4- Ohm’s law and power

1st law

Voltage and current

General

introduction

Now that the foundation for the study of electricity/electronics has been established, the concepts of voltage and current can be investigated. The term **voltages** encountered practically every day.

We have all replaced batteries in our flashlights, answering machines, calculators, automobiles, and so on, that had specific voltage ratings. We are aware that most outlets in our homes are 220 volts.

continue

ATOMS AND THEIR STRUCTURE

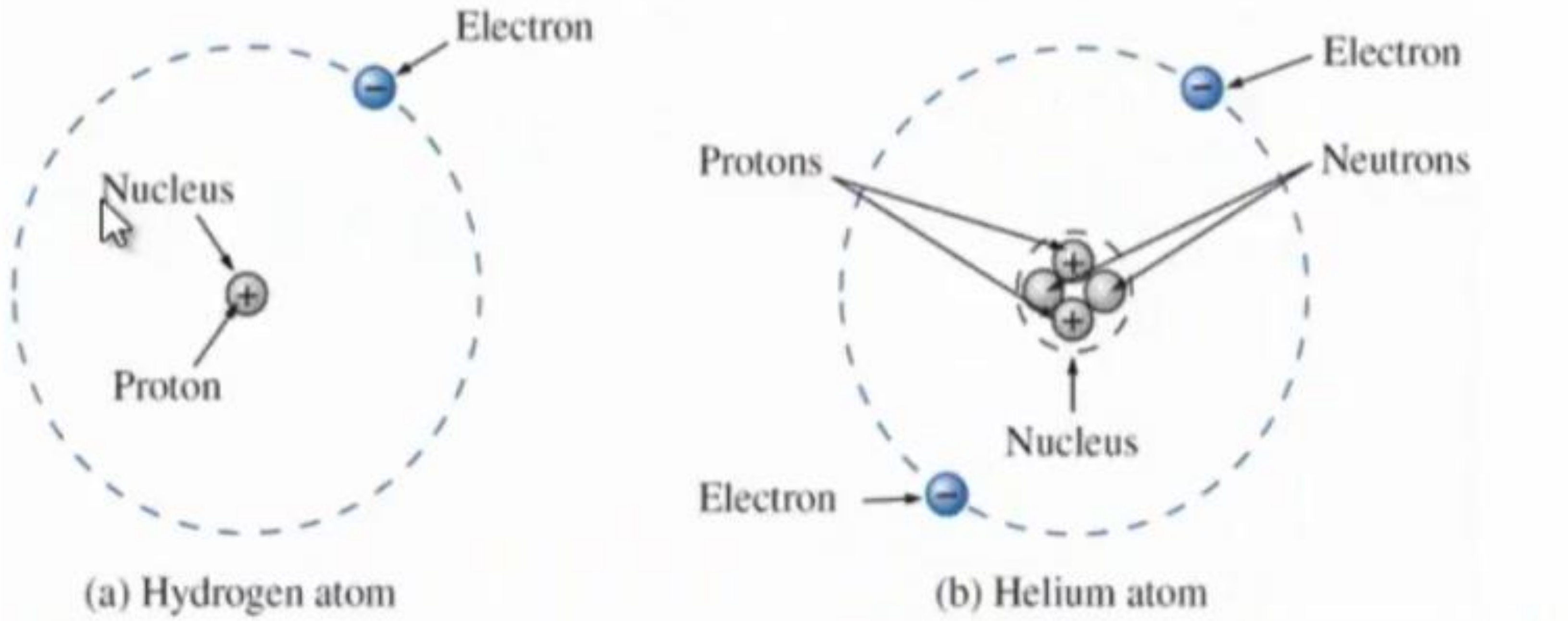


FIG. 2.1 *Hydrogen and helium atoms.*

continue

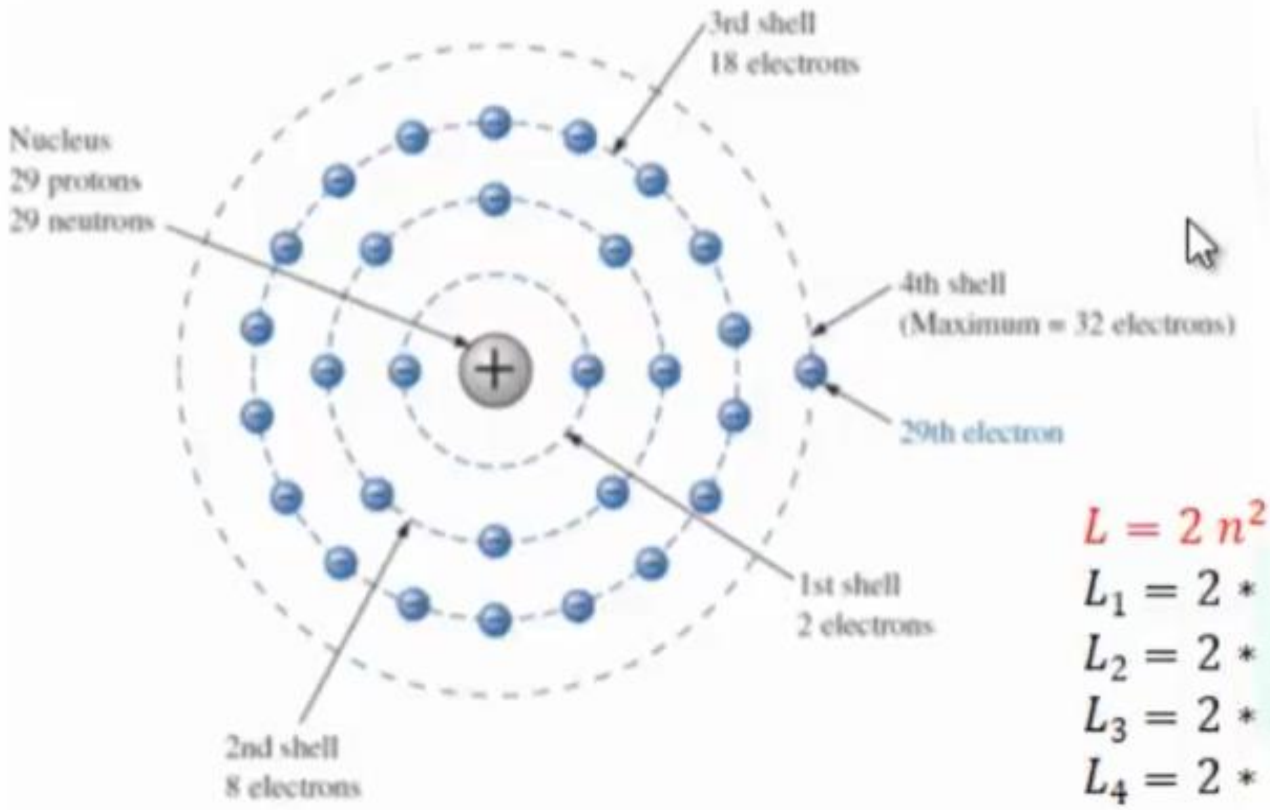
Copper is the most commonly used metal in the electrical/electronics industry.

An examination of its atomic structure will reveal why it has such widespread application.

It has 29 electrons in orbits around the nucleus, with the 29th electron appearing all by itself in the 4^{th} shell.

continue

ATOMS AND THEIR STRUCTURE



$$L = 2\,n^2$$

$$L_1 = 2 * 1^2 = 2$$

$$L_2 = 2 * 2^2 = 8$$

$$L_3 = 2 * 3^2 = 18$$

$$L_4 = 2 * 4^2 = 32$$

FIG. 2.2 *The atomic structure of copper.*

Voltage

VOLTAGE

If we separate the 29th electron in Fig. 2.2 from the rest of the atomic structure of copper by a dashed line as shown in Fig. 2.3 we create regions that have a net positive and negative charge as shown in Fig.

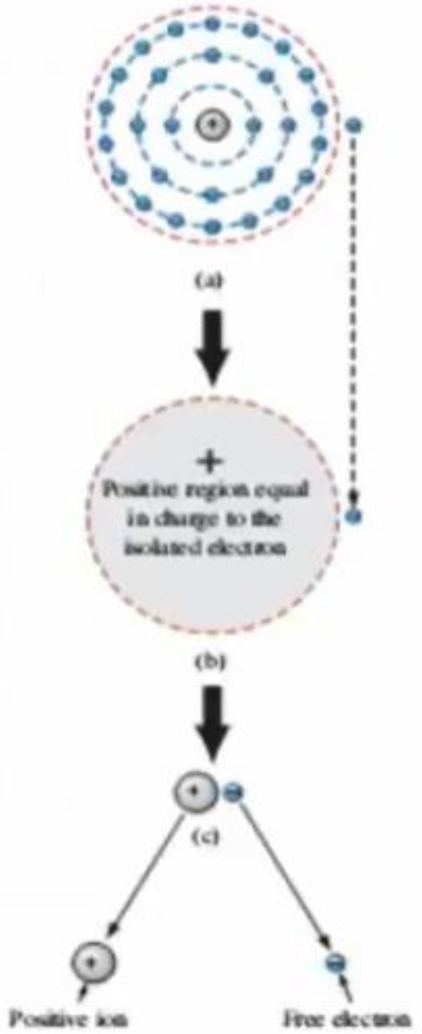


FIG. 2.3 *Defining the positive ion.*

Voltage

VOLTAGE

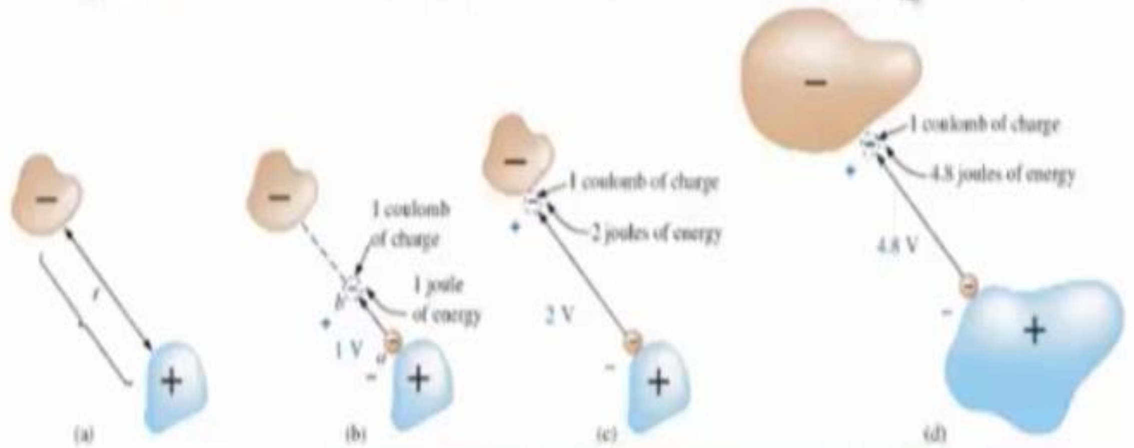
- This positive region created by separating the free electron from the basic atomic structure is called a **positive ion.**

- In general, every source of voltage is established by simply creating a separation of positive and negative charges.

Voltage

VOLTAGE

A potential difference of 1 volt (V) exists between two points if 1 joule (J) o
energy is exchanged in moving 1 coulomb (C) of charge
between the two points.



In general, the potential difference between two points is determined by

$$V = \frac{W}{Q} \quad \text{(volts)}$$

Examples

EXAMPLE 2.3 Find the potential difference between two points in an electrical system if 60 J of energy are expended by a charge of 20 C between these two points.

Solution: Eq. (2.6):

$$V = \frac{W}{Q} = \frac{60\ \text{J}}{20\ \text{C}} = \mathbf{3\ V}$$

EXAMPLE 2.4 Determine the energy expended moving a charge of 50 μC through a potential difference of 6 V.

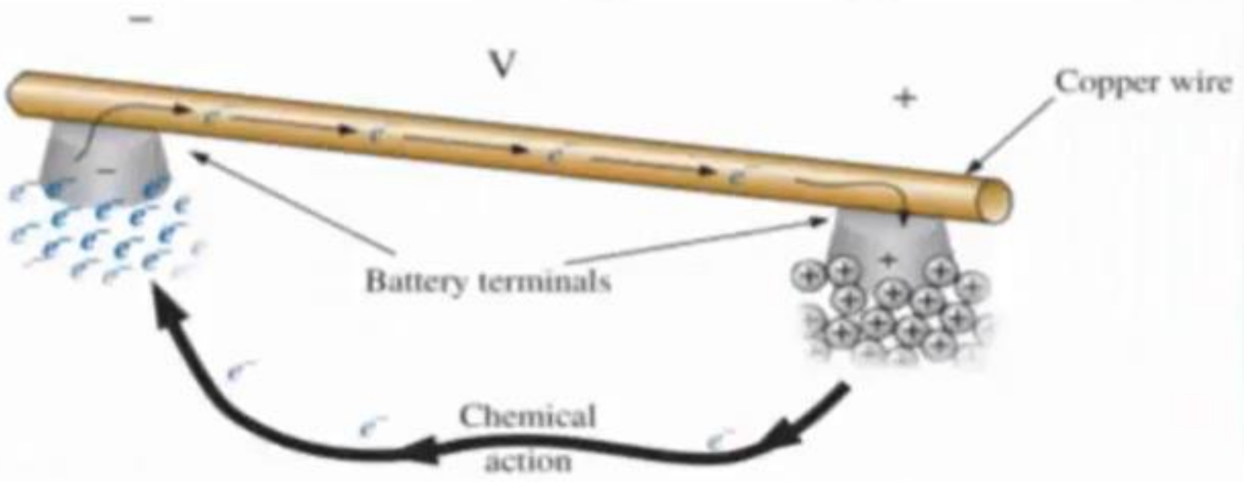
Solution: Eq. (2.7):

$$W = QV = (50 \times 10^{-6}\ \text{C})(6\ \text{V}) = 300 \times 10^{-6}\ \text{J} = \mathbf{300\ \mu J}$$

Current

CURRENT

The applied voltage is the starting mechanism the current is a reaction to the applied voltage.

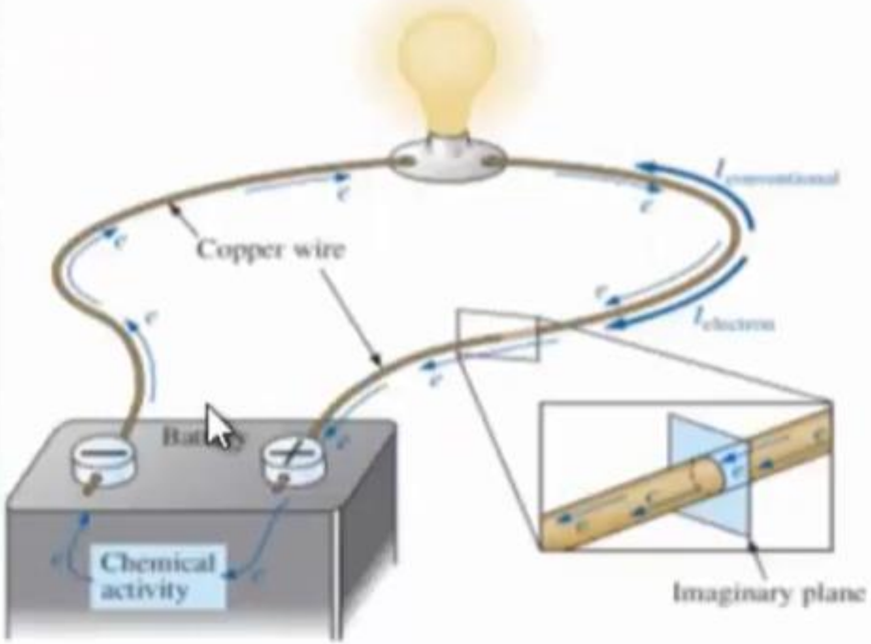


Motion of negatively charged electrons in a copper wire when placed across battery terminals with a difference in potential of volts (V).

Current

CURRENT

If 6.24×10^{18} electrons pass through the imaginary plane in fig 2.6 in 1 second, the flow of charge, or current, is said to be 1 ampere(A)



Basic electric circuit.

continue

CURRENT

The current in amperes can now be calculated using the following equation:

$$I = \frac{Q}{t}$$

I = amperes (A)
Q = coulombs (C)
t = seconds (s)

The unit of current measurement, **ampere**, was chosen to honor the efforts of André Ampère in the study of electricity in motion.

Examples

CURRENT

EXAMPLE 3 The charge flowing through the imaginary surface in Fig. 9 is 0.16 C every 64 ms. Determine the current in amperes.

Solution: Eq. (5):

$$I = \frac{Q}{t} = \frac{0.16\ \text{C}}{64 \times 10^{-3}\text{s}} = \frac{160 \times 10^{-3}\ \text{C}}{64 \times 10^{-3}\ \text{s}} = \mathbf{2.50\,A}$$

EXAMPLE 4 Determine how long it will take 4×10^{16} electrons to pass through the imaginary surface in Fig. 9 if the current is 5 mA.

Solution: Determine the charge in coulombs:

$$4 \times 10^{16}\ \cancel{\text{electrons}}\left(\frac{1\ \text{C}}{6.242 \times 10^{18}\ \cancel{\text{electrons}}}\right) = 0.641 \times 10^{-2}\ \text{C}$$

$$= 6.41\ \text{mC}$$

Eq. (7): $$t = \frac{Q}{I} = \frac{6.41 \times 10^{-3}\ \text{C}}{5 \times 10^{-3}\text{A}} = \mathbf{1.28\ s}$$

Voltage sources

VOLTAGE SOURCES

The term **dc,** used throughout this text, is an abbreviation for **direct current,** which encompasses all systems where there is a unidirectional (one direction) flow of charge.

Standard symbol for a dc voltage source.

continue

VOLTAGE SOURCES

In general, DC voltage sources can be divided into three basic types:

- Batteries (chemical action or solar energy)
- Generators (electromechanical)
- Power supplies (rectification a conversion process to be described in your electronics courses).

continue

Electric Circuits Analysis

VOLTAGE SOURCES

Batteries

FIG. 2.10 *Lithium primary batteries.*

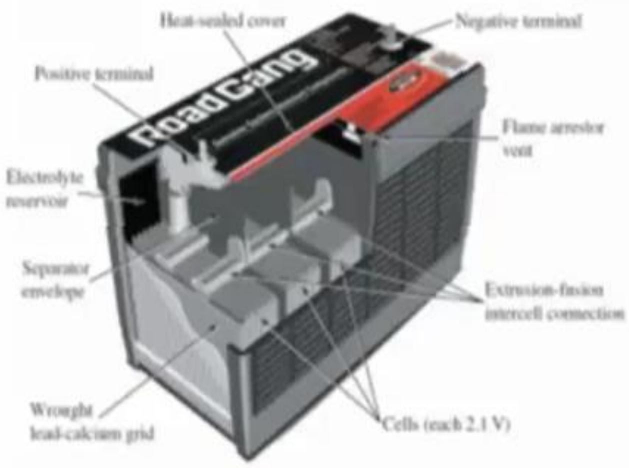


FIG. 2.8: *12 V (actually 12.6 V) lead-acid battery.*

FIG. 2.9 *Nickel–metal hydride (NiMH) rechargeable batteries.*

continue

Electric Circuits Analysis

VOLTAGE SOURCES

FIG. 2.11 *Solar System: (a) panels on roof of garage; (b) system operation.*

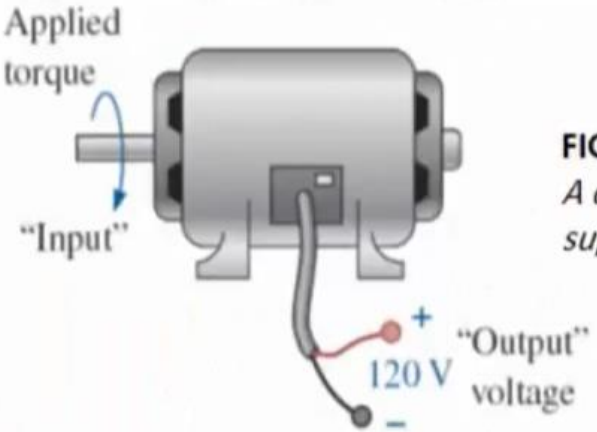


FIG. 2.12 *dc generator.*

FIG. 2.13 *A 0 V to 60 V, 0 to 1.5 A digital display dc power supply*

Ammeters and Voltages

AMMETERS AND VOLTMETERS

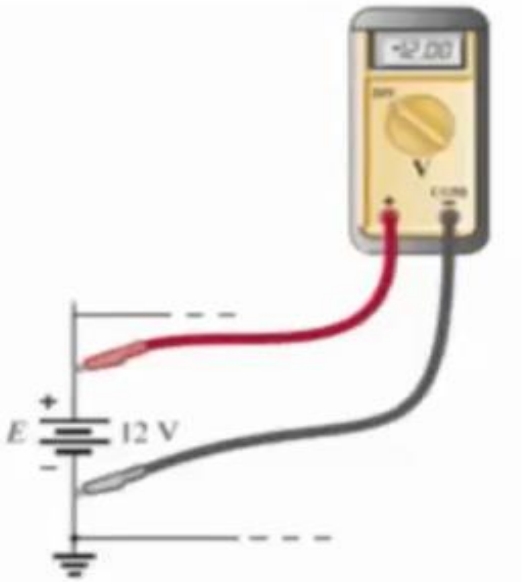


FIG. 2.14 *Voltmeter connection for an up-scale (+) reading.*

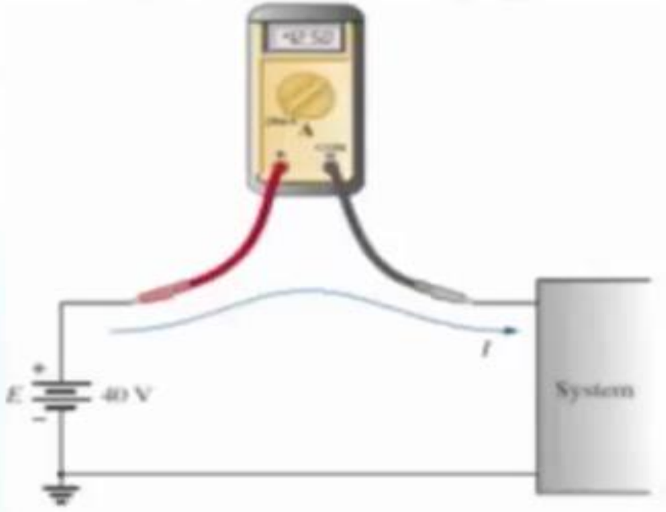


FIG. 2.15 *Ammeter connection for an up-scale (+) reading.*

Ohm's law

INTRODUCTION

Ohm's Law is The first equation to be described is without question one of the most important to be learned in this field. It is not particularly difficult mathematically, but it is very powerful because it can be applied to any network in any time frame. That is, it is applicable to dc circuits, ac circuits, digital and microwave circuits, and, in fact, any type of applied signal.

continue

OHM'S LAW

$$I = \frac{E}{R}$$ (amperes, A)

$$E = IR$$ (volts, V)

$$R = \frac{E}{I}$$ (ohms, Ω)

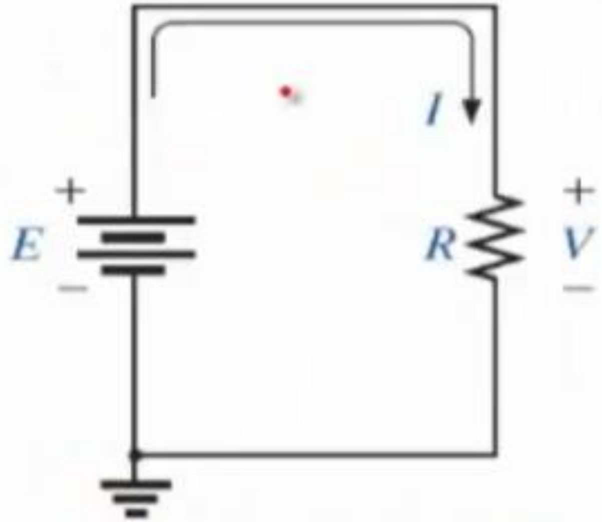


FIG. 4.1 *Basic circuit.*

continue

<u>Voltage polarity</u>

OHM'S LAW

For any resistor, in any network, the direction of current through a resistor will define the polarity of the voltage drop across the resistor

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

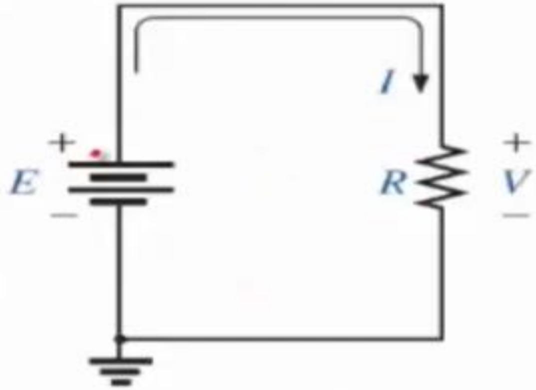


FIG. 4.1 *Basic circuit.*

FIG. 4.2 *Defining polarities.*

Examples

OHM'S LAW

EXAMPLE 1 Determine the current resulting from the application of a 9 V battery across a network with a resistance of 2.2 Ω.

Solution: Eq. (2):

$$I = \frac{V_R}{R} = \frac{E}{R} = \frac{9\text{ V}}{2.2\ \Omega} = \mathbf{4.09\ A}$$

EXAMPLE 2 Calculate the resistance of a 60 W bulb if a current of 500 mA results from an applied voltage of 120 V.

Solution: Eq. (4):

$$R = \frac{V_R}{I} = \frac{E}{I} = \frac{120\text{ V}}{500 \times 10^{-3}\text{ A}} = \mathbf{240\ \Omega}$$

Examples

OHM'S LAW

EXAMPLE 3 Calculate the current through the 2 kΩ resistor in Fig. 4 if the voltage drop across it is 16 V.

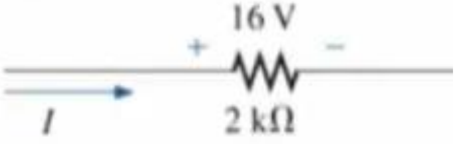


FIG. 4
Example 3.

Solution:

$$I = \frac{V}{R} = \frac{16\text{ V}}{2 \times 10^3\ \Omega} = \mathbf{8\ mA}$$

EXAMPLE 4 Calculate the voltage that must be applied across the dering iron in Fig. 5 to establish a current of 1.5 A through the iron i internal resistance is 80 Ω.

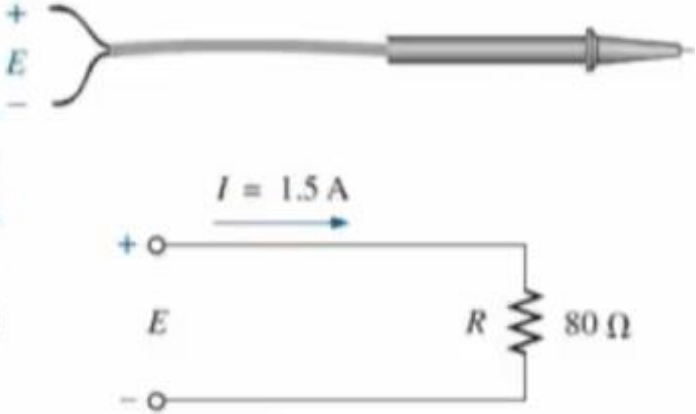


FIG. 5

Solution:

$$E = V_R = IR = (1.5\text{ A})(80\ \Omega) = \mathbf{120\ V}$$

Plotting ohm's law

PLOTTING OHM'S LAW

- Graphs, characteristics, plots, and the like play an important role in every technical field as modes through which the broad picture of the behavior or response of a system can be conveniently displayed.

- It is therefore critical to develop the skills necessary both to read data and to plot them in such a manner that they can be interpreted easily.

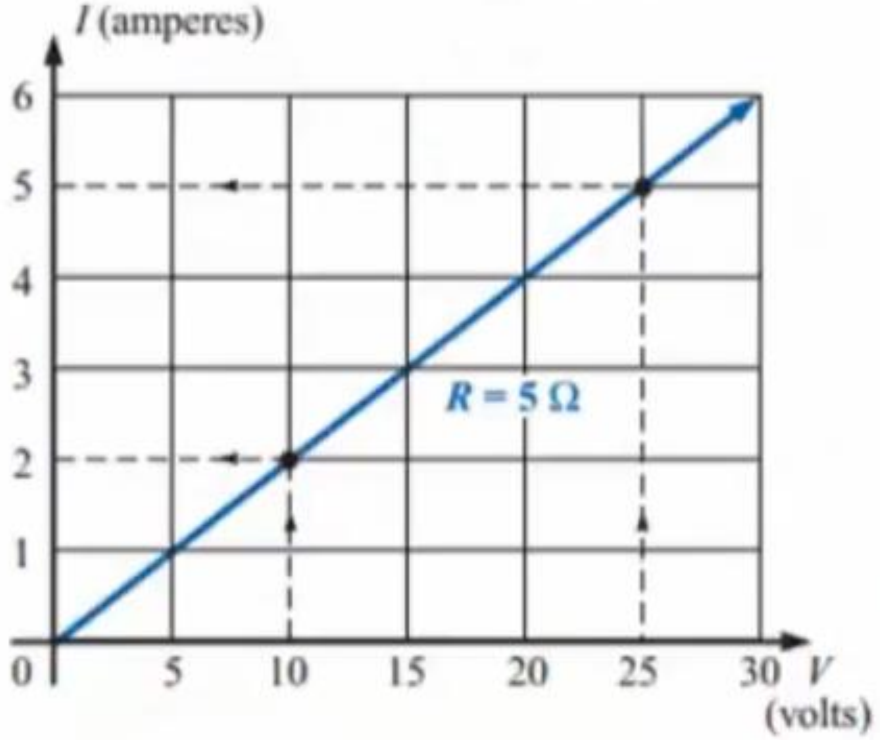
continue

PLOTTING OHM'S LAW

$$I = \frac{1}{R} \cdot E + 0$$

$$\downarrow \quad \downarrow \quad \downarrow \quad \downarrow$$

$$y = m \cdot x + b$$



Plotting Ohm's Law

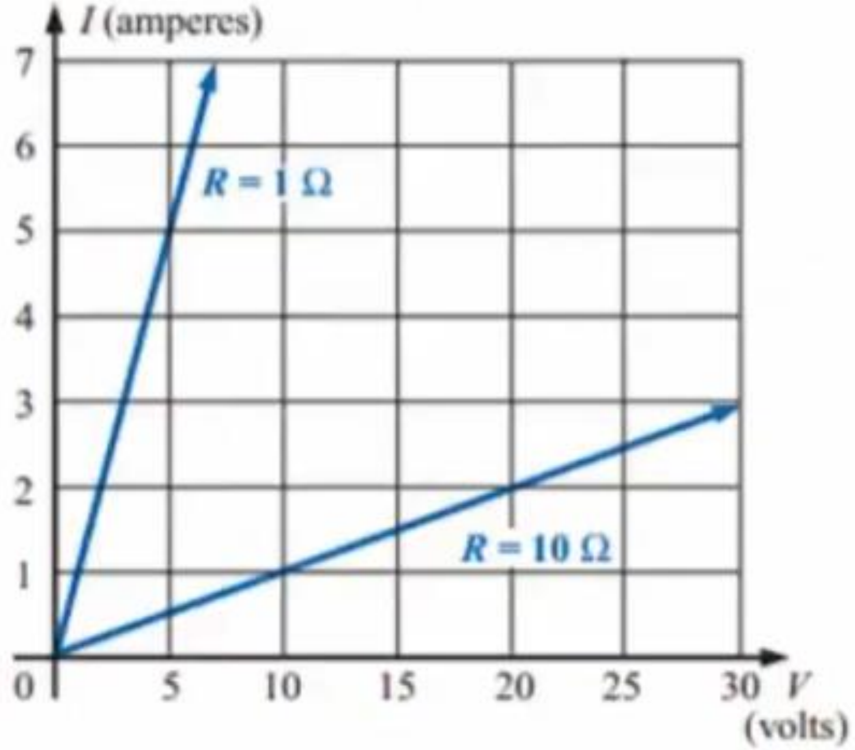
continue

PLOTTING OHM'S LAW

$$I = \frac{1}{R} \cdot E + 0$$

$$\downarrow \quad \downarrow \quad \downarrow \quad \downarrow$$

$$y = m \cdot x + b$$



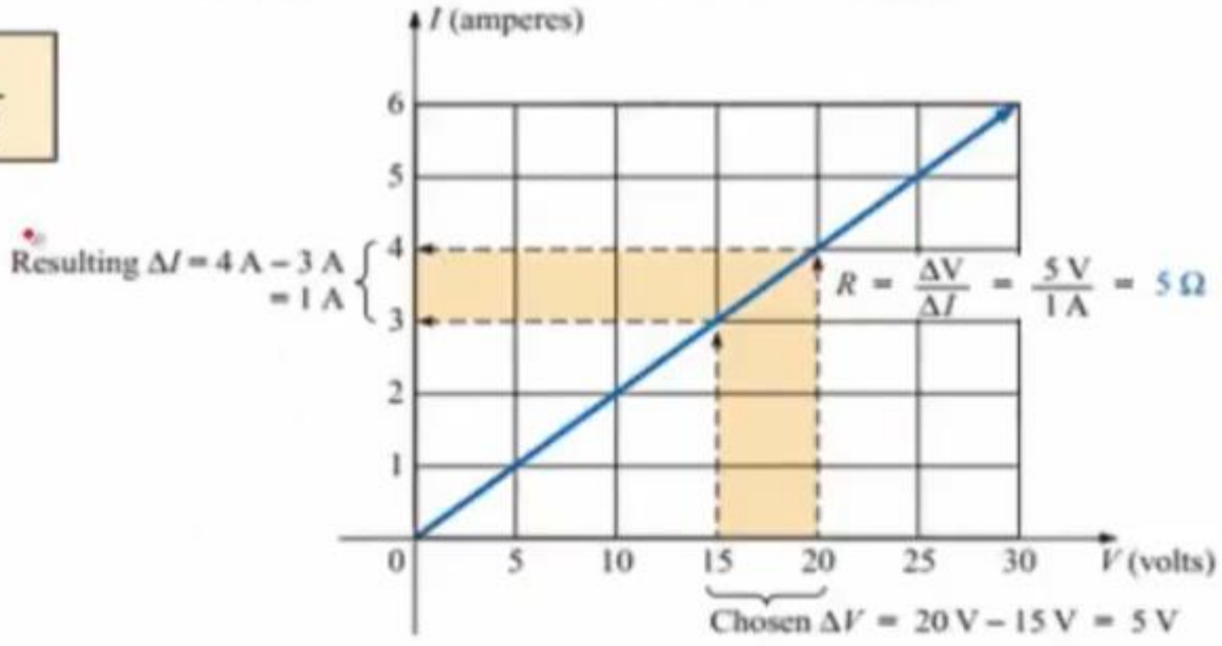
Demonstrating on an I-V plot that the lower the resistance, the steeper is the slope.

Continue

PLOTTING OHM'S LAW

$$m = \text{slope} = \frac{\Delta y}{\Delta x} = \frac{\Delta I}{\Delta V} = \frac{1}{R}$$

$$R = \frac{\Delta V}{\Delta I} \quad \text{(ohms)}$$



Apply OHM'S LAW to calculate unknown resistance

Continue

PLOTTING OHM'S LAW

EXAMPLE 4.5 Determine the resistance associated with the curve of Fig. 4.9 using Eqs. (4.5) and (4.7), and compare results.

Solution: At $V = 6$ V, $I = 3$ mA, and

$$R_{dc} = \frac{V}{I} = \frac{6\text{ V}}{3\text{ mA}} = \mathbf{2\ k\Omega}$$

For the interval between 6 V and 8 V,

$$R = \frac{\Delta V}{\Delta I} = \frac{2\text{ V}}{1\text{ mA}} = \mathbf{2\ k\Omega}$$

The results are equivalent.

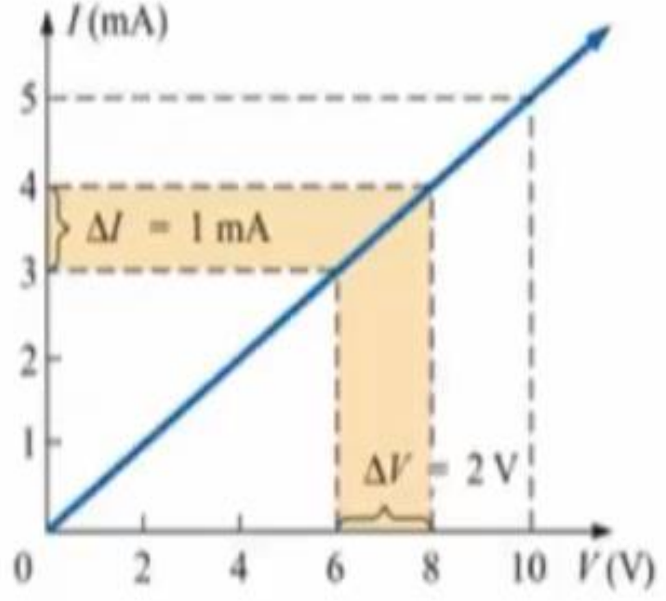


FIG. 4.9
Example 4.5.

power

POWER

- In general, *the term power is applied to provide an indication of how much work (energy conversion) can be accomplished in a specified amount of time; that is, power is a rate of doing work.*

$$1 \text{ watt (W)} = 1 \text{ joule/second (J/s)}$$

In equation form, power is determined by

$$P = \frac{W}{t} \quad \text{(watts, W, or joules/second, J/s)}$$

continue

POWER

$$P = \frac{W}{t}$$ (watts, W, or joules/second, J/s)

- Since energy is measured in joules (J) and time in seconds (s), power is measured in joules/second (J/s).
- The electrical unit of measurement for power is the watt (W), defined by:

$$1 \text{ watt (W)} = 1 \text{ joule/second (J/s)}$$

continue

POWER

$$P = \frac{W}{t} = \frac{QV}{t} = V\frac{Q}{t}$$

$$I = \frac{Q}{t}$$

$$\boxed{P = VI} \quad \text{(watts, W)}$$

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

$$\boxed{P = \frac{V^2}{R}} \quad \text{(watts, W)}$$

$$P = VI = (IR)I$$

$$\boxed{P = I^2R} \quad \text{(watts)}$$

The magnitude of the power delivered or absorbed by a battery is given by :

$$\boxed{P = EI} \quad \text{(watts)}$$

Examples

POWER

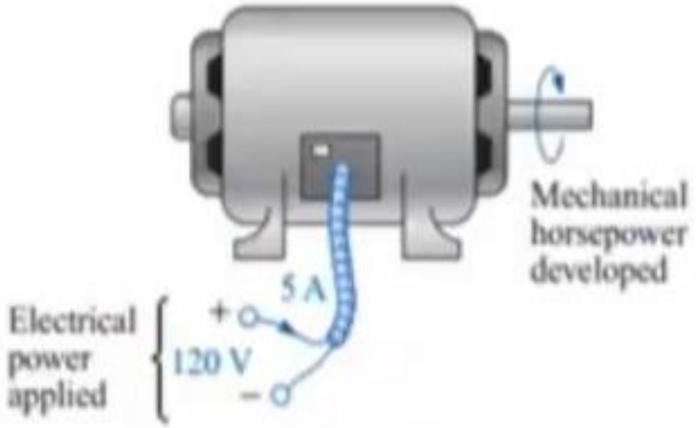


FIG. 4.14
Example 4.6.

EXAMPLE 4.6 Find the power delivered to the dc motor of Fig. 4.14.

Solution:

$$P = VI = (120\text{ V})(5\text{ A}) = 600\text{ W} = \mathbf{0.6\ kW}$$

EXAMPLE 4.7 What is the power dissipated by a 5-Ω resistor if the current is 4 A?

Solution:

$$P = I^2R = (4\text{ A})^2(5\ \Omega) = \mathbf{80\ W}$$

Energy

5 ENERGY

For power, which is the rate of doing work, to produce an energy conversion of any form, it must be *used over a period of time.* For example, a motor may have the horsepower to run a heavy load, but unless the motor is *used* over a period of time, there will be no energy conversion. In addition, the longer the motor is used to drive the load, the greater will be the energy expended.

The **energy** (W) lost or gained by any system is therefore determined by

$$W = Pt \quad \text{(wattseconds, Ws, or joules)} \tag{16}$$

continue

Since power is measured in watts (or joules per second) and time in seconds, the unit of energy is the *wattsecond* or *joule* (note Fig. 15). The wattsecond, however, is too small a quantity for most practical purposes, so the *watthour* (Wh) and the *kilowatthour* (kWh) are defined, as follows:

$$\text{Energy (Wh)} = \text{power (W)} \times \text{time (h)} \qquad \textbf{(17)}$$

$$\text{Energy (kWh)} = \frac{\text{power (W)} \times \text{time (h)}}{1000} \qquad \textbf{(18)}$$

Note that the energy in kilowatthours is simply the energy in watthours divided by 1000. To develop some sense for the kilowatthour energy level, consider that *1 kWh is the energy dissipated by a 100 W bulb in 10 h.*

Examples

EXAMPLE 11 How much energy (in kilowatthours) is required to light a 60 W bulb continuously for 1 year (365 days)?

Solution:

$$W = \frac{Pt}{1000} = \frac{(60\text{ W})(24\text{ h/day})(365\text{ days})}{1000} = \frac{525{,}600\text{ Wh}}{1000}$$
$$= \mathbf{525.60\ kWh}$$

EXAMPLE 12 How long can a 340 W plasma TV be on before it uses more than 4 kWh of energy?

Solution:

$$W = \frac{Pt}{1000} \Rightarrow t\text{ (hours)} = \frac{(W)(1000)}{P} = \frac{(4\text{ kWh})(1000)}{340\text{ W}} = \mathbf{11.76\ h}$$

EXAMPLE 13 What is the cost of using a 5 hp motor for 2 h if the rate is 11¢ per kilowatthour?

Solution:

$$W\text{ (kilowatthours)} = \frac{Pt}{1000} = \frac{(5\text{ hp} \times 746\text{ W/hp})(2\text{ h})}{1000} = 7.46\text{ kWh}$$
$$\text{Cost} = (7.46\text{ kWh})(11¢/\text{kWh}) = \mathbf{82.06¢}$$

Conclusion

OHM'S LAW

Conclusion

This chapter reveals how the three important quantities of an electric circuit are interrelated. The most important equation in the study of electric circuits is introduced, and various other equations that allow us to find power and energy levels are discussed in detail. It is the chapter where we tie things together and develop a feeling for the way an electric circuit behaves and what affects its response.