Lectures in Physics (1)

First Year - Faculty of Science

(Biological Sciences)

Dr. Khaled Ali

2024-2025

Part One (Electricity)

General Introduction

Electricity is a term that encompasses a variety of phenomena resulting from the presence and flow of electric charge. These phenomena include lightning, as shown in (Figure 1), and static electricity. However, it also includes less common concepts such as the electromagnetic field and electromagnetic induction. In general usage, it is appropriate to use the word "electricity" to refer to a number of physical effects. However, in scientific usage, the term can be ambiguous. It is preferable to define these related concepts using more precise terminology as follows:

- **Electric Charge**

  It is a property of certain subatomic particles that determines their specific electromagnetic interactions. Charged matter is affected by and produces electromagnetic fields.

- **Electric Current**

  It is the movement or flow of charged particles, typically measured in amperes.

- **Electric Field**

  It is the effect produced by an electric charge on other charges located nearby.

- **Electric Voltage**

  It is the capacity of the electric field to perform work, typically measured in volts.

- **Electromagnetism**

  It is the fundamental interaction that occurs between the magnetic field and the presence and movement of electric charge.

Figure (1) Lightning is one of the most prominent natural phenomena that indicates the presence of electricity.

Electrical phenomena have been studied since ancient times; however, the science of electricity did not witness significant progress until the seventeenth and eighteenth centuries. Nevertheless, practical applications related to electricity remained few in number, and engineers were unable to apply electrical science in industrial fields and residential uses until the late nineteenth century. The rapid advancement in electrical technology during that time brought about changes in the industrial sector and society as well. The multiple and amazing uses of electricity as a source of energy demonstrated its potential in various applications such as transportation, heating, lighting, communications, and computation. The foundation of modern industrial society relies on the use of electrical energy, and it can be anticipated that reliance on electricity will continue in the future.

Etymology

The word "electricity" is a Persian term composed of "kāh," meaning straw, and "rubāy," meaning attractive, thus collectively referring to the "straw attractor." The term "kahraba" in Persian refers to amber, known in Arabic as "al-ʻanbar al-ashhab." The meaning of "electricity" in Arabic refers to the "attraction of amber," which was originally termed "the property of electricity," but the term "property" was omitted, resulting in the use of just "electricity." Thus, it transitioned from Persian to Arabic from the meaning of the doer (the attractor) to the meaning of the action (the attraction). The Greek name for amber is "ēlektron," which was Arabized to "electron," meaning "the shining one," leading to the term "electron" in physics. Consequently, the Persian term for electricity is "barq," which inspired the term for its action, called "electromagnetism." In Latin, the word for electricity is "electristas," derived from "electrix," meaning "similar to amber."

History of Electricity

Long before the understanding of electricity, people were aware of the shocks produced by the torpedo fish. Texts left by the ancient Egyptians, dating back to 2750 BC, referred to these fish as the "lightning of the Nile," describing them as protectors of all other fish. About a thousand years later, the Greeks and Romans, as well as Muslim naturalists and physicians, also referred to them. Ancient writers like Pliny the Elder and Scribonius Largus confirmed the tingling sensation resulting from electrical shocks produced by the electric catfish and the electric eel. These writers discovered that these shocks could be transmitted through conductive bodies. In any case, the oldest and closest method of discovering the nature of lightning and electricity emitted from any other source is attributed to the Arabs, who referred to the rattle of the electric eel as "ra'd" in Arabic before the fifteenth century. It was known in ancient cultures along the Mediterranean that certain objects, such as amber rods, could attract light objects like feathers when rubbed with cat fur. The Greek philosopher Thales of Miletus, shown in (Figure 2), recorded a set of observations regarding static electricity around 600 BC.

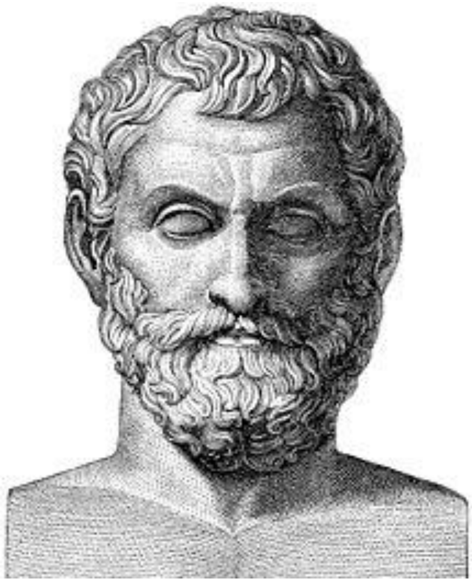


Figure (2) The philosopher Thales of Miletus

After these observations, Thales concluded that friction turns amber into a magnetic material. In contrast, metals, such as magnetite (known as iron(III) oxide), do not require friction to acquire magnetic properties. However, Thales was mistaken in believing that the cause of attraction was due to magnetic influence; scientific research later proved a connection between magnetism and electricity. According to one controversial theory, the Parthians, a people of Persia, recognized electric coating, based on information obtained from the discovery of the Baghdad Battery in 1936. Although this battery resembles a galvanic cell, it remains uncertain whether it has an electrical nature.

For thousands of years, electricity meant little more than an intellectual curiosity until 1600. In that year, the English physician William Gilbert conducted a thorough study of electricity and magnetism, distinguishing between the effects of magnetite and static electricity produced by rubbing amber. He coined the term "electricus," which in New Latin means "from amber" or "similar to amber," derived from "ήλεκτρον" (ēlektron), the Greek equivalent of "amber," to describe the property of attracting small objects after being rubbed. This association led to the emergence of the terms "Electric" and "Electricity," which first appeared in Thomas Browne's book "Vulgar Errors," published in 1646.

Otto von Guericke, Robert Boyle, Stephen Gray, and C. F. Du Fay contributed further research. Benjamin Franklin, shown in (Figure 3), conducted extensive studies on electricity in the eighteenth century, to the extent that he had to sell his possessions to fund his research. It is said that in June 1752, he attached a metal key to a wet kite string and launched the kite into a stormy sky. He then observed a series of sparks leap from the key to the back of his hand, proving that lightning is indeed of an electrical nature. In 1791, Luigi Galvani published his discovery of bioelectricity, demonstrating that electricity is the medium through which nerve cells transmit signals to muscles.

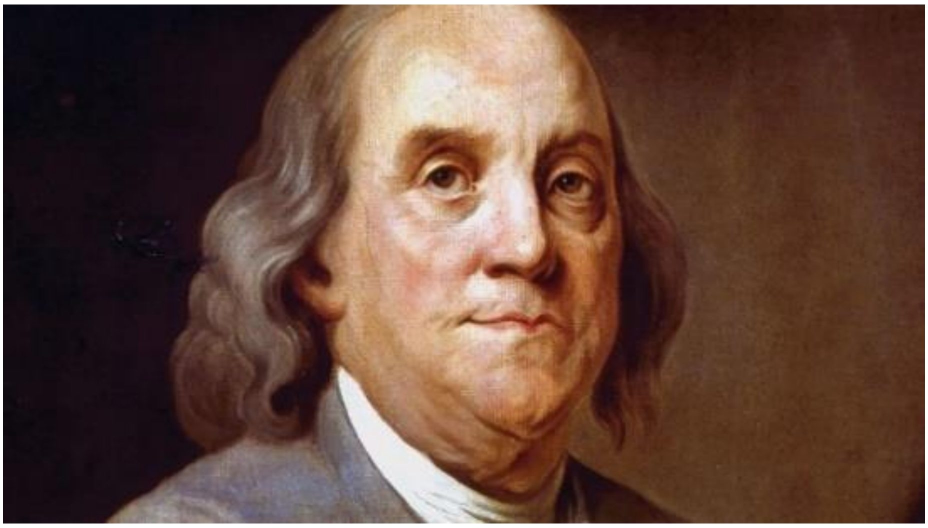


Figure (3) The scientist Benjamin Franklin

In 1800, Alessandro Volta invented the first electric battery, which he called the "Voltaic Pile." It was made of alternating layers of zinc and copper. This battery provided scientists with a more reliable source of electrical energy compared to the electrostatic machines previously used. The recognition of electromagnetism, the unity of electrical and magnetic phenomena, is credited to Hans Christian Ørsted and André-Marie Ampère between 1819 and 1820. Subsequently, the scientist Michael Faraday invented the electric motor in 1821, as shown in (Figure 4). George Ohm also analyzed electrical circuits mathematically in 1827.

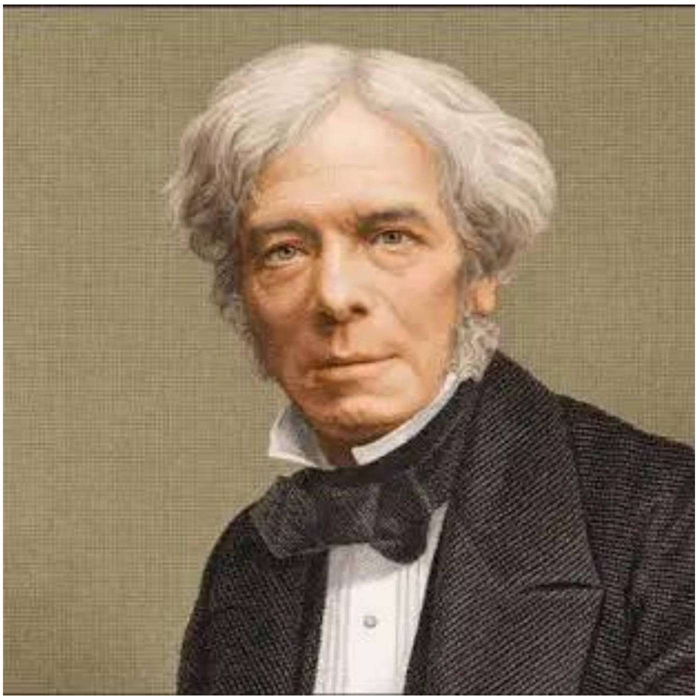


Figure (4) The scientist Michael Faraday

Although the early nineteenth century witnessed rapid advancements in the science of electricity, the latter part of the century saw the greatest progress in electrical engineering. Electricity transformed from a puzzling scientific curiosity into an indispensable tool in modern life, becoming the driving force behind the Second Industrial Revolution. This was made possible thanks to several individuals, including Nikola Tesla, Thomas Edison, Otto Plath, George Westinghouse, Ernst Werner von Siemens, Alexander Graham Bell, Lord William Thomson, Baron Kelvin.

Electric Charges

Electric charge is a property found in a certain group of subatomic particles and is responsible for generating electromagnetic force and interacting with it. The electromagnetic force is one of the four fundamental forces in nature. Charge arises in the atom, with the electron and proton being the most well-known carriers. It is also a conserved quantity, meaning that the charge within an isolated system remains constant regardless of any changes occurring within that system. Charge can be transferred between bodies within the system, either through direct contact or by passing through a conductive material, such as a wire.

The term "static electricity" refers to the presence (or imbalance) of charges on a body. This typically occurs when different materials are rubbed together, resulting in the transfer of charge from one material to another. The electric charge present on a gold leaf electroscope causes them to repel each other noticeably. The existence of an electric charge generates electromagnetic force: charges repel each other with a force, a phenomenon known since ancient times, albeit not fully understood. For example, a lightweight ball hanging from a wire can be charged by contacting it with a glass rod rubbed with a piece of cloth. When another similar ball is charged with the same glass rod, it is observed to repel the first ball; the electric charge pushes the two balls away from each other. Similarly, the two charged balls will repel each other when they contact a rod of amber rubbed with a cloth. However, if the first ball is charged with the glass rod and the second with the amber rod, they will be attracted to each other, as shown in Figure (5).

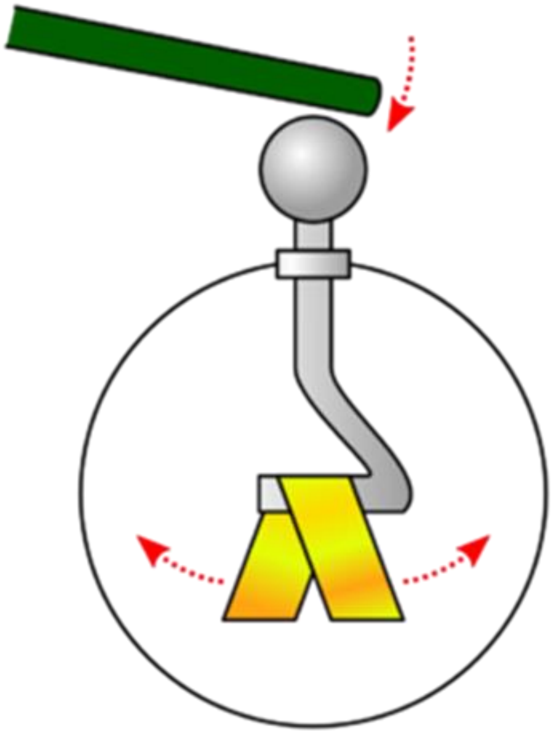


Figure (5) Gold Leaf Electroscope

Charles-Augustin de Coulomb researched these phenomena in the eighteenth century and found that electric charge exists in two opposing forms. This discovery led to the well-known principle that like charges repel each other while opposite charges attract. The force acts on charged particles themselves, causing the charge to spread as evenly as possible over the surface of a conductor. Whether attractive or repulsive, this is described by Coulomb's Law, which relates the force to the product of the charges and the inverse square of the distance between them. This led to the famous axiom: "The force of repulsion between two small charged spherical bodies of the same type of electricity is inversely proportional to the square of the distance between their centers".

The electromagnetic force is extraordinarily strong, ranking second only to the strong nuclear force in terms of interactions. However, unlike that force, the effects of electromagnetism extend across all distances. Compared to the much weaker gravitational force, the electromagnetic force that pushes two electrons away from each other is about 10^42 times greater than the gravitational force that pulls them together.

The electric charge on electrons and protons is opposite, so the amount of charge is described as negative or positive. It has become conventional to consider the charge carried by electrons as negative and that carried by protons as positive. This convention began with the work of Benjamin Franklin. The amount of charge is typically symbolized by "Q" and expressed in coulombs. Each electron carries the same charge, which is approximately 1.6022×10^{-19} coulombs. A proton has a neutral and opposite charge, equal to $+1.6022 \times 10^{-19}$ coulombs. Electric charge is not limited to matter; it also exists in antimatter. Each antiparticle carries a charge that is neutral and opposite to its corresponding particle.

Moreover, electric charge can be measured by various means, such as the gold leaf electroscope, which contains two thin strips of gold leaves hanging in a glass container that repel each other when charged. The angle of their separation depends on the amount of charge. While the use of this electroscope continues today in illustrative experiments within classrooms, the electronic electrometer has largely replaced it.

Electric Current

The movement of electric charge is known as electric current, which is typically measured in amperes. Electric current consists of any charged particles in motion. Electrons are the most common among these particles, but any moving charge can constitute a current. Conventionally, positive current is defined as the flow in the same direction as any positive charge would flow; or it is the flow from the most positive terminal of the electrical circuit to the most negative terminal. This type of current is called conventional current. Thus, the movement of negative electrons around the electrical circuit—one of the most well-known forms of electric current—flows in the opposite direction to the flow of positive current. However, depending on surrounding conditions, electric current can consist of the flow of charged particles in either direction or even in both directions simultaneously. The terms negative and positive are commonly used to simplify this scenario.

Additionally, the process through which electric current passes through a material is called electrical conduction. The nature of electrical conduction differs depending on the charged particles and the material they pass through. Examples of electric currents include metallic conduction, where electrons flow through a conductor like a metal. Furthermore, there is electrolysis, where ions (charged atoms) flow through liquids. While the particles themselves move at terribly slow speeds, with average drift velocities sometimes reaching fractions of a millimeter per second, the electric field through which these particles flow propagates at nearly the speed of light, allowing electrical signals to travel quickly through wires.

Electric current results in several noticeable effects—previously considered the means by which individuals detected the presence of electric current. William Nicholson and Anthony Carlisle discovered in 1800 that electric current could split water from a voltaic battery, a process now known as electrolysis. Michael Faraday conducted extensive studies on Nicholson and Carlisle's discovery in 1833. Current flowing through resistance generates a type of heating in the surrounding area, an effect that James Prescott studied mathematically in 1840. Among the most significant discoveries related to electric current was Hans Christian Ørsted's accidental finding in 1820 while giving a lecture, where he noticed that electric current in a wire disturbed the motion of a magnetic compass needle, thus discovering electromagnetism, a fundamental interaction between electricity and magnets.

Electric current is usually described in engineering applications and homes as either direct current (DC) or alternating current (AC). These two terms refer to how electric current changes over time. Direct current, produced by batteries, for example, flows in one direction from the positive terminal of the electrical circuit to the negative terminal. If electrons are the carriers of this flowing current, which is most common, they will flow in the opposite direction. In contrast, alternating current is any current that reverses direction periodically. This current often takes the form of a sine wave. Thus, alternating current oscillates back and forth within the conductor without the electric charge moving any distance over time. The average time period for alternating current is zero. However, it delivers energy in one direction first and then reverses. Alternating current is affected by electrical properties that are difficult to observe in the steady-state conditions characteristic of direct current.

Examples of these properties include inductance and capacitance. However, these properties become more significant when a set of electrical circuits experiences a transient in the current, such as when power is supplied to them for the first time.

Electric Field

Michael Faraday discussed the concept of the electric field, stating that it arises from a charged body in the surrounding space, as shown in Figure (6), and exerts a force on any other charges within the field. The electric field operates between two charges in the same manner that the gravitational field operates between two masses. Just like the gravitational field, the electric field extends to infinity and exhibits an inverse square relationship with distance; however, there is a crucial difference: gravity always acts as an attractive force, pulling masses towards one another, while an electric field can either attract or repel particles. Since large bodies, like planets, typically do not carry any net charge, the electric field at a distance equals zero. Thus, gravity is the dominant force in the universe, despite its relative weakness compared to other forces.

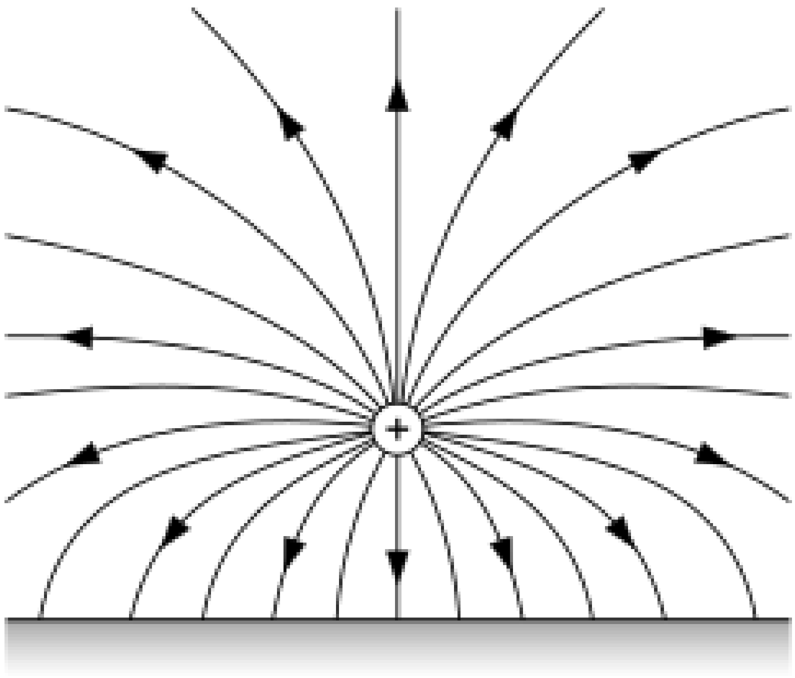


Figure (6): Electric field lines emitted from a positive charge over a flat conductor

In general, the area occupied by the electric field varies, and its intensity at any point is defined as the force (per unit charge) experienced by a small, stationary, test charge placed at that point. The test charge, referred to as a "test charge," should be extremely small to prevent its electric field from interfering with the main field. It should also be stationary to avoid creating magnetic fields. Since the electric field is defined in terms of force, and force is a vector, the electric field is also a vector with both magnitude and direction. More precisely, the electric field is a vector field. Moreover, the study of electric fields generated by stationary charges is known as electrostatics. The electric field can be visualized through a set of imaginary lines, where the direction at any point corresponds to the direction of the field .

Faraday was the first to introduce this concept, and his term "lines of force" is still used occasionally. These field lines represent the paths that a positive charge would take if it moved within the field. However, these lines are purely imaginary and do not physically exist. The field occupies the space between the lines. The field lines emitted from stationary charges possess several key properties: the first is that they originate from positive charges and terminate at negative charges. The second property is that they must enter any good conductor at right angles. The third property is that they never intersect or form loops.

Any hollow conductive object carries all its electric charges on its outer surface. Consequently, the electric field inside such an object is zero everywhere. This principle is the foundation of the Faraday cage, a conductive structure that shields its contents from external electric influences. Electrostatics is especially important when designing high-voltage equipment. There is a certain threshold where the intensity of the electric field in any medium can no longer be sustained. When this happens, electrical breakdown occurs, resulting in an electric arc (Figure 7), which is a transient flash between charged components. For example, air forms a curved path through small gaps when the electric field strength exceeds 30 kilovolts per centimeter. In larger gaps, the breakdown strength is lower, potentially around one kilovolt per centimeter. A clear natural example of this phenomenon is lightning, which occurs when electrical charges in clouds are separated by rising air columns, and the charges increase the electric field in the air beyond its capacity. The voltage in a large lightning cloud can reach up to 100 megavolts and discharge a massive amount of energy, up to 250 kilowatt-hours. The field intensity is greatly influenced by nearby conductive objects, especially when it bends around pointed surfaces. This principle is used in lightning rods, which are pointed metal rods designed to attract electrical currents from lightning, preventing them from striking the building they protect.

Figure (7): The Electric Arc

Electric Potential Difference

The concept of electric potential is closely related to the electric field. A small charge placed in an electric field experiences a force, and moving this charge to a point against the direction of this force requires some work. The electric potential at any point is defined as the energy required to slowly bring a unit test charge from an infinite distance to that point. Electric potential is usually measured in volts, where one volt is the potential that requires one joule of work to bring one coulomb of charge from infinity. Although the definition of electric potential is somewhat theoretical, it has a simple practical aspect. The more important concept is the electric potential difference, which is defined as the energy needed to move a unit charge between two specific points.

One distinguishing characteristic of the electric field is that it is "conservative," meaning that the path taken by the test charge does not matter—every path between two specific points requires the same amount of energy. Therefore, a unique value for the potential difference can be determined. The volt is the unit used to measure and describe the electric potential difference, and the term "voltage" has become widely used in everyday language.

For practical purposes, it is useful to define a common reference point against which potentials are expressed and compared. While this reference could theoretically be at infinity, the most useful reference is the Earth itself, which is assumed by some to have a constant potential everywhere. This reference point is commonly called "ground," referred to as "Earth" in British English and "ground" in US English. The Earth is considered to be an infinite source of equal amounts of positive and negative charges, making it electrically neutral and incapable of becoming charged. Figure (8) illustrates a constant voltage battery.

Figure (8): Pair of AA Batteries, where the + sign indicates the polarity of the potential difference across the battery terminals

Electric potential is a scalar quantity, meaning it has magnitude only, without any direction. It can be thought of as similar to height: just as a free object falls from different heights due to gravity, an electric charge "falls" across different potentials due to the electric field. Similar to topographic maps that display contour lines representing points of equal height, we can draw a set of lines indicating points of equal electric potential around a stationary charged object. These lines cross all field lines at right angles. They must also run parallel to the surface of a conductor; otherwise, they would create a force on charge carriers, and the field would not be static. While the electric field was originally defined as the force per unit charge, the concept of electric potential allows for a more useful alternative definition: the electric field is the local gradient of the electric potential. It is typically expressed in volts per meter, and the direction of the electric field vector is along the line of greatest potential gradient, where the equipotential lines are closest together.

Electromagnetism

Hans Christian Ørsted's discovery in 1821, that there is a magnetic field surrounding all sides of a current-carrying wire, demonstrated a direct link between electricity and magnetism. Moreover, the interaction seemed different from gravitational and electrostatic forces, which were the natural forces understood at the time. The force acting on a compass needle neither pointed it towards nor away from the current-carrying wire, but rather directed it at right angles to the wire. Ørsted's words, though somewhat cryptic, were: "The electric conflict acts in a revolving manner." The force also depended on the direction of the current; if the current reversed, so did the force.

In fact, Ørsted did not fully comprehend his own discovery, but he noted that the effect was mutual or reciprocal, meaning the current exerts a force on the magnet, and the magnetic field exerts a force on the current. André-Marie Ampère explored this phenomenon more deeply and discovered that two parallel wires carrying electric currents exert forces on each other: wires carrying current in the same direction attract, while those carrying current in opposite directions repel. This interaction is mediated by the magnetic field produced by each current, and it forms the basis for the international definition of the ampere, as illustrated in Figure (9).

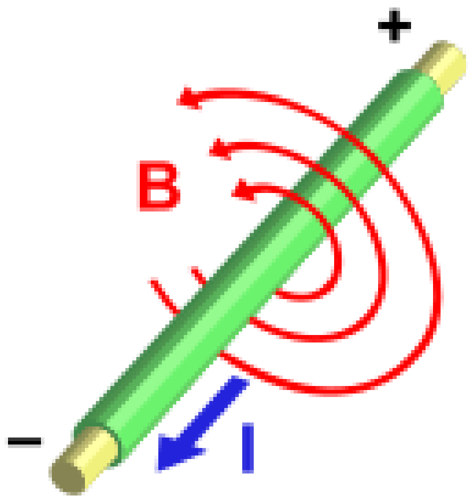


Figure (9): Magnetic Field Circles Around an Electric Current

The relationship between magnetic fields and electric currents is of great importance, as it led to Michael Faraday’s invention of the electric motor in 1821, as shown in Figure (10). Faraday’s motor, known as a unipolar motor, consisted of a permanent magnet placed inside a basin of mercury. An electric current was passed through a wire hanging from a pivot above the magnet, submerged in the mercury. The magnet exerted a tangential force on the wire, causing it to rotate around the magnet as long as the current flowed.

In 1831, Faraday's experiment demonstrated that a wire moving perpendicularly to a magnetic field generates a voltage across its ends. His further analysis of this process, known as electromagnetic induction, allowed him to establish the principle now referred to as Faraday’s Law of Induction. This law states that the induced voltage in a closed circuit is proportional to the rate of change of magnetic flux through the circuit. Using this discovery, Faraday invented the first electric generator in 1831, converting the kinetic energy of a rotating copper disk into electrical energy. While Faraday's disk was inefficient and limited as a practical generator, it illustrated the possibility of generating electric power through magnetism, paving the way for future advancements.

The work of Faraday and André-Marie Ampère revealed that a time-varying magnetic field acts as a source for an electric field, and a time-varying electric field acts as a source for a magnetic field. Therefore, when one of these fields changes over time, it necessarily induces the other. This phenomenon has wave-like properties and is commonly referred to as an electromagnetic wave. In 1864, James Clerk Maxwell theoretically analyzed electromagnetic waves and developed a set of equations that clearly describe the interrelation between electric fields, magnetic fields, electric charges, and electric currents. Furthermore, Maxwell demonstrated that these waves must propagate at the speed of light, thereby identifying light itself as a form of electromagnetic radiation. Maxwell's equations, which connect light with electric and magnetic fields and electric charge, are considered one of the greatest achievements in theoretical physics.

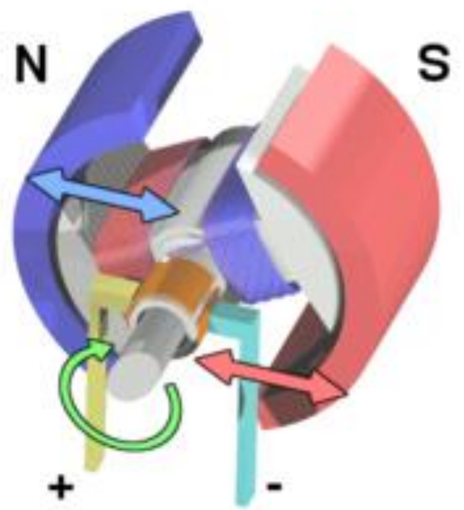


Figure (10): The Electric Motor

Electrical Circuit Components

Concept of an Electrical Circuit

An electrical circuit is a closed path through which electric current flows, transporting electrical charge from a power source, such as batteries or generators, through wires and various components, and then returning to the source to complete the circuit. The conductive elements of a circuit include a wide variety of devices that perform specific functions, such as resistors, capacitors, and inductors. These components are essential for controlling and directing the flow of current to accomplish specific tasks like lighting, heating, or powering electrical devices.

Electric current is one of the most fundamental physical phenomena, defined as the flow of electric charges through a conductive material. The current can be either direct or alternating, as shown in Figure (11):

- Direct Current (DC):

Direct current flows in only one direction. It is generated by batteries and is used in many applications, such as electronic devices that require a constant flow of energy.

- Alternating Current (AC):

Alternating current changes direction periodically. AC is used in power generation and distribution systems worldwide because it can be transmitted over long distances with high efficiency.

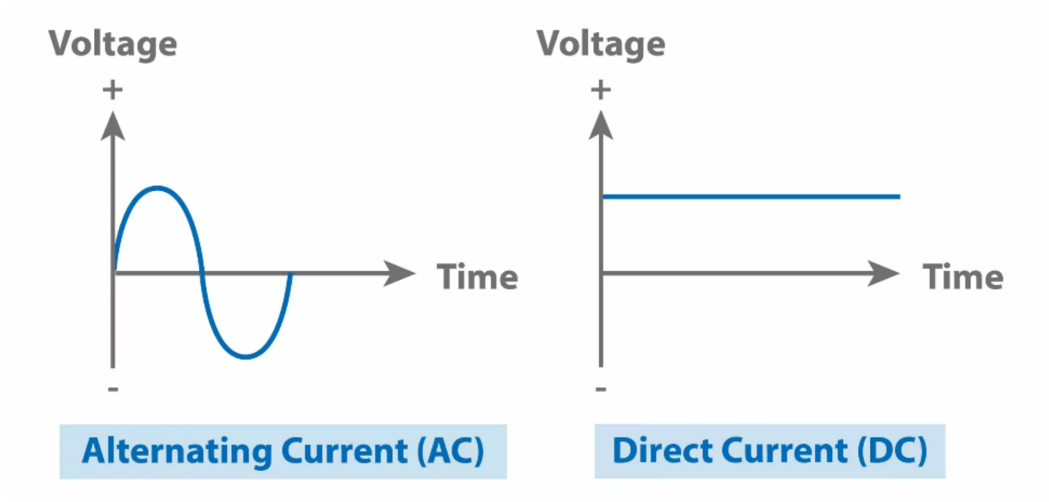


Figure (11) Direct Current and Alternating Current

Resistor

A resistor is a fundamental component in an electrical circuit that opposes the flow of electric current. It is measured in ohms (Ω). Resistors regulate the amount of current passing through the circuit by converting electrical energy into thermal energy, and they are used in all types of electrical and electronic circuits.

Types of Resistors

- **Fixed Resistors:**

These have a fixed value that cannot be changed. They are used to control current and distribute voltage, as shown in Figure (12).

Figure (12): Fixed Resistor

- **Variable Resistors:**

These resistors have values that can be adjusted, such as variable resistors (potentiometers), which are used in applications like volume control.

- **Thermistors:**

Their resistance values depend on temperature and are used in applications like temperature sensing devices, as shown in Figure.(13)

Figure (13): Thermistor

- **Practical Applications of Resistors:**

Resistors play a fundamental role in a wide range of electrical and electronic applications, such as:

  - **Voltage Division:**

Resistors are used to create specific voltage values needed in different parts of the circuit. Figure (14) illustrates the symbol for a voltage divider resistor in electrical circuits.

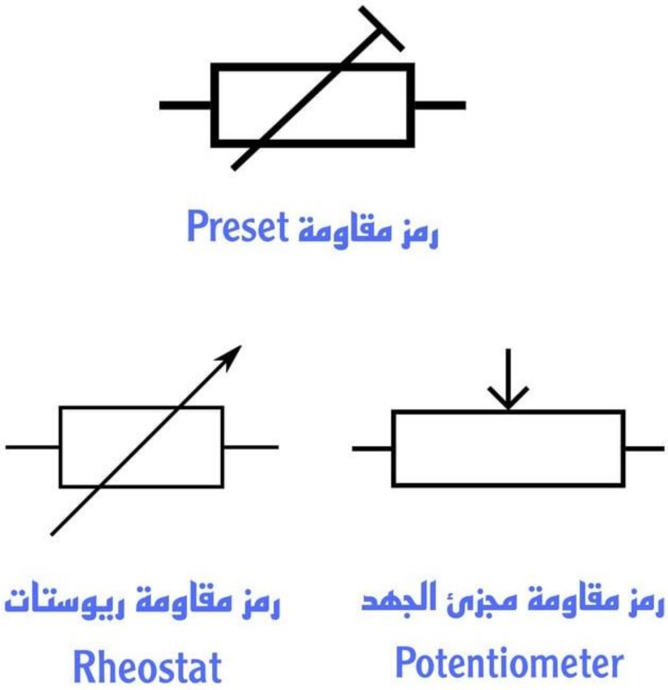


Figure (14): Variable Resistor

- **<u>Protection</u>**

Resistors are used to reduce current in sensitive circuits and to protect other components from excess currents.

Ohm's Law

- **Definition of Ohm's Law**

Ohm's Law is a fundamental law in electricity and electronics that describes the relationship between electric voltage, electric current, and resistance. The law states that the current flowing through a conductor between two points is directly proportional to the voltage difference between them and inversely proportional to the resistance of the conductor. In simpler terms: if the voltage is higher, the current will flow more. And if the resistance is higher, the current will flow less. The mathematical formula for Ohm's Law is:

$$V = IR$$

where V is the electric voltage in volts, I is the electric current in amperes (A), and R is the electric resistance in ohms (Ω).

- **Explanation of Ohm's Law Simply**

Imagine that electric current is like water flowing through a pipe. Voltage is like the pressure that pushes the water to move, and resistance is like the size of the pipe that hinders the flow of water. The higher the pressure (voltage), the faster the water (current) flows. However, if the pipe is narrower (higher resistance), the water will flow slower.

Examples

- ✓ If the voltage (water pressure) increases while the resistance (pipe size) remains constant, the current will increase.
- ✓ If the resistance (smaller pipe size) increases while the voltage remains constant, the current will decrease.

- **How to Use Ohm's Law**

We can use Ohm's Law to calculate voltage, current, or resistance in an electrical circuit, provided we know two of these variables. Here is how to calculate each case:

- **Calculating Voltage (V)**

If you know the current and resistance, you can calculate the voltage using the formula:

$$V = IR$$

Where V is the electric voltage (measured in volts, V), I is the electric current (measured in amperes, A), and R is the electrical resistance (measured in ohms, Ω).

Example

If the current is 2 amperes and the resistance is 10 ohms, the voltage will be:

$$V = 2 \times 10 = 20\ volts$$

- **Calculating the Current (I):**

If you know the voltage and resistance, you can calculate the current using the formula:

$$I = \frac{V}{R}$$

Example

If the voltage is 24 volts and the resistance is 12 ohms, the current will be:

$$I = \frac{V}{R} = \frac{24}{12} = 2\ Amper$$

- **Calculating Resistance (R)**

If you know the voltage and the current, you can calculate the resistance using the formula:

$$R = \frac{V}{I}$$

Example

If the voltage is 15 volts and the current is 3 amperes, the resistance will be:

$$R = \frac{V}{I} = \frac{15}{3} = 5\ \Omega$$

- **Applications of Ohm's Law in Electrical Circuits**
  - **Series Circuit**

In a series circuit, all components are connected in sequence, and the current is the same through all the components, while the voltage is distributed among them.

- **Total Resistance (RTotal):**

$$R_{total} = R_1 + R_2 + R_3 + ...$$

This means that the resistances are added together to determine the total resistance.

- **Current**

In a series circuit, the same current flows through all the components.

- **Voltage**

The total voltage is the sum of the voltages across all the resistors.

- **Parallel Circuit**

In a parallel circuit, the components are connected in parallel, so the voltage across each component is the same, while the current is distributed among the components.

- **Total Resistance (R_{Total})**

The total resistance is calculated using the equation:

$$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

- **Voltage**

The voltage across each component is the same.

- **Total Current (I_{Total})**

The total current in a parallel circuit is the sum of the currents through all the components.

- **Effect of Temperature on Ohm's Law**

In some cases, the resistance value changes with temperature variation. For example, in metals, resistance increases with rising temperature. Therefore, if the temperature is high, the current will decrease because the resistance increases, which may require adjustments in Ohm's Law calculations.

- **Importance of Ohm's Law in Practical Life**

Ohm's Law is fundamental to understanding how electrical circuits work. It is used in designing electrical systems in our daily lives, such as household appliances, lights, computers, and mobile phones. Through this law, engineers and technicians can calculate the requirements for voltage and current to ensure that systems operate correctly and safely.

- **Limitations of Ohm's Law**

Ohm's Law does not apply to all materials. In some materials, such as semiconductors or non-linear materials, the relationship between voltage and current is not linear, and thus Ohm's Law cannot be used directly. Additionally, in superconductors, which have zero resistance at certain temperatures, the traditional Ohm's Law does not apply.

- **Numerical Examples**

1. If we have a voltage source of 10 volts and a resistance of 5 ohms, the current flowing through the circuit can be calculated using Ohm's Law:

$$I = \frac{V}{R} = \frac{10}{5} = 2\ Ampere$$

2. If the voltage across a resistance of 100 ohms is 5 volts, then the current is:

$$I = \frac{V}{R} = \frac{5}{100} = 0.05\ Ampere$$

Capacitor

- **Definition of a Capacitor**

A capacitor is an electrical component that stores energy in the form of an electric field between two metal plates insulated by a dielectric material. Electric charge is stored in the capacitor when it is connected to a voltage source, and this charge is released when needed in the circuit.

- **Electric Capacitance**

Capacitance is a measure of a capacitor's ability to store charge per unit voltage and is measured in farads (F). The capacitance is determined by the relationship:

$$Q = V \times C$$

where Q is the charge stored in the capacitor (coulombs), C is the capacitance (farads), and V is the voltage across the capacitor (volts).

- **Types of Capacitors**
    - Fixed Capacitors: These have fixed capacitance values and are used in many applications such as filtering circuits and temporary energy storage, as shown in Figure (15).

Figure (15): Fixed Capacitors

- Variable Capacitors: Variable capacitors are capacitors whose capacitance can be changed. They are used in applications such as radios to adjust the frequency.

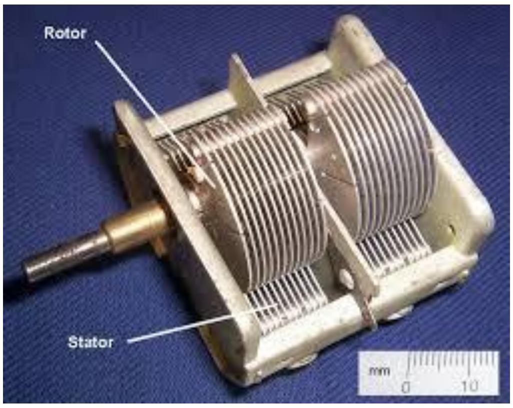


Figure (16): Variable Capacitors

Practical Applications of Capacitors

- **Smoothing**

  Capacitors are used in direct current (DC) circuits to smooth voltage and remove ripples.

- **Filtering**

  In alternating current (AC) circuits, capacitors are used to filter high or low-frequency signals.

Numerical Examples

If a capacitor with a value of 10 microfarads is connected to a voltage of 12 volts, the charge stored in the capacitor will be:

$$Q = V \times C = 10 \times 10^{-6} \times 12 = 120\ \mu C$$

Inductor

An inductor is an electrical component that stores energy in the form of a magnetic field. It consists of wire wound around a magnetic core or air. When current flows through the inductor, a magnetic field is generated around it that stores energy.

- **Self-Inductance**

Self-inductance is the ability to generate a counter-voltage when there is a change in electric current through the inductor. The inductance factor is measured in henries (H). The relationship between voltage and current in the inductor is expressed by the following equation:

$$V = L\frac{dI}{dt}$$

where V is the voltage generated across the inductor (V), L is the inductance (henries), and $\frac{dI}{dt}$ is the rate of change of current (amperes/second).

- **Types of Inductors**
  - <u>Air-core Inductors:</u> These do not contain a magnetic core and are used in applications that require low inductance, as shown in Figure (17).

Figure (17): Inductor Coil

  - <u>Inductors with Magnetic Cores:</u> These inductors contain a core made of magnetic material and are used in applications that require higher inductance, as shown in Figure (18).

Figure (18): An inductor with a magnetic core

Practical Applications of Inductors

- **Filters**

Inductors are used with capacitors in filter circuits to control frequencies.

- **Transformers**

Inductors are used in transformers to transfer energy between electrical circuits through magnetic induction.

Numerical Examples

If an inductor with a value of 5 henries has a current increasing at a rate of 2 amperes per second, the voltage generated across the inductor is:

$$V = L\frac{dI}{dt} = 5 \times 2 = 10\,Volts$$

Voltage and Electric Current

- **Voltage**

Voltage is the difference in electric potential energy between two points in a circuit. It is considered the force that pushes electric charges to move through the conductor. Voltage is measured in volts (V).

- **Electric Current**

Electric current is the flow of electric charges in the circuit and is measured in amperes (A). Current can be divided into two main types:

- Direct Current (DC): Flows in a fixed direction.
- Alternating Current (AC): Changes direction periodically.

Electric Power Source

A power source is the element that provides voltage and current in the electrical circuit. The power source can be either a direct current source like batteries or an alternating current source like electricity generators used in homes.

- **Batteries**

Batteries are one of the most well-known sources of direct current energy, used in portable applications like smartphones and medical devices. Figure (19) shows some types of batteries.

Figure (19): Some Types of Batteries

- **Generators**

Generators are devices that convert mechanical energy into electrical energy. They are primarily used to generate alternating current (AC) in public power grids. Figure (20) illustrates some types of generators.

Figure (20) The Electric Generator

Kirchhoff's Law

Kirchhoff's laws are fundamental for analyzing electrical circuits, especially when dealing with complex systems that cannot be analyzed using Ohm's simple law alone. These laws provide a method for calculating currents and voltages in multi-component and multi-source circuits, allowing for accurate analysis of each part of the circuit.

A. Kirchhoff's First Law: Current Conservation (Node Law)

a. Definition of the Law

Kirchhoff's first law, or the "node law," states that the sum of currents entering any node in an electrical circuit equals the sum of currents leaving it. In other words, the current that enters any point in the circuit must exit by the same amount, as current cannot be stored at any point in an electrical circuit.

b. Mathematical Formula

$$\sum I_{in} = \sum I_{out}$$

where I_{in} is the sum of currents entering the node, and I_{out} is the sum of currents leaving the node.

c. The Physics Behind Kirchhoff's Law

This law is based on the principle of charge conservation, where electric charges (electrons) do not accumulate at a single point in a steady circuit. Therefore, at any node, the incoming current is equal to the outgoing current to ensure a continuous flow of charge.

d. Applications of the Node Law

This rule is used to analyze electrical circuits that contain multiple intersections. It allows for the calculation of current in each branch of the circuit.

Example 1

Suppose you have a node where three wires intersect, as shown in Figure (21).

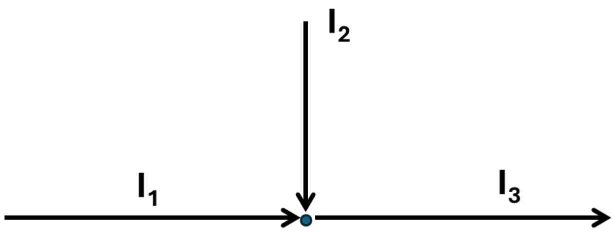


Figure (21) A node with three currents

Current I_1=4 A, enters the node, current I_2=6 A also enters the node, and current I_3 exits the node. Using the node law applied in Kirchhoff's Law:

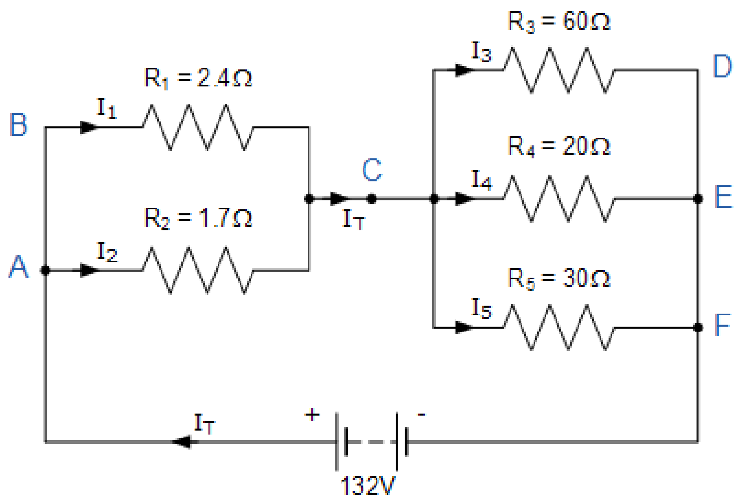
$$I_3 = I_1 + I_2$$

$$I_3 = 4 + 6 = 10\ A$$

This means that the current leaving the node is equal to 10 amperes.

Example 2

In a complex network as shown in Figure (22) containing multiple intersections, Kirchhoff's first law can be used to calculate the currents in the branches of the circuit. For each node, we calculate the incoming and outgoing currents and solve the algebraic system to obtain the unknown values.



شكل (22) شبكة معقدة

In this example, there are four distinct branching points for current flow, either splitting or merging at nodes A, C, E, and node F. The supplied current (I_T) splits at node A, flowing through resistors R_1 and R_2, then it gathers again at node C before splitting again through resistors R_3, R_4, and R_5, and finally gathers again at node F. However, before we can calculate the individual currents flowing through each branch of the resistors, we must first calculate the total current in the circuit (I_T). Ohm's law states that ($I = V/R$), and since we know the value of V is 132 volts, we need to calculate the resistances of the circuit as follows:

<u>The resistance of the circuit R_{AC}</u>

$$\frac{1}{R_{(AC)}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{2.4} + \frac{1}{1.7}$$

$$\frac{1}{R_{(AC)}} = 1 \qquad \therefore R_{(AC)} = 1\Omega$$

Thus, the equivalent resistance of the circuit between nodes A and C is calculated as follows: 1 ohm.

<u>The resistance of the circuit R_{CF}</u>

$$\frac{1}{R_{(CF)}} = \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5} = \frac{1}{60} + \frac{1}{20} + \frac{1}{30}$$

$$\frac{1}{R_{(CF)}} = 0.1 \qquad \therefore R_{(CF)} = 10\Omega$$

Thus, the equivalent resistance of the circuit between nodes C and F is calculated as follows: 10 ohms. Then, the total current of the circuit I_T is calculated as follows:

$$R_T = R_{(AC)} + R_{(CF)} = 1+10 = 11\,\Omega$$

$$I_T = \frac{V}{R_T} = \frac{132}{11} = 12 \text{ Amperes}$$

This gives us the circuit in Figure (23) as an equivalent circuit for Kirchhoff's current law.

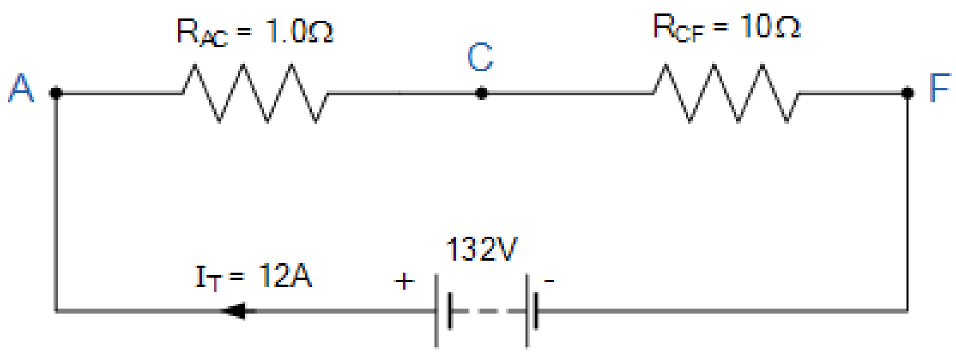


Figure (23) - Equivalent Circuit for Kirchhoff's Current Law

Therefore:

$$V = 132V$$

$$R_{AC} = 1\Omega$$

$$R_{CF} = 10\ \Omega\text{'s}$$

$$I_T = 12\ A$$

After determining the equivalent parallel resistances and the supplied current, we can now calculate the individual currents in each branch and verify the results using Kirchhoff's junction rule as follows:

$$V_{AC} = I_T \times R_{AC} = 12 \times 1 = 12\,\text{Volts}$$

$$V_{CF} = I_T \times R_{CF} = 12 \times 10 = 120\,\text{Volts}$$

$$I_1 = \frac{V_{AC}}{R_1} = \frac{12}{2.4} = 5\,\text{Amps}$$

$$I_2 = \frac{V_{AC}}{R_2} = \frac{12}{1.7} = 7\,\text{Amps}$$

$$I_3 = \frac{V_{CF}}{R_3} = \frac{120}{60} = 2\,\text{Amps}$$

$$I_4 = \frac{V_{CF}}{R_4} = \frac{120}{20} = 6\,\text{Amps}$$

$$I_5 = \frac{V_{CF}}{R_5} = \frac{120}{30} = 4\,\text{Amps}$$

Therefore:

$$I_1 = 5\,A,$$

$$I_2 = 7\,A,$$

$$I_3 = 2\,A,$$

$$I_4 = 6\,A,$$

$$I_5 = 4\,A$$

We can confirm that Kirchhoff's current law holds true in the circuit by using node C as a reference point to calculate the currents entering and leaving the junction as follows:

$$\text{At node C} \quad \sum I_{IN} = \sum I_{OUT}$$

$$I_T = I_1 + I_2 = I_3 + I_4 + I_5$$

$$\therefore 12 = (5 + 7) = (2 + 6 + 4)$$

We can also verify again whether Kirchhoff's current law is correct, where the currents entering the node are positive, while the currents leaving it are negative. Therefore, the algebraic sum is:

$$I_1 + I_2 - I_3 - I_4 - I_5 = 0$$

Which equals:

$$5 + 7 - 2 - 6 - 4 = 0$$

Thus, we can confirm through analysis that Kirchhoff's Current Law (KCL), which states that the algebraic sum of currents at a junction in a circuit network is always zero, is true and validated in this example.

Example 3

Find the currents flowing around the following circuit (Figure 24) using Kirchhoff's Current Law only.

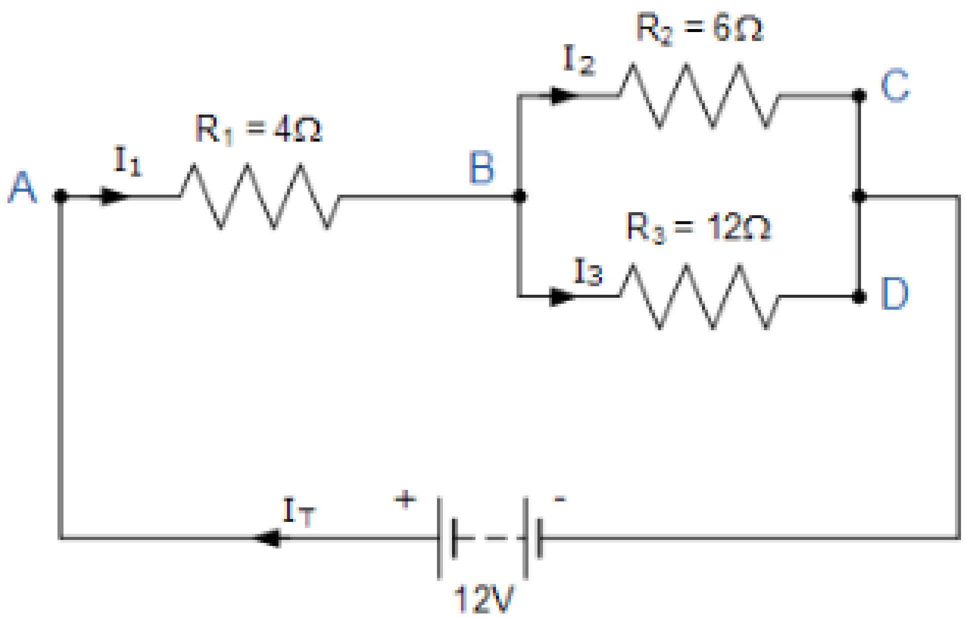


Figure (24) a circle from Kirchhoff's laws.

I_T is the total current flowing around the circuit resulting from a 12-volt power source. At point A, I_1 equals I_T, and thus there will be a voltage drop of $R \times I_1$ across resistor R_1. The circuit contains two branches, three points B, C, and D, and two independent loops. Therefore, the voltage drops $R \times I$ around the two loops will be as follows:

Loop ABC:

$$12 = 4I_1 + 6I_2$$

Loop ABD:

$$12 = 4\,I_1 + 12\,I_3$$

Since Kirchhoff's current law states that at node B:

$$I_1 = I_2 + I_3$$

We can substitute the current I_1 with the value $(I_2 + I_3)$ in both loop equations and then simplify them. Thus, Kirchhoff's equations can be applied as follows:

Loop (ABC)	Loop (ABD)
$12 = 4I_1 + 6I_2$	$12 = 4I_1 + 12I_3$
$12 = 4(I_2 + I_3) + 6I_2$	$12 = 4(I_2 + I_3) + 12I_3$
$12 = 4I_2 + 4I_3 + 6I_2$	$12 = 4I_2 + 4I_3 + 12I_3$
$12 = 10I_2 + 4I_3$	$12 = 4I_2 + 16I_3$

We now have two simultaneous equations related to the currents flowing around the circuit.

Equation 1:

$$12 = 10\,I_2 + 4\,I_3$$

Equation 2:

$$12 = 4\,I_2 + 16\,I_3$$

By multiplying the first equation (Loop ABC) by 4 and subtracting Loop ABD from Loop ABC, we can simplify both equations to obtain the values of I_2 and I_3:

Equation 1:

$$12 = 10I_2 + 4I_3 \,(\times\ 4) \Rightarrow 48 = 40I_2 + 16I_3$$

Equation 2:

$$12 = 4I_2 + 16I_3 \,(\times\ 1) \Rightarrow 12 = 4I_2 + 16I_3$$

Equation 1 - Equation 2

$$36 = 36\,I_2 + 0$$

Substituting I_2 in terms of I_3 gives the value of I_2 as 1.0 ampere. Now, we can perform the same procedure to find the value of I_3 by multiplying the first equation (Loop ABC) by 4 and the second equation (Loop ABD) by 10. Again, by subtracting Loop ABC from Loop ABD, we can simplify both equations to obtain the values of I_2 and I_3.

Equation 1:

$$12 = 10I_2 + 4I_3 \,(\times\ 4) \Rightarrow 48 = 40I_2 + 16I_3$$

Equation 2:

$$12 = 4I_2 + 16I_3 \,(\times\ 10) \Rightarrow 120 = 40I_2 + 160\,I_3$$

Equation 1 - Equation 2

$$72 = 0 + 144\,I_3$$

Thus, substituting I_3 in terms of I_2 gives us the value of I_3 as 0.5 amperes. As Kirchhoff's law for junction's states:

$$I_1 = I_2 + I_3$$

The supplied current flowing through resistor R_1 is given as follows:

$$1.0 + 0.5 = 1.5\,A$$

Thus, $I_1 = I_t = 1.5$ amperes, $I_2 = 1.0$ ampere, and $I_3 = 0.5$ amperes. From this information, we can calculate the voltage drops ($I \times R$) across the devices and at the various points (nodes) around the circuit. We could have easily solved the second example circuit using Ohm's Law alone, but we used Kirchhoff's current law here to demonstrate how it is possible to solve more complex circuits when Ohm's Law cannot be simply applied.

B. **Kirchhoff's Second Law: Voltage Conservation (Loop Law)**

- **Definition of the Law**

Kirchhoff's second law, or the "Loop Law," states that the sum of the voltage differences around any closed loop in an electrical circuit equals zero. This law expresses the conservation of energy in the circuit, as the electrical energy gained from voltage sources is fully consumed by the other components in the circuit.

- **Mathematical Formula**

$$\sum V = 0$$

where V is the voltage difference across each component in the loop.

- **The Physics Behind the Law**

The loop law is based on the principle of energy conservation, where the energy generated from voltage sources (such as batteries) is distributed among the components of the circuit (such as resistors and capacitors). Consequently, the sum of the voltage differences in a closed circuit is zero, as the resistor or capacitor consumes the supplied energy. This idea from Kirchhoff is generally known as energy conservation, where moving around a closed loop, or circuit, will bring you back to where you started in the circuit, thereby returning to the same initial voltage without losing voltage around the loop. Therefore, any voltage drops around the loop must equal any opposing voltage sources encountered along the way. Thus, when applying Kirchhoff's Voltage Law (KVL) to a specific circuit element, it is crucial to pay particular attention to the algebraic signs (+ and -) of the voltage drops across elements and the emf of the voltage sources, otherwise our calculations may be incorrect. However, before we closely examine Kirchhoff's Voltage Law (KVL), let us first understand the voltage drop across a single element such as a resistor.

- **Single Circuit Element**

In this simple example, as shown in Figure (25), we will assume that the current I flow in the same direction as the flow of positive charge, which is known as conventional current flow. Here, the current flows through the resistor from point A to point B, that is, from the positive terminal to the negative terminal. Therefore, as we move in the same direction as the current flow, there will be a voltage drop across the resistive element, resulting in a voltage drop of $-(I \times R)$. If the current flows in the opposite direction from point B to point A, there will be a voltage rise across the resistive element, as we move from a negative voltage to a positive voltage, resulting in a voltage drop of $+(I \times R)$.

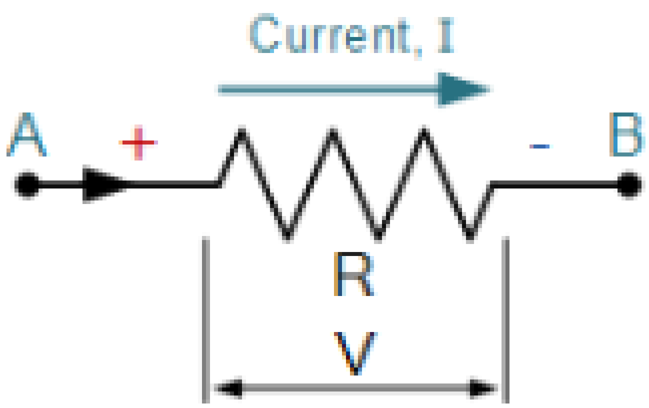
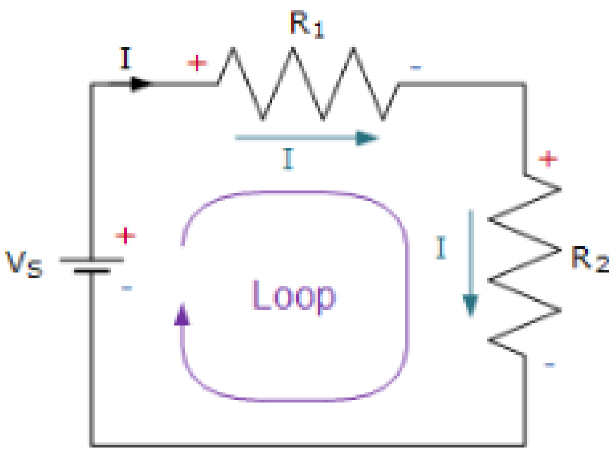


Figure (25) A single element circuit

Therefore, to correctly apply Kirchhoff's Voltage Law to an electrical circuit, one must first understand the direction of polarity. As we can see, the sign of the voltage drop across the resistive element will depend on the direction of the current flowing through it. As a general rule, there will be a voltage loss in the same direction as the current through the element and a voltage gain when moving towards the source of the electromotive force (emf). The direction of current flow around a closed circuit can be assumed to be either clockwise or counterclockwise, and either can be chosen. If the chosen direction is different from the actual direction of current flow, the result will still be valid and correct, but it will yield an algebraic answer with a negative sign. To better understand this idea, let us take a look at a single loop circuit to see if Kirchhoff's Voltage Law holds true.

- **Single Loop Circuit**

Kirchhoff's Voltage Law states that the algebraic sum of the potential differences in any loop must equal zero as follows: $\Sigma V = 0$. Since the resistors R_1 and R_2 are connected in series as shown in Figure (26), they are part of the same loop, and therefore the same current must flow through each resistor. Thus, the voltage drop across resistor R_1 is $I \times R_1$, and the voltage drop across resistor R_2 is $I \times R_2$, which gives us, according to Kirchhoff's Voltage Law:



شكل (26) دائرة حلقة مغلقة

$$V_S + (-IR_1) + (-IR_2) = 0$$

$$\therefore V_S = IR_1 + IR_2$$

$$V_S = I(R_1 + R_2)$$

$$V_S = IR_T$$

$$\text{Where: } R_T = R_1 + R_2$$

We can see that applying Kirchhoff's Voltage Law to this single closed loop results in a formula for the equivalent or total resistance in the series circuit. We can expand on this to find the values of the voltage drops around the loop.

$$R_T = R_1 + R_2$$

$$I = \frac{V_S}{R_T} = \frac{V_S}{R_1 + R_2}$$

$$V_{R1} = IR_1 = V_S\left(\frac{R_1}{R_1 + R_2}\right)$$

$$V_{R2} = IR_2 = V_S\left(\frac{R_2}{R_1 + R_2}\right)$$

Example 1

A simple circuit containing a battery and a resistor as shown in Figure (27). Let us assume a circuit with a battery of 9 volts and a resistor of 3 ohms. Using Kirchhoff's Second Law, we calculate the current flowing in the circuit as follows:

$$V = IR$$

$$\therefore I = \frac{V}{R} = \frac{9}{3} = 3\ A$$

Thus, the current flowing in the circuit is 3 amperes.

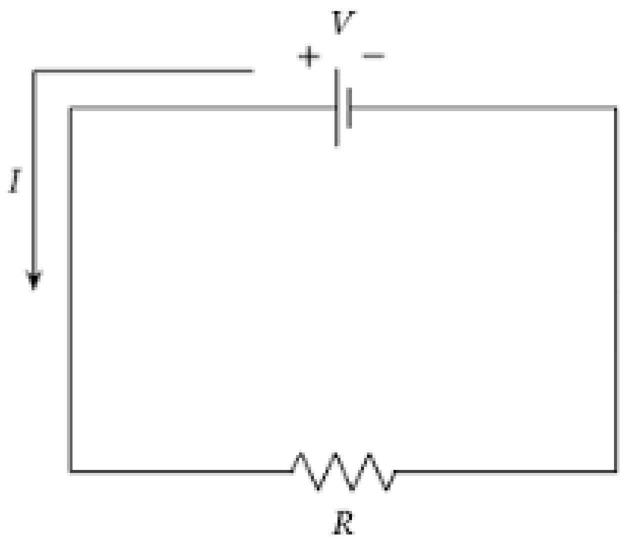


Figure (27) Battery and Resistor

Example 2: Complex Circuit with Two Loops

Assume a circuit containing two voltage sources (V_1 = 12 V) and (V_2 = 6 V), and two resistors (R_1 = 4 ohms) and (R_2 = 2 ohms). Using Kirchhoff's Second Law to analyze the first loop:

$$V_1 - I_1R_1 - I_2R_2 = 0$$

$$12 - I_1 \cdot 4 - I_2 \cdot 2 = 0$$

We apply the same method for the second loop.

Applications of Kirchhoff's Laws in Analyzing Complex Circuits

- Analyzing Circuits

When using Kirchhoff's laws to analyze complex circuits, we follow these steps:

- Identify Nodes and Loops: Identify all points where wires intersect and any closed loops in the circuit.
- Apply the Junction Law: Calculate the currents flowing through each branch at each node.
- Apply the Loop Law: For each closed loop, calculate the sum of the voltage differences, which should equal zero.

- Solve the Equations: After obtaining the equations from both laws, use algebra to solve the complex system and find the unknown values.

Example: Circuit with Two Voltage Sources

Assume a circuit containing two voltage sources, one of 9 volts and the other of 6 volts, along with three resistors connected in two loops. Using Kirchhoff's First and Second Laws, we determine the currents flowing in the circuit.

Example: Simple Circuit with Resistor and Voltage Source

A circuit containing a battery with a voltage of 12 volts and a resistor of 6 ohms. We use the Loop Law to calculate the current flowing in the circuit:

$$V = IR$$

$$I = \frac{V}{R} = \frac{12}{6} = 6\ A$$

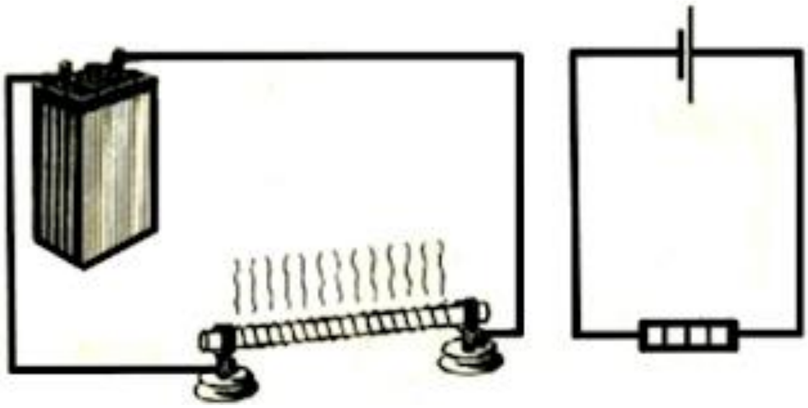
Thus, the current flowing in the circuit is 2 amperes.

Effects of Electric Current

Electric current is defined as the amount of electric charge transferred per unit of time, representing the flow of electrons through conductive materials such as metal wires and other conductive substances. When electric current flows through conductive materials in a closed circuit, several different effects of electric current occur, including:

1. **Thermal Effect of Electric Current (Joule's Law)**
    a. A. Basic Concept

When electric current flows through wires and metallic conductive materials, resistance occurs to the movement of electrons through resistors or wires, converting this resistance into thermal energy. Thus, electrical energy is transformed into heating energy, as shown in Figure (28). This principle serves as the operating mechanism for many important devices, such as solar heaters, electric heating appliances, and toasters.



شكل (28) التأثير الحراري للتيار الكهربائي

b. Joule's Law of Heating

Joule's Law states that the thermal energy produced by the flow of electric current through a resistor is directly proportional to the square of the current, the resistance, and the time for which the current flows. It is expressed by the following equation:

$$Q = I^2 \times R \times t$$

Where:

- Q is the heat energy generated (in joules),
- I is the current (in amperes),
- R is the resistance (in ohms),
- t is the time (in seconds).

An increase in the electric current flowing through a conductor or an increase in the resistance of the material leads to the generation of more heat. This is why electrical wires heat up when a large current passes through them.

c. Practical Applications of the Thermal Effect:

i. Home Applications

-Electric Heaters: These operate by converting electrical energy into heat using high resistance.

-Irons: They rely on generating sufficient heat to enable pressing and ironing clothes.

-Electric Ovens: These use resistors to generate heat for cooking, as shown in Figure (29).

Figure (29): Home Applications of the Thermal Effect of Electric Current

ii. Medical Applications

-Electric Heating Therapy: The heat generated by the flow of current is used to treat damaged muscles and tissues, as it improves blood circulation and accelerates the healing process, as shown in Figure (30).

Figure (30): Electric Heating Therapy

2. **Magnetic Effect of Electric Current (Magnetic Field Generated by Current)**

   a. Basic Concept

When electrons move through a conductor or wire, they generate a magnetic field around the conductor, perpendicular to the direction of the electric current, as shown in Figure (31). The direction of the magnetic field is determined using the right-hand rule, as discovered by the scientist Oersted. This magnetic field produced by electric current is utilized in the manufacturing of various electronic and electrical equipment.

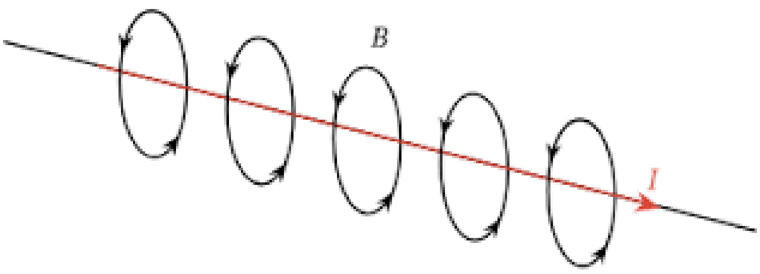


Figure (31): Magnetic Field of Electric Current

b. Right-Hand Rule

The direction of the magnetic field generated by an electric current can be determined using the right-hand rule: If the thumb points in the direction of the current, then the curled fingers around the wire indicate the direction of the magnetic field, as shown in Figure (32).

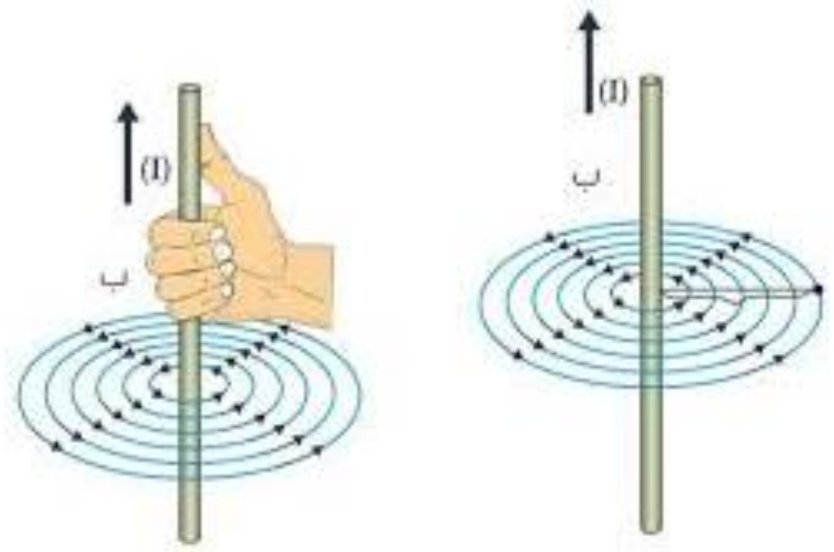


Figure (32): Right-Hand Rule for Magnetic Force

c. Magnetic Field Strength

The magnetic field strength around an infinitely long straight wire is calculated using the following formula:

$$B = \frac{I \times \mu_0}{2\pi r}$$

where B is the magnetic field strength (in Teslas), I is the electric current (in Amperes), r is the distance from the wire (in meters), and μ_0 is the magnetic permeability of free space, equal to $4\pi \times 10^{-74}$ Henries per meter.

Practical Applications of the Magnetic Effect

1. **Electric Motors**

Motors rely on the interaction between electric current and the magnetic field to generate motion. This technology is used in a variety of devices, including fans and manufacturing machines.

2. **Electric Generators**

Electric generators convert mechanical energy into electrical energy by rotating a coil within a magnetic field, which induces an electric current, as shown in Figure (34).

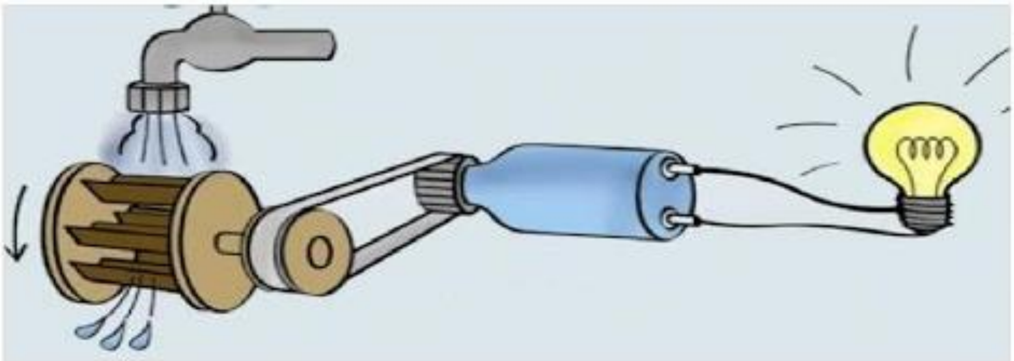


Figure (34) The Electric Generator

3. **Medical Devices**

Magnetic Resonance Imaging (MRI): MRI relies on generating strong magnetic fields to target and receive signals from the body's tissues, allowing for the creation of detailed images of internal organs. Figure (35) illustrates an MRI machine used in hospitals.

Figure (35) Magnetic Resonance Imaging (MRI) Device

3. Chemical Effect (Electrolysis)

The chemical effect of electric current is a broad topic that encompasses many applications and phenomena. This effect occurs when electric current passes through a conductive liquid (such as an electrolytic solution), leading to chemical reactions within that solution. This phenomenon is known as electrolysis. Let us discuss the topic in detail, using equations, diagrams, and examples.

- What is Electrolysis?

Electrolysis is the process of decomposing a chemical compound using electric current. This typically takes place in a solution containing ions (an electrolytic solution), where electricity causes the movement of ions, thus triggering reactions at the electrodes.

- Devices Used in Electrolysis
  - Electrolysis Cell: This consists of two electrodes (anode and cathode) submerged in an electrolytic solution, as shown in Figure (36).
  - Anode: This is the electrode where oxidation occurs (loss of electrons).
  - Cathode: This is the electrode where reduction occurs (gain of electrons).

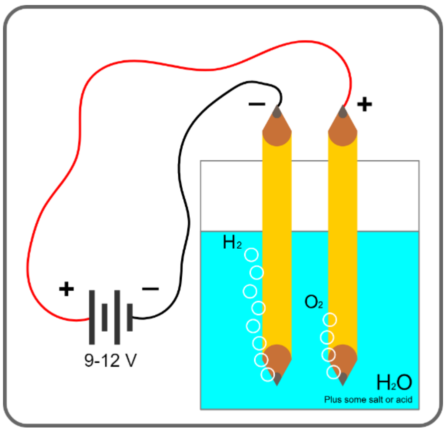


Figure (36) Electrolysis Cell for Water

- Chemical Reactions in Electrolysis

Oxidation and reduction reactions occur at the electrodes in an electrolysis cell. Positive ions in the solution move toward the cathode, where they gain electrons (reduction). Negative ions move toward the anode, where they lose electrons (oxidation).

- Oxidation and Reduction Equations

Let us assume we are performing the electrolysis of sodium chloride (NaCl) solution in water. When electric current passes through the solution, the following reactions occur:

- At the Anode:

Chloride ions (Cl^-) are oxidized to form chlorine gas (Cl_2):

$$2Cl^- \rightarrow Cl_2 + 2e^-$$

- At the Cathode:

Sodium ions (Na^+) or water are reduced, leading to the formation of hydrogen gas (H_2):

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

- Practical Examples of Electrolysis
  - Water Electrolysis for Hydrogen and Oxygen Production:

Electrolysis of water is a common application where water is split into hydrogen gas and oxygen gas. Hydrogen gas is generated at the cathode (reduction), while oxygen gas is produced at the anode (oxidation):

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

- Metal Purification:

Electrolysis is used for the purification of metals, such as copper. Impure copper (anode) and pure copper (cathode) are placed in an electrolytic solution.

Pure copper is deposited at the cathode while impure copper is oxidized at the anode, as shown in Figure (37):

$$Cu^{2+} + 2e^{-} \rightarrow Cu\ (Pure\ at\ the\ cathode)$$

$Cu^{2+} + 2e^{-} \rightarrow Cu$ (نقي عند الكاثود)

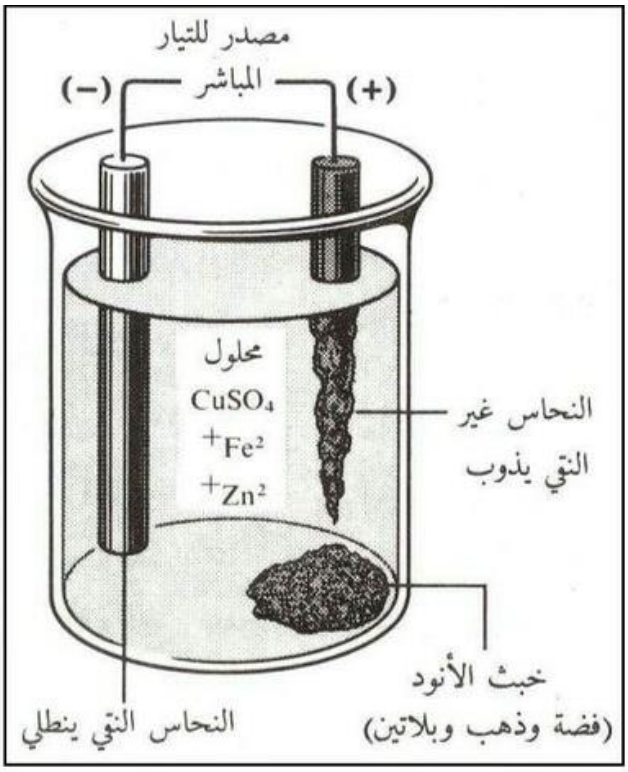


Figure (37): Copper Purification by Electrolysis

- Electroplating

In electroplating, electric current is used to deposit a layer of metal onto the surface of another material. For example, if we want to plate a spoon with silver, the spoon is placed as a cathode in an electrolytic cell using a solution containing silver ions. The silver ions move towards the spoon and are deposited on it as a thin layer:

$$Ag^{+} + e^{-} \rightarrow Ag\ (Silver\ deposition\ on\ the\ spoon)$$

Factors Affecting Electrolysis

- Electric Voltage

The success of electrolysis depends on the applied voltage between the electrodes. If the voltage is insufficient, the required chemical reactions will not occur.

- Type of Electrolyte

The type of electrolyte used affects the type of reactions that take place. For instance, the products formed during the electrolysis of sodium chloride solution differ from those produced during the electrolysis of copper sulfate solution.

- Electric Current

As the current intensity increases, the reaction speed increases, and the number of substances being decomposed also increases.

Importance of Faraday's Laws in Electrolysis

- Faraday's First Law of Electrolysis: The amount of substance decomposed at one of the electrodes is directly proportional to the amount of electricity passed through the solution.
- Faraday's Second Law of Electrolysis: The quantities of substances decomposed or deposited at different electrodes due to the same amount of electricity are proportional to their chemical equivalents.

Faraday's Equation

$$m = (Q / F) \times (M / n)$$

- m is the mass of the decomposed substance,
- Q is the total charge passed ($Q = I \times t$),
- I is the current,
- t is the time,
- F is Faraday's constant, equal to F=96.485 coulombs/mole,
- M is the molar mass of the substance,

- n is the number of electrons per ion.

Conclusion

The chemical effect of electric current is a vital process that relies on the principles of oxidation and reduction and the movement of ions in the solution under the influence of electric current. This process plays a crucial role in many industrial applications, such as metal purification, gas production (like hydrogen), electroplating, and more.

Applications of Different Electric Current Effects in Biological Systems

The effects of electric current in biological systems are diverse and complex, impacting nerve signals, muscles, tissues, and even the chemical composition of living organisms. Applications of these effects in medical and therapeutic fields are rapidly advancing, making a deep understanding of these effects essential. Here, we will cover the thermal, magnetic, chemical, and physiological effects of electric current on biological systems, mentioning modern applications and supporting explanations with equations and illustrations wherever possible.

Thermal Effects of Electric Current in Biological Systems

When electric current passes through living tissues, a phenomenon known as thermal effect or Joule Effect occurs. Due to the resistance of the tissues, electrical energy is converted into thermal energy, leading to an increase in temperature in the area where the current flows. Some applications include:

- **Electrosurgery**

Electrosurgery (as shown in Figure 38) relies on high-frequency electric current to cut tissues or coagulate blood vessels. High-frequency current is directed through body tissues, generating enough localized heat to cut the tissues or coagulate blood to stop bleeding.

Figure (38) Electric Surgery

An example of electric surgery involves placing a small electrode in the surgical area to pass current. The high-frequency current generates enough heat to precisely fragment or cut the tissues, reducing surrounding damage and aiding in immediate bleeding control.

A. Hyperthermia Therapy for Cancer

This technique relies on locally raising the temperature of a tumor using electric current. The increase in temperature leads to the destruction of cancer cells or makes them more sensitive to chemotherapy and radiation therapy. However, there are some adverse effects associated with these treatment methods, summarized as electrical burns. If the electric current is too strong or if it lasts for too long, it can cause deep electrical burns. The severity of the burns varies based on the intensity of the current and the duration of exposure.

Magnetic Effects of Electric Current in Biological Systems

When electric current passes through a conductor, a magnetic field is generated around it. In biological systems, this effect plays a significant role in neurology and medical research. It has several applications, including:

A. Magnetic Resonance Imaging (MRI)

One of the primary applications of the magnetic effect of electric current is Magnetic Resonance Imaging (MRI). MRI machines use an extraordinarily strong magnetic field generated by electric current to image internal tissues in high detail. The response of the tissues inside the body varies based on their type, providing detailed images of bones and soft tissues, as shown in Figure (39).

Figure (39): Magnetic Resonance Imaging (MRI)

A. Transcranial Magnetic Stimulation (TMS):

In transcranial magnetic stimulation, powerful magnetic pulses are directed to specific brain areas to stimulate neural activity. This technique is used to treat conditions like treatment-resistant depression, targeting mood-related brain regions and neural circuits with magnetic fields. However, excessive exposure to strong magnetic fields can disrupt neural tissues, which is why the strength and frequency of magnetic fields must be carefully controlled to avoid harmful effects.

B. Chemical Effects of Electric Current in Biological Systems:

Electric current can alter chemical balances in the body. In biological fluids like blood or interstitial fluid, the current stimulates chemical reactions, used in various medical applications. Some of these applications include:

- **Iontophoresis:**

This technique utilizes electric current to transport medications or ions through the skin, as shown in Figure (40). A low-intensity electric current is applied across the skin, allowing therapeutic substances to penetrate the affected area without the need for injections. The mechanism involves placing the medication on the skin, followed by positioning an electrode over the area. The electric current then drives the therapeutic ions through the skin directly into the targeted tissues.

Figure (40) Iontophoresis Treatment

- **Electrical Bone Stimulation**

This technique uses electrical currents to stimulate bone growth in cases where fractures do not heal easily. Electrical stimulation increases cellular activity and promotes the production of bone proteins. However, this technique has some negative effects, as excessively high current intensity may damage vital proteins and enzymes in the body, disrupting tissue functions.

Physiological Effects of Electric Current in Biological Systems

Electric current directly affects the nervous and muscular systems. The nerve signals transmitted in the body rely on minute electrical currents. Therefore, electric current can be used to control or modify these signals in certain conditions. Some applications of these effects include:

- **Pacemaker**

A pacemaker, as shown in Figure (41), sends small electrical pulses to the heart muscle to regulate its rhythm in cases of irregular heartbeat. The device is implanted under the skin and connected to the heart through small wires to deliver electric current when needed.

Figure (41) Pacemaker

- **Electrical Muscle Stimulation (EMS)**

Electric current is used to stimulate muscles in physical therapy for rehabilitation, where weak or injured muscles are stimulated to strengthen them. Small electrical pulses are applied to the muscles, leading to natural contractions.

- **Transcutaneous Electrical Nerve Stimulation (TENS)**

This technique uses small electrical pulses to relieve pain. The electric current is directed through the skin to stimulate the nerves that control the sensation of pain, reducing the feeling of pain. However, this technique has some negative effects known as ventricular fibrillation, where exposure to strong electric current can lead to a heart rhythm disturbance known as ventricular fibrillation, a serious condition that can lead to death.

Future Applications

- **Neuroprosthetics**

Rapid advancements in neural technology have led to the development of devices that can be connected to the nervous system to control prosthetic limbs. Electric current is used to link external devices with the nervous system, allowing for precise control of movements using natural nerve signals.

- **Neuromodulation**

In current research, electric current is being used to stimulate or inhibit specific areas of the brain to treat neurological disorders such as depression, anxiety, and Parkinson's disease.

Conclusion

The various effects of electric current on biological systems include thermal, magnetic, chemical, and physiological effects. The biological applications of these effects play a crucial role in modern medicine, ranging from electrosurgery to pacemakers and neural stimulation. Despite the significant benefits, controlling these effects requires precision and caution to avoid potential risks such as burns, tissue damage, or cardiac arrhythmias.

Alternating Current and Reactive Circuits

Alternating Current (AC) vs. Direct Current (DC)

- **<u>Direct Current (DC)</u>**

Direct current is a type of electric current that flows in a steady, one-way direction. It can be considered a constant and stable flow of electric charges. This type of current is typically represented by horizontal lines in time charts, where the voltage remains constant.

- **Sources**

DC is generated from a variety of sources:

1. Batteries: These are the most common sources of DC. Batteries contain chemical reactions that convert chemical energy into electrical energy, generating a continuous current.
2. Solar Cells: These convert sunlight into electrical energy using the photovoltaic effect, producing direct current.
3. DC Generators: Used in some industrial and commercial applications, such as automotive DC generators.

- **Uses**

DC is used in many applications:

1. Electronic Devices: Most electronic devices, such as mobile phones and laptops, use direct current.
2. Charging: Charging batteries in phones and tablets.
3. Renewable Energy Systems: Used in solar panels that generate electrical energy to power devices in homes.

<u>Alternating Current (AC)</u>

Alternating current is a type of electric current that periodically changes direction. In this case, the voltage oscillates between positive and negative values over time. The common form of alternating current is the sine wave.

- **Sources**

AC is generated using:

1. Power Generators: These operate on the principle of electromagnetic induction, where a coil is moved within a magnetic field to generate alternating electric current. This is referred to as the AC generator circuit, as shown in Figure (42).

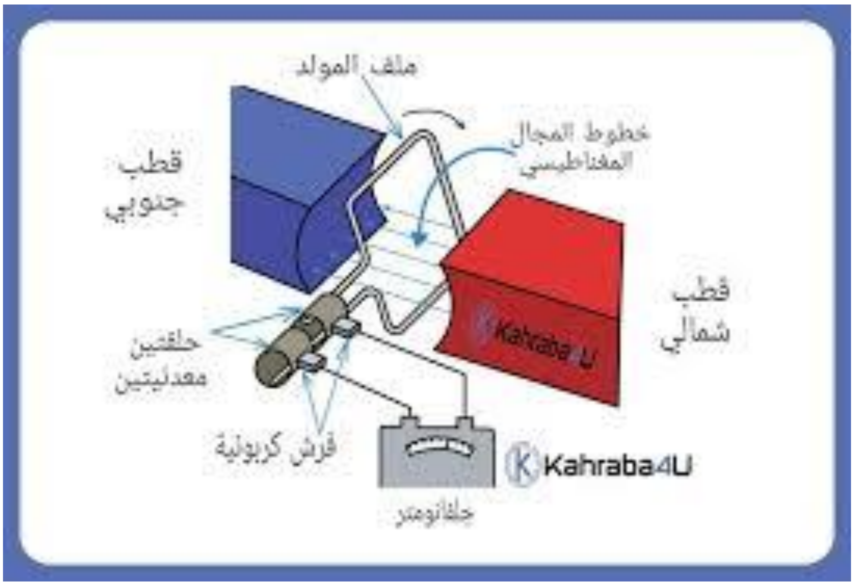


Figure (42): AC Generator Circuit

- **Uses**

Alternating current (AC) is used in the following:

- ✓ Electrical Grids: Most residential and industrial electrical grids rely on AC.
- ✓ Operating Electric Motors: Electric motors in factories and household appliances operate on AC.
- ✓ Lighting Systems: Most public lighting systems depend on AC.

Table (1): Difference Between DC and AC

	Alternating Current (AC)	Direct Current (DC)
Flow Direction	Changes direction periodically	Flows in one direction
Electrical Value	Varies over time	Constant
Uses	Electrical networks, motors	Electronic devices, charging

- **Waveform of Alternating Current**

The sine wave represents the common form of alternating current, where the voltage fluctuates over time. The instantaneous voltage of alternating current is expressed by the following equation:

$$V_{max}\sin(2\pi f t) = V(t)$$

Where *V(t)* is the instantaneous voltage, V_{max} is the maximum voltage, *f* is the frequency (number of cycles per second measured in hertz), and t is time. Figure (43) illustrates the sine wave.

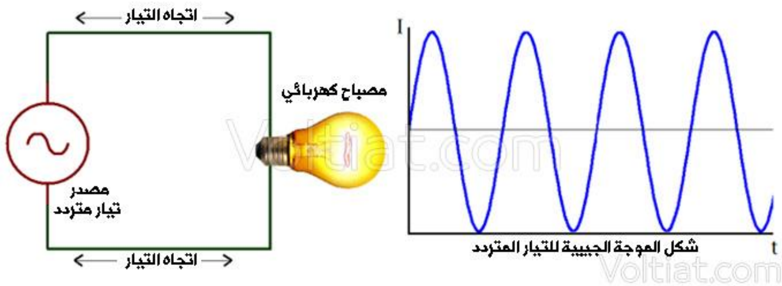


Figure (43) The sine wave of alternating current

- **The importance of alternating current and direct current in biological sciences**

Understanding the nature of alternating current and direct current is particularly important in biological sciences, as they are used in a range of medical applications such as:

1. **Medical devices:** Such as electrocardiogram (ECG) machines and magnetic resonance imaging (MRI) machines that rely on alternating current for analysis processes.

2. **Electrical stimulation:** Direct current is used in certain types of electrical therapies to stimulate nerves or muscles in cases of paralysis or injuries.

Generating Alternating Current

Generating alternating current is the process of converting mechanical energy into electrical energy, where the direction of the current changes regularly. Alternating current is the preferred choice in electrical power systems due to its efficiency in transmitting power over long distances and the ease of changing voltage levels using transformers.

- **Mechanism of Alternating Current Generation**

The alternator is the main device used to generate alternating current. Alternators rely on the principle of electromagnetic induction, where a conductor coil is rotated within a magnetic field to generate electrical current.

- **Components of the Generator**

1. Rotor: The moving part of the generator that rotates within the magnetic field. The rotor can be a permanent magnet or an electromagnet.
2. Stator: The stationary part that contains copper windings, where the alternating current is generated.

Mechanism of Operation

1. **Rotation:** The rotor is rotated by a mechanical power source such as wind, water, or steam turbines.
2. **Electromagnetic Induction:** As the rotor spins within the magnetic field, the field lines are cut by the windings of the stator, generating an electrical current.

3. **Voltage Generation:** The voltage produced by the generator represents a circular relationship that can be expressed by the previously mentioned equation.

Characteristics of Alternating Current

1. **Frequency and Voltage**
   - **Frequency:** Represents the number of cycles that alternating current undergoes per second and is measured in hertz (Hz). In most countries, the frequency of alternating current is either 50 or 60 Hz.
   - **Voltage:** Represents the amount of energy that can be used. Alternating current can change voltage levels using transformers, making it ideal for transmitting power over long distances.

Systems for Generating Alternating Current

1. **Conventional Power Generators**
   - Rely on fossil fuels (such as coal or natural gas) to produce steam, which rotates the turbines to generate electricity.
   - **Hydroelectric Power Plants:** Use the flow of water to rotate turbines, leading to the generation of alternating current.

Renewable Energy Sources

1. **Wind Power Generation:** Utilizes wind energy to rotate turbine blades, resulting in the production of alternating current.
2. **Solar Power Generation:** Although solar cells produce direct current, inverters convert this current into alternating current.

Nuclear Power Systems

1. **Nuclear Reactors:** Used to generate steam, which drives the turbines to produce alternating current. This method is one of the most important ways to generate energy worldwide.

Practical Applications of Alternating Current

1. **Electrical Grids**

Most electrical grids use alternating current due to its efficiency in transmitting power over long distances, which reduces energy loss.

2. **Electric Motors**

Alternating current motors are used in a variety of applications, such as industrial machinery, household electrical appliances, and commercial equipment.

3. **Lighting Systems**

Most public lighting systems in streets and buildings rely on alternating current, allowing for easy control of lighting.

Benefits and Drawbacks

Benefits

- **Transmission Efficiency:** Alternating current can be transmitted efficiently over long distances due to voltage-changing technologies.
- **Flexibility of Conversion:** Voltage can be easily changed using transformers, making alternating current ideal for various applications.

Drawbacks

- **System Complexity:** Alternating current systems require additional components like transformers and other electrical parts, increasing design complexity.
- **Power Loss:** Energy loss can occur due to resistance to the wires, especially in long connections.

Impedance and Reactance

- **Impedance**

Impedance is an electrical property that expresses the ability of an electrical circuit to resist alternating current. It is measured in ohms (Ω) and includes both resistance (R) and reactance (X). Reactance pertains to the properties of non-linear components such as capacitors and inductors.

Impedance represents the relationship between voltage and current in an alternating circuit and can be mathematically expressed as:

$$Z = R + jX$$

where:

- Z is the total impedance,
- R is the resistance,
- j is the imaginary unit ($j^2 = -1$),
- X is the reactance.

- **Reactance**

Reactance is a property that represents the resistance of surface components (such as capacitors and inductors) to the flow of alternating current. It can be divided into two main types:

1. Capacitive Reactance (X_C): Represents the resistance of a capacitor to the flow of current.
2. Inductive Reactance (X_L): Represents the resistance of an inductor to the flow of current.

- **Capacitive Reactance**

Capacitive reactance (X_C) is calculated using the following formula:

$$X_C = \frac{1}{2\pi f C}$$

where:

- f is the frequency in hertz (Hz),
- C is the capacitance in farads (F).

The effect of capacitive reactance is that when the capacitor is connected in an alternating circuit, it stores energy in the form of an electric field. Capacitive reactance is negative, which affects the phase angles in the circuit and reflects changes in voltage and current.

- <u>**Inductive Reactance**</u>

Inductive reactance (X_L) is calculated using the following formula:

$$X_L = 2\pi f L$$

where:

- L is the inductance in henries (H).

The effect of inductive reactance is that inductors store energy in the form of a magnetic field. Inductive reactance causes the current to lag behind the voltage, which affects the performance of the alternating circuit.

- <u>**Relationship Between Impedance and Reactance**</u>

The total reactance XXX in an alternating circuit can be represented as:

$$X = X_L - X_C$$

The total impedance can be calculated by adding resistance and reactance:

$$Z = R + j(X_L - X_C)$$

- <u>**Angle Between Voltage and Current**</u>

The relationship between voltage and current in the alternating circuit is expressed by the phase angle ϕ:

$$\tan(\phi) = \frac{X}{R}$$

- **Waveform of Alternating Current**

In alternating circuits, the waveform is affected by the resistance and reactance, and the voltage and current can be represented as shown in the graph depicted in Figure (44):

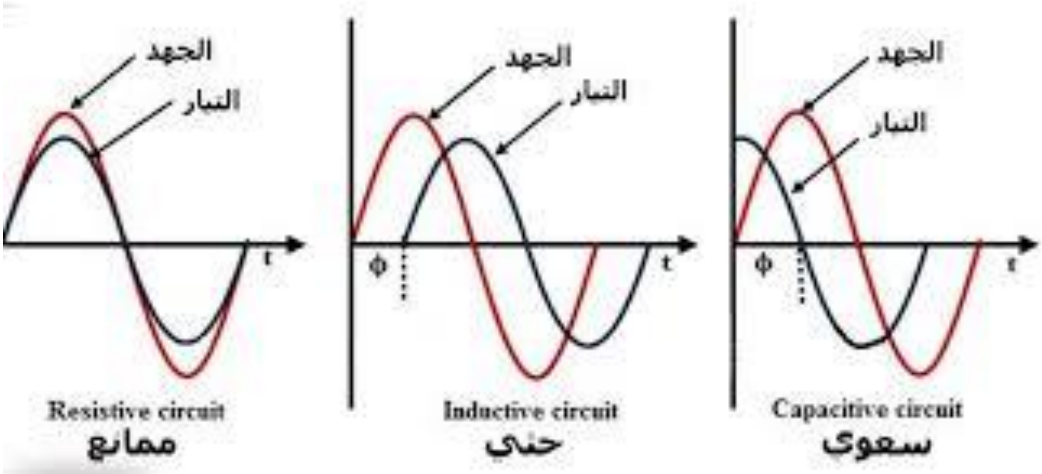


Figure (44) Voltage and Current in the AC Circuit

Practical Applications of Impedance and Reactance

1. **Circuit Design**

   Impedance is used to analyze and design AC electrical circuits. Understanding reactance helps in selecting appropriate components to meet circuit requirements.

2. **Improving Device Performance**

   Reactance aids in enhancing the performance of electronic devices, such as filters and amplifiers. Reactance-based designs can be used to improve the frequency response of devices.

3. **Power Systems**

   Impedance is a fundamental element in the design of electrical power networks. Understanding reactance impacts the efficiency of power transmission and reduces energy loss in networks.

Importance of Impedance and Reactance

1. **Circuit Analysis**

   Impedance assists in analyzing AC circuits, facilitating efficient circuit design.

2. **Reducing Losses**

   Impedance can be used to improve system performance and minimize energy losses.

RC, RL, and RLC Circuits

1. RC Circuits (Resistor-Capacitor Circuits)

RC circuits consist of two main components: a resistor (R) and a capacitor (C) connected to a power source. RC circuits are among the most important in electronics, contributing to a wide range of applications such as filters, timers, and signal modulation. These components can be connected in series or parallel.

- Series RC Circuit: The current is the same throughout the circuit, but the voltage is divided between the resistor and the capacitor.
- Parallel RC Circuit: The voltage across all components is the same, but the current is divided between the resistor and the capacitor.

○ Harmonic Analysis of RC Circuit

When an AC power source is connected to the circuit, the current flows through the resistor and capacitor. The voltage across the resistor and capacitor differs, and a phase shift occurs between the voltage and current due to the capacitor. The circuit's frequency response can be described through capacitive reactance (X_C):

$$X_C = \frac{1}{2\pi f C}$$

where XC is the capacitive reactance (in ohms), representing the capacitor's resistance to AC, f is the frequency (in hertz), and C is the capacitance (in farads).

○ Phase in RC Circuit

The phase difference between voltage and current in an RC circuit depends on the ratio of capacitive reactance to resistance. The phase angle ϕ is calculated as follows:

$$\tan(\phi) = \frac{X_C}{R}$$

where ϕ is the phase angle, R is the resistance in ohms, and X_C is the capacitive reactance. In an RC circuit, the current leads the voltage by a time that depends on the values of the capacitor, resistance, and frequency.

- **Time Response in RC Circuits**

When a constant or variable voltage is applied, the voltage across the capacitor increases over time according to the charging rate, known as the "time constant." The time constant τ represents the time it takes for the capacitor to charge to 63% of the source voltage:

$$\tau = R \times C$$

where τ is the time constant in seconds, R is the resistance in ohms, and C is the capacitance in farads. Charging and discharging can be described by the following equations:

$$V_C(t) = V_{source}(1 - e^{-t/\tau}) \text{ for charging}$$

$$V_C(t) = V_0 \times e^{-t/\tau} \text{ for discharging}$$

- **Practical Applications of RC Circuits**

RC circuits are widely used in the following applications:

1. Frequency Filters: Low-pass and high-pass filters can be designed using RC circuits.
2. Timer Circuits: Used for timing and response control in electronic applications.
3. Signal Modulation: RC circuits are fundamental in signal modulation techniques.

The following figure (45) illustrates a series of RC circuits.

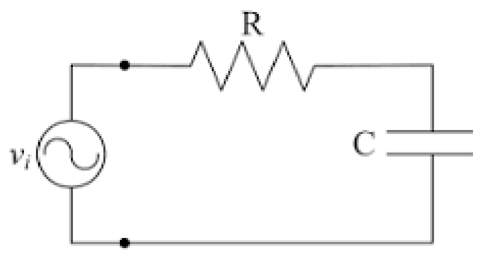


Figure (45) RC circuit.

2. **RL Circuits (Resistor-Inductor Circuits)**

An RL circuit consists of a resistor (R) and an inductor (L). The inductor stores energy in the form of a magnetic field, thus providing resistance to changing currents (inductive reactance). These circuits are widely used in systems that rely on electromagnetic induction, such as motors and generators.

- **Sinusoidal Analysis of RL Circuit**

A phase difference occurs between voltage and current in RL circuits due to the effect of the inductor. The inductive reactance X_L is determined by the equation:

$$X_L = 2\pi f L$$

where X_L is the inductive reactance (in ohms), f is the frequency (in hertz), and L is the self-inductance of the coil (in henries).

- **Phase Angle in RL Circuit**

It is noteworthy that in RL circuits, the current lags behind the voltage by a phase angle that depends on the ratio of inductive reactance to resistance. The phase angle ϕ is calculated as follows:

$$\tan(\phi) = \frac{X_L}{R}$$

- **Time Response in RL Circuits**

As in RC circuits, RL circuits have a time constant that determines the speed of the circuit's response. The time constant for an RL circuit is expressed by the relationship:

$$\tau = \frac{L}{R}$$

The change in current is described as follows:

- Current Increase in RL Circuit:

$$I(t) = I_{max}(1 - e^{-t/\tau})$$

- Current Decrease:

$$I(t) = I_0 \times e^{-t/\tau}$$

- **Practical Applications of RL Circuits**
  - **Electric Motors:** RL circuits are used in motor drive circuits.
  - **Frequency Filters:** Used to tune frequency ranges in electronic devices.
  - **Power Systems:** Control the transmission of power in electrical networks.

The following figure (46) illustrates the RL circuit diagram.

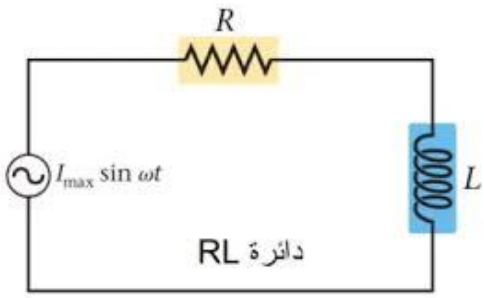


Figure (46) RL circuit

3. **RLC Circuits (Resistor-Inductor-Capacitor Circuits)**

RLC circuits consist of a resistor (R), an inductor (L), and a capacitor (C) within the same circuit. They are widely used in applications involving electrical resonance due to their ability to generate resonance at a specific frequency, known as the resonant frequency.

- **Resonant Frequency of RLC Circuit**

In series RLC circuits, resonance occurs when the inductive reactance equals the capacitive reactance. The resonant frequency f_0 is calculated using the equation:

$$f_0 = \frac{1}{\sqrt{2\pi LC}}$$

- **Quality Factor of RLC Circuit**

The quality factor Q is a measure of the efficiency of the resonant circuit and is defined by the following relationship:

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

- **Practical Applications of RLC Circuits**
  - **Electrical Resonance:** RLC circuits are used to achieve resonance in radio systems.
  - **Frequency Filters:** They are utilized to tune specific frequencies in electronic circuits.
  - **Magnetic Resonance Imaging Devices:** Medical equipment, such as MRI machines, relies on RLC circuits to generate the necessary magnetic fields.

The following figure (47) illustrates the RLC circuit diagram.

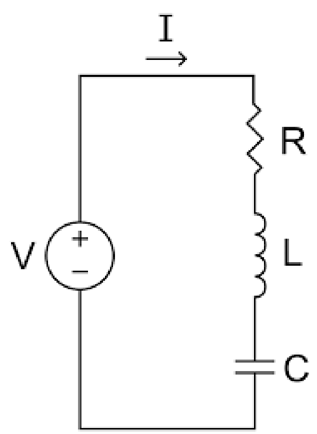


Figure (47) RLC circuit

Applications of Alternating Current in Biological Devices and Medical Equipment

Alternating current (AC) is a fundamental component in the operation of modern medical devices due to its efficiency in transmission and stability when used in sensitive environments such as hospitals. Electrical impedance plays a significant role in various medical applications such as electrocardiography and neurostimulation, requiring precise adjustments to ensure patient safety and device accuracy. All medical devices must adhere to strict electrical safety standards to ensure the protection of patients and healthcare workers.

1. **Alternating Current (AC) in Medical Equipment**

In the medical field, alternating current (AC) is widely used to power most modern medical devices. AC is the primary source of electrical energy and is characterized by its ability to transmit over long distances more efficiently than direct current (DC) due to the ease of voltage transformation through electrical transformers. In biological systems, medical devices require stable and consistent current to ensure accuracy and safety in sensitive environments like hospitals and clinics. Therefore, these devices are designed to manage AC characteristics such as frequency, voltage, and impedance, as any deviation in these parameters can adversely affect medical performance.

a. **Examples of AC Usage in Medical Devices**

i. X-Ray Machines

X-ray machines rely heavily on alternating current to operate the vacuum tubes that generate X-rays. AC supplies high-voltage energy to the tubes, accelerating electrons that collide with a metallic target (usually tungsten), producing the X-rays necessary for medical imaging. The AC is directed to a step-up transformer that increases the voltage difference between the electrodes, followed by the acceleration of electrons towards the anode, resulting in enough energy to release X-rays that penetrate the body and produce the desired image.

b. Magnetic Resonance Imaging (MRI)

MRI machines depend on the magnetic fields and radio waves generated by alternating current to create detailed images of the body. These machines operate on the principle that hydrogen molecules in the body interact with magnetic fields and emit signals that are captured by the device and translated into three-dimensional images.

i. AC in the Inductor: AC is used to generate a strong and stable magnetic field, directing hydrogen molecules to align with its direction.

ii. Radio Waves: Radio waves are applied using AC to stimulate the molecules and alter their orientation. When the molecules return to their normal state, they emit electromagnetic signals that are captured and used to form the image.

c. Ventilators

Ventilators are among the most important devices used in caring for patients with respiratory issues. These devices rely on alternating current to power the motors and electronic systems that control the flow of air or oxygen to the lungs.

i. Electric Motors: Electric motors are powered by AC to control air pumping and adjust pressure according to the patient's needs.

ii. Control Systems: The electronic circuits within the device precisely control the oxygen levels and adjust the breathing rate to match the patient's condition.

2. Impedance in Medical Applications

As previously mentioned, electrical impedance is the total resistance presented by the body or electrical system to the flow of alternating current, consisting of a combination of resistance and reactance. Impedance is a crucial factor in medical applications, directly affecting how the body responds to electrical currents.

a. Impedance in Electrocardiography (ECG) Devices

In ECG devices, controlling impedance plays a vital role in ensuring clear and accurate heart signal recording. The skin and body provide a certain resistance to electrical current, thus the electrodes in ECG devices need to have as low impedance as possible to avoid signal distortion.

i. Electrodes: Electrodes in contact with the skin must be capable of transmitting current with minimal resistance to achieve the best results.

ii. Electronic Circuits: The electronic circuits in ECG devices are adjusted to manage changes in impedance resulting from variations in skin resistance among different patients.

b. Neuromuscular Electrical Stimulation

Many medical devices use alternating currents to stimulate nerves or muscles, a technique used in physical therapy, pain relief, and rehabilitation following injuries or surgeries.

i. Tissue Impedance: Impedance varies among biological tissues, so medical devices must accommodate variations in resistance and reactance to ensure effective current delivery to target tissues.

ii. Current Frequency: The frequency of AC is adjusted for optimal interaction with nerves and muscles, as lower frequencies may cause muscle contractions while higher frequencies may be used for pain relief.

3. Electrical Safety in Medical Devices

When using alternating current in medical devices, safety is a top priority. Several measures are taken to ensure the protection of patients and healthcare workers from electrical shock hazards:

a. Electrical Isolation

Medical devices incorporate robust electrical isolation systems separating high-voltage circuits from those connected to the body, ensuring that current does not flow into the patient's body.

b. Grounding

Grounding is a primary safety procedure aimed at discharging any unwanted electrical current to the ground, reducing the risk of electric shock for patients and healthcare workers.

c. Uninterruptible Power Supply (UPS)

In medical environments, vital devices must remain operational even during power outages. Therefore, many hospitals rely on UPS systems that provide instant backup power to medical devices until the main electrical supply is restored.

4. Biological Applications of Alternating Current

a. Electrical Impedance Spectroscopy (EIS)

The technique of electrical impedance spectroscopy involves applying alternating current at various frequencies to the body to measure tissue resistance. This technique is used to:

i. Determine Tissue Condition: This type of analysis is used to assess tissue integrity, body mass, and composition analysis (such as fat-to-lean mass ratio).

ii. Diagnose Diseases: EIS can assist in detecting changes in tissues associated with diseases such as cancer or dehydration.

b. Electrotherapeutic Heating Techniques

Electrotherapeutic heating techniques use alternating current to generate heat in deep tissues, helping to:

i. Relieve Pain: This technique is used to heat injured muscles and joints, improving blood flow and alleviating pain.

ii. Treat Injuries: The heat generated by alternating current can be used to enhance the healing process of tissues, particularly in cases of sports injuries.

Part Two: (Geometric Optics)

Nature of Light

Plato believed that the perception of objects occurs through light emanating from the eye and reaching the objects, enabling vision. However, Aristotle, a student of Plato, disagreed, claiming that light does not exist in itself, and that perception occurs when images of objects are imprinted on the eye. Ibn al-Haytham (Alhazen), as illustrated in Figure 48, was able to resolve the ancient disputes regarding the definition of light and the explanation of the sense of sight by attributing the sensation of vision to an external factor he termed "light." Ibn al-Haytham defined light as "a fiery heat composed of rays that have lengths and widths, emitted from luminous bodies such as the sun and glowing objects. When these rays fall on a dense body, they heat it; and when they reflect off a concave mirror and converge at a single point, they can ignite a combustible object present at that point." Ibn al-Haytham also studied the phenomenon of light reflection and established a theoretical foundation for the law of reflection, which had been reached by the Greek philosophers. This law states that:

"The angle of incidence equals the angle of reflection"

He added another law stating that:

"The angles of incidence and reflection lie in a single plane perpendicular to the vertical surface."

Figure (48): Abu Ali al-Hasan ibn al-Hasan ibn al-Haytham

- **Particle Theory of Light by Newton**

Newton believed that light consists of tiny particles that spread in space at extremely high speeds. This theory succeeded in explaining the phenomena of diffusion and reflection but failed to explain refraction, as it assumed that the speed of light in a medium with higher optical density, like water, is greater than its speed in a medium with lower optical density, like air.

- **Wave Theory of Light by Huygens**

This theory assumed that light consists of waves, and that every point on the wavefront is a source of secondary disturbances. It also proposed that a material medium must exist for these waves to propagate, and Huygens, as shown in Figure (49), gave these medium special characteristics and called it the "ether." This theory managed to explain the phenomenon of refraction by suggesting that the speed of light in a medium with higher optical density, like water, is less than its speed in a medium with lower optical density, like air. However, the theory failed to prove the existence of this "ether" and was also unsuccessful in explaining the phenomenon of polarization.

Figure (49) Christian Huygens, a Dutch astronomer, algebraist, and mathematician, lived from 1629 to 1695. His contributions to analysis led to the discovery of calculus.

- **Maxwell's Electromagnetic Theory**

This theory, Figure (50) considered light as transverse electromagnetic waves that propagate in a vacuum. It is known that an electromagnetic wave consists of two perpendicular fields: an electric field and a magnetic field, both perpendicular to the direction of wave propagation. This theory successfully explained the phenomenon of polarization and dismissed the need for a medium, as these waves can travel through a vacuum. However, an important physical phenomenon, the photoelectric effect, emerged, which this theory was unable to explain.

Figure (50) James Clerk Maxwell (June 13, 1831 – November 5, 1879)

- **Einstein and the Quantum Theory of Light (1905)**

Any of the previous theories may succeed in explaining light phenomena based on light-to-light interactions, such as diffraction, interference, and polarization. However, when studying the interaction of light with matter (emission, absorption, and the photoelectric effect), such phenomena can only be explained through the quantum nature of light. This theory proposed that light consists of a stream of photons (quanta), which are massless, and the energy of each photon is given by the equation $E = h\nu$, where h is Planck's constant, and ν is the frequency of the light wave (which is related to the wavelength and speed of light).

Einstein's quantum theory, Figure (51), was able to explain the emission of electrons from the surface of certain metals when light is shone on them, a phenomenon known as the photoelectric effect. Thus, light waves are electromagnetic waves, meaning they are disturbances that propagate energy through space in the form of two oscillating fields—one electric and the other magnetic—perpendicular to each other and to the direction of wave propagation. These waves do not require a physical medium to propagate; they can travel through a vacuum, as illustrated in Figure (52).

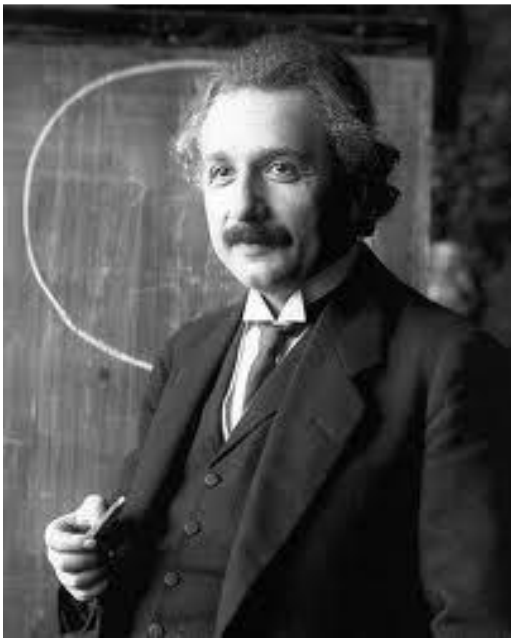


Figure (51) Theoretical physicist Albert Einstein (1879–1955)

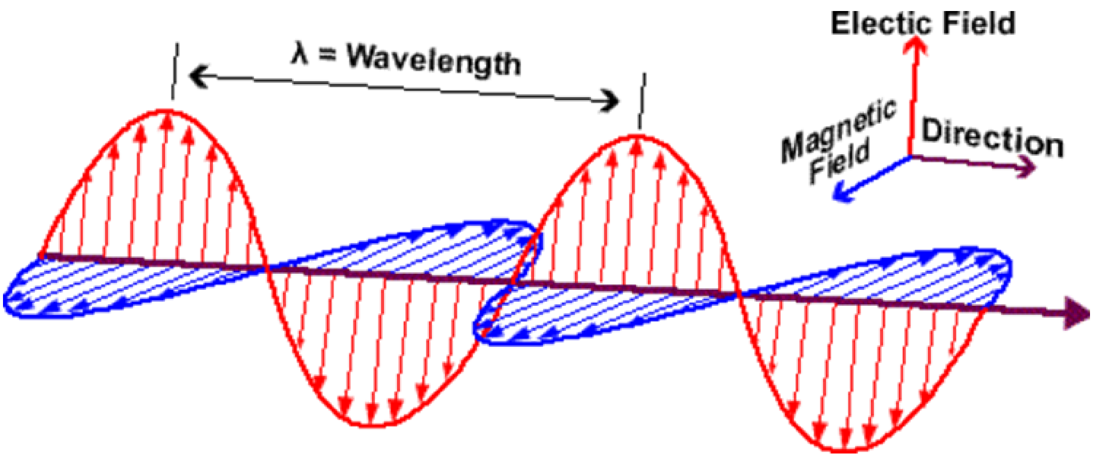


Figure (52) The propagation of light as electromagnetic waves

Light waves occupy a small portion of the electromagnetic spectrum, which is divided into: radio waves, microwaves, infrared radiation, visible light, ultraviolet rays, X-rays, and gamma rays, as shown in Figure (53).

Figure (53) The Electromagnetic Spectrum

- **Reflection of Light**

Reflection is defined as "the return of light rays when they encounter a reflective surface." There are two types: reflection on flat surfaces and reflection on curved surfaces.

- **Reflection at a Flat Surface**

When a light ray strikes a reflective surface, we define the angle of incidence (θi) as the angle between the incident ray and the perpendicular (normal) line to the reflective surface at the point of incidence. The angle of reflection (θr) is defined as the angle between the reflected ray and the normal line at the point of reflection, as shown in Figure (54). Light reflects off the reflective surface according to the following laws:

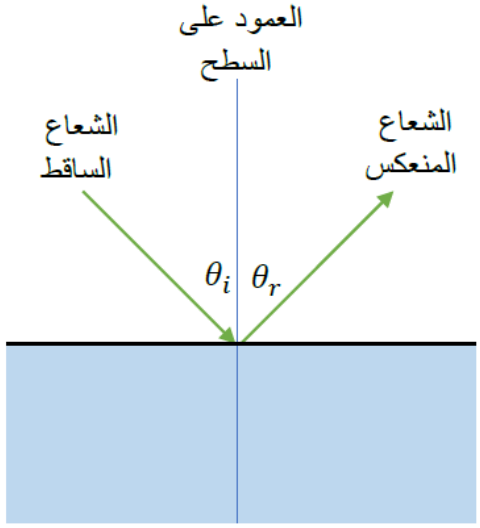


Figure (54) Reflection of Light at a Flat Surface

First Law: The angle formed by the incident ray with the perpendicular line from the point of incidence is equal to the angle formed by the reflected ray with that perpendicular line (the angle of incidence equals the angle of reflection), as shown in the following relationship:

$$(\theta_i) = (\theta_r)$$

Second Law: The incident ray, the normal line, and the reflected ray all lie in the same plane perpendicular to the boundary surface between the two media.

- **Image Formed by a Plane Mirror**

The image formed by a plane mirror has the following properties: it is upright, equal to the object, and virtual. If an object of height h is placed in front of a mirror at a distance p from it, an image will be formed inside the mirror at a distance q from it, with an image height h′, as shown in Figure (55).

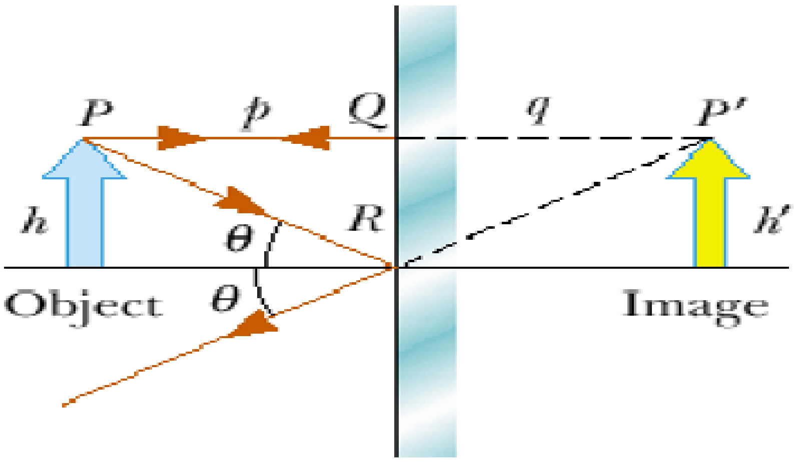


Figure (55) Formation of the Image by a Plane Mirror

From the geometry of the figure, the magnification factor MMM is given by the following relationship:

$$M = \frac{h^{`}}{h} = 1$$

$$h = h^{`}$$

$$S = S^{`}$$

Where h is the height of the object and h′ is the height of the image. Thus, the distance of the object from the mirror p equals the distance of the image from the mirror q, and the height of the object h equals the height of the image h′. Therefore, the magnification factor M equals one.

Real Image: An image formed at the intersection of two or more reflected rays and located in front of the mirror.

Virtual Image: An image formed at the intersection of the extensions of two or more reflected rays and located behind the mirror.

- **Sign Convention**
  1. The arrangement of components (including the light source and optical components like mirrors) is from left to right.
  2. All distances (measured from the mirror's pole) are negative if directed to the left and positive if directed to the right.

3. The focal length is positive for concave mirrors and negative for convex mirrors.
4. The focal length is positive for convex lenses (converging) and negative for concave lenses (diverging).
5. For vertical lengths, measurements start from the optical axis: they are positive if directed upwards and negative if directed downwards.

- **Reflection at a Spherical Surface**

A spherical mirror is defined as the surface formed by the intersection of a hollow sphere with a plane, as shown in Figure (56):

1. If the reflective surface is the outer surface of the sphere, it is called a convex mirror, which diverges the rays.
2. If the reflective surface is the inner surface of the sphere, it is called a concave mirror, which converges the rays.

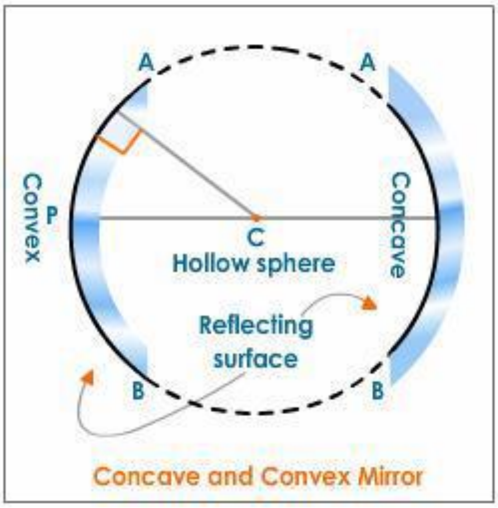


Figure (56) Illustrative Diagram of Convex and Concave Mirrors

- **Some Important Definitions Related to Spherical Mirrors Using Figure (57)**

1. **<u>Center of Curvature (C)</u>**: This represents the center of the sphere of which the mirror is a part.

2. **Pole of the Mirror (A)**: This is the point at the midpoint of the spherical mirror.
3. **Radius of Curvature (r)**: This is equal to the distance between the pole of the mirror (A) and the center of curvature (C).
4. **Focus (F)**: This is the point where the reflections of the ray's incident on the mirror converge.
5. **Focal Length (f)**: This is the distance between the focus and the pole of the mirror.
6. **Principal Axis:** This is the line connecting both the center of curvature (C) and the pole (A) of the mirror.

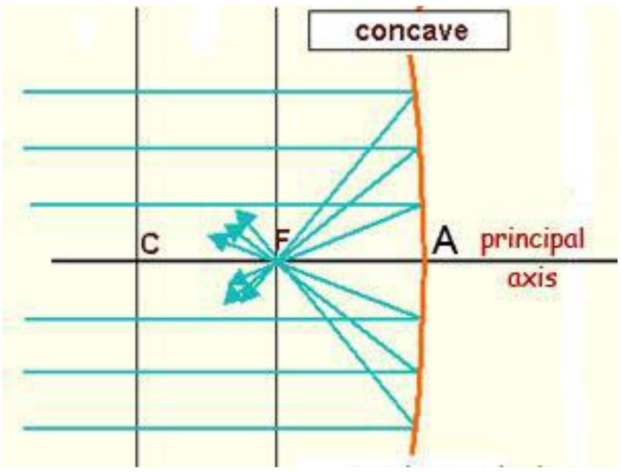


Figure (57) Illustrates Some Definitions Related to Spherical Mirrors

Figures (58) and (59) illustrate the reflection process at a concave mirror and a convex mirror, respectively. If an object is placed in front of a concave mirror at a distance O, an image will be formed at a distance iii from the mirror, with the focal length of the mirror being f. The relationship connecting these three variables is called the Mirrors Equation, given by the following formula:

$$\frac{1}{O} + \frac{1}{i} = \frac{1}{f}$$

Additionally, there is a relationship connecting the radius of the mirror r and the focal length f as follows:

$$r = 2f$$

The magnification factor M for the image is defined as the ratio of the image height to the object height and is given by the following relationship:

$$M = \frac{image\ height}{object\ height} = -\frac{i}{O}$$

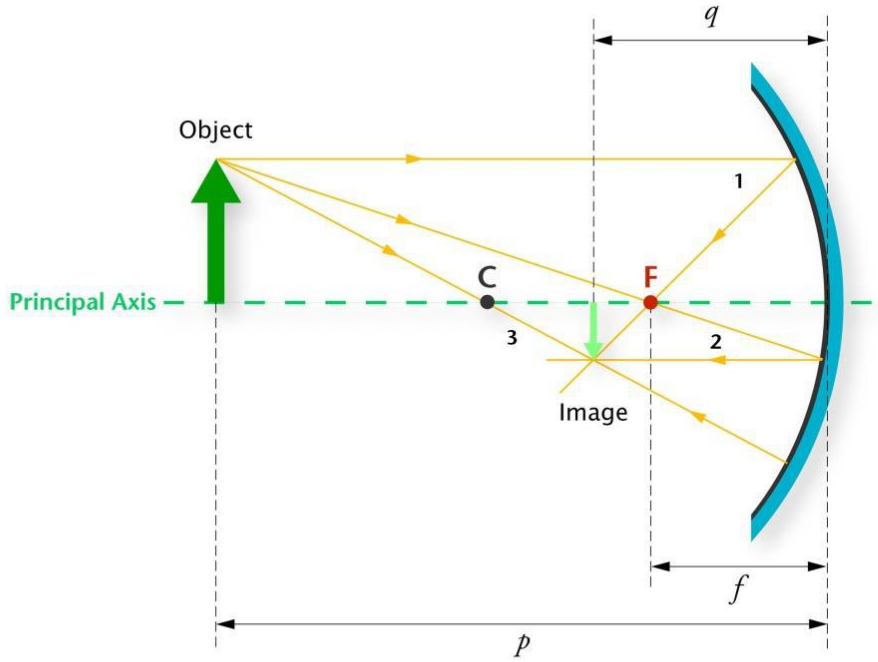


Figure (58) Reflection at a Concave Mirror

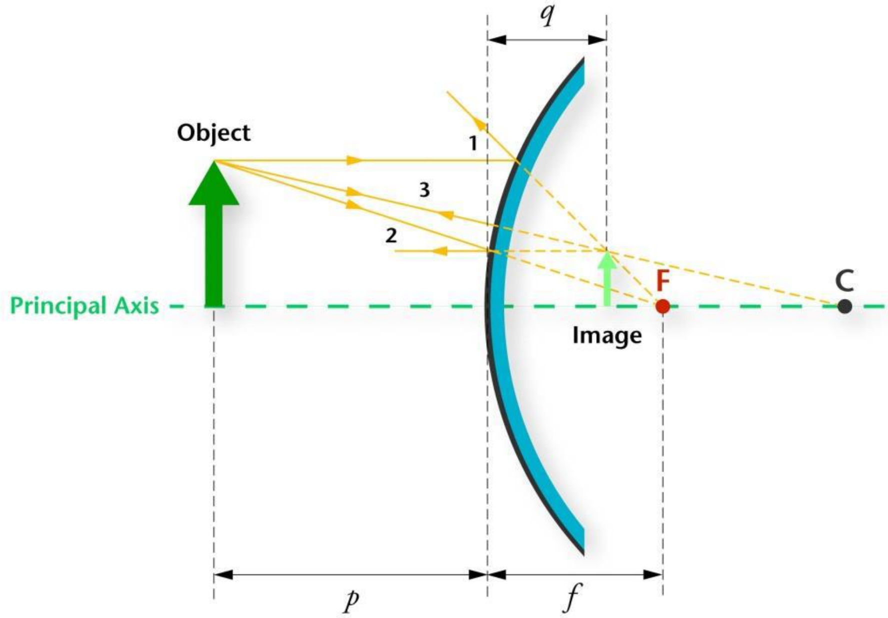


Figure (59) Reflection at a Convex Mirror

- **Specifications of the Image Formed by Spherical Mirrors**

The characteristics of the image produced by spherical mirrors can be determined by drawing two rays from the top of the object. One ray is drawn parallel to the optical axis and reflects through the focal point, while the second ray passes through the focal point and reflects parallel to the optical axis. The point where these two rays intersect is the point where the image is formed, as shown in the following figures.

First: For the Concave Mirror

1. If the object is placed beyond the center of curvature (C), the image formed will be located between C and the focal point (F). The image will be real, inverted, and smaller, as illustrated in Figure (60).

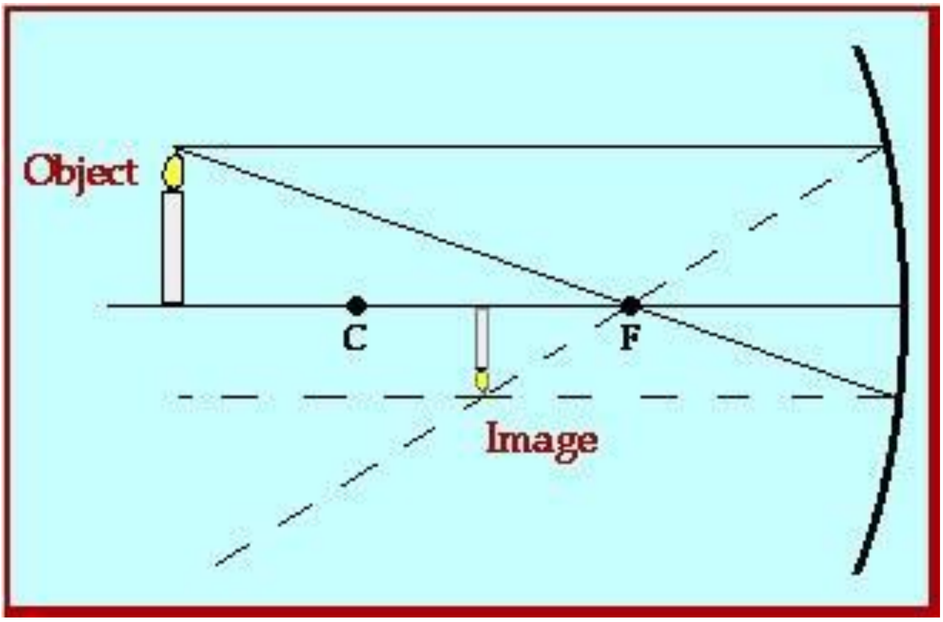


Figure (60) Object Placed Beyond the Center of Curvature of the Mirror

2. If the object is placed at the center of curvature (C), the image formed will be located at C as well. The image will be real, inverted, and the size of the image will be equal to the size of the object, as illustrated in Figure (61).

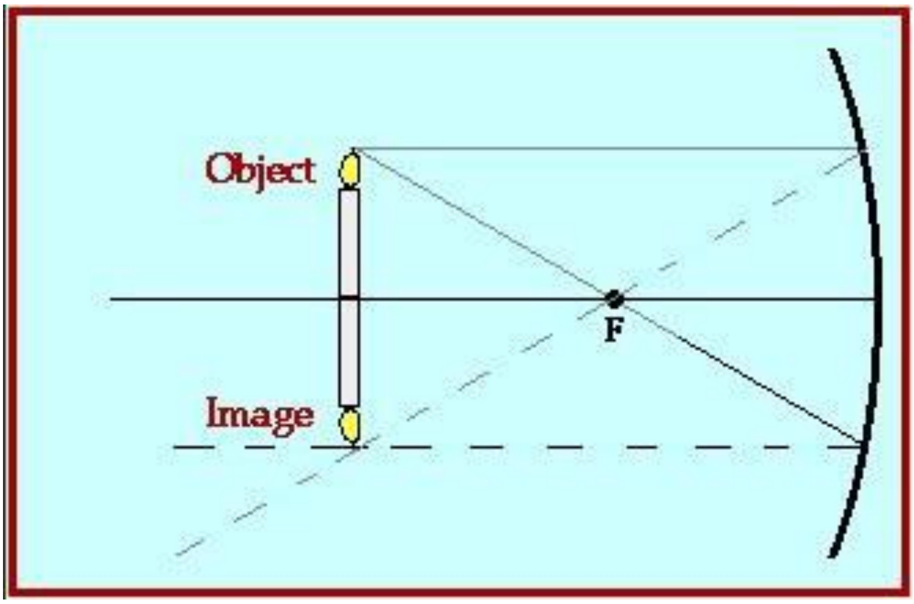


Figure (61) Object Placed at the Center of Curvature of the Mirror

If the object is placed between the center of curvature (C) and the focal point (F), the image formed beyond point C will be real, inverted, and magnified, as illustrated in Figure (62).

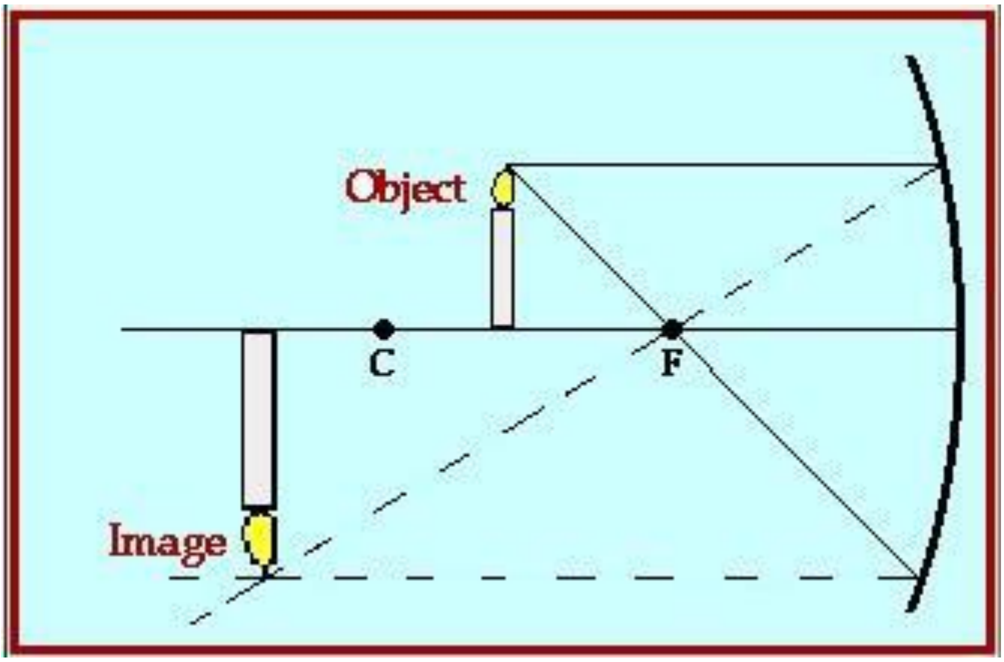


Figure (62) Object Placed at a Distance Between the Focal Point and the Center of Curvature of the Mirror

Second: For the Convex Mirror

1. If the object is placed closer than the focal point (F), the image formed will be located behind the mirror. The image will be virtual, upright, and magnified, as illustrated in Figure (63).

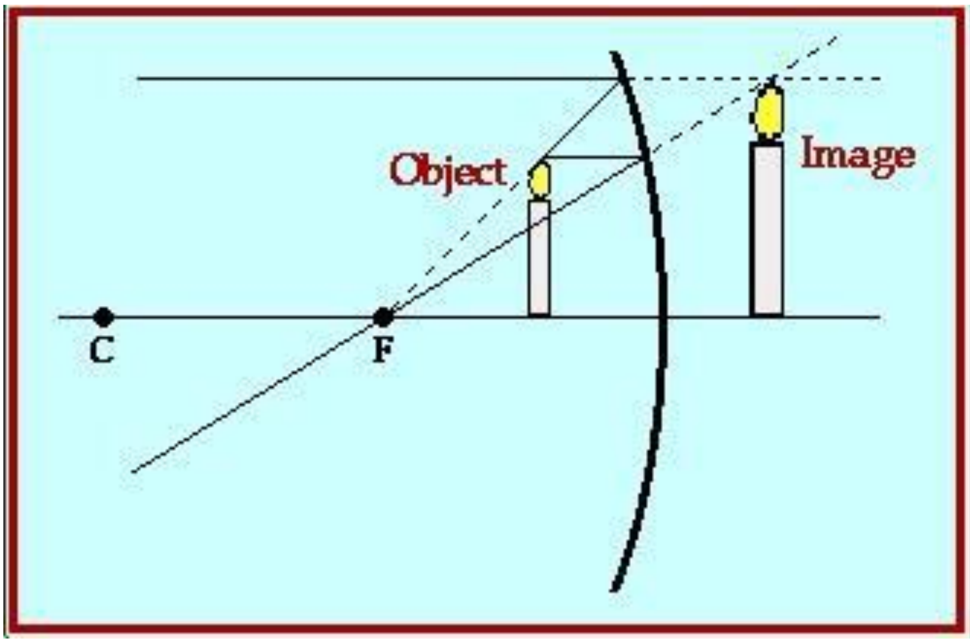


Figure (63) Object Placed at a Distance Less Than the Focal Length of the Mirror

2. In the case of the convex mirror, the image formed is located behind the mirror and is virtual, upright, and reduced in size, as illustrated in Figure (64).

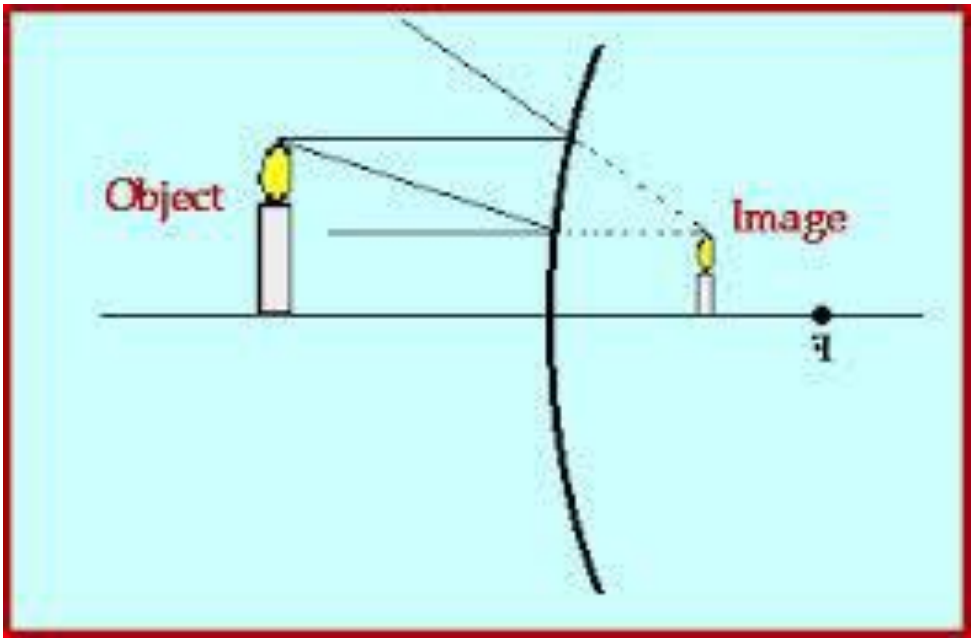


Figure (64) Object at a Distance from a Convex Mirror

Example (1)

If an object is placed 20 cm from the pole of a concave mirror with a diameter of 10 cm, find the distance of the image formed from the pole of the mirror as well as the focal length of this mirror.

Solution

Radius of the mirror = 5 cm, thus the focal length of the mirror = 2.5 cm.

$$\frac{1}{O}+\frac{1}{i}=\frac{1}{f}$$

$$\frac{1}{20}+\frac{1}{i}=\frac{1}{2.5}=\frac{8}{20}$$

$$\frac{1}{i}=\frac{8}{20}-\frac{1}{20}=\frac{7}{20}$$

$$i=2.86\ cm$$

Example (2)

A concave mirror has a focal length of 20 cm, and an object is placed 30 cm from it. Find the position of the image formed, its type, and magnification.

Solution

From the general mirror equation:

$$\frac{1}{O}+\frac{1}{i}=\frac{1}{f}$$

$$\frac{1}{30}+\frac{1}{i}=\frac{1}{20}$$

$$\frac{1}{i}=\frac{1}{20}-\frac{1}{30}=\frac{1}{60}$$

$$i=60\ cm$$

$$M=-\frac{i}{O}=-\frac{60}{30}=-2$$

The image is real, inverted, and magnified.

Example (3)

An object is located in front of a spherical mirror at a distance of 20 cm, resulting in a virtual, reduced image formed at a distance of 15 cm from the mirror. Calculate the focal length and magnification of the mirror, indicating its type.

Solution

From the general mirror equation:

$$\frac{1}{O} + \frac{1}{i} = \frac{1}{f}$$

$$\frac{1}{20} + \frac{1}{15} = \frac{1}{f}$$

$$\frac{1}{f} = \frac{1}{20} + \frac{1}{15} = \frac{3+4}{60} = \frac{7}{60} = 8.57\ cm$$

$$M = -\frac{i}{O} = -\frac{15}{20} = -0.75$$

The image formed by the mirror is real, inverted, and reduced, and the focal length of the mirror is positive, indicating that it is a concave mirror.

- **Refraction of Light**

Refraction of light is the phenomenon of light bending from its path when it transitions between two media that allow light to pass through and differ in optical density (such as glass and air or glass and water). Refraction occurs due to the difference in the speed of light in the two media.

- **Refraction at a Flat Surface**

It is known that all electromagnetic waves, regardless of their wavelengths, travel at the same speed in a vacuum; however, they differ in other media or materials, and their wavelength varies while the frequency remains constant. The ratio of the speed of light in a vacuum (air) to its speed in a medium is called the refractive index of the medium.

$$n = \frac{c}{v}$$

where c is the speed of light in a vacuum, and v is the speed of light in the medium. Note that the speed of light in a vacuum ≈ the speed of light in air (3×10^8 m/s).

- **Snell's Law**

If a light ray passes from one homogeneous transparent medium to another, it refracts at the flat surface according to a set of laws, the first of which is Snell's Law. It states that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is equal to a constant for all angles of incidence, as shown in Figure (65).

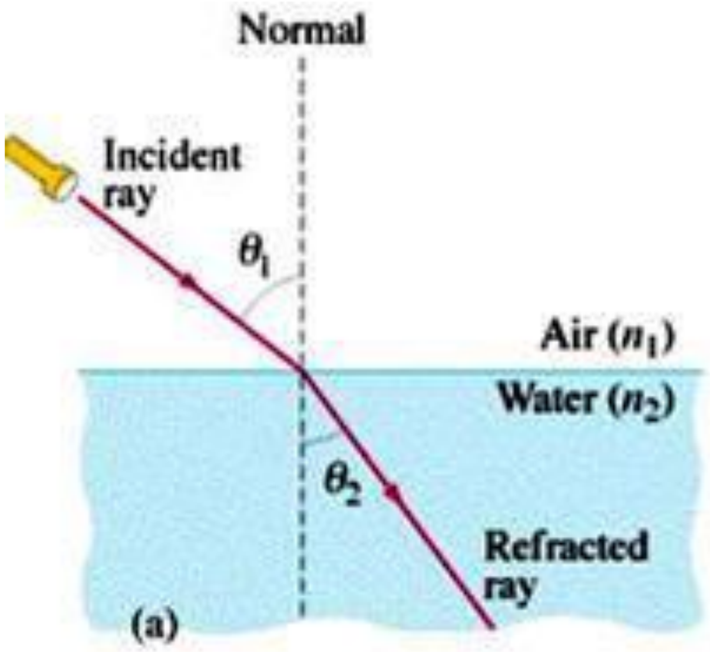


Figure (65) Refraction of Light at a Flat Interface

If XY represents a flat surface separating two media with refractive indices n_1 and n_2, and AB represents the incident light ray while BC represents the refracted ray, then:

$$\frac{\sin(\theta_1)}{\sin(\theta_2)} = const$$

This law is known as Snell's Law. Snell demonstrated that the value of the constant is the ratio of the refractive indices of the two media. Thus, this relationship takes the form:

$$\frac{\sin\,(\theta_1)}{\sin\,(\theta_2)} = \frac{n_2}{n_1}$$

which can be written as:

$$n_1\, sin(\theta_1) \;=\; n_2\, sin(\theta_2)$$

This relationship is called Snell's Law, and the medium with the lower refractive index is termed a medium of lower optical density.

- **Second Law**

The incident ray, the normal, and the refracted ray all lie in the same plane perpendicular to the interface between the two media.

- **Critical Angle and Total Internal Reflection**

When a ray passes from a denser medium to a medium of lower optical density, it refracts away from the normal at the interface, meaning that the angle of refraction is greater than the angle of incidence, as shown in Figure (66).

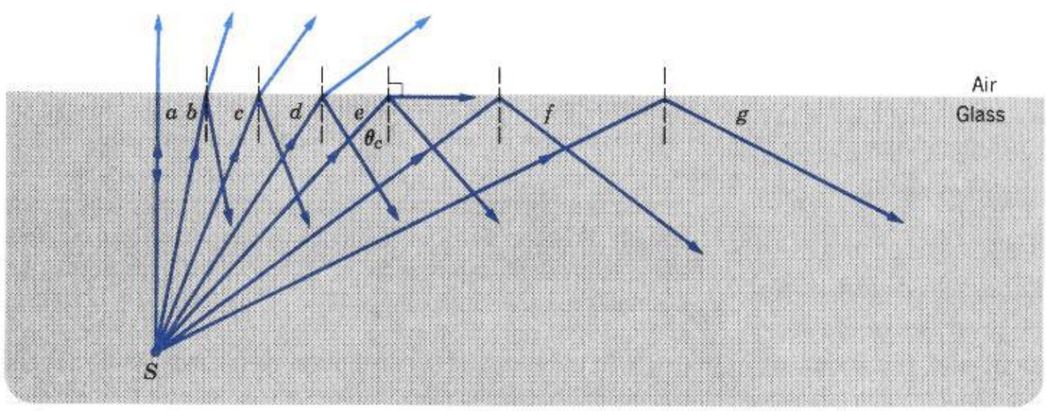


Figure (66) Total Internal Reflection

From the previous figure, we find that:

$$\frac{\sin(\theta)}{\sin(\emptyset)} = \frac{n_2}{n_1}$$

It is observed that as the angle of incidence increases, the angle of refraction also increases until the angle of incidence reaches a certain value θ_c such that the refracted ray exits into the second medium parallel to the interface, meaning it exits at an angle of refraction equal to $\phi=90^\circ$. Thus, at the angle θ_c:

$$\frac{\sin(\theta_C)}{\sin(90)} = \frac{n_2}{n_1}$$

$$\sin(\theta_C) = \frac{n_2}{n_1}$$

The angle of incidence θ_c in the denser medium that corresponds to a refraction angle of 90° is called the critical angle for the two media. If the angle of incidence in the denser medium exceeds the critical angle, the ray does not pass into the less dense medium; instead, it reflects at the interface completely according to the law of reflection. This phenomenon is called total internal reflection, as the light does not pass into the lighter medium. The critical angle θ_c can be calculated using the relationship:

$$\theta c = sin^{-1}\frac{n_2}{n_1}$$

Example

A light beam falls in the air on a triangular prism made of glass, as shown in Figure (67), at an angle of incidence θ, which has been chosen such that it is also equal to the angle of exit from the prism, as illustrated in the figure. Derive a mathematical expression for the refractive index of the prism material n, given that the refractive index of air = 1.

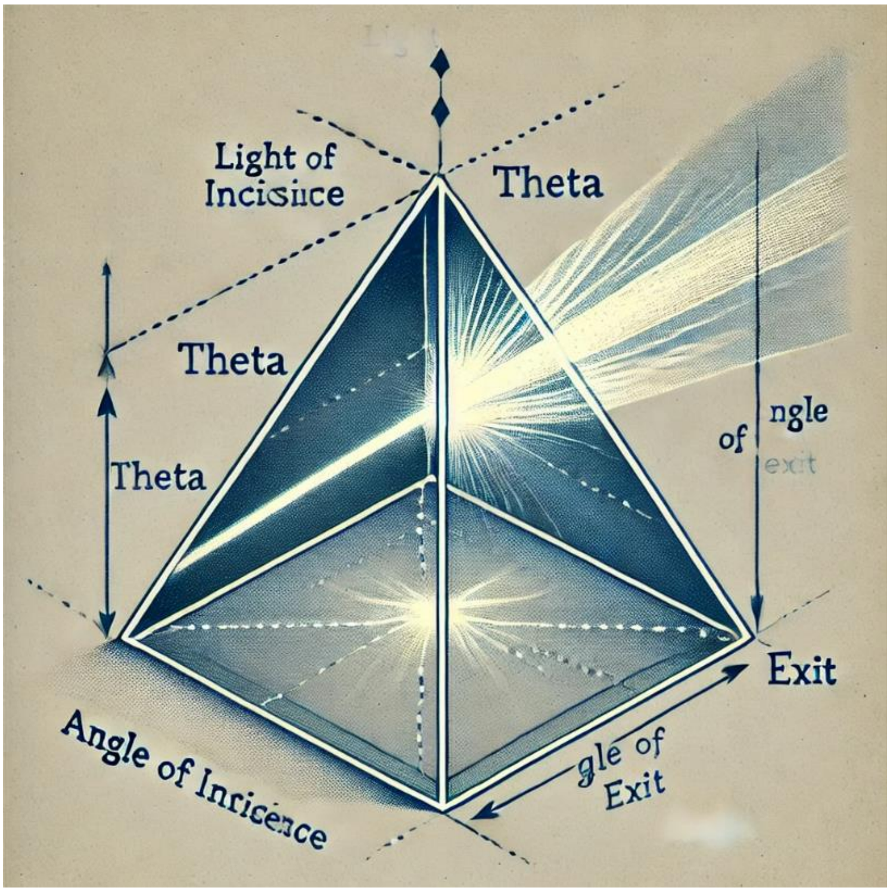


Figure (67) the triangular prism

Solution

$$\angle bad + \alpha = \frac{\pi}{2}, and$$

$$\angle bad + \frac{\emptyset}{2} = \frac{\pi}{2}$$

$$\therefore \alpha = \frac{1}{2}\emptyset$$

$$\Psi = 2(\theta - \alpha)$$

$$\theta = \frac{\Psi}{2} + \alpha = \frac{\Psi}{2} + \frac{\emptyset}{2} = \frac{1}{2}(\Psi + \emptyset)$$

$$n = \frac{\sin(\theta)}{\sin(\alpha)} = \frac{\sin(\Psi + \emptyset)/2}{\sin(\emptyset/2)}$$

Example

The figure shows a glass prism to be designed so that when light strikes one of its faces perpendicularly, it will experience total internal reflection, with the angle θ_1=45°. What is the appropriate refractive index for the material of the prism as shown in Figure (68)?

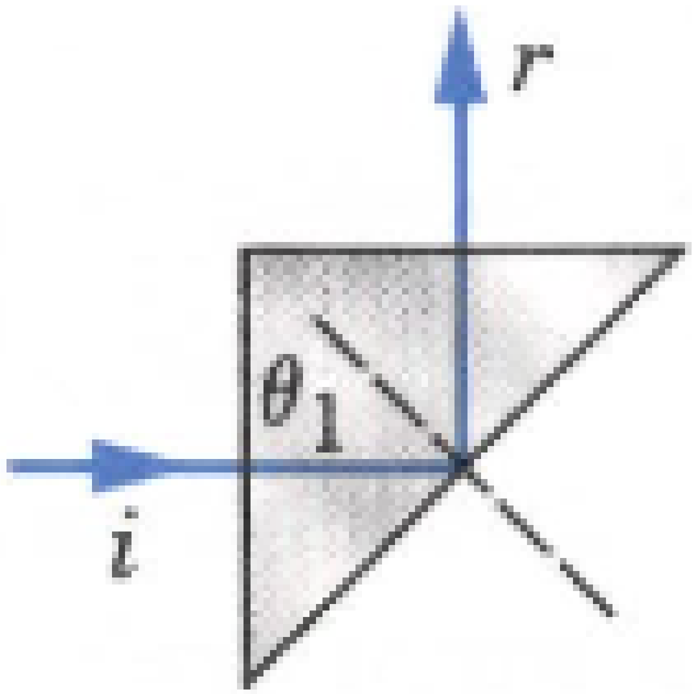


Figure (68) Simple triangular prism

Solution

The angle θ_1 must be equal to or greater than the critical angle θ_c to achieve total internal reflection within the prism. From the definition of the critical angle, we find that:

$$\theta_c = \sin^{-1}\frac{n_2}{n_1} = \sin^{-1}\frac{1}{n}$$

$$n = \frac{1}{\sin\theta_c}$$

$$n \geq \frac{1}{\sin 45} = 1.41$$

- **Lenses**

Lenses are among the most important optical devices; you can find lenses in eyeglasses, cameras, telescopes, microscopes, and projectors. There are two types of lenses:

- The first type is the convex lens, also known as the converging lens.
- The second type is the concave lens, also known as the diverging lens.

- **Convex Lens**

When a parallel beam of light strikes a convex lens parallel to the optical axis, the rays converge at a point called the focus (F) after passing through the lens. The distance between the lens and the focus is called the focal length (f). In this case, the focus is a real focus, meaning that an image can be formed and received at a screen. The convex lens has two surfaces, each with a radius of curvature r_1 and r_2, as shown in Figure (69). The relationship between the radii of curvature, the refractive index of the lens material, and the focal length is given by:

$$\frac{1}{f} = (n-1)(\frac{1}{r_1} - \frac{1}{r_1})$$

The signs of the focal length and the radii of curvature follow the sign convention mentioned earlier. Thus, r_1 has a positive sign while r_2 takes a negative sign. Additionally, the focal length takes a positive sign.

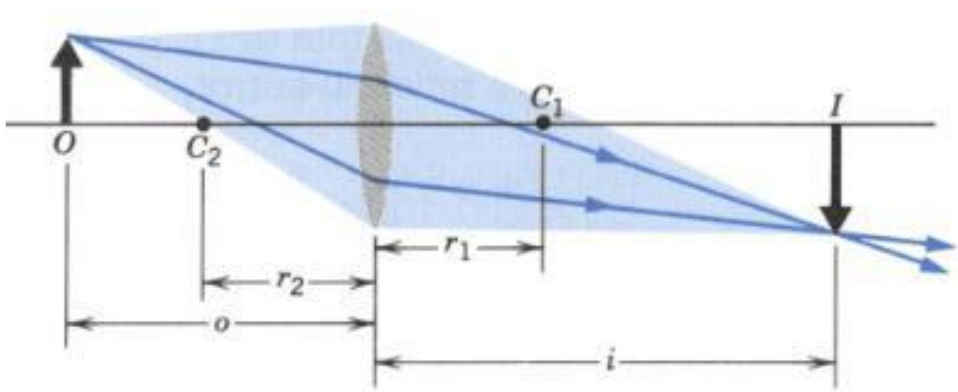


Figure (69) Convex Lens

This equation applies to both converging and diverging lenses. The relationship between the image distance, object distance, and focal length is:

$$\frac{1}{O} + \frac{1}{i} = \frac{1}{f}$$

where i is the image distance from the lens and O is the object distance from the lens. The previous relationship is known as the general lens equation and is used for both converging and diverging lenses.

- ✓ **Concave Lens**

If a parallel beam of light strikes a concave lens parallel to the optical axis, the rays do not converge; instead, they diverge after passing through the lens. However, if we extend the diverging rays exiting from the concave lens, they will meet at a point on the opposite side. This point is also called the focus, but it is a virtual focus. The distance between the virtual focus and the diverging lens is called the focal length, but it takes a negative sign, as shown in Figure (70).

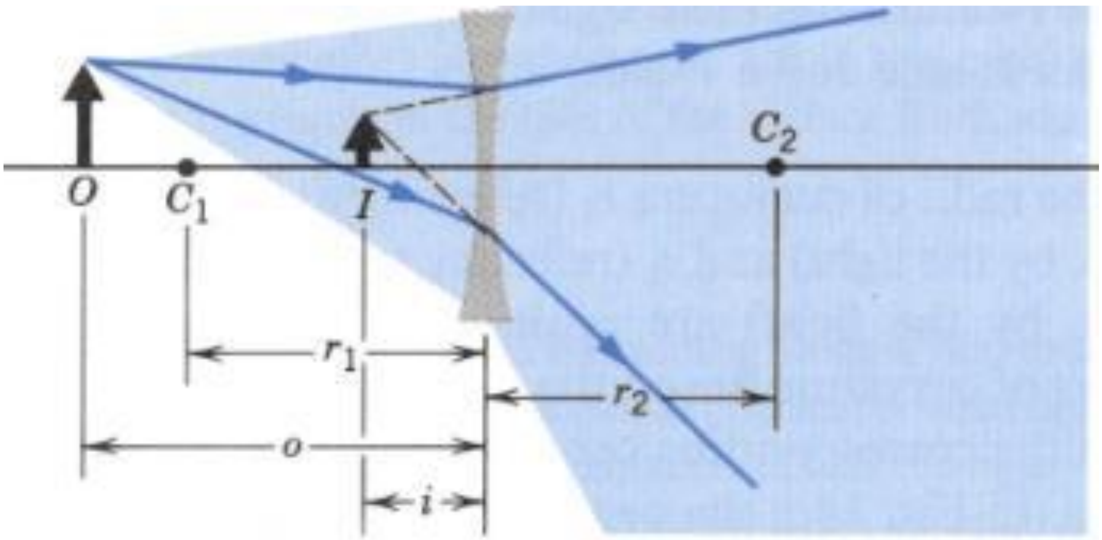


Figure (70) Concave Lens

The general lens equation mentioned earlier also applies to diverging lenses, and the sign conventions are also applicable for diverging lenses. For example, we find that r_1 in this case is negative, while r_2 is positive.

Example

The lenses shown in the following illustration, Figure (71), have radii of curvature of 42 cm and are made of glass with a refractive index of n=1.65n = 1.65n=1.65. Calculate the focal length.

Solution

In the case of

$$r_1 = 42\ cm\ ,$$

$$r_2 = -42\ cm$$

$$\frac{1}{f} = (n-1)(\frac{1}{r_1} - \frac{1}{r_2}) = (1.65-1)(\frac{1}{42\ cm} - \frac{1}{-42\ cm})$$

$$f = 32\ cm$$

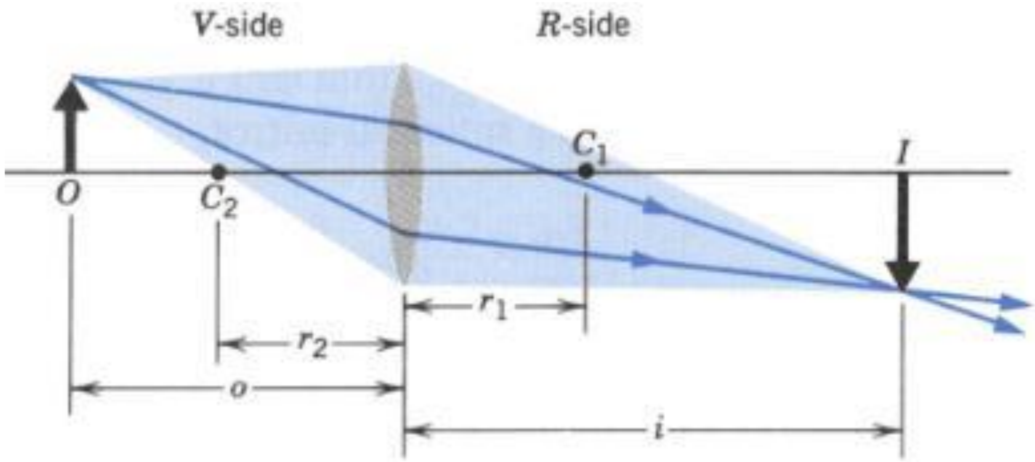


Figure (71) Refraction in the Convex Lens

In the case of

$$r_1 = -42\ cm\ ,$$

$$r_2 = 42\ cm$$

$$\frac{1}{f} = (n-1)(\frac{1}{r_1} - \frac{1}{r_2}) = (1.65-1)(\frac{1}{-42\ cm} - \frac{1}{42\ cm})$$

$$f = -32\ cm$$

Example

An object is placed at a distance of 38 cm in front of a concave lens, with a focal length of $f = -24\, cm$. Find the position of the image and the magnification.

Solution

$$\frac{1}{O} + \frac{1}{i} = \frac{1}{f}$$

$$\frac{1}{38} + \frac{1}{i} = \frac{1}{-24\, cm}$$

The position of the image can be found using the lens formula:

$$i = -15\, cm$$

The magnification (M)

$$M = -\frac{i}{O} = -\frac{-15\, cm}{38\, cm} = +\, 0.39$$

- ✓ **Optical Devices**

Optical devices are considered one of the most important scientific tools used in the study of natural phenomena and living organisms, whether at the microscopic level or on the scale of celestial bodies. These devices are based on precise physical and optical principles used in many applications in the fields of biological sciences and biomedical research. In this part of the textbook, we will discuss the different types of optical devices such as microscopes and telescopes, as well as medical optical devices such as endoscopes, in addition to applications of geometrical optics in biotechnology.

1. **Microscopes (Microscopes)**

A microscope is a device used to magnify exceedingly small objects so that they become visible to the naked eye. The microscope is a vital tool in biological sciences, as it allows researchers to study the fine details of cells, tissues, and microorganisms. There are two main types of microscopes:

a. **<u>Optical Microscope</u>**: It relies on using visible light and optical lenses to magnify the sample. This type is used in fields such as cellular biology and histology. Magnification can reach approximately 1000 to 1500 times. Optical microscopes typically consist of objective lenses and ocular lenses, with light focused on the sample using a condenser. The image below in Figure (72) illustrates the components of the optical microscope:

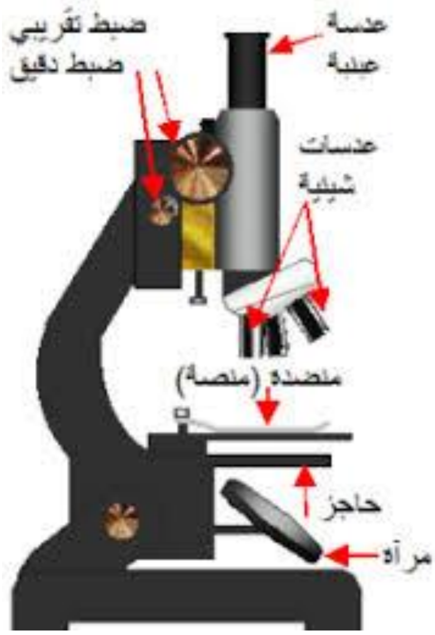


Figure (72) Optical Microscope

b. **<u>Electron Microscope</u>**: It uses electrons instead of light to create a detailed image of the sample. This type can provide magnification of up to millions of times, allowing for the study of the molecular structure of cells and biological molecules. There are two main types of electron microscopes:

   i. <u>Transmission Electron Microscope (TEM)</u>: It allows for the study of the internal structure of the sample by passing electrons through the sample, as shown in Figure (73).

Figure (73) Transmission Electron Microscope

ii. Scanning Electron Microscope (SEM): It provides three-dimensional images of the external surfaces of the sample by scanning electrons across its surface, as shown in Figure (74).

Figure (73) Scanning Electron Microscope (SEM)

The electron microscopes are characterized by their ability to achieve high resolution down to the nanometer level, and they are particularly useful in fields such as molecular biology and biotechnology.

2. **Telescopes**

A telescope is a device used to view distant objects, and it is an essential tool in astronomy. The telescope relies on gathering light from the distant object and magnifying it to enable clear viewing. There are two main types of telescopes:

a. **Refracting Telescope**: It relies on a convex lens to gather and focus light to magnify the image. This type is commonly used in terrestrial astronomical observations but is limited due to optical distortions caused by large lenses. The refracting telescope has high performance in observing celestial bodies such as planets and nearby stars, as shown in Figure (75).

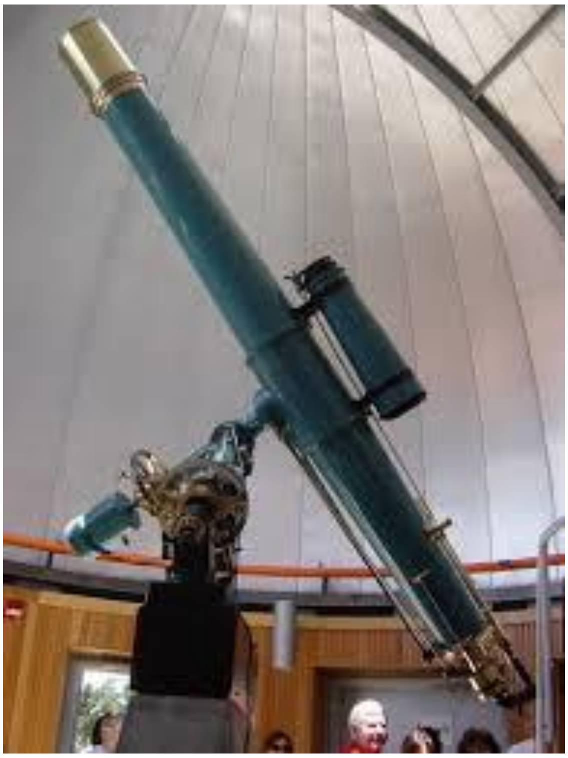


Figure (75) Refracting Telescope

b. **Reflecting Telescope**: It relies on concave mirrors to gather and focus light. The design of the reflecting telescope allows for the construction of large telescopes with large mirror diameters, enabling the collection of greater amounts of light and the observation of distant celestial objects, as shown in Figure (76). This type is used in large astronomical observatories, such as the Hubble Space Telescope.

Figure (76) Reflecting Telescope

The following illustration shows the difference between the refracting telescope and the reflecting telescope:

3. **Medical Optical Devices such as Endoscopes**
    a. **Medical Endoscopes**: Endoscopes are optical devices used in medical examination of the internal organs of the body. They are an essential part of modern medicine for examining and diagnosing diseases without the need for major surgical intervention. The endoscope relies on a small camera and optical guiding lenses placed in a flexible tube, allowing the doctor to examine the organs from the inside.
        i. **Endoscope**: It is used for examining internal organs, such as the stomach and intestines, and is inserted through natural openings in the body such as the mouth or the anus, as shown in Figure (77).

Figure (77) Endoscope

ii. **Laparoscope**: It is used in abdominal surgeries through small incisions and contains a camera that displays a live image of the internal organs. This device is commonly used in procedures such as appendectomy and cholecystectomy, as shown in Figure (79).

Figure (79) Laparoscope

Endoscopes provide a live image from inside the body, facilitating doctors in conducting examinations and treatments with minimal surgical intervention. These devices rely on advanced optical technologies such as fiber optics to transmit light and images.

b. Applications of Geometrical Optics in Biotechnology

i. Biophotonics

Geometrical optics, or biophotonics, relies on the use of light to study biological systems. This field is considered advanced biotechnology used in examining biological samples and analyzing vital processes. Applications include:

- ✓ **Spectroscopic Imaging:** A technique used to analyze chemical reactions within living cells. It relies on measuring changes in the light spectra resulting from biological processes.
- ✓ **DNA Optical Analysis:** Optical techniques are used to read DNA sequences and examine genetic mutations.

ii. Medical Optical Imaging Techniques

Optical imaging techniques are used in the non-invasive diagnosis of diseases. For example, infrared imaging is used to diagnose cancerous tumors due to its ability to detect thermal differences in tissues. Another important application is fluorescence imaging to identify the locations of proteins and molecules within cells.

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