Chapter 1: Electricity

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Polarity

- Two components of an electric charge in an atom are a
  - Proton – [+ charge
  - Electron – [- charge
- Normally in an atom the net charge is neutral
  - Balance of [+ and [- charges
Basic Structure of an Atom

Figure 1–2  Electron and proton in hydrogen (H) atom.
Conductors

- Electrons move easily from one atom to another
- Most metals are conductors
- Examples: Copper, silver, gold
Insulators

- Electrons stay in their orbits
- Inhibit the sharing of electrons
- Do not easily conduct electricity
- Can also store an electrical charge
  - Dielectric
Electrical Charge
Electrical Charge

- Imbalance in a substance between the number of protons and electrons
- Known as *static electricity*
  - Protons and electrons are not in motion
- Caused by an external force
  - Example: Rubbing silk cloth on glass
Basic Unit of a Charge

- Coulomb [C]
- \(6.25 \times 10^{18}\) electrons or protons which are stored in a dielectric
- Symbols for electric charge is \(Q\) or \(q\)
Coulomb of Charge
Polarity

- **Negative charge** – excess of electrons
  - Examples: rubber and amber
- **Positive charge** – excess of protons
  - Examples: glass
Attraction & Repulsion

Figure 1–5  Physical force between electric charges. (a) Opposite charges attract. (b) Two negative charges repel each other. (c) Two positive charges repel.
Elements

- **Element** – a substance that cannot be decomposed further by chemical means
- **Atom** is the smallest particle of an element
# Examples of Elements

<table>
<thead>
<tr>
<th>Group</th>
<th>Element</th>
<th>Symbol</th>
<th>Atomic Number</th>
<th>Electron Valence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal conductors, in order of conductance</td>
<td>Silver</td>
<td>Ag</td>
<td>47</td>
<td>+1</td>
</tr>
<tr>
<td></td>
<td>Copper</td>
<td>Cu</td>
<td>29</td>
<td>+1*</td>
</tr>
<tr>
<td></td>
<td>Gold</td>
<td>Au</td>
<td>79</td>
<td>+1*</td>
</tr>
<tr>
<td></td>
<td>Aluminum</td>
<td>Al</td>
<td>13</td>
<td>+3</td>
</tr>
<tr>
<td></td>
<td>Iron</td>
<td>Fe</td>
<td>26</td>
<td>+2*</td>
</tr>
<tr>
<td>Semiconductors</td>
<td>Carbon</td>
<td>C</td>
<td>6</td>
<td>±4</td>
</tr>
<tr>
<td></td>
<td>Silicon</td>
<td>Si</td>
<td>14</td>
<td>±4</td>
</tr>
<tr>
<td></td>
<td>Germanium</td>
<td>Ge</td>
<td>32</td>
<td>±4</td>
</tr>
<tr>
<td>Active gases</td>
<td>Hydrogen</td>
<td>H</td>
<td>1</td>
<td>±1</td>
</tr>
<tr>
<td></td>
<td>Oxygen</td>
<td>O</td>
<td>8</td>
<td>−2</td>
</tr>
<tr>
<td>Inert gases</td>
<td>Helium</td>
<td>He</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Neon</td>
<td>Ne</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>
Molecules

- Combination of atoms which are chemically bonded together
- Example is water (H₂O)
  - 2 atoms of hydrogen
  - 1 atom of oxygen
Structure of an Atom
Atomic Number

- Number of protons and electrons
- Copper atom has an atomic number of 29
  - 29 protons
  - 29 electrons
Orbital Rings

- Orbits of electrons are layers in discrete rings or shells
- Each shell is required to have a certain number of electrons in order to be stable
Basic Structure of an Atom

Figure 1-3  Atomic structure showing the nucleus and its orbital rings of electrons. (a) Carbon (C) atom has six orbital electrons to balance six protons in nucleus. (b) Copper (Cu) atom has 29 protons in nucleus and 29 orbital electrons.
## Shells of Orbital Electrons

<table>
<thead>
<tr>
<th>Shell</th>
<th>Maximum Electrons</th>
<th>Inert Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>2</td>
<td>Helium</td>
</tr>
<tr>
<td>L</td>
<td>8</td>
<td>Neon</td>
</tr>
<tr>
<td>M</td>
<td>8 (up to calcium) or 18</td>
<td>Argon</td>
</tr>
<tr>
<td>N</td>
<td>8, 18, or 32</td>
<td>Krypton</td>
</tr>
<tr>
<td>O</td>
<td>8 or 18</td>
<td>Xenon</td>
</tr>
<tr>
<td>P</td>
<td>8 or 18</td>
<td>Radon</td>
</tr>
<tr>
<td>Q</td>
<td>8</td>
<td></td>
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Electron Valence

- Number of electrons in the outermost shell
- A competed outer shell has a valence of 0
- Indicates how easily atoms can lose or gain electrons
Electron Valence

- Atoms with a valence of +1 can lose an electron to atoms which need an atom to complete the outer valence shell
  - Copper valence is +7 or –1
  - Carbon valence is +4 or –4
  - Inert gases have a valence of 0
## Electron Valence Table

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Particles in Nucleus

- Protons – [+ ] charge
- Neutrons – neutral charge
- In a stable state the number of protons = the number of electrons in an atom
## Atomic Particle Properties

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<tr>
<th>Particle</th>
<th>Charge</th>
<th>Mass</th>
</tr>
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<tbody>
<tr>
<td>Electron, in orbital shells</td>
<td>$0.16 \times 10^{-18}$ C, negative</td>
<td>$9.108 \times 10^{-28}$ g</td>
</tr>
<tr>
<td>Proton, in nucleus</td>
<td>$0.16 \times 10^{-18}$ C, positive</td>
<td>$1.672 \times 10^{-24}$ g</td>
</tr>
<tr>
<td>Neutron, in nucleus</td>
<td>None</td>
<td>$1.675 \times 10^{-24}$ g</td>
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</table>
Electrical Units of Measure
Charge

- **Coulomb** = $6.25 \times 10^{18}$ electrons
  - Abbreviation is **C**
- Use the letter **Q** or **q** for electric charge
- $-$ **Q** is a negative charge
- $+$ **Q** is a positive charge
Example 1-2

A dielectric has a positive charge of $12.5 \times 10^{18}$ protons. What is its charge in coulombs?

**ANSWER** This is the same amount of charge as in Example 1 but positive. Therefore $+Q = 2 \text{ C.}$
Example #2

Example 1-3
A dielectric with $+Q$ of 2 C has $12.5 \times 10^{18}$ electrons added. What is its charge then?

**Answer** The 2 C of negative charge added by the electrons cancels the 2 C of positive charge, making the dielectric neutral, for $Q = 0$. 
Another Example

**Example 1-4**

A neutral dielectric has $12.5 \times 10^{18}$ electrons removed. What is its charge?

**ANSWER** The $2 \text{ C}$ of electron charge removed allows an excess of $12.5 \times 10^{18}$ protons. Since the proton and electron have exactly the same amount of charge, now the dielectric has a positive charge of $+Q = 2 \text{ C}$. 
Electric Field

- Static charge generates an electric field around it.
- Attract or repel other statically charged particles.
Attraction & Repulsion

Figure 1–5  Physical force between electric charges. (a) Opposite charges attract. (b) Two negative charges repel each other. (c) Two positive charges repel.
Potential Difference

- Potential – possibility of doing work
- Work is produced when two bodies have unbalanced charges
Unbalanced Charges

Figure 1–7  The amount of work required to move electrons between two charges depends on their difference of potential. This potential difference (PD) is equivalent for the examples in (a), (b), and (c).
Definition of a Volt

- Unit of potential difference
- Measure of the amount of energy needed to move a given electric charge
Definition of a Volt

- When 0.7376 ft-lb of work is required to move $6.25 \times 10^{18}$ electrons [1 C] between two points. (English units)
- When 1 Joule of work is required to move $6.25 \times 10^{18}$ electrons [1 C] between two points (Metric Units)
Voltage Source & Symbol
Basic Equation

- \( V = \frac{W}{Q} \)
  - \( V \) - voltage in volts
  - \( W \) – work units in joules
  - \( Q \) – charge in coulombs
Example 1–5

What is the output voltage of a battery that expends 3.6 J of energy in moving 0.5 C of charge?

**ANSWER** Use Equation 1–1.

\[ V = \frac{W}{Q} \]

\[ = \frac{3.6 \text{ J}}{0.5 \text{ C}} \]

\[ = 7.2 \text{ V} \]
Electrical Current

- Movement of electrons from an excess (-) to a (+) point
- Occurs when
  - a charge potential exists
  - material allows the flow of electrons
Electrical Current

Figure 1–9 Potential difference across two ends of wire conductor causes drift of free electrons throughout the wire to produce electric current.

Potential difference = 1.5 V applied voltage
Definition of an Ampere

- Measure of the amount of electrical current flowing
- $6.25 \times 10^{18}$ electrons moving past a given point in one second
- A – abbreviation for ampere
- I – symbol for current
Equation for Current

\[ I = \frac{Q}{t} \]

- **I** – current flow in amperes
- **Q** – Number of electrons in coulombs
- **t** – time interval in seconds
Example 1–6

The charge of 12 C moves past a given point every second. How much is the intensity of charge flow?

**ANSWER**

\[ I = \frac{Q}{T} = \frac{12 \text{ C}}{1 \text{ s}} \]

\[ I = 12 \text{ A} \]
Example 1–7

The charge of 5 C moves past a given point in 1 s. How much is the current?

**ANSWER**

\[ I = \frac{Q}{T} = \frac{5 \text{ C}}{1 \text{ s}} \]

\[ I = 5 \text{ A} \]
Resistance

- Opposition to the flow of electrical current
- Property of the material which conduct the current flow
- Conductors – low resistance
- Insulators – high resistance
Conductor

- Example: Copper
  - Has a lot of free electrons that can be moved easily when a potential difference is applied
Insulator

- Example: Carbon
  - Contain fewer free electrons
  - When a voltage is applied relatively few electrons will flow
Definition of an Ohm

- Unit of resistance
- A resistance that develops 0.24 calories of heat when 1 ampere of current flows through it for 1 second is defined to have a resistance of 1 ohm
Notation for Ohms

- Indicated by the Greek letter *omega* (Ω)
- Symbol for resistance is \( R \)
View of a Resistor

Figure 1–10  (a) Wire-wound type of resistor with cement coating for insulation. (b) Schematic symbol for any type of fixed resistor.
Conductance

- Reciprocal of resistance
- Symbol is for conductance is $G$
- $G = 1/R$
- Unit of measurement is the siemens ($S$)
- (older unit is the mho)
Example 1–8

Calculate the resistance for the following conductance values: (a) 0.05 S (b) 0.1 S

**ANSWER**

(a) \( R = \frac{1}{G} \)

\[ = \frac{1}{0.05 \text{ S}} \]

\[ = 20 \Omega \]

(b) \( R = \frac{1}{G} \)

\[ = \frac{1}{0.1 \text{ S}} \]

\[ = 10 \Omega \]

Notice that a higher value of conductance corresponds to a lower value of resistance.
Example #2

Example 1-9

Calculate the conductance for the following resistance values: (a) 1 kΩ (b) 5 kΩ.

ANSWER

(a) \( G = \frac{1}{R} \)
   \( = \frac{1}{1000 \ \Omega} \)
   \( = 0.001 \text{ S or } 1 \text{ mS} \)

(b) \( G = \frac{1}{R} \)
   \( = \frac{1}{5000 \ \Omega} \)
   \( = 0.0002 \text{ S or } 200 \mu\text{S} \)

Notice that a higher value of resistance corresponds to a lower value of conductance.
Electrical Circuits
Closed Circuit

- Uninterrupted path for electrical current to flow
Criteria for a Closed Circuit

- There must be a voltage source
- The path for current to flow must be complete and uninterrupted
- Current path has resistance which generates heat and/or limits the flow of current
Closed Circuit Example
Closed Circuit Schematic

Voltage source $V = 1.5 \text{ V}$

Resistance load $R = 300 \text{ }\Omega$
Voltage, Current, & Resistance

Figure 1–12 Comparison of voltage (V) across a resistance and the current (I) through R.
Voltage and Current

- In any circuit:
  - Voltage can exist without current
  - Current cannot exist without voltage
Role of the Battery

- The battery is the *source* in the circuit
- Provides the potential energy to be used
Circuit Definitions

- Part circuit connected to the voltage source
- Called the *load resistance*
  - Determines how much energy the source must supply
- *Load Current* – current flow through the load
  - Also known as the *load*. 
Circuit Definitions

- **Open circuit**
  - Incomplete path
  - Infinite resistance
  - Voltage present but no current
Circuit Definitions

- **Short circuit**
  - Source has a close path across its terminals
  - Close to zero resistance
  - Usually bypasses the load resistance
  - Generally hazardous to components & people
Current Direction

- In a closed electrical circuit negative electrons and positive charges move in opposite directions.

- *Electron flow & conventional current*
Electron Flow

- Flow of negative electrons
- Flows from the (-) terminal of the voltage source to the (+) terminal
Electron Flow – Effect of Polarity

(a) Voltage source \( V \), External circuit \( R \)

(c) Voltage source \( V \), External circuit \( R \)
Conventional Current

- Motion of positive charges
- Opposite the flow of electrons
- Used in physics and electrical engineering in circuit analysis
Electron Flow vs. Conventional Current

(a) Electron Flow Current

(b) Conventional Current
Conventional Current Flow – Effect of Polarity

(b)

(d)
Textbook Convention

- In this textbook
  - Electrical current is considered as **electron** flow
    - In applications where electrons are the moving charges
  - The **dashed** arrows in circuit are **electron** flow
  - The **solid** arrows are **conventional** current flow
Mobile Positive Charges

- **Ion**
  - Atom that has gained or lost one or more valence electrons
    - Gains electrons – negative charge
    - Loses electrons – positive charge
Mobile Positive Charge

- **Hole**
  - Exists in semiconductors such as silicon
  - Positive polarity
  - Absence of electrons
Current Flow
Types of Current Flow

- Direct Current (DC)
- Alternating Current (AC)
Direct Current (DC)

- Flows in one direction
- Does not change polarity
- Example: battery
Direct Current & Source
Alternating Current (AC)

- Periodically reverses polarity
- Current changes in direction
- A complete reversal is a *cycle*
  - *Frequency* (1 cycle = 1 Hz)
- US – 60 Hz, Europe – 50 Hz
Alternating Current & Source
Comparison of DC & AC

<table>
<thead>
<tr>
<th>DC Voltage</th>
<th>AC Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed polarity</td>
<td>Reverses in polarity</td>
</tr>
<tr>
<td>Can be steady or vary in magnitude</td>
<td>Varies between reversals in polarity</td>
</tr>
<tr>
<td>Steady value cannot be stepped up or down by a transformer</td>
<td>Can be stepped up or down for electric power distribution</td>
</tr>
<tr>
<td>Terminal voltages for transistor amplifiers</td>
<td>Signal input and output for amplifiers</td>
</tr>
<tr>
<td>Easier to measure</td>
<td>Easier to amplify</td>
</tr>
</tbody>
</table>

Heating effect is the same for direct or alternating current
Sources of Electricity

- Static electricity by friction
- Conversion of chemical energy (battery)
- Electromagnetism (generator)
- Photoelectricity (solar cell)
## Summary Table

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge</td>
<td>$Q$ or $q^*$</td>
<td>Coulomb (C)</td>
<td>Quantity of electrons or protons; $Q = I \times T$</td>
</tr>
<tr>
<td>Current</td>
<td>$I$ or $i^*$</td>
<td>Ampere (A)</td>
<td>Charge in motion; $I = Q/T$</td>
</tr>
<tr>
<td>Voltage</td>
<td>$V$ or $v^{*\dagger}$</td>
<td>Volt (V)</td>
<td>Potential difference between two unlike charges; makes charge move to produce $I$</td>
</tr>
<tr>
<td>Resistance</td>
<td>$R$ or $r^*$</td>
<td>Ohm (Ω)</td>
<td>Opposition that reduces amount of current; $R = 1/G$</td>
</tr>
<tr>
<td>Conductance</td>
<td>$G$ or $g^{\dagger}$</td>
<td>Siemens (S)</td>
<td>Reciprocal of $R$, or $G = 1/R$</td>
</tr>
</tbody>
</table>

* Small letter $q$, $i$, or $v$ is used for an instantaneous value of a varying charge, current, or voltage.

† For $e$ is sometimes used for a generated emf; but the standard symbol for any potential difference is $V$ or $v$ in the international system of units (SI).

‡ Small letter $r$ or $g$ is used for internal resistance or conductance of transistors.