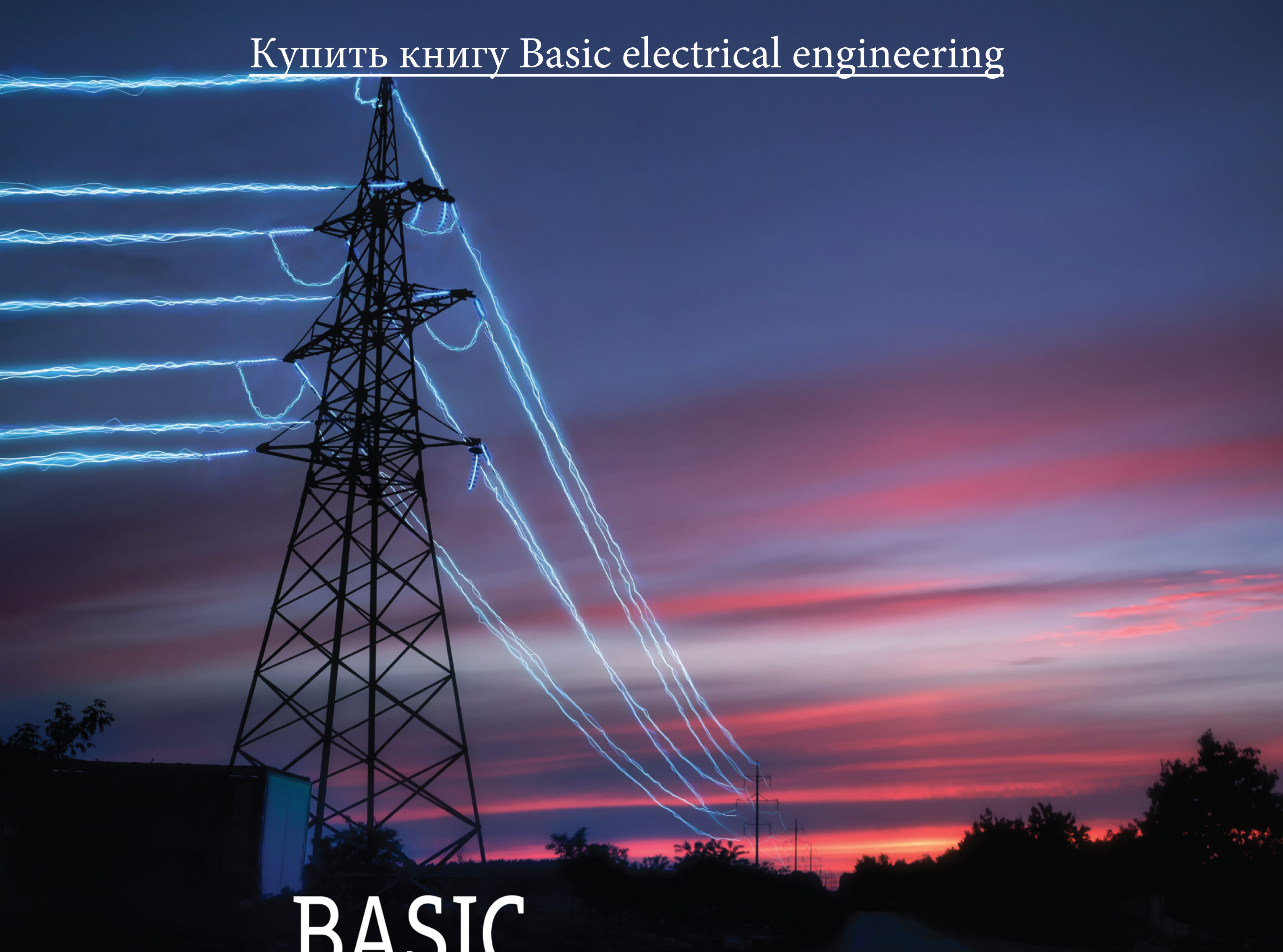

BASIC ELECTRICAL ENGINEERING

Edited by: **Draženko Macanović**

TAP

CHAPTER

1

Fundamentals of Electric Circuits

LEARNING OBJECTIVES

After studying this chapter, you will be able to:

- Give an overview of electric circuit
- Explain circuit elements and sources
- Illustrate circuit theorems

KEY TERMS FROM THIS CHAPTER

Ammeter	Amperes	Capacitor
Circuit	Closed circuit	Current
Ideal current	Inductor	Load
Mesh analysis	Open circuit	Resistance
Switch	Voltage	Voltage polarity

INTRODUCTION

The fundamentals of electric circuits form the backbone of modern electrical engineering and technology. At the core of electric circuits is the flow of electric current through a pathway composed of various electronic components. These pathways, or circuits, are driven by a potential difference known as voltage, which propels the movement of electrons, creating an electric current measured in amperes. The concept of resistance, measured in ohms, plays a crucial role in determining the extent of this current flow by opposing it. This relationship between current, voltage, and resistance is elegantly described by Ohm's Law, which states that the current passing through a conductor between two points is directly proportional to the voltage across those points and inversely proportional to the resistance, formulated as $V=IR$.

Key to understanding complex circuits are Kirchhoff's Laws. Kirchhoff's Current Law (KCL) asserts that the total current entering a junction in a circuit must equal the total current leaving it, ensuring the conservation of charge. Kirchhoff's Voltage Law (KVL) maintains that the sum of all electrical potential differences around a closed loop is zero, which helps in analyzing the energy conservation within the circuit. Circuit components like resistors, which impede current flow and drop voltage; capacitors, which store and release electrical energy; and inductors, which store energy in a magnetic field when current flows through them, are fundamental elements in the design and functioning of electric circuits. Power sources such as batteries or power supplies provide the necessary voltage and current to drive these circuits. Mastery of these basics enables the design, analysis, and troubleshooting of more complex electronic systems, forming the basis for advancements in electronics, communications, and a myriad of technological applications that power our modern world. Understanding these principles is essential for anyone involved in the study or application of electrical engineering.

1.1. ELECTRIC CIRCUIT

An electric circuit is a model of an actual circuit which links various devices together. Electric circuits consist of different components, and understanding these components is essential in comprehending the flow of current within the circuit.

In 1800, Alessandro Volta became the first person to conceive of an electric circuit. Through his experiments, Volta found that by connecting bowls of salt solution with metal strips, he could generate a constant stream of electricity. He later constructed a voltaic pile using layers of copper, zinc, and soaked cardboard discs, creating an early version of a battery. By linking a wire from top to bottom, Volta successfully directed the flow of electric current through the circuit.

An electric circuit is a closed loop or path through which current flows. Various components are added to electric circuits to perform specific tasks. Essentially, an electric circuit is a collection of elements arranged to guide electric current in a specific direction. The source is where the current begins, and the return points are where it ends.

The diagram of the electric circuit is show in Figure 1.1, let's learn about the electric circuit through the diagram.

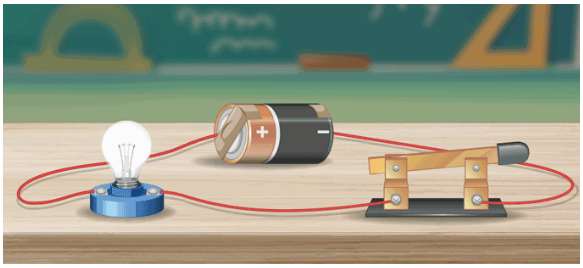

Figure 1.1. The diagram of the electric circuit.

Source: https://media.geeksforgeeks.org/wp-content/uploads/20230227144415/Circuit-on-off-gif.gif.

The above electric circuit has;

- Electric bulb
- Wire (Conductor)
- A battery

When the positive end of the battery is connected to the positive terminal of the bulb, the bulb does not light up. However, when the other end of the battery is connected to the bulb, completing the circuit, the bulb lights up. This shows that current only flows in an electric circuit when it is closed, and circuits that allow current to flow are called complete circuits.

Failure to secure all connections in a circuit could potentially lead to a fire that cannot be put out using conventional methods. It is important to note that using water to extinguish an electrical fire is dangerous and can result in electric shock.

1.1.1. Types of Electric Circuits

Many types of electrical circuits are used in our daily life some of the most common electric circuits are;

- Open Circuit
- Closed Circuit
- Short Circuit
- Series Circuit
- Parallel Circuit
- **Open Circuit:** An open circuit is a circuit where the switch is open and no current is flowing through

it. Figure 1.2 illustrates an open circuit.

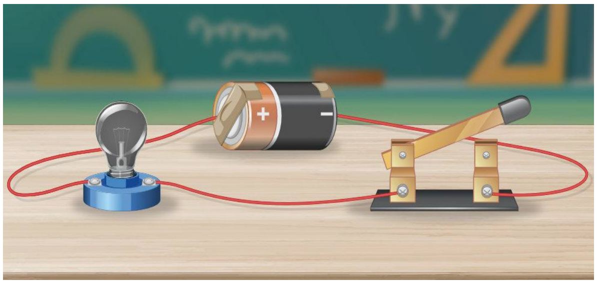

Figure 1.2. *An open circuit.*

Source: https://media.geeksforgeeks.org/wp-content/uploads/20230227144444/Electric-Circuit-4.jpg.

- **Closed Circuit:** An open circuit is a circuit in which the switch is closed and allows current to flow through it. Figure 1.3 illustrates a closed circuit.

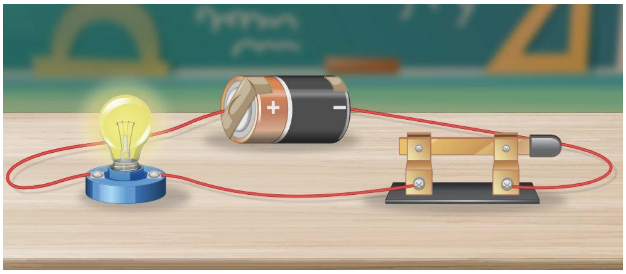

Figure 1.3. *A closed circuit.*

Source: https://media.geeksforgeeks.org/wp-content/uploads/20230227144514/Electric-Circuit-3.jpg.

- **Short Circuit:** A short circuit occurs when the current in the circuit takes a shorter path than its intended route. Figure 1.4 illustrates a short circuit.

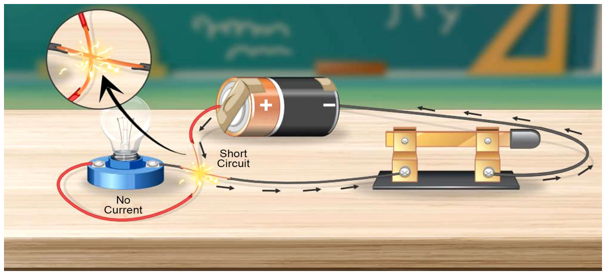

Figure 1.4. *A short circuit.*

Source: https://media.geeksforgeeks.org/wp-content/uploads/20230402112108/Electric-Circuit-5.jpg.

The result of a short circuit is the potential ignition of the electric board or system. The primary reason behind electric fires is often attributed to short circuits. The picture below depicts a fire ignited by a short circuit.

- **Series Circuit:** A series circuit is formed when all resistors are connected in a series combination, as shown in the Figure 1.5.

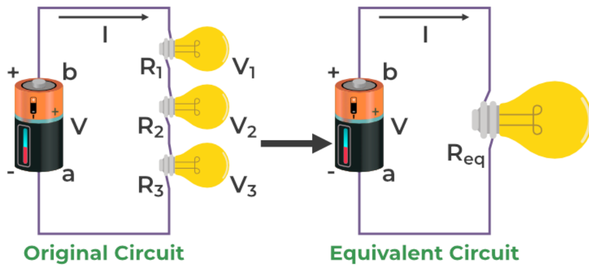

Figure 1.5. *A series circuit.*

Source: https://media.geeksforgeeks.org/wp-content/uploads/20230227151617/Comb-1-(2).png.

- **Parallel Circuit:** A parallel circuit is formed when all the resistors are connected in parallel. Figure 1.6 displays a parallel circuit.

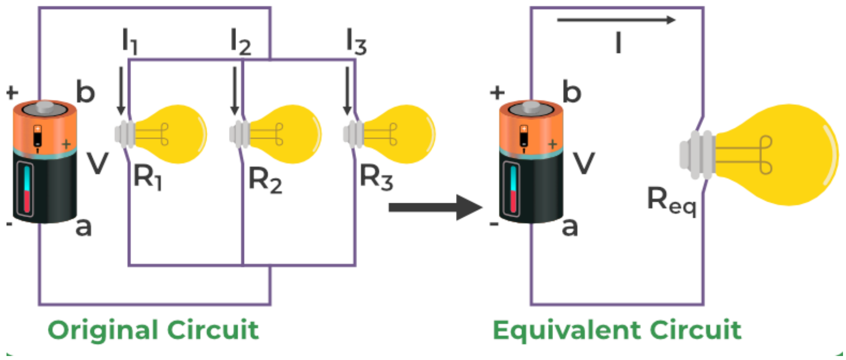

Figure 1.6. *A parallel circuit.*

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1.1.2. Domestic Electric Circuit

The electrical circuit utilized in our household is known as a Domestic circuit, designed specifically for residential use. Several components included in the domestic circuit are:

- **Mains Supply:** Electric power we receive in our houses is called the main supply.
- **Cables:** Electric power is supplied by cables which are either open or underground.

There are three types of wires used in domestic circuits which are:

- Earth Wire;
- Live Wire; and
- Neutral Wire.
- **Potential Difference (or Voltage):** In our country, the current is supplied at 220 V in domestic circuits.

Our house receives electric current at 220 volts through a circuit protection element known as a fuse. If the current supplied exceeds the allowed amount, the fuse wire will break/melt, halting the flow of current. The current then goes through the meter board.

From the meter board generally, two types of current are supplied to the circuit:

- **15 Amp Current:** This current is used by appliances with higher power ratings, like geysers, ACs, refrigerators, electric motors, and others; and
- **5 Amp Current:** This current is used by appliances with lower power ratings, like TV, fans, bulbs, computers, smartphones, and others.

1.1.3. Electric Circuit Symbols

In the drawing of electric circuits, a variety of symbols are utilized. Among the key symbols used in physics for this purpose are (Figure 1.7):

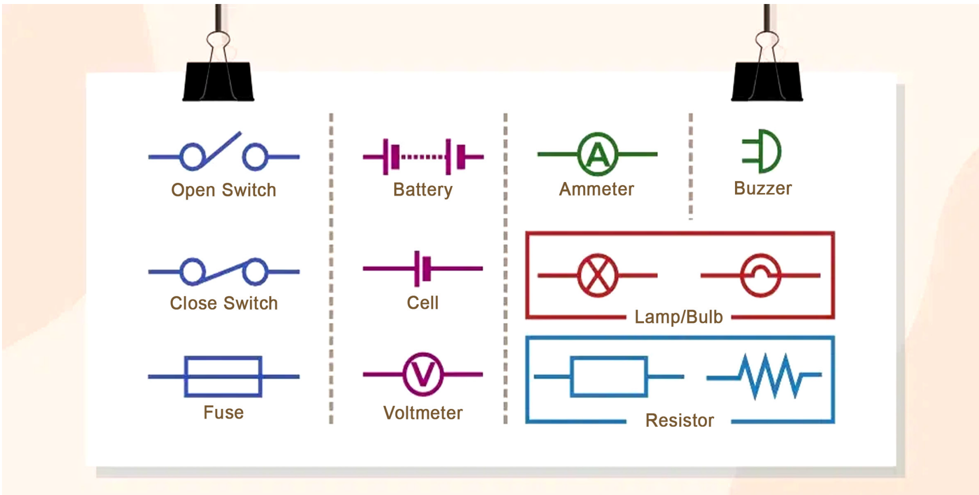


Figure 1.7. *Electric circuit symbols.*

Source: https://media.geeksforgeeks.org/wp-content/uploads/20230419183956/Electric-Circuit-2.webp.

1.1.4. Simple Circuit

A basic circuit includes a power source, conductors, switch, and load. It does not contain multiple components, and the Figure 1.8 displays an example of a simple circuit.

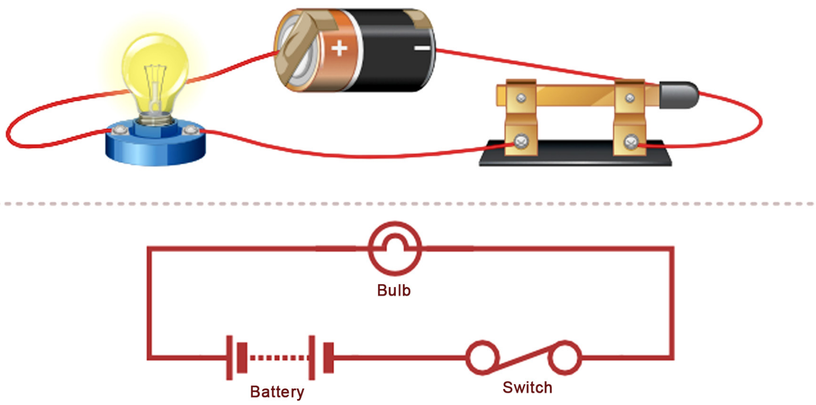


Figure 1.8. *A simple circuit.*

Source: https://media.geeksforgeeks.org/wp-content/uploads/20230227144647/Electric-Circuit-1.png.

- **Cell:** It is the power source that provides the potential difference in the electric circuit.
- **Load:** A resistor that consumes electrical power in a circuit is called the load. Generally, a load is a bulb.

- **Conductors:** Copper conductors that conduct electricity in a circuit are called conductors.
- **Switch:** A device that controls the incoming flow of current in an electric circuit is called a switch.

1.1.5. Electric Circuit Formula (Table 1.1)

Table 1.1. Various Formulas that are Used in Solving Electric Circuits

	Formula	Notations
Electric current	$I = Q/t$	• I is the current flowing • Q is the charge flowing • t is the time period
Voltage	$V = IR$	• V is the potential difference
Resistance	$R = \rho\, l/A$	• R is the resistance of the circuit • ρ is the specific resistivity per length of the wire • l is the length of the wire • A is the cross-sectional area
Power	$P = VI$ or E/t	• P is the power • E is the energy gain or loss • t is the time period
Series Resistance	$R_{eq} = R_1 + R_2 + \ldots + R_n$	• R_{eq} is the equivalent resistance of the resistors in series • $R_1, R_2 \ldots R_n$ are the individual resistors added in series
Parallel Resistance	$1/R_{eq} = 1/R_1 + 1/R_2 + \ldots + 1/R_n$	• R_{eq} is the equivalent resistance of the resistors in parallel • $R_1, R_2 \ldots R_n$ are the individual resistors added in parallel

Source: https://www.geeksforgeeks.org/electric-circuit/.

1.2. CIRCUIT ELEMENTS AND SOURCES

This gives an overview of the most frequently used elements in electric circuits, including the laws that govern current flow and voltage across these components, as well as the power supplied/dissipated and energy storage within this context. It also discusses the difference between ideal and non-ideal voltage and current sources, highlighting the importance of understanding sign conventions such as voltage polarity and current direction.

The concepts of current and voltage are initially presented as they are essential components in electronics and electrical engineering.

1.2.1. Current

Current is the movement of electric charge through a conductor. The unit of current is Ampere, while charge is measured in Coulombs.

- **Definition of an Ampere:** An Ampere is defined as the amount of total charge that flows through any random cross section of a conducting material in one second.

Mathematically;

$$I = \frac{Q}{t} \, or \, Q = It \tag{1}$$

Where; Q is the symbol of charge measured in Coulombs (C), I is the current in amperes (A) and t is the time in seconds (s).

The current can also be defined as the rate of charge passing through a point in an electric circuit i.e.,

$$i = \frac{dQ}{dt} \tag{2}$$

A constant current, represented by the symbol I, is also known as direct current or DC. On the other hand, a time-varying current, symbolized by i or i(t), is also known as alternating current or AC. Current is always measured across a circuit element. In Figure 1.9, an ampere-meter or ammeter is shown connected in series with a circuit element, R, to measure the current flowing through it (Naeem, 2009).

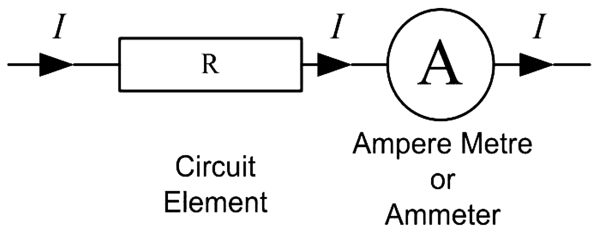


Figure 1.9. *An ammeter is connected in series to measure current, I, through the element, R.*

Source: https://sietm.com/wp-content/uploads/2015/03/concepts-in-electric-circuits.pdf.

Example

Determine the current in a circuit if a charge of 80 coulombs (C) passes a given point in 20 seconds (s).

$$Q = 80\ \mathrm{C}, t = 20\ \mathrm{s}, I = ?$$

$$I = \frac{Q}{t} = \frac{80}{20} = 4\ \mathrm{A} \tag{3}$$

1.2.2. Voltage or Potential Difference

If 1 joule of energy is used to transfer 1 coulomb of charge between two points in an electric circuit, the voltage or potential difference between those points is 1 volt.

Voltage is typically represented by the symbol V and measured in volts (V). It's worth noting that both the symbol and unit of voltage are denoted by the same letter, but this rarely leads to confusion.

The symbol V represents a constant voltage (DC), while a time-varying voltage (AC) is represented by the symbol v or v(t).

Voltage is consistently measured across a circuit component, as depicted in Figure 1.10 by Wasif Naeem in 2009.

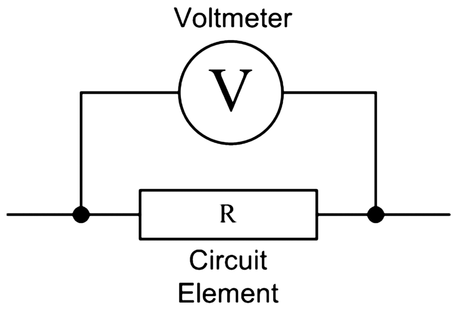


Figure 1.10. *A voltmeter is connected in parallel with the circuit element, R to measure the voltage across it.*

Source: https://sietm.com/wp-content/uploads/2015/03/concepts-in-electric-circuits.pdf.

An energy source, such as a voltage source, is necessary to provide the electromotive force needed for current flow. However, current will only flow if there is a potential difference and a clear path for it to follow.

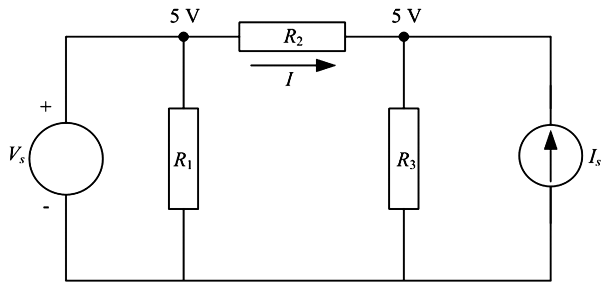


Figure 1.11. *The potential difference across R_2 is 0 V, hence the current I is 0 A where V_s and I_s are the voltage and current sources respectively.*

Source: https://sietm.com/wp-content/uploads/2015/03/concepts-in-electric-circuits.pdf.

If there is no potential difference, indicated by a voltage of 0 V between two points, then no current will flow. In the scenario shown in Figure 1.11, the current I is 0 A because there is no potential difference across R_2. This means that although there is a physical path for the current to travel, there is no potential difference driving it, essentially creating an open circuit (Wasif Naeem, 2009).

Table 1.2 summarizes the fundamental electric circuit quantities, their symbols and standard units.

1.2.3. Circuit Loads

The term "load" typically describes a device or item that is connected to the output of an electrical circuit. This could include various circuit elements such as resistors, capacitors, or inductors.

- Resistor (R)
- Inductor (L)
- Capacitor (C)

Table 1.2. Standard Quantities and Their Units Commonly Found in Electric Circuits

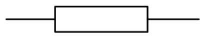
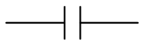
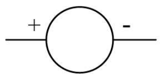
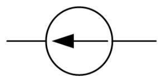
Quantity	Symbol	Unit
Voltage	V	Volts (V)
Current	I	Ampere (A)
Charge	Q	Coulomb (C)
Power	P	Watts (W)
Energy	W	Joules (J)
Time	t	seconds (s)

Source: https://sietm.com/wp-content/uploads/2015/03/concepts-in-electric-circuits.pdf.

Loads can be resistive, inductive, or capacitive, or a combination. For instance, a light bulb is purely resistive, while a transformer is both inductive and resistive. A circuit load is also known as a sink, as it consumes energy, while the voltage or current supply is a source.

Table 1.3 displays the fundamental circuit components, including their symbols and schematics, utilized in an electric circuit. The components R, L, and C are considered passive, meaning they do not produce their own electromotive force (emf). Contrastingly, the DC voltage and current sources are considered active elements.

Table 1.3. Common Circuit Elements and Their Representation in an Electric Circuit

Circuit Element	Symbol	Schematic
Resistor	R	 or 
Inductor	L	
Capacitor	C	
DC Voltage Source	V_s	 or 
DC Current Source	I_s	

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1.2.4. Sign Convention

Many people believe that current is the movement of electrons, but the usual practice is to consider the movement of protons when determining the direction of the current.

The direction of current in a circuit is determined by the polarity of the source voltage. Current flows from the positive (high potential) side to the negative (low potential) side of the source, as illustrated in Figure 1.12(a). This diagram shows V_s as the source voltage, V_L as the voltage across the load, and I as the loop current moving in a clockwise direction (Naeem, 2009).

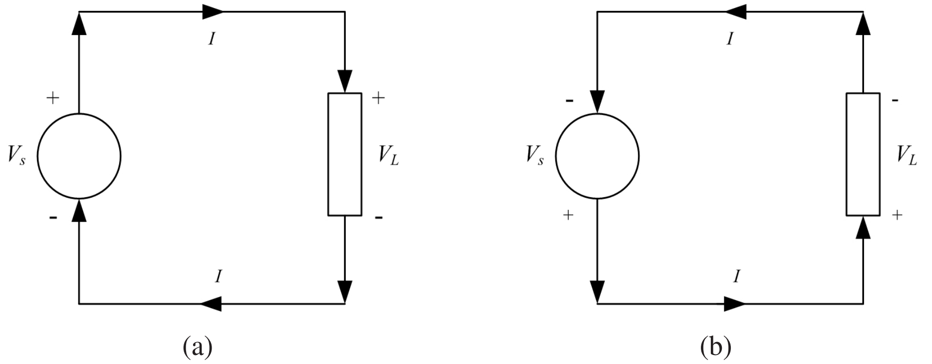

Figure 1.12. *Effect of reversing the voltage polarity on current direction.*

Source: https://sietm.com/wp-content/uploads/2015/03/concepts-in-electric-circuits.pdf.

Please observe that the voltage polarity and current direction in a sink is opposite to that of the source.

In Source current leaves from the positive terminal

In Load (Sink) current enters from the positive terminal

A reversal in source voltage polarity changes the direction of the current flow and vice versa as depicted in Figure 1.12(a) and 1.12(b).

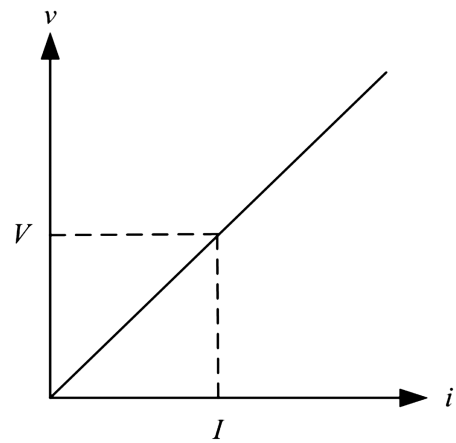

Figure 1.13. *V–I relationship for a resistor according to Ohm's law.*

Source: https://sietm.com/wp-content/uploads/2015/03/concepts-in-electric-circuits.pdf.

At any given point in the above graph, the ratio of voltage to current is always constant.

1.2.5. Passive Circuit Elements

- **Resistor:** In order to understand the resistance and characteristics of a resistor, it is crucial to define Ohm's law.
- **Ohm's Law:** The most basic principle utilized in circuit analysis is Ohm's Law, which offers a straightforward equation that explains the relationship between voltage and current in a conducting material.
  - **Statement:** The voltage across a conducting material is directly proportional to the current passing through it.
  - **Mathematically:**

$$V \propto I$$

$$V = RI \text{ or } I = \frac{V}{R} \text{ or } R = \frac{V}{I} \quad (4)$$

Where the constant of proportionality R is called the resistance or electrical resistance, measured in ohms (Ω). Graphically, the V–I relationship for a resistor according to Ohm's law is depicted in Figure 1.13 (Wasif Naeem, 2009).

Example

Find R if the voltage V and current I in Figure 1.13 are equal to 10 V and 5 A respectively.

$$V = 10 \text{ V}, I = 5 \text{ A}, R = ? \quad (5)$$

Using Ohm's Law

$$V = IR \text{ or } R = \frac{V}{I} = \frac{10}{5} \quad (6)$$

$$\therefore R = 2\ \Omega \quad (7)$$

A short circuit between two points represents a zero resistance whereas an open circuit corresponds to an infinite resistance as demonstrated in Figure 1.14 (Wasif Naeem, 2009).

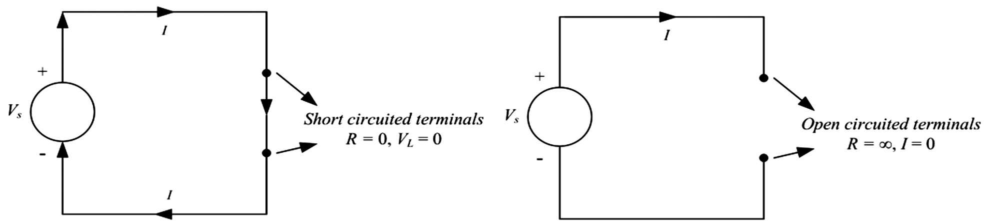

Figure 1.14. *Short circuit and open circuit resistance characteristics.*

Source: https://sietm.com/wp-content/uploads/2015/03/concepts-in-electric-circuits.pdf.

Using Ohm's law;

When R = 0 (short circuit), V = 0 V

When R = ∞ (open circuit), I = 0 A

- **Conductance:** Conductance (G) is the exact opposite of resistance. In mathematical terms;

$$G = \frac{1}{R}$$

$$\therefore I = \frac{V}{R} = VG \tag{8}$$

Where; G is measured in siemens (S) and sometimes also represented by the unit mho $(\mho)$ (upside-down omega).

- **Capacitor:** A capacitor is a passive component in circuits that can store charge in an electric field. It is commonly used in electric circuits as a filter. The relationship between voltage and current in a capacitor is determined by the following equation:

$$i = C\frac{dv}{dt} \text{ or } v = \frac{1}{C}\int_0^t idt + v(0) \tag{9}$$

Where; C is the capacitance measured in Farads (F) and v(0) is the initial voltage or initial charge stored in the capacitor

When; v = V (constant DC voltage), $\frac{dv}{dt} = 0$, and i = 0. Hence a capacitor acts as an open circuit to DC.

Example

For the circuit diagram shown in Figure 1.15, determine the current, I flowing through the 5 Ω resistance (Wasif Naeem, 2009).

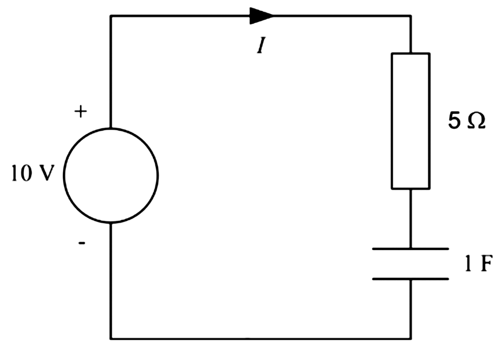

Figure 1.15. *In the circuit diagram determine the current.*

Source: https://sietm.com/wp-content/uploads/2015/03/concepts-in-electric-circuits.pdf.

Since the supply voltage is DC, therefore the capacitor will act as an open circuit. Hence no current can flow through the circuit regardless of the values of capacitor and resistor i.e.,

$$I = 0$$

- **Inductor:** An inductor is a conducting wire wound around a ferromagnetic core. While they can be used as filters like capacitors, their most common application is in AC transformers and power supplies to convert voltage levels.

In an inductor, the V – I relationship is given by the following differential equation:

$$v = L\frac{di}{dt} \text{ or } i = \frac{1}{L}\int_0^t v\,dt + i(0) \qquad (10)$$

Where; L is the inductance in Henrys (H) and i(0) is the initial current stored in the magnetic field of the inductor.

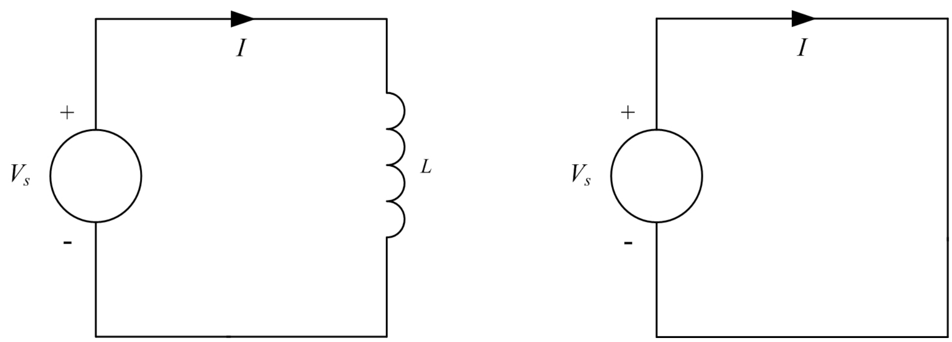

Figure 1.16. *An ideal inductor can be replaced by a short circuit when the supply voltage is DC.*

Source: https://sietm.com/wp-content/uploads/2015/03/concepts-in-electric-circuits.pdf.

When i = I (constant DC current), $\frac{di}{dt} = 0, v = 0$. Hence an inductor acts as a short circuit to DC. An ideal inductor is just a piece of conducting material with no internal resistance or capacitance. The schematics in Figure 1.16 are equivalent when the supply voltage is DC (Wasif Naeem, 2009).

A summary of the V–I relationships for the three passive circuit elements is provided in Table 1.4.

Table 1.4. V–I Relationships for a Resistor, Inductor and Capacitor

Circuit Element	Voltage	Current
Resistor	$V = IR$	$I = \frac{V}{R}$
Inductor	$v = L\frac{di}{dt},\ v = 0$ for DC	$i = \frac{1}{L}\int_0^t v dt + i(0)$
Capacitor	$v = \frac{1}{C}\int_0^t i dt + v(0)$	$i = C\frac{dv}{dt},\ i = 0$ for DC

Source: https://sietm.com/wp-content/uploads/2015/03/concepts-in-electric-circuits.pdf.

1.2.6. DC Sources

In generally, there are two main types of DC sources:

1. Independent (Voltage and Current) Source
2. Dependent (Voltage and Current) Sources

Independent sources generate their own voltage and current through a chemical reaction and are not influenced by any other variables in the circuit. On the contrary, the output of a dependent source is impacted by changes in a specific parameter (voltage or current) in a circuit element. This discussion will focus solely on independent sources.

- **DC Voltage Source:** This can be further subcategorized into ideal and non-ideal sources.
  - **The Ideal Voltage Source:** According to Figure 1.17(a), an ideal voltage source maintains a consistent terminal voltage regardless of load changes. While the supply current may fluctuate, the terminal voltage (VL) remains steady. This property is illustrated in Figure 1.17(b) (Naeem, 2009).