Chapter 2

Voltage, Current, and Resistance

Objectives

- Describe the basic structure of an atom
- Explain the concept of electrical charge
- Define *voltage* and discuss its characteristics
- Define *current* and discuss its characteristics
- Define *resistance* and discuss its characteristics
- Describe a basic electric circuit
- Make basic circuit measurements

Atomic Structure

- An atom is the smallest particle of an element that retains the characteristics of that element
- An atom has a **nucleus**, consisting of positively charged particles called **protons**, and uncharged particles called **neutrons**
- The basic particles of negative charge, called **electrons**, orbit the nucleus

Electron shells and Orbits

- Electrons orbit the nucleus at discrete distances from the nucleus
- Orbits are grouped onto energy bands known as **shells**
- A given atom has a fixed number of shells
- Each shell has a fixed maximum number of electrons permissible at energy levels (orbits)

Valence Electrons

- Electrons with the highest energy exist in the outermost shell, known as the **valence** shell, and electrons in this shell are called **valence electrons**
- Valence electrons possess more energy and are relatively loosely bound to the atom
- If a valence electron acquires enough external energy to leave the atom, the process is known as **ionization**
- The escaped electron is called a **free electron**

Categories of Materials

- Conductors readily permit current flow, due to a large number of free electrons in the material
  - Conductors are characterized by 1, 2, or 3 valence electrons in their atomic structure
- Semiconductors have 4 valence electrons
- Insulators have few free electrons, and tend not to permit current to flow through them

Electrical Charge

- The charge of an electron and that of a proton are equal in magnitude but opposite in polarity
- The force acting between charges is called an electric field

Coulomb

- Electrical charge (Q) is measured in **coulombs** (C)
- By definition:

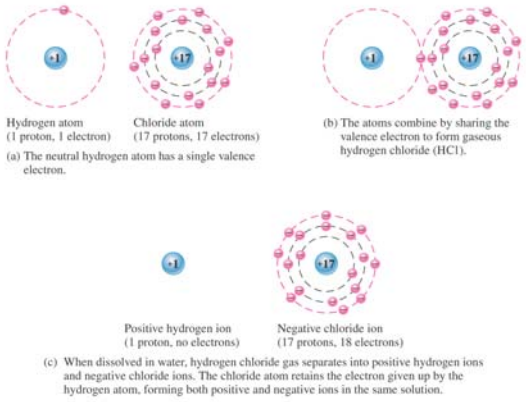
One coulomb is the total charge possessed by 6.25×10^{18} electrons

$Q = (\text{number of electrons})/(6.25 \times 10^{18})$

Positive and Negative Charge

- A neutral atom has the same number of electrons and protons, hence no net charge
- If a valence electron acquires enough energy to move away from an atom, the atom is left with a net positive charge (positive ion)
- If an atom acquires an extra electron in its outer shell, it has a net negative charge (negative ion)

Formation of positive and negative ions



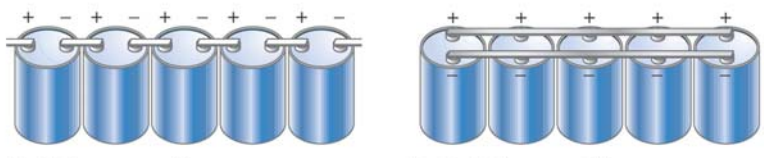
Voltage

- The unit of voltage is the **volt** (V)
- By definition:

One volt is the potential difference (voltage) between two points when one joule of energy is used to move one coulomb of charge from one point to the other

Batteries

- A battery is a type of voltage source that converts chemical energy into electrical energy
- The way cells are connected, and the type of cells, determines the voltage and capacity of a battery



(a) Series-connected battery (b) Parallel-connected battery

Other Voltage Sources

- Solar Cells convert light energy into electrical energy
- Generators convert mechanical energy into electrical energy
- Electronic power supplies do not produce electrical energy, but they convert the ac voltage from the wall outlet into a constant dc voltage for use in our circuits

Current

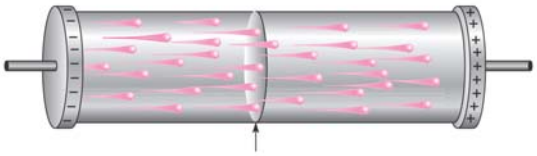
- The movement of free electrons from negative to positive is electrical **current** (I)
- By definition:

electrical current is the rate of flow of charge

$$\mathbf{I = Q/t}$$

Ampere: The Unit of Current

- One ampere is the amount of current that exists when a number of electrons having a total charge of one coulomb move through a given cross-sectional area in one second



When a number of electrons having 1 coulomb of charge pass through this cross-sectional area in 1 second, there is 1 ampere of current.

Resistance

- The property of a material that restricts the flow of electrons is called **resistance** (R)
- By definition:

  Resistance is the opposition to current

- Where there is current through any material that has resistance, heat is produced by the collisions of electrons and atoms

Ohm: The unit of Resistance

- **By definition:**

One ohm of resistance exists if there is one ampere of current in a material when one volt is applied across the material

The symbol of an ohm is omega (Ω)

Conductance

- Conductance (G) is the reciprocal of resistance:

$$G = 1/R$$

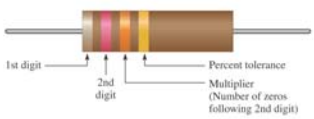
- The unit of conductance is **siemens** (S)

Resistors

- Resistors are used to limit current or divide voltage, and in some cases, generate heat
- Common resistors are carbon-composition, carbon film, metal film, and wirewound
  - surface mount resistors are available as small resistor chips
  - wirewound resistors are used where high power ratings are required

Color-code bands on a resistor

- 1st band is the first digit of the resistance value
- 2nd band is the second digit of the resistance value
- 3rd band is the multiplier (number of zeros)
- 4th band indicates the tolerance



Resistor color code

	Digit	Color
Resistance value, first three bands: First band—1st digit Second band—2nd digit *Third band—multiplier (number of zeros following the 2nd digit)	0	Black
	1	Brown
	2	Red
	3	Orange
	4	Yellow
	5	Green
	6	Blue
	7	Violet
	8	Gray
	9	White
Fourth band—tolerance	±5%	Gold
	±10%	Silver
	±20%	No band

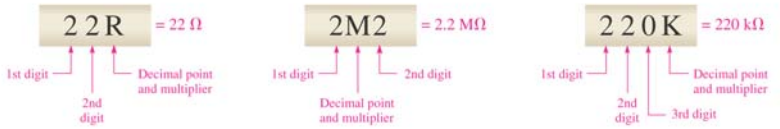
* For resistance values less than 10 Ω, the third band is either gold or silver. Gold is for a multiplier of 0.1 and silver is for a multiplier of 0.01.

Precision Resistors

- Precision resistor values are identified with 5 color bands, the first 3 bands indicate resistance value, the 4th band is the multiplier, and the 5th band indicates the tolerance
- Precision resistors will have a tolerance of 2%, 1%, 0.5%, 0.25% or 0.1%

Alphanumeric Labeling

- Two or three digits, and one of the letters **R**, **K**, or **M** are used to identify a resistance value
- The letter is used to indicate the multiplier, and its position is used to indicate decimal point position



Variable Resistors

- Variable resistors are designed so that their resistance values can be changed with manual or automatic adjustment
- A **potentiometer** is a variable resistor used to divide voltage
- A **rheostat** is a variable resistor used to control current

The Basic Circuit

- An electric **circuit** consists of a voltage source, a load, and a path for current between the source and the load
- A **closed circuit** is one in which the current has a complete path
- An **open circuit** is one in which the current path is broken, or incomplete

Ground

- **Ground** is the reference point in electric circuits and has a potential of 0 V with respect to other points in the circuit
- All ground points in a circuit are electrically the same and are therefore common points

(a) (b)

Basic Circuit Measurements

- A voltmeter measures voltage across (in parallel) a resistance or load
- An ammeter is inserted in the current path (in series) to measure current
- Resistance is measured across a resistor, out-of-circuit, with an ohmmeter
- Digital Multimeters (DMM's) measure voltage, current and resistance

Summary

- An atom is the smallest particle of an element that retains the characteristics of that element
- Free electrons make current possible
- Like charges repel, opposite charges attract
- One coulomb is the charge of 6.25×10^{18} electrons
- One volt is the potential difference between two points when one joule of energy is used to move one coulomb from one point to the other

Summary

- Voltage must be applied to a circuit to produce current
- One ampere is the amount of current that exists when one coulomb of charge moves through a given cross-sectional area in one second
- Resistance limits current
- One ohm is the resistance when there is one ampere of current in a material with one volt applied across the material

Summary

- An electric circuit consists of a source, a load, and a current path
- An open circuit has an incomplete current path
- A closed circuit has a complete current path
- An ammeter is connected in line with the current path
- A voltmeter is connected across the current path
- An ohmmeter is connected across a resistor (the resistor must be out-of-circuit)