected in parallel)



Using Eq. 4.10 for equivalent resistance for resistors connected in parallel

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

$$= \frac{1}{3} + \frac{1}{4} + \frac{1}{6} + \frac{1}{8}$$

$$= \frac{8+6+4+3}{24} = \frac{7}{8} \text{ mho}$$

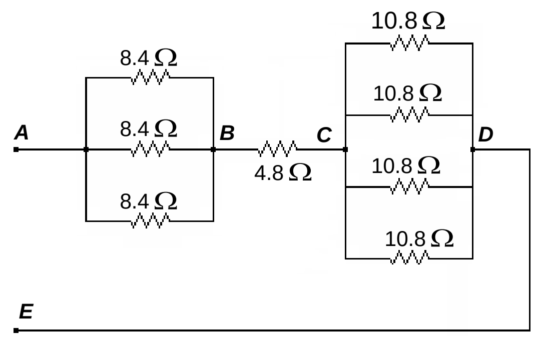
Hence

$$R_{eq.} = \frac{8}{7} = 1.143\ \Omega$$

Series-Parallel Connection of Resistors - *In series parallel connection of resistances, apply Equation 4.9 for the series connected resistors and Equation 4.10 for the parallel connected resistors. Then, replace them with their equivalent and simplify.*

Illustrative Problem 4.15

Three resistors each 8.4 ohms are connected in parallel. This parallel combination is in series with resistance of 4.8 ohms and another parallel group of four resistors, each equal to 10.8 ohms. Determine resistance between terminals (a) AB; (b) CD; (c) AE.

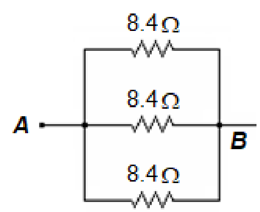


Solution:

(a) Resistance between terminals AB

Note: We have three resistors connected in parallel each 8.4Ω,

using Eq. 4.10



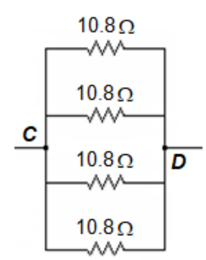
$$\frac{1}{R_{AB.}} = \frac{1}{8.4} + \frac{1}{8.4} + \frac{1}{8.4}$$

Hence,

$$R_{AB} = 2.8\ \Omega$$

(b) Resistance between terminals CD

Note: We have four resistors connected in parallel each 10.8Ω, using Eq. 4.10



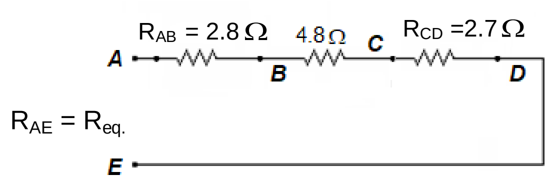
$$\frac{1}{R_{CD.}} = \frac{1}{10.8} + \frac{1}{10.8} + \frac{1}{10.8} + \frac{1}{10.8}$$

Hence,

$$R_{CD} = 2.7\ \Omega$$

(b) Resistance between terminals AE, the equivalent resistance of the circuit.

Note: Replacing the equivalent resistance for the parallel circuits, the simplified equivalent circuit will be that of the circuit below.



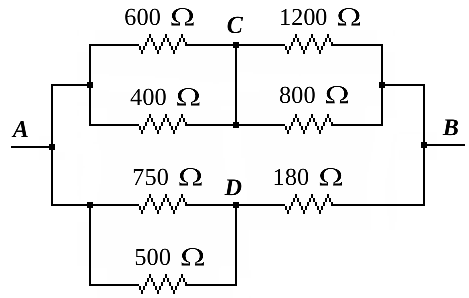
By inspection, we now have an equivalent simple series circuit, with three resistors in sries.

Using Eq. 4.9

$$R_{AE} = R_{eq.} = 2.8 + 4.8 + 2.7$$
$$= 10.3\ \Omega$$

Illustrative Problem 4.16

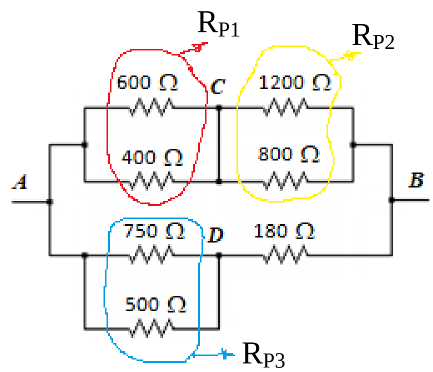
In the circuit shown a series-parallel combination of seven resistors. Determine resistance between points (a) *AB*; (b) *CD*; (c) *AD*; (d) *CB*.



Solution:

(a) Resistance between terminals AB

Note: By inspection, there are three parallel combinations in the circuit as highlighted shown in the right. We call them R_{P1}, R_{P2} and R_{P3} respectively.



Where: From Eq. 4.12 for two-branch circuit

$$R_{eq.} = \frac{R_1 R_2}{R_1 + R_2}$$

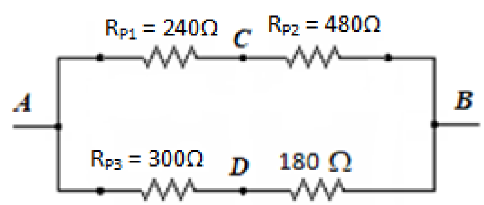
so,

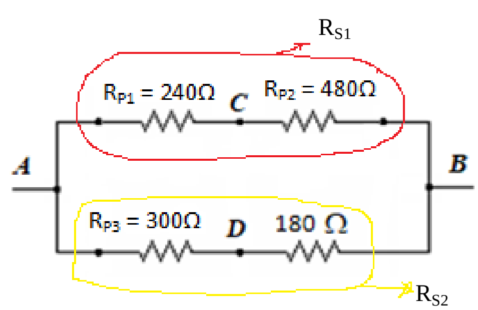
$$R_{P1.} = \frac{600 \cdot (400)}{600 + 400} = 240\ \Omega$$

$$R_{P2.} = \frac{1{,}200 \cdot (800)}{1{,}200 + 800} = 480\ \Omega$$

$$R_{P3} = \frac{750 \cdot (500)}{750 + 500} = 300\ \Omega$$

Simplifying the circuit by substituting the equivalent of the parallel combinations give the equivalent circuit on the right, with R_{P1} and R_{P2} in series (R_{S1}), and also R_{P3} and the 180Ω (R_{S2}).



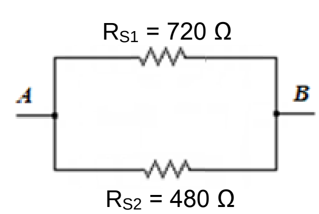


Thence,

$$R_{S1} = 240 + 480 = 720\Omega$$

$$R_{S2} = 300 + 180 = 480\Omega$$

Finally R_{S1} and R_{S2} are in parallel, with equivalent resistance of the combination equals:



From Eq. 4.12 for two-branch circuit

$$R_{eq.} = \frac{R_{S1} R_{S2}}{R_{S1} + R_{S2}}$$

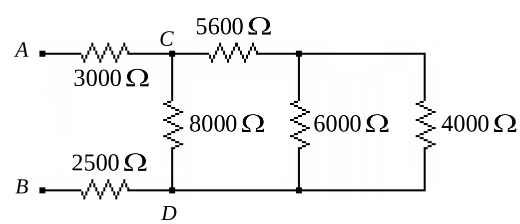
Thus,

$$R_{eq..} = \frac{720 \cdot (480)}{720 + 480} = 288\ \Omega$$

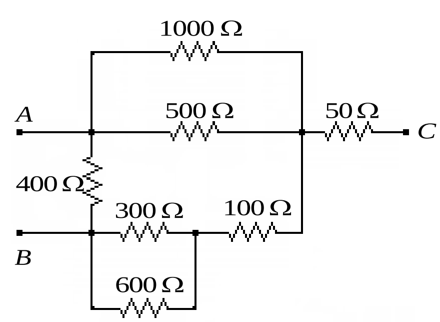
Learning Activity 4.4	**Self-Assessment 4.4** **Calculation of Equivalent Conductance and Equivalent Resistance: Series Connection, Parallel Connection and Series-Parallel Connection**

Direction. Analyze and identify data given on the following problems and employ related equations to determine the corresponding required data for each problem. (See Answer-Key to verify your answers)

1. The conductivity of copper is 1,471,887 mho-in^{-1} @ 20^{o}C. Determine (a) conductance and resistance @ 20^{o}C of a copper bus-bar 4 by ½ in. and 16 ft. long; (b) weight in kilograms. Refer to Table 1.1 for the density of copper.
2. Five resistors connected in series having resistance R_1 = 22.4 Ohms; R_2 = 64.3 Ohms; R_3 = 18.5 Ohms; R_4 = 42.9 Ohms; R_5 = 50.6 Ohms. Determine the (a) value of a single resistance R, which is equivalent to these five in series; (b) equivalent conductance.
3. Five resistors connected in parallel having resistance R_1 = 24 Ohms; R_2 = 36 Ohms; R_3 = 18 Ohms; R_4 = 42 Ohms; R_5 = 50 Ohms. Determine (a) equivalent conductance; (b) value of a single resistance R, which is equivalent to these five in parallel;
4. In a series-parallel combination of resistors shown, determine the resistance as measured between terminals (a) *AB*; (b) *CD* (terminals *A* and *B* being disconnected). 9500Ω /



5. In figure shown, a resistor with three terminals A,B,C. Determine resistance between terminals (a) *AB*; (b) *BC*; (c) *CA*.



Assessment 4.0

I. Direction. Answer each question quietly and encircle the letter of the correct answer.

1. The following are resistivities of copper at 20^{0}C except one.

   (a) 10.371 Ω-CM.Ft (b) 0.67879 μΩ-in
   (c) 172.41 μΩ-m (d) 17.241 μΩ-cm

2. The resistance of conductor varies directly as the ______ and inversely as the _______ when the volume is fixed.

   (a) Length, square of area (b) Square of length, square of area
   (c) Square of length, area (d) Length, area

3. Which of the following is not a unit of current?

   (a) Coulomb per second (b) Farad-Volt per second
   (c) Volt per Ohm (d) Newton-Farad per second^2

4. The following are resistivities of aluminum at 20^{0}C except one.

   (a) Ω-CM17.01.Ft (b) 1.113 μΩ-in
   (c) 282.8 μΩ-m (d) 28.28 μΩ-cm

5. Current is analogous to ________ in mechanical and analogous to ______ in hydraulic?

   (a) Flow, velocity (b) Pressure, velocity
   (c) Pressure, flow (d) Velocity, flow

II. Direction. Analyze and identify data given on the following problems and employ related equations to determine the corresponding required data for each problem.

6. The resistivity of copper is 1.724 microhm-cm at 20^{o}C. Determine for copper, at the same temperature, the resistance (a) between opposite faces of an inch cube; (b) of a wire 1 foot long and 0.001 in. diameter (one-circular mil); (c) of a rod one-meter long having a diameter of 1 mm.

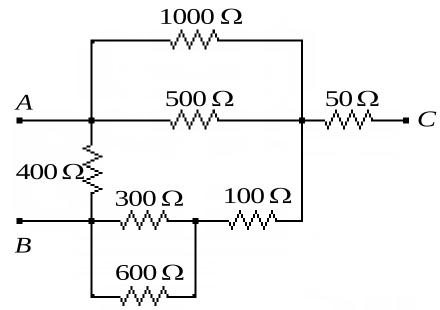
7. The resistivity of a ferric-chromium alloy is 51.0 microhm-in. A sheet of the material is 15 in. long, 6 in. wide, and 0.014 in thick. Determine the resistance between (a) opposite ends (b) opposite sides.

8. The resistance of a 10 ft. length of resistor material having a cross section of 0.00204 in.^2 is 4.1 ohms, the resistance of a 12 ft. length of the same material is 7.7 ohms. Determine its cross section in sq. inches.

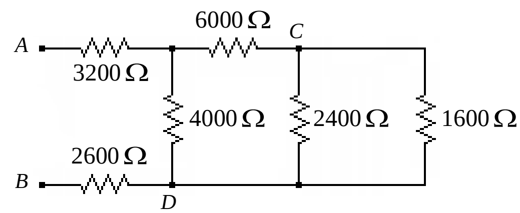
9. Tungsten wire has a temperature coefficient of resistance of 0.0045 at 20 ^{o}C. The hot resistance of a 100-watt 115-volt lamp is 132 Ohms at its operating temperature of 2580 ^{o}C. Determine its cold resistance at a room temperature of 25 ^{o}C.

10. The resistance of a certain conductor is 46 Ohm @ 25 ^{o}C. The temperature coefficient of resistance is 0.00454545 per C^{o} @ 20 ^{o}C. At what temperature will its resistance be 92 Ohms?

11. In figure shown, a resistor with three terminals A,B,C. Determine resistance between terminals *CA*.



12. In a series-parallel combination of resistors shown, determine the resistance as measured between terminals (a) *AB*; (b) *CB*



Answer Key

Pre-Test 4.0

1. *c*
2. *c*
3. *d*
4. *c*
5. *b*
6. c
7. b
8. a
9. d
10. c

Learning Activity 4.I

1. c
2. c
3. a
4. c
5. d
6. (a) 190,214 sq.mils (b) 242,188 CM
7. (a) 133,079 CM (b) 0.4115 Ohm
8. 0.227 Ohm
9. (a) 290 CM (b) 0.152 mil

Learning Activity 4.2

1. *(a) L = 40 Ft; (b) R = 0.2138 Ω*
2. *(a) L = 645.85 m; (b) R = 5.327Ω*

Learning Activity 4.3

1. *(a) R = 0.078 Ω; (b) R = 0.098 Ω*
2. $\Lambda t = 40.32^{0C} \left(t_2 = 60.32^{0C}\right)$

Learning Activity 4.4

1. *(a) G = 15,332.16 Mhos; R = 65.222 μΩ (b) 55.941 kg*
2. *(a) $R_{eq.}$ = 198.7 Ω; (b) $G_{eq.}$ = 0.005033 Mho*
3. *(a) $G_{eq.}$ = 0.169 Mhos; (b) $R_{eq.}$ = 5.924 Ω*
4. *(a) R_{AB} = 9,500 Ω; (b) R_{CD} = 4,000 Ω*
5. *(a) R_{AB} = 245.161 Ω; (b) R_{BC} = 262.903 Ω; (c) R_{CA} = 225.806 Ω*