Chapter 1: Electricity

Version 0.5 – 08/30/2010

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

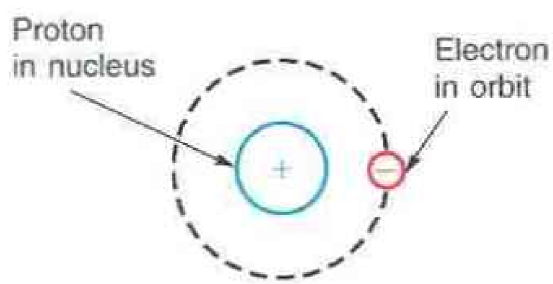


Figure 1–2 Electron and proton in hydrogen (H) atom.

Conductors

- 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

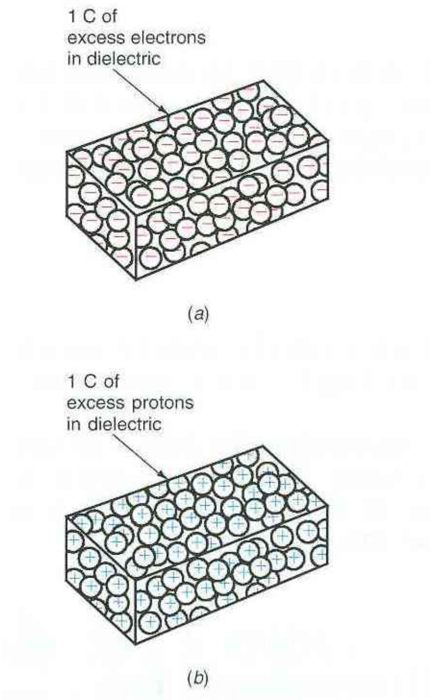
Electrical Charge

- 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**]
- 6.25×10^{18} electrons or protons which are stored in a dielectric
- Symbols for electric charge is ***Q*** or ***q***

Coulomb of Charge

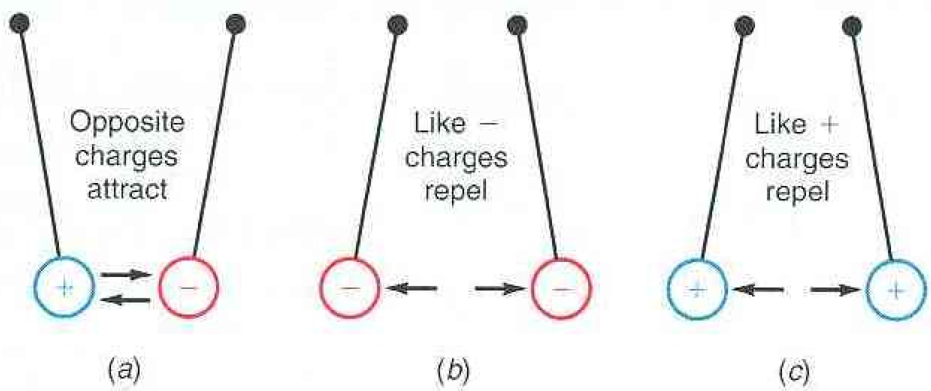


Polarity

- *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 1–1	Examples of the Chemical Elements			
Group	Element	Symbol	Atomic Number	Electron Valence
Metal conductors, in order of conductance	Silver	Ag	47	+1
	Copper	Cu	29	+1*
	Gold	Au	79	+1*
	Aluminum	Al	13	+3
	Iron	Fe	26	+2*
Semiconductors	Carbon	C	6	±4
	Silicon	Si	14	±4
	Germanium	Ge	32	±4
Active gases	Hydrogen	H	1	±1
	Oxygen	O	8	−2
Inert gases	Helium	He	2	0
	Neon	Ne	10	0

Molecules

- Combination of atoms which are chemically bonded together
- Example is water (H_2O)
  - 2 atoms of hydrogen
  - 1 atom of oxygen

Structure of an Atom

Atomic Number

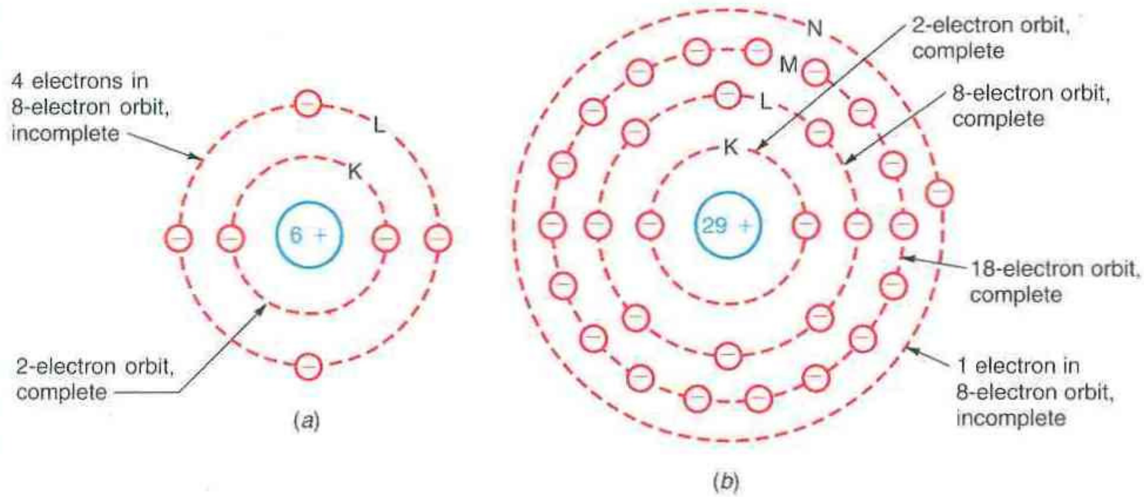
- Number of protons and electrons
- Copper atom has an atomic number of 29
  - 29 protons
  - 29 electrons

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 1–2 Shells of Orbital Electrons in the Atom

Shell	Maximum Electrons	Inert Gas
K	2	Helium
L	8	Neon
M	8 (up to calcium) or 18	Argon
N	8, 18, or 32	Krypton
O	8 or 18	Xenon
P	8 or 18	Radon
Q	8	—

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

Table 1–1 Examples of the Chemical Elements

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

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

Table 1–3	Stable Particles in the Atom	
Particle	Charge	Mass
Electron, in orbital shells	0.16×10^{-18} C, negative	9.108×10^{-28} g
Proton, in nucleus	0.16×10^{-18} C, positive	1.672×10^{-24} g
Neutron, in nucleus	None	1.675×10^{-24} g

Electrical Units of Measure

Charge

- **Coulomb** = 6.25×10^{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

Example 1-2

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

ANSWER This is the same amount of charge as in Example 1 but positive. Therefore $+Q = 2$ C.

Example #2

Example 1-3

A dielectric with $+Q$ of 2 C has 12.5×10^{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

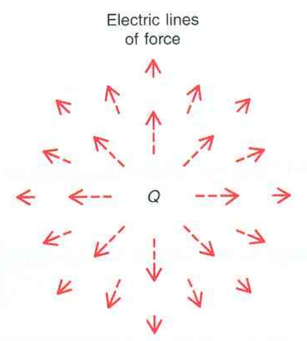
A neutral dielectric has 12.5×10^{18} electrons removed. What is its charge?

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

Electric Field

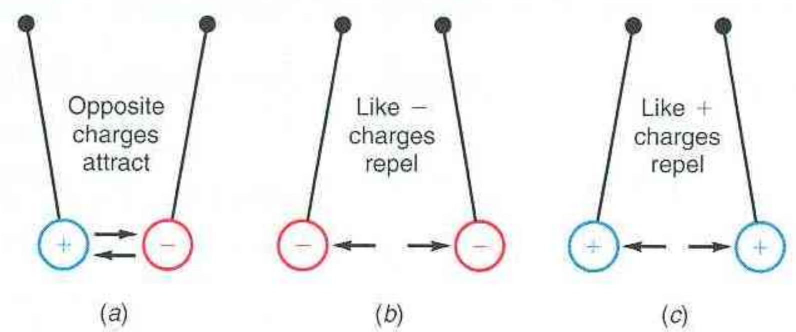
- Static charge generates an field around it
- Attract or repel other statically particles

Figure 1–6 Arrows to indicate electric field around a stationary charge Q.



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

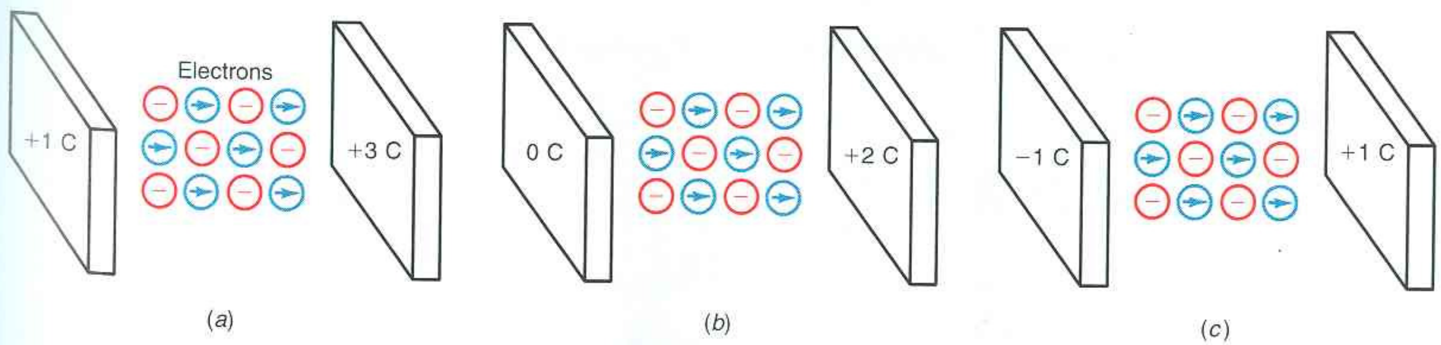


Figure 1–7 The amount of work required to move electrons between two charges depends on their difference of potential. This potential difference (PD) is equivalent for the examples in (*a*), (*b*), and (*c*).

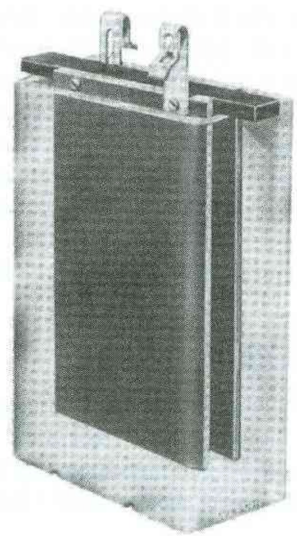
Definition of a Volt

- Unit of potential difference
- Measure of the amount of energy need to move a given electric charge

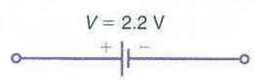
Definition of a Volt

- When 0.7376 ft-lb of work is required to move 6.25×10^{18} electrons [1 C] between two points. (English units)
- When 1 Joule of work is required to move 6.25×10^{18} electrons [1 C] between two points (Metric Units)

Voltage Source & Symbol



(a)



(b)

Basic Equation

- **V = W/Q**
  - **V** - voltage in volts
  - **W** – work units in joules
  - **Q** – charge in coulombs

Example

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.

$$V = \frac{W}{Q}$$

$$= \frac{3.6\ \text{J}}{0.5\ \text{C}}$$

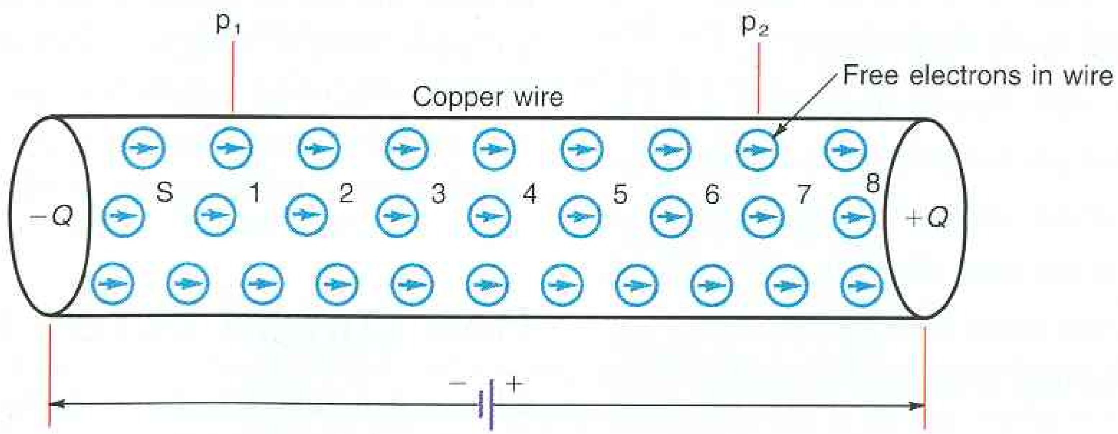
$$= 7.2\ \text{V}$$

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

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



Definition of an Ampere

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

Equation for Current

- **$I = Q/t$**
  - **I** – current flow in amperes
  - **Q** – Number of electrons in coulombs
  - **t** – time interval in seconds

Example #1

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 #2

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

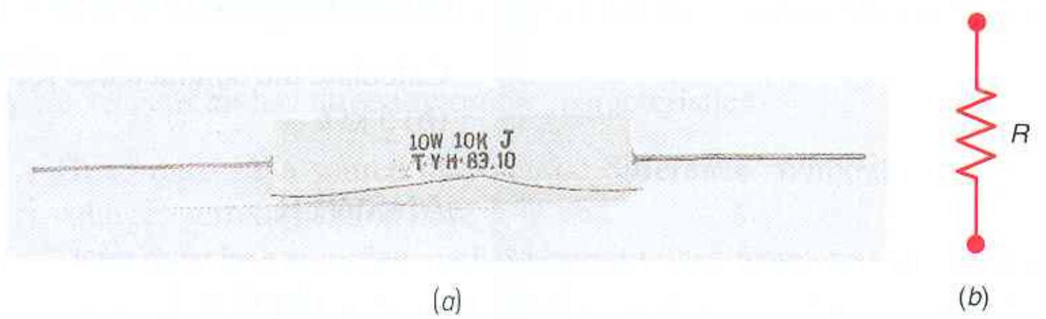
- Unit of resistance
- A resistance that develops 0.24 calories of heat when 1 ampere of current flows through it for 1 second is defined to have a resistance of 1 ohm

Notation for Ohms

- Indicated by the Greek letter *omega* **(Ω)**
- Symbol for resistance is **R**

View of a Resistor

MultiSim **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

Example 1-8

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

ANSWER

$$\text{(a) } R = \frac{1}{G} = \frac{1}{0.05\ \text{S}} = 20\ \Omega$$

$$\text{(b) } R = \frac{1}{G} = \frac{1}{0.1\ \text{S}} = 10\ \Omega$$

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

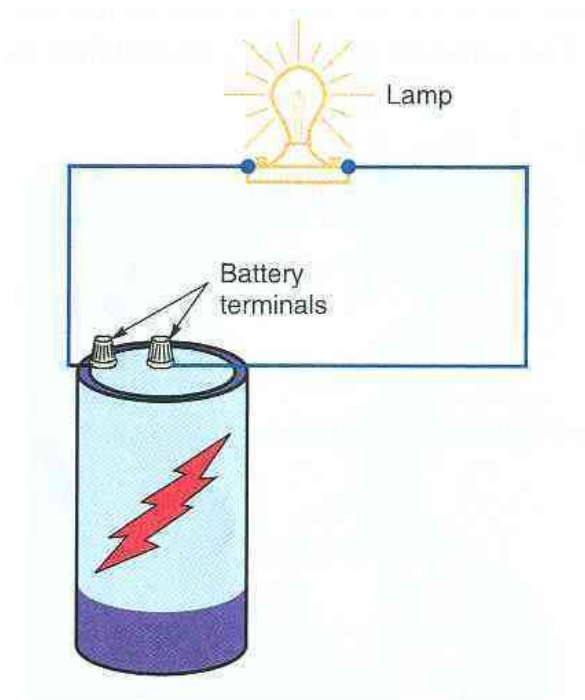
Closed Circuit

- Uninterrupted path for electrical current to flow

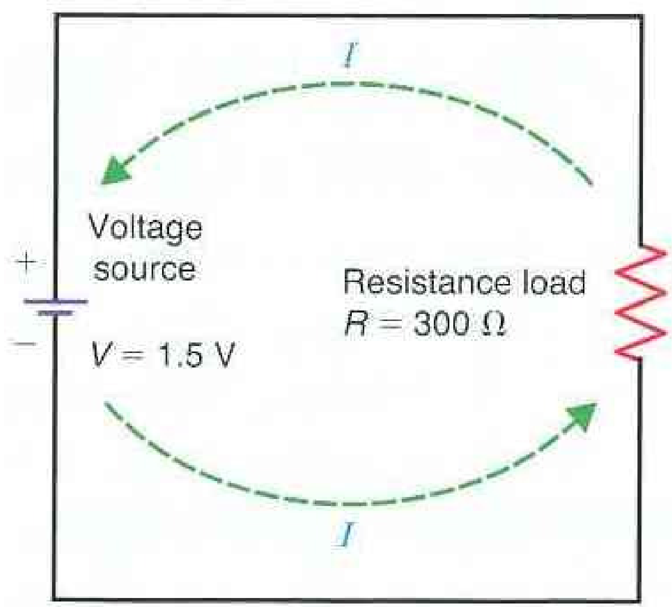
Criteria for a Closed Circuit

- 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

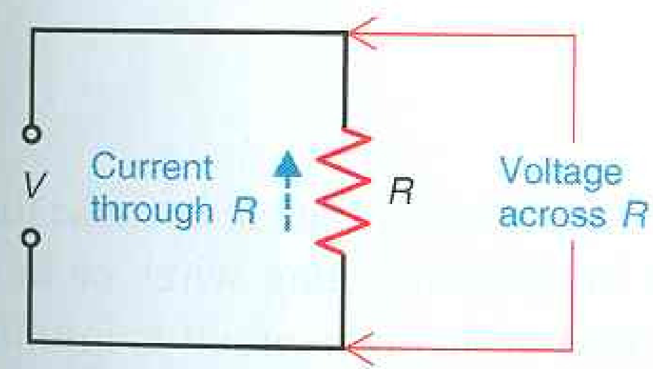


Closed Circuit Schematic



Voltage, 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 knows 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 it terminals
  - Close to zero resistance
  - Usually bypasses the load resistance
  - Generally hazardous to components & people

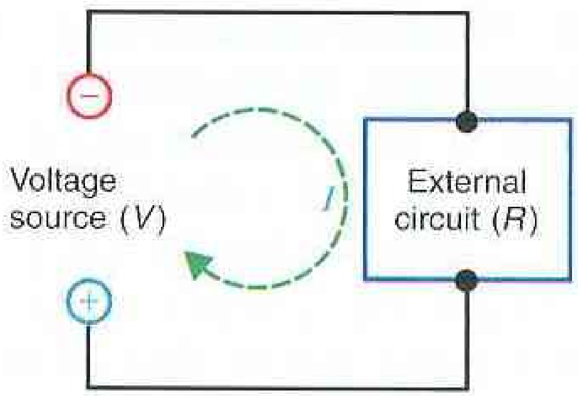
Current Direction

- In a closed electrical circuit negative electrons and positive charges move in opposite directions.
- ***Electron flow & conventional current***

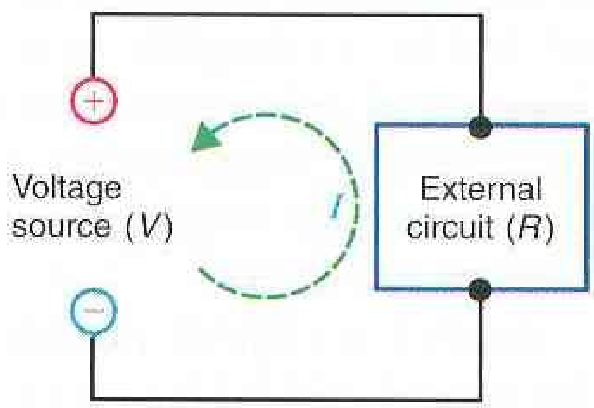
Electron Flow

- Flow of negative electrons
- Flows from the **(-)** terminal of the voltage source to the **(+)** terminal

Electron Flow – Effect of Polarity



(a)



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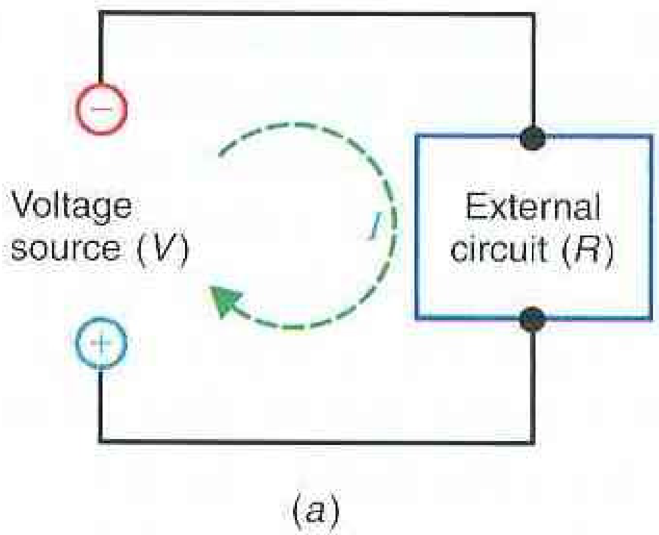
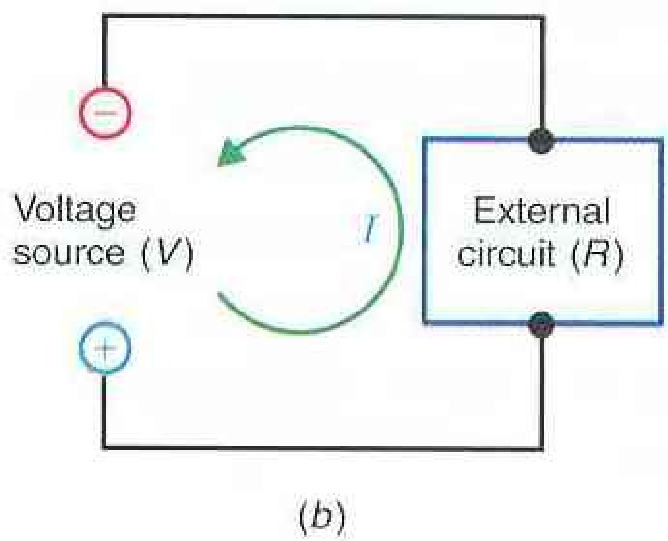
Conventional Current

- Motion of positive charges
- Opposite the flow of electrons
- Used in physics and electrical engineering in circuit analysis

Electron Flow vs. Conventional Current

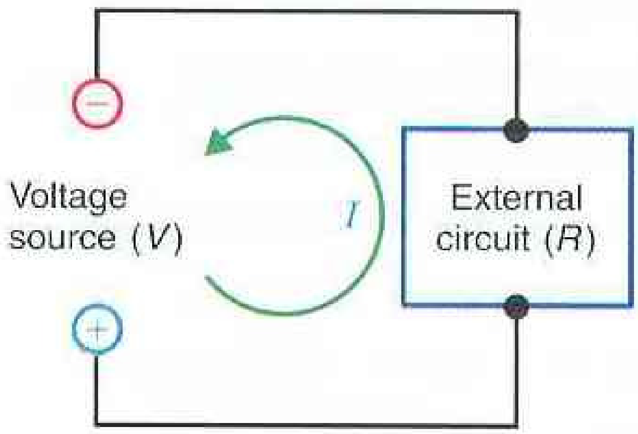


Electron Flow Current



Conventional Current

Conventional Current Flow – Effect of Polarity



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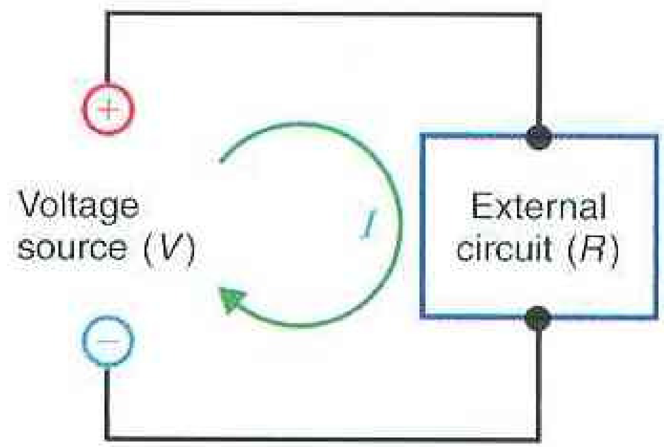


(d)

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

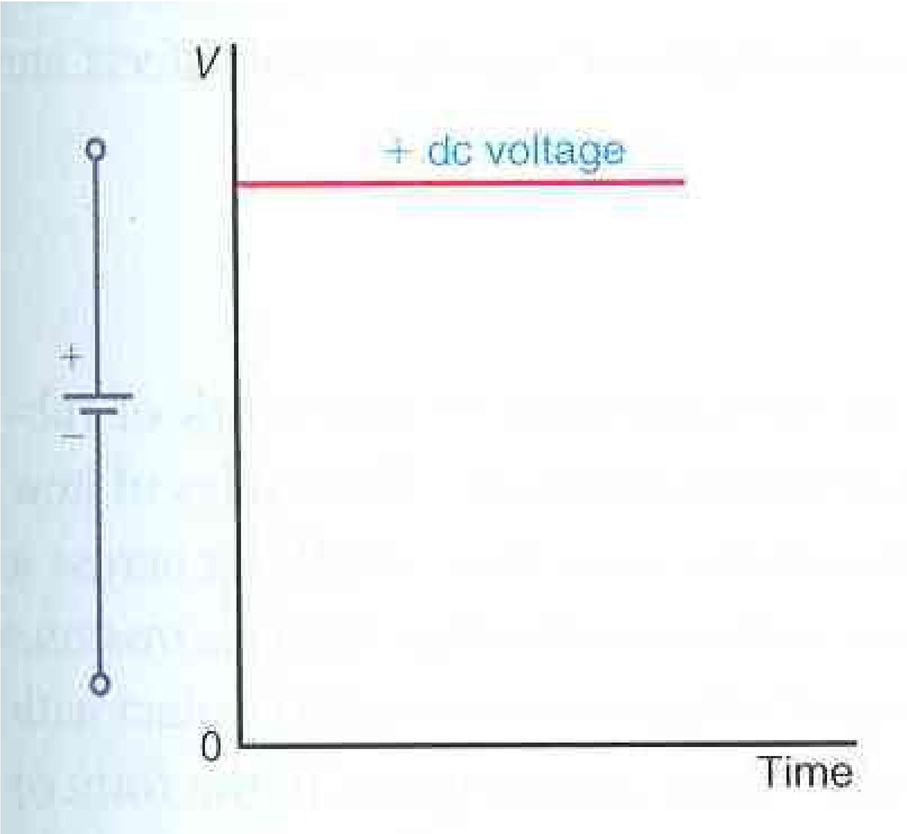
Types of Current Flow

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

Direct Current (DC)

- Flows in one direction
- Does not change polarity
- Example: battery

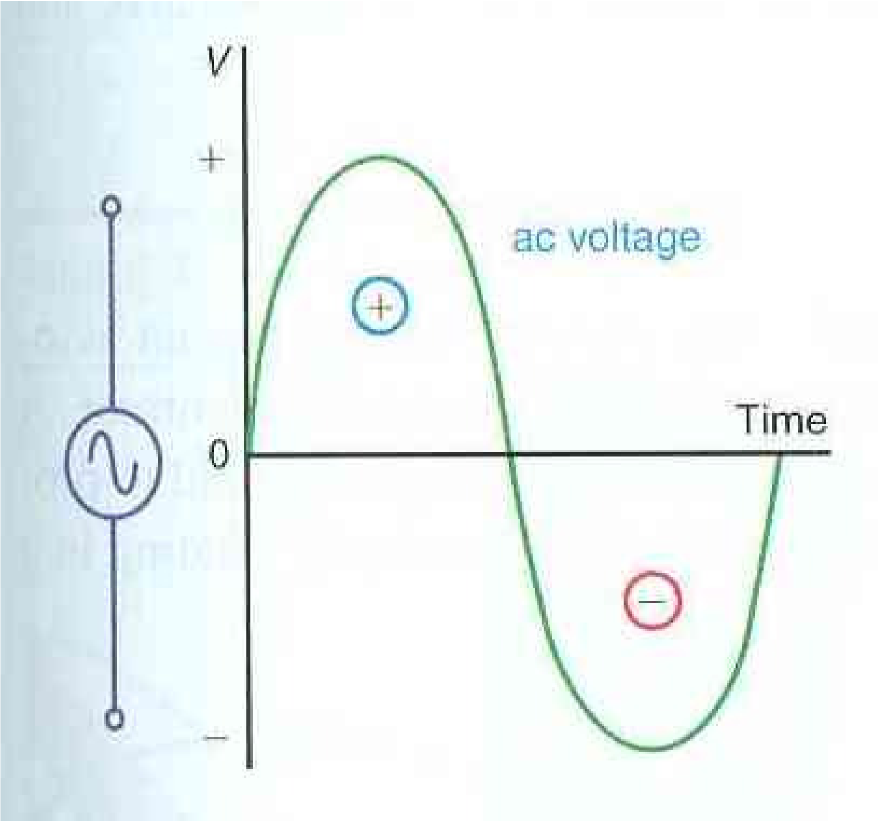
Direct Current & Source



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 1–5 Comparison of DC Voltage and AC Voltage

DC Voltage	AC Voltage
Fixed polarity	Reverses in polarity
Can be steady or vary in magnitude	Varies between reversals in polarity
Steady value cannot be stepped up or down by a transformer	Can be stepped up or down for electric power distribution
Terminal voltages for transistor amplifiers	Signal input and output for amplifiers
Easier to measure	Easier to amplify
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 1–6 Electrical Characteristics

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

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