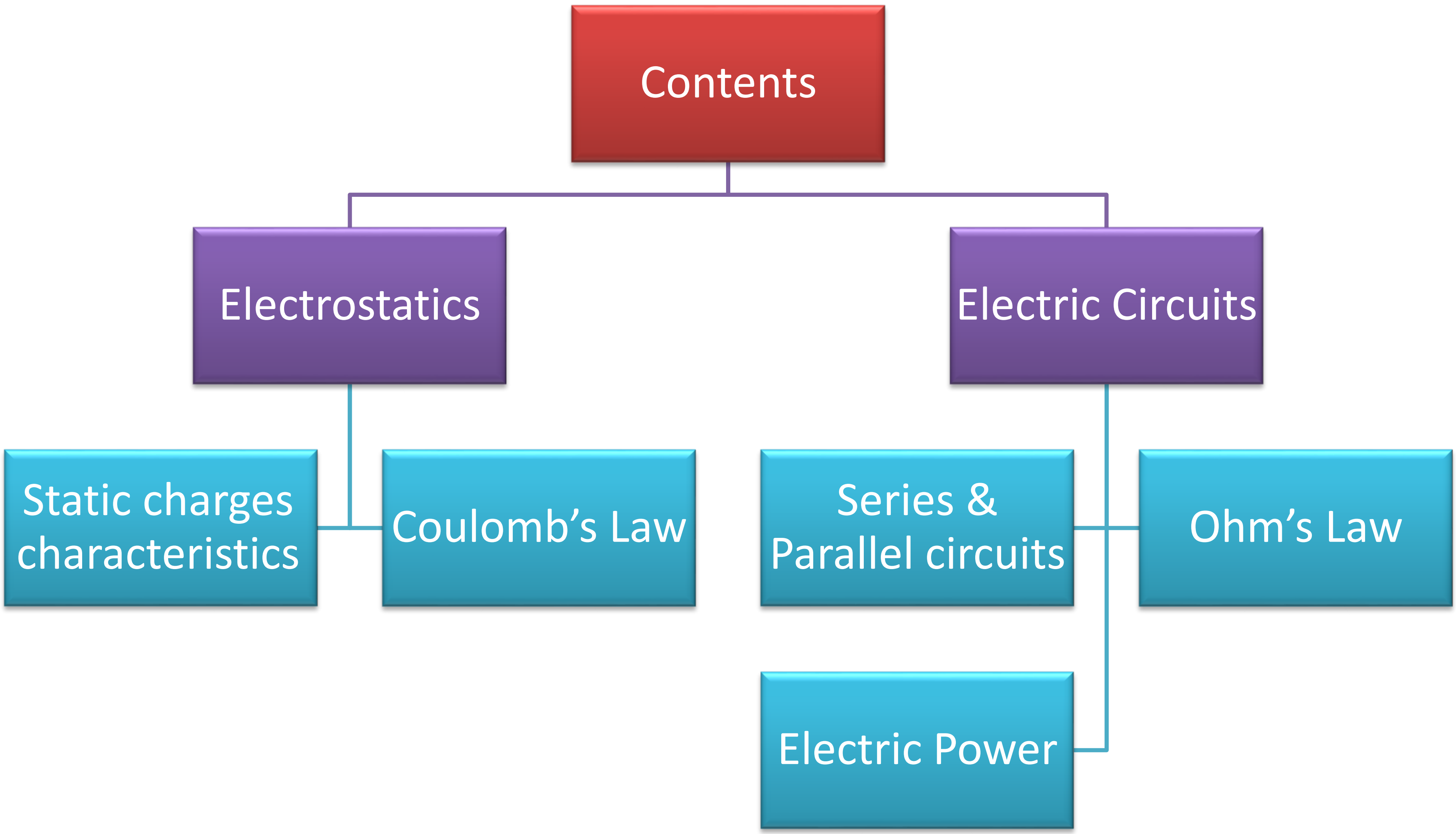
Chapter Four

Fundamental of Electricity


Contents
Electrostatics
Electric Circuits
Static charges characteristics
Coulomb’s Law
Series & Parallel circuits
Ohm’s Law
Electric Power

1. Electrostatics

Electricity is the name given to a wide range of electrical phenomena, such as

- lightning.

- spark when we strike a match.

- what holds atoms together.

Electrostatics involves :

electric charges,

the forces between them,

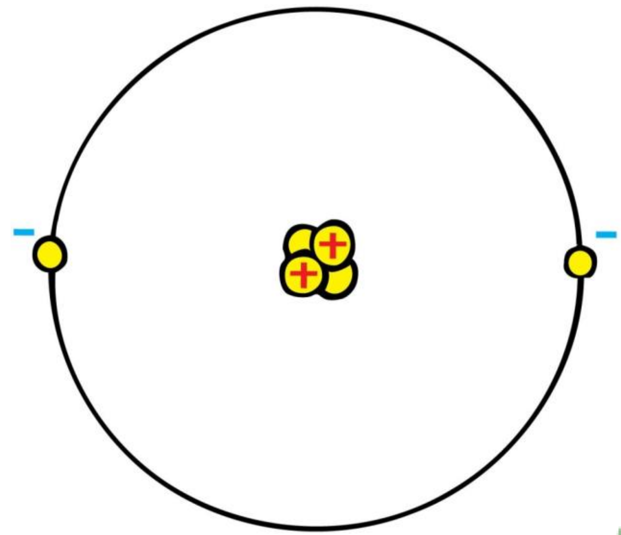
the aura that surrounds them, and

their behavior in materials.

Electric Force and Charges

Fundamental facts about atoms

1. Every atom is composed of a positively charged nucleus surrounded by negatively charged electrons.
2. Each of the electrons in any atom has the same quantity of negative charge and the same mass.



Protons

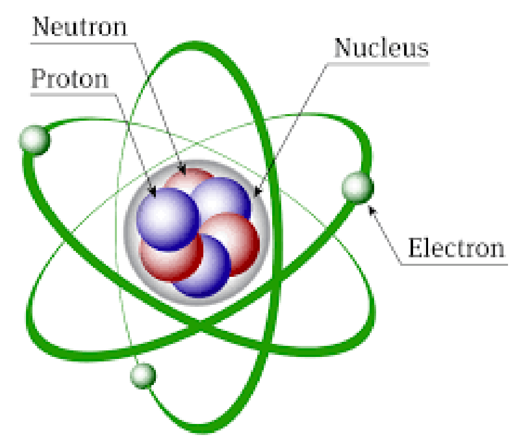
- Positive electric charges
- Repel positives, but attract negatives

Electrons

- Negative electric charges
- Repel negatives, but attract positives

Neutrons

- Neutral electric charge



Electric Force and Charges

Fundamental facts about atoms (continued)

3. Protons and neutrons compose the nucleus.

$$m_p \cong m_n > 1800 m_e$$

Neutrons have no net charge.

4. Atoms usually have as many electrons as protons, so the stable atom has **zero net charge**.

Electric Force and Charges

Ion

- Positive ion—atom losing one or more electrons has positive net charge.
- Negative ion—atom gaining one or more electrons has negative net charge.

Electric Force and Charges

Electrons in an atom

- Innermost—attracted very strongly to oppositely charged atomic nucleus
- Outermost—attracted loosely and can be easily dislodged

Examples:

- When rubbing a comb through your hair, electrons transfer from your hair to the comb. Your hair has a deficiency of electrons (positively charged).
- When rubbing a glass rod with silk, electrons transfer from the rod onto the silk and the rod becomes positively charged.

Coulomb's Law

Coulomb's law (continued)

- If the charges are alike in sign, the force is repelling; if the charges are not alike, the force is attractive.
- In equation form:

$$F = k\frac{q_1 q_2}{d^2}$$

k = 9,000,000,000 Nm^2/C^2

=$(9x10^9)$ Nm^2/C^2

- Unit of charge is coulomb, C
- Similar to Newton's law of gravitation for masses
- Underlies the bonding forces between molecules

Electric Field

Electric field

- Space surrounding an electric charge (an energetic aura)
- Describes electric force
- Around a charged particle obeys inverse-square law
- Force per unit charge (unit: N/C)

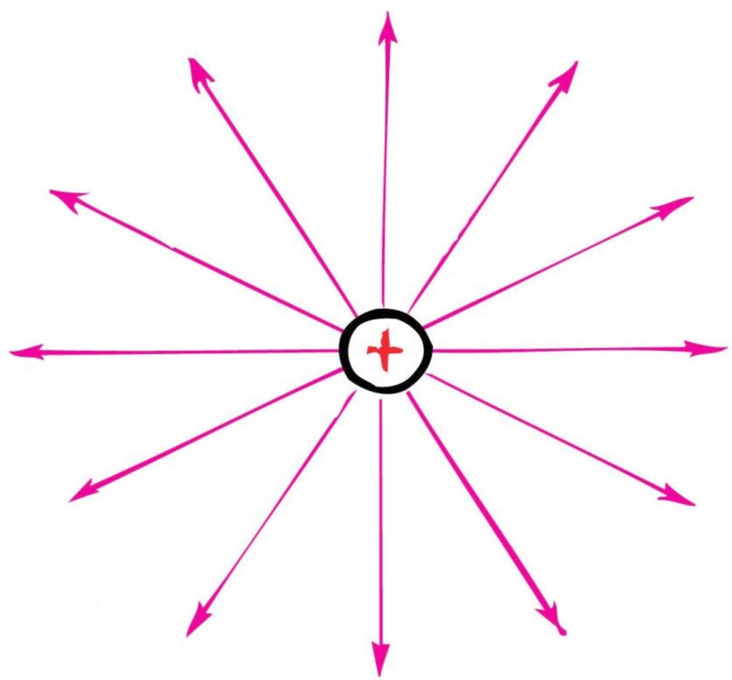
If a body with charge q experiences a force F at some point in space, then the electric field E at that point is

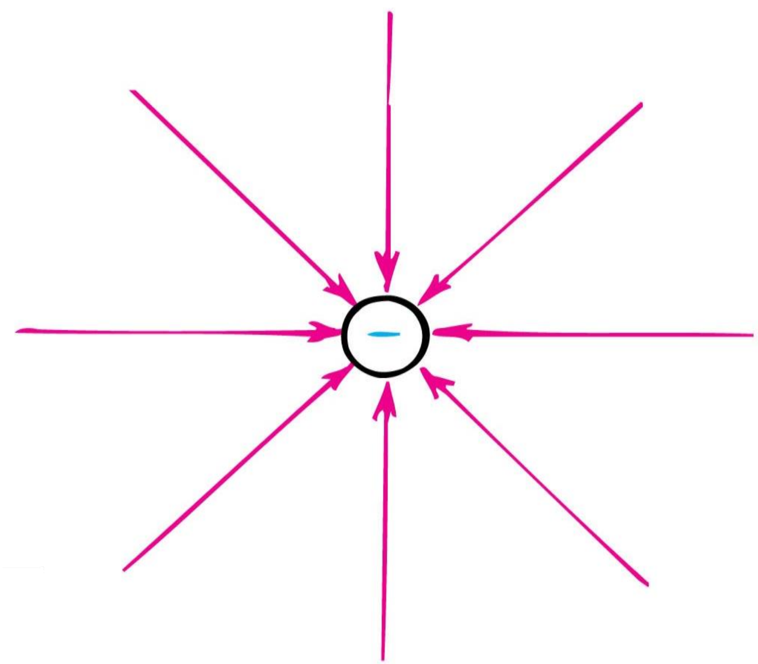
$$E = \frac{F}{q}$$

Electric Field

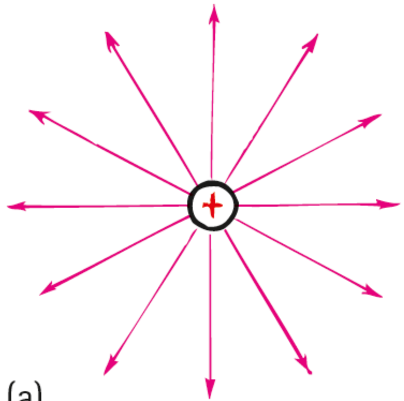
Electric field direction

- Same direction as the force on a small positive test charge
- Opposite direction to the force on an electron



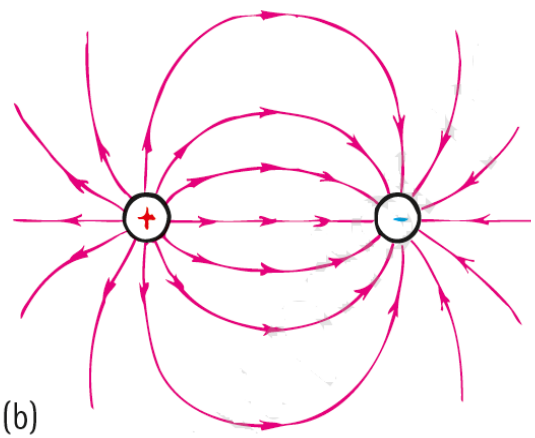


Some electric-field configurations.



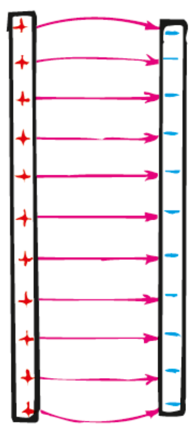
(a)

(a) Lines of force emanating from a single positively charged particle.



(b)

(b) Lines of force for a pair of equal but oppositely charged particles. Note that the lines emanate from the positive particle and terminate on the negative particle.



(c)

(c) Uniform lines of force between two oppositely charged parallel plates.

Example 4.1:
Two charges, each with magnitude +6.5 μC, are separated by a distance of 0.200 cm. Find the force of repulsion between them.

Data:

$q_1 = q_2 = +6.5 \times 10^{-6} C$

r = 0.200 cm = 0.00200 m 2.00 x 10^{-3}m

F= ?

Basic Equation:

$$\boldsymbol{F} = \frac{\boldsymbol{k}\mathbf{q_1}\ \mathbf{q_2}}{\boldsymbol{r}^2}$$

Substitution gives:

$$F = \frac{9.00x10^9x6.5x10^{-6}x6.5x10^{-6}}{(2.00x10^{-3}m)^2}$$

= 9.51 x 10^4 N

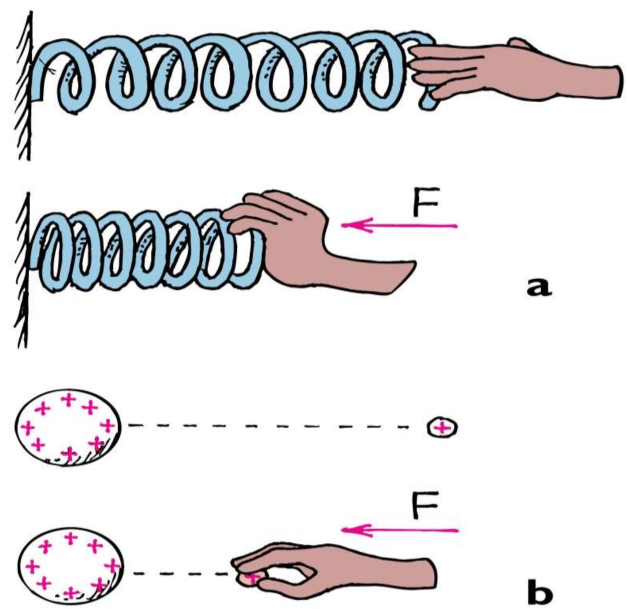
Electric Potential

Electric potential energy (unit: Joule (J))

- Energy possessed by a charged particle due to its location in an electric field. Work is required to push a charged particle against the electric field of a charged body.

(a) The spring has more elastic PE when compressed.

(b) The small charge similarly has more PE when pushed closer to the charged sphere. In both cases, the increased PE is the result of work input.



Electric Potential

Electric potential (voltage)

- Energy *per charge* possessed by a charged particle due to its location
- May be called *voltage*—potential energy per charge
- In equation form:

$$\text{Electric potential} = \frac{\text{electric potential energy}}{\text{amount of charge}}$$

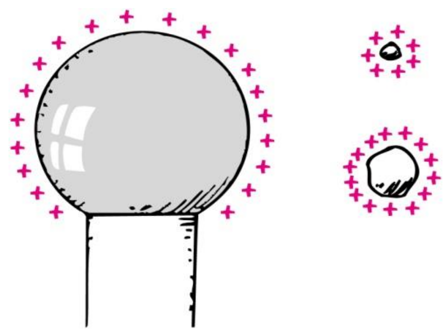
Electric Potential

Electric potential (voltage) (continued)

- Unit of measurement: volt, $1 \text{ volt} = \dfrac{1 \text{ joule}}{1 \text{ coulomb}}$

  Example:

  - Twice the charge in same location has twice the electric potential energy but the same electric potential.



  - 3 times the charge in same location has 3 times the electric potential energy but the same electric potential ($2\,E/2\,q = 3\,E/3\,q = V$)

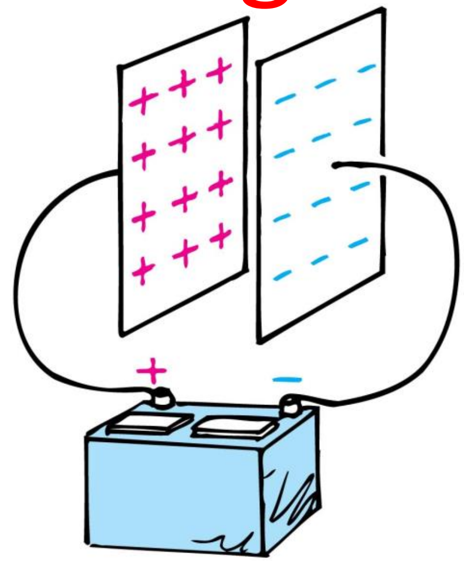
Electric Potential
CHECK YOUR NEIGHBOR

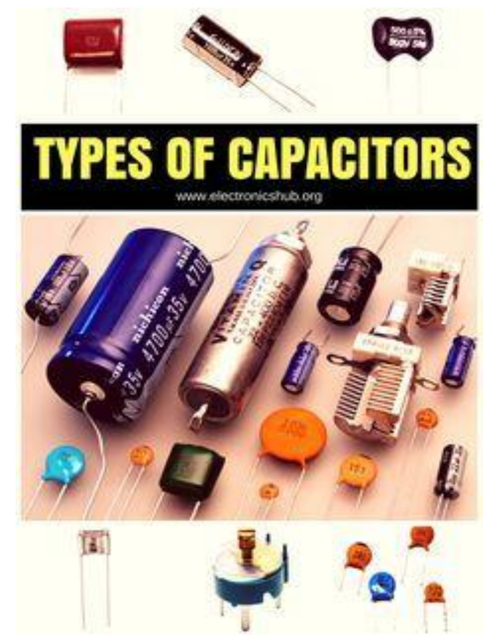
Electric potential energy is measured in joules. Electric potential, on the other hand (electric potential energy per charge), is measured

A. in volts.
B. in watts.
C. in amperes.
D. also in joules.

Electric Energy Storage

- Electrical energy can be stored in a common device called a **capacitor.**
- The simplest capacitor is a pair of conducting plates separated by a small distance, but not touching each other.
- When the plates are connected to a charging device, such as the battery, electrons are transferred from one plate to the other.





Electric Energy Storage

- This occurs as the positive battery terminal pulls electrons from the plate connected to it.
- These electrons, in effect, are pumped through the battery and through the negative terminal to the opposite plate.
- The capacitor plates then have equal and opposite charges:
  - The positive plate connected to the positive battery terminal, and
  - The negative plate connected to the negative terminal.

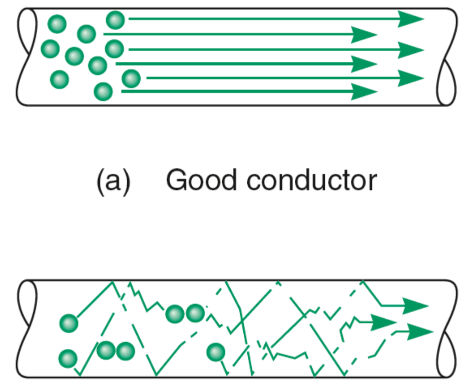
2. Electric Circuits

Electric Current

$$1 \text{ ampere } (A) = \frac{1 \text{ coulomb } (C)}{1 \text{ second } (s)}$$

Rate of electric flow

- Measured in ampere (1 coulomb of charge per second).
- Speed of electrons (drift speed) through a wire is slow because of continuous bumping of electrons in wire.



VOLTAGE

The *potential difference* between two points in an electric field is the work done per unit of charge as the charge is moved between two points. That is,

$$\text{potential difference} = \frac{\text{work}}{\text{charge}}$$

In *sources*, the raising of the potential energy of electrons that results in a potential difference across a source is called **emf** (E). In *circuits*, the lowering of the potential difference across a load is called **voltage drop**.

The *volt* (V), named after **Allessandro Volta**, is the unit of both emf and voltage drop. We define the volt as the potential difference between two points if 1 J of work is produced or used in moving 1 C of charge from one point to another:

$$1 \text{ volt (V)} = \frac{1 \text{ joule (J)}}{1 \text{ coulomb (C)}}$$

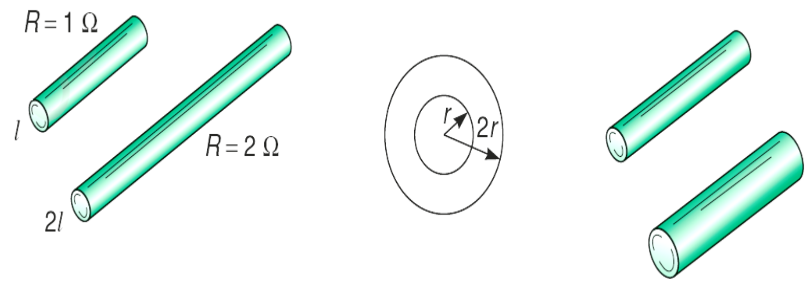
RESISTANCE

The opposition to current flow is called **resistance**. The unit of resistance is the *ohm* (Ω).

The resistance of a wire depends mainly on its length (L), cross-sectional area (A) and a property of the material called resistivity.

These factors are related by the equation

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



(a) Resistance varies directly with length.

(b) Doubling the radius more than doubles the cross-sectional area.

Example 4.2:

Find the resistance of a copper wire 20.0m with cross-sectional area of $6.56x10^{-3}cm^2$ at 20°C. (*Note: the resistivity of copper at 20°C is* $1.72x10^{-6}$ *Ωcm*).

Data:

$l = 20.0m = 2.00x10^3$ cm

$A = 6.56 \times 10^{-3} cm^2$

$\rho = 1.72 \times 10^{-6}$ Ωcm

R = ?

Basic Equation:

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

Substitution gives:

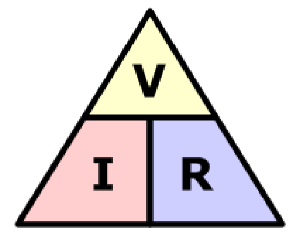
$$R = \frac{(1.72x10^{-6}\,\Omega cm)(2.00x10^{3} cm)}{(6.56x10^{-3} cm)}$$

$= 0.524\ \Omega$

Ohm's Law

Ohm's law

$$I = \frac{V}{R}$$



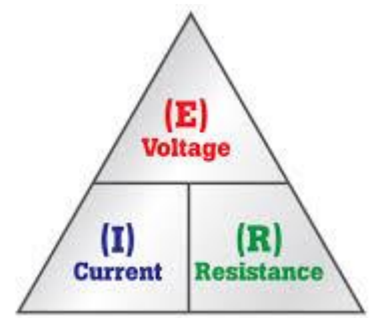
where I = current *through* the resistance

V = voltage drop *across* the resistance

R = resistance

Ohm's law can also be written

$$I = \frac{E}{R}$$



where E = emf of the source of electrical energy

EXAMPLE 4.3

A heating element on an electric range operating on 240 V has a resistance of 30.0 Ω. What current does it draw?

Data:

$$E = 240 \text{ V}$$
$$R = 30.0\ \Omega$$
$$I = ?$$

Basic Equation:

$$I = \frac{E}{R}$$

Working Equation: Same

Substitution:

$$I = \frac{240 \text{ V}}{30.0\ \Omega}$$
$$= 8.0 \text{ V}/\Omega$$
$$= 8.0 \text{ A}$$

$$\boxed{\frac{\text{V}}{\Omega} = \text{A}}$$

Electric Power

The rate of consuming energy is called **power.**

Unit = ***Watt* (W)**

$$\boxed{P = VI} \Rightarrow = \text{volt} \bullet \text{ampere} = \frac{\mathrm{J}}{\mathrm{C}} \cdot \frac{\mathrm{C}}{\mathrm{s}} = \frac{\mathrm{J}}{\mathrm{s}}$$

P = power (watts)

V = voltage drop (V)

I = current (A)

$$\boxed{\text{Thus, } 1\ \mathrm{W} = 1\ \mathrm{J/s}}$$

Since the watt is a relatively small unit, the kilowatt ($1\ \mathrm{kW} = 1000\ \mathrm{W}$) is commonly used in industry.

Electric Power

Recalling Ohm's law, $I = V/R$, we find two other equations for power:
Given

$$P = VI$$

substitute for V using $V = IR$ to obtain

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

$$\boxed{P = I^2R}$$

Note from the following unit analysis that amps squared times ohms gives watts:

$$\boxed{A^2\,\Omega = A^2 \cdot \frac{V}{A} = AV = \frac{C}{s} \cdot \frac{J}{C} = \frac{J}{s} = W}$$

$$I = \frac{V}{R} \Rightarrow P = I^2R \Rightarrow P = \left(\frac{V}{R}\right)^2 R = \frac{V^2}{R^2} \cdot R \Rightarrow \boxed{P = \frac{V^2}{R}}$$

EXAMPLE

A soldering iron draws 7.50 A in a 115-V circuit. What is its wattage rating?

Data:

$$I = 7.50\ \text{A}$$
$$V = 115\ \text{V}$$
$$P = ?$$

Basic Equation:

$$P = VI$$

Working Equation: Same

Substitution:

$$P = (115\ \text{V})(7.50\ \text{A})$$
$$= 863\ \text{W}$$

Therefore, a soldering iron drawing 7.50 A in a 115-V circuit has a rating of 863 W.

EXAMPLE 4.5

A hand drill draws 4.00 A and has a resistance of 14.6 Ω. What power does it use?

Data:

$$I = 4.00 \text{ A}$$
$$R = 14.6\ \Omega$$
$$P = ?$$

Basic Equation:

$$P = I^2R$$

Working Equation: Same

Substitution:

$$P = (4.00 \text{ A})^2(14.6\ \Omega)$$
$$= 234 \text{ W}$$

Thus, a drill that draws 4.00 A with a resistance of 14.6 Ω has a rating of 234 W.

The amount of energy consumed is

$$\text{energy} = \text{power} \times \text{time}$$

$$\text{energy (in kWh)} = (VI)t$$

$$\text{number of kWh} = VIt$$

V (in volts), ***I*** (in Amperes), and ***t*** (in seconds)

The cost of operating an electric device may be found as follows:

$$\text{cost} = \text{energy} \times \text{cost per unit energy}$$

$$\text{cost} = (\text{kWh})\left(\frac{\text{cents}}{\text{kWh}}\right)$$

Halala (h) in KSA

$$\boxed{\text{cost (in cents)} = \text{power (in W)} \times \text{hours} \times \underbrace{\frac{1\ \text{kW}}{1000\ \text{W}}}_{\text{conversion factor}} \times \frac{\text{cents}}{\text{kWh}}}$$

Example:

An iron is rated at 550 W. How much it cost to operate it for 2.50 h at SR 0.18/kWh?

Solution:

Cost = 0.55 x 2.50 x 0.18

= SR 0.25 (25 hallala)

Home Work:

In your home, the electricity meter reading at the beginning of January was 109420 and at the end of March it was 110520. Calculate the average payment per month.

Example:

An air-condition draws 15 A working at 220 V for 10 hours every day. How much the cost (in SA) at the end of the month if the unit is SR 0.18/kWh?

Solution:

Energy consumed = Power x time

= Voltage x Current x time

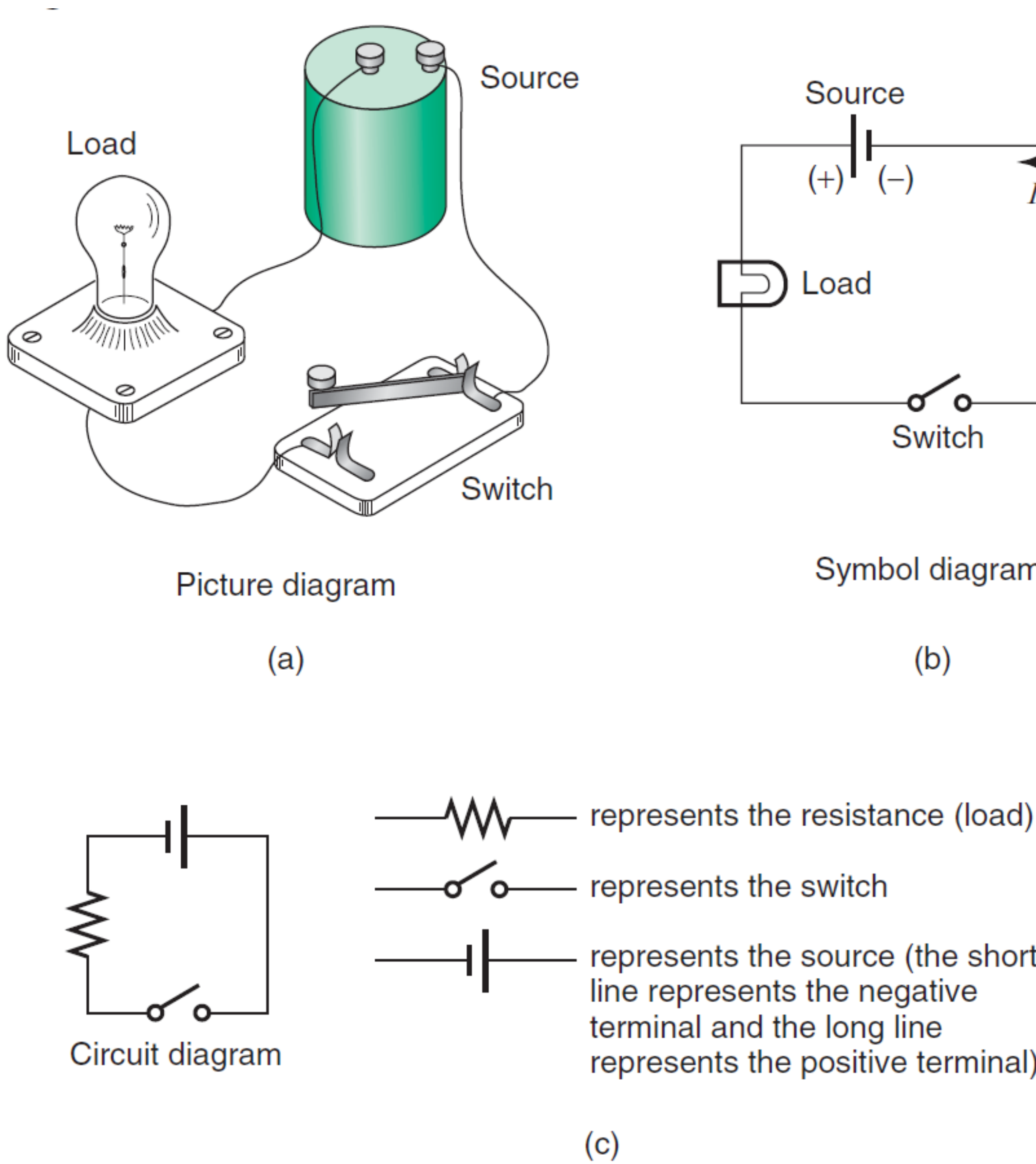
= 220 x 15 x 10 x 30

= 99 kWh

Cost = 99 x 0.18

17.8 Riyals

Electric Circuits



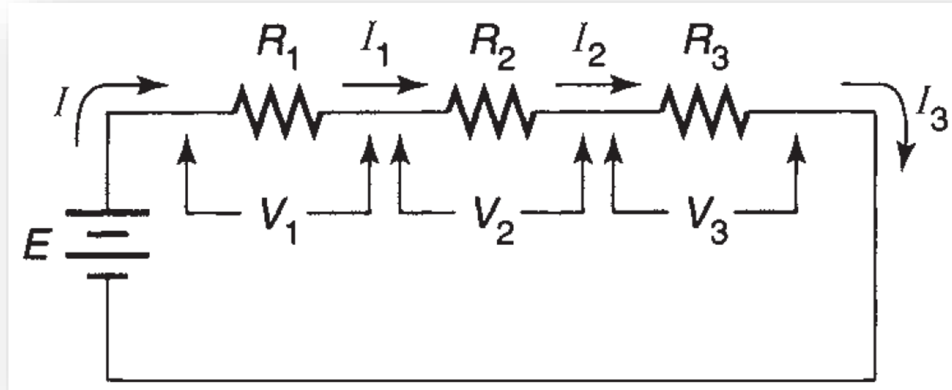
SERIES CIRCUITS

SERIES

$$I = I_1 = I_2 = I_3 = \cdots$$

I = total current I_1 = current through R_1

I_2 = current through R_2 I_3 = current through R_3



An electric circuit with only one path for the current to flow is called a *series circuit.*

SERIES

$$E = V_1 + V_2 + V_3 + \cdots$$

E = emf of the source V_1 = voltage drop across R_1

V_2 = voltage drop across R_2 V_3 = voltage drop across R_3

SERIES

$$R = R_1 + R_2 + R_3 + \cdots$$

R = total or equivalent resistance of the circuit R_1 = resistance of first load

R_2 = resistance of second load R_3 = resistance of third load

Example 4.7:
Three resisters 7.0 Ω, 9.0 Ω and 21.0 Ω connected in series.
Find the total resistance

Solution:
$R = R1 + R2 + R3$
$= 7.0 + 9.0 + 21.0 = 37.0\ \Omega$

EXAMPLE 4.8

Find the current in the circuit shown in Figure 4.9.

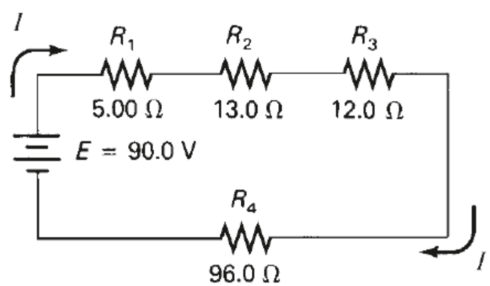


FIGURE 4.9

Data:

$R_1 = 5.00\ \Omega$ $\quad R_4 = 96.0\ \Omega$
$R_2 = 13.0\ \Omega$ $\quad E = 90.0\ \text{V}$
$R_3 = 12.0\ \Omega$ $\quad I = ?$

Basic Equations: $R = R_1 + R_2 + R_3 + R_4$ and $I = \dfrac{E}{R}$

Working Equations: Same

Substitutions:

$$R = 5.00\ \Omega + 13.0\ \Omega + 12.0\ \Omega + 96.0\ \Omega$$
$$= 126.0\ \Omega$$

$$I = \frac{90.0\ \text{V}}{126.0\ \Omega}$$
$$= 0.714\ \text{A}$$

EXAMPLE 4.9

Find the value of R_3 in the circuit shown in Figure 4.10.

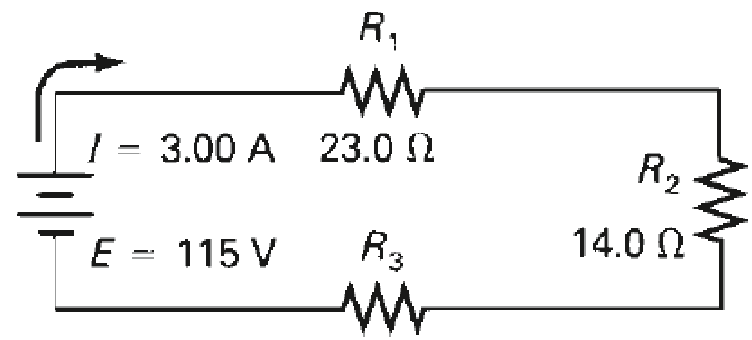


FIGURE 4.10

Data:

$I = 3.00 \text{ A}$ $\quad R_2 = 14.0\ \Omega$

$E = 115 \text{ V}$ $\quad R_3 = ?$

$R_1 = 23.0\ \Omega$

Basic Equations: $I = \dfrac{E}{R}$ and $R = R_1 + R_2 + R_3$

Working Equations:

$$R = \frac{E}{I} \quad \text{and} \quad R_3 = R - R_1 - R_2$$

Substitutions:

$$R = \frac{115 \text{ V}}{3.00 \text{ A}}$$

$$= 38.3\ \Omega$$

$$R_3 = 38.3\ \Omega - 23.0\ \Omega - 14.0\ \Omega$$

$$= 1.3\ \Omega$$

EXAMPLE 4.10

Find the voltage drop across R_3 in Figure 4.10.

Data:

$$I = I_3 = 3.00\text{ A}$$
$$R_3 = 1.3\ \Omega$$
$$V_3 = ?$$

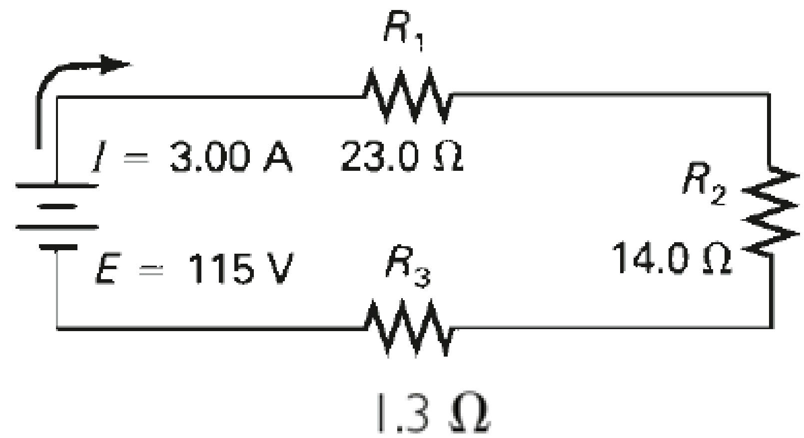


FIGURE 4.10

Basic Equation:

$$I_3 = \frac{V_3}{R_3}$$

Working Equation:

$$V_3 = I_3R_3$$

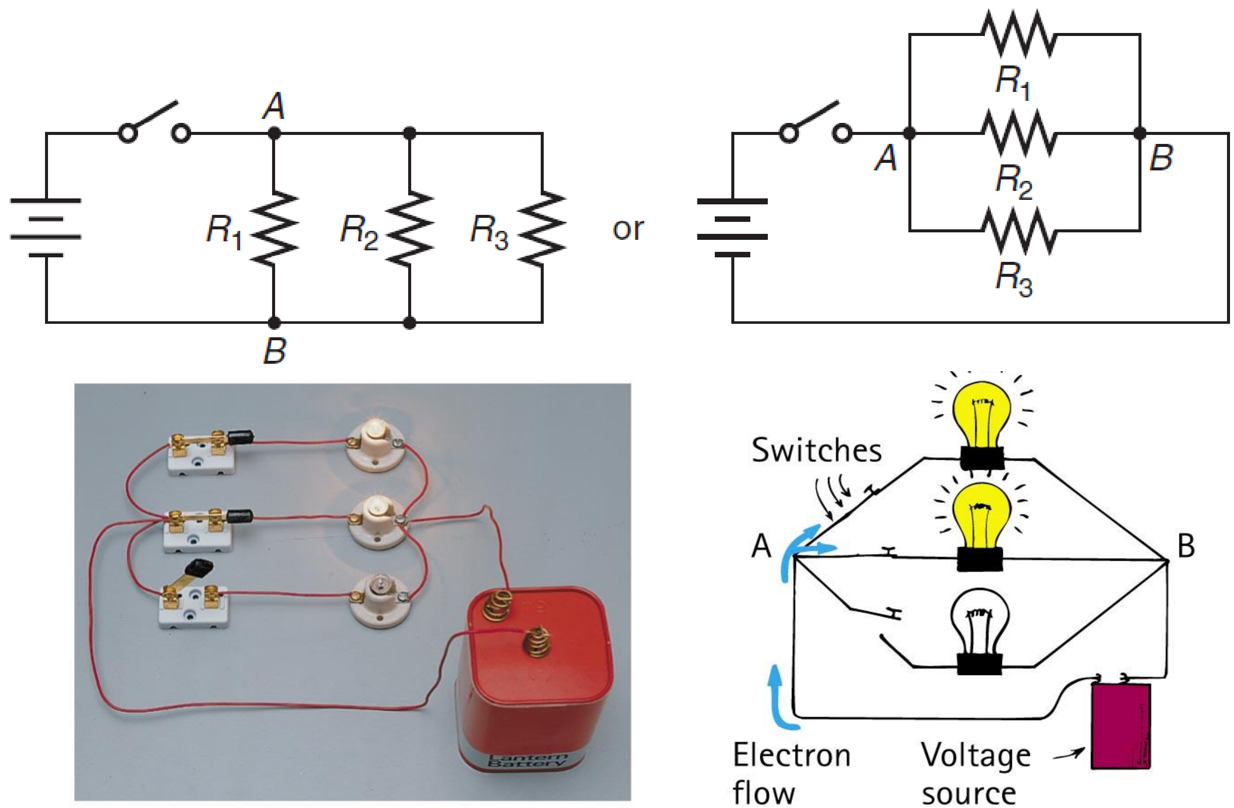
Substitution:

$$V_3 = (3.00\text{ A})(1.3\ \Omega)$$
$$= 3.9\text{ V}$$

PARALLEL CIRCUITS

An electric circuit with more than one path for the current to flow is called a parallel circuit.

Different ways to represent a parallel circuit



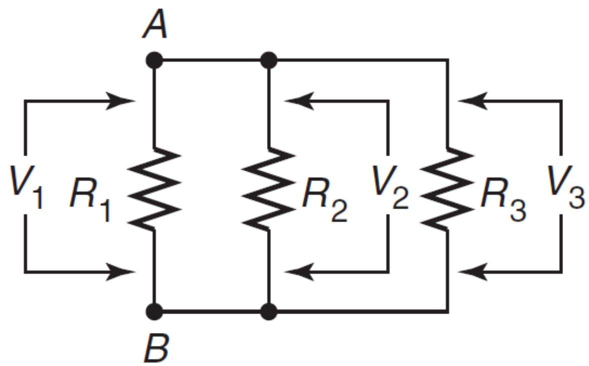
PARALLEL CIRCUITS

PARALLEL

$$I = I_1 + I_2 + I_3 + \cdots$$

I = total current in the circuit
I_1 = current through R_1
I_2 = current through R_2
I_3 = current through R_3

$$I = I_1 + I_2 + I_3.$$



PARALLEL

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

R = equivalent resistance
R_1 = resistance of R_1
R_2 = resistance of R_2
R_3 = resistance of R_3

PARALLEL

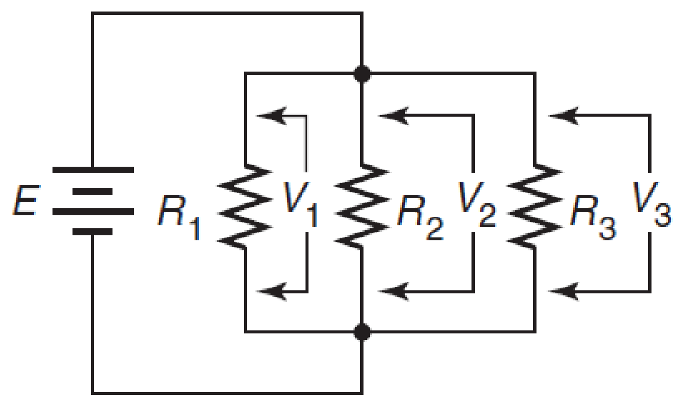
$$V_1 = V_2 = V_3 = \cdots$$

PARALLEL WITH VOLTAGE SOURCE

$$E = V_1 = V_2 = V_3 = \cdots$$

E = emf of the source
V_1 = voltage drop across R_1
V_2 = voltage drop across R_2
V_3 = voltage drop across R_3

$$E = V_1 = V_2 = V_3.$$



EXAMPLE 4.11

Find the equivalent resistance of the circuit shown in Figure 4.16.

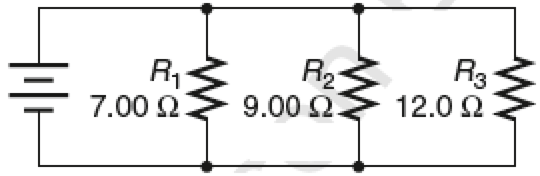


FIGURE 4.16

Data:

$$R_1 = 7.00\ \Omega$$
$$R_2 = 9.00\ \Omega$$
$$R_3 = 12.0\ \Omega$$
$$R = ?$$

Basic Equation:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Working Equation:

When using this formula, you should solve for the reciprocal of the unknown, then substitute.

Substitution:

$$\frac{1}{R} = \frac{1}{7.00\ \Omega} + \frac{1}{9.00\ \Omega} + \frac{1}{12.0\ \Omega}$$
$$R = 2.96\ \Omega$$

EXAMPLE 4.13

Find the current through R_2 in Figure 4.17 from Example 4.12.

Data:

$$R_2 = 14.0\ \Omega$$
$$E = 90.0\ \text{V} = V_2$$
$$I_2 = ?$$

Basic Equation:

$$I_2 = \frac{V_2}{R_2}$$

Working Equation: Same

Substitution:

$$I_2 = \frac{90.0\ \text{V}}{14.0\ \Omega}$$
$$= 6.43\ \text{A}$$

EXAMPLE 4.14

Find the equivalent resistance and the value of R_3 in the circuit shown in Figure 4.18.

Data:

$$E = 115\text{ V}$$
$$I = 7.00\text{ A}$$
$$R_1 = 38.0\ \Omega$$
$$R_2 = 49.0\ \Omega$$
$$R_3 = ?$$

First find R:

Basic Equation:

$$I = \frac{E}{R}$$

Working Equation:

$$R = \frac{E}{I}$$

Substitution:

$$R = \frac{115\text{ V}}{7.00\text{ A}}$$
$$= 16.4\ \Omega$$

To find R_3:

Basic Equation:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Working Equation:

$$\frac{1}{R_3} = \frac{1}{R} - \frac{1}{R_1} - \frac{1}{R_2}$$

Substitution:

$$\frac{1}{R_3} = \frac{1}{16.4\ \Omega} - \frac{1}{38.0\ \Omega} - \frac{1}{49.0\ \Omega}$$
$$R_3 = 70.2\ \Omega$$

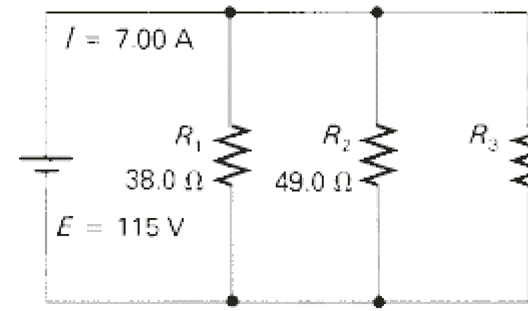


FIGURE 4.18