

Introduction to Electricity and Ohm's Law

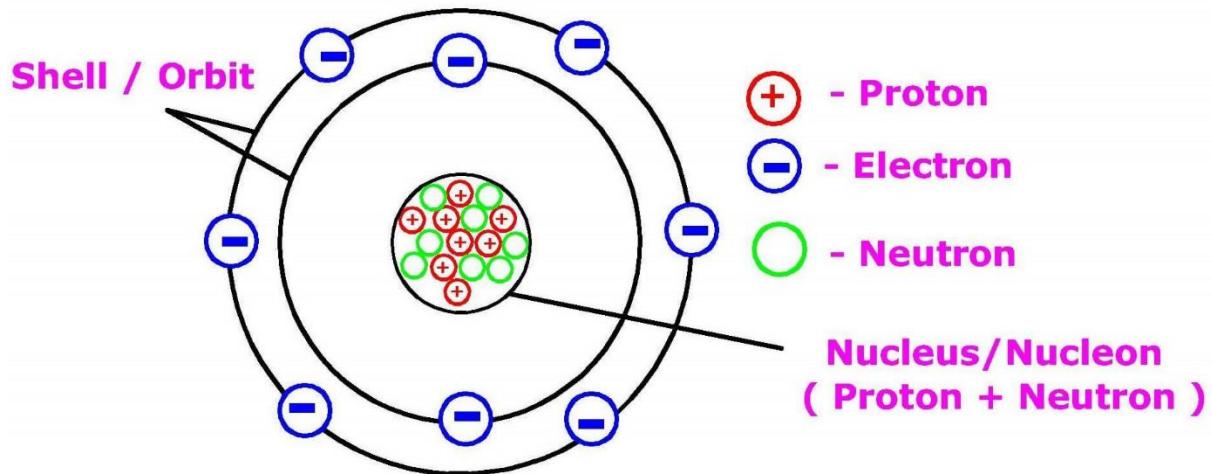
The Fundamentals of Matter and Charge

These notes provide a foundational understanding of the atom, electric charge, and the forces between charges, which are the building blocks for all electrical and electronic principles. They are designed to be a clear, in-depth introduction for anyone new to the topic.

1. The Atom: The Building Block of Everything

Everything around us, from a copper wire to the air we breathe, is made up of tiny particles called **atoms**. An atom is the smallest unit of an element that maintains the properties of that element. For example, a single atom of copper is the smallest possible piece that is still identifiable as copper. To give you a sense of scale, a single copper penny contains about 24,000,000,000,000,000,000 atoms.

A simple way to visualize an atom is like a tiny solar system. It has two main parts, and it's important to realize that an atom is almost entirely empty space.



- **The Nucleus:** This is the incredibly dense, heavy centre of the atom. If an atom were the size of a sports stadium, the nucleus would be the size of a marble in the centre. It contains two types of particles packed tightly together:
 - **Protons:** These have a **positive (+)** electrical charge. The number of protons is the atom's "atomic number" and it uniquely defines the element. For example, hydrogen has 1 proton, carbon has 6, and copper has 29.
 - **Neutrons:** These are neutral; they have **no charge (0)**. Their main role is to add mass and act as a kind of "glue" that holds the positively-charged protons together in the nucleus (since, as we'll see, like charges repel).
- **Electrons:** These are extremely small, lightweight particles that have a **negative (-)** electrical charge. They orbit the nucleus at incredible speeds in specific paths, or "shells," which exist at different energy levels.
 - The electrons are kept in orbit by the force of attraction from the positive protons in the nucleus (opposites attract). This is balanced by the high speed of the electrons, which prevents them from being pulled into the nucleus.

- **Valence Shell and Valence Electrons:** The outermost shell of an atom is called the **valence shell**. The electrons in this shell are called **valence electrons**. These are the most important electrons for understanding electricity because they are the farthest from the nucleus and are held with the weakest grip. The number of valence electrons determines an element's electrical properties.

2. Electric Charge: The Property That Makes Electricity Possible

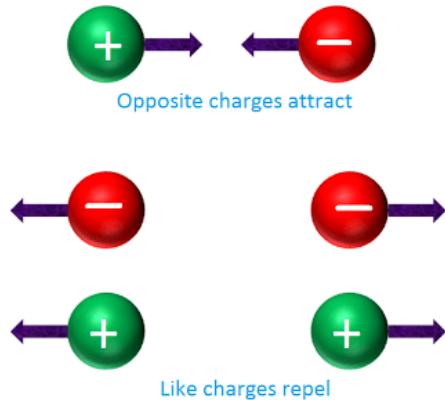
Charge is a fundamental property of the protons and electrons in an atom. It is the source of all electrical phenomena. The principle of **Conservation of Charge** states that charge cannot be created or destroyed, only transferred from one object to another.

- **Charge Balance:** In its natural state, an atom is electrically **neutral**. This is because it has an equal number of protons (positive charges) and electrons (negative charges). The positive pull of the nucleus is perfectly balanced by the negative pull of the electrons, resulting in no overall charge.
 - *Example:* A neutral carbon atom has 6 protons in its nucleus and 6 electrons orbiting it. $(+6) + (-6) = 0$.
- **How Things Become Charged (Ionization):** An atom becomes charged if this balance is upset by gaining or losing electrons. This process is called **ionization**, and the resulting charged atom is called an **ion**.
 - If an atom **loses** an electron from its outer shell, it has more protons than electrons. This leaves it with a net **positive charge** (it becomes a positive ion).
 - If an atom **gains** an extra electron in its outer shell, it has more electrons than protons. This gives it a net **negative charge** (it becomes a negative ion).
 - **Free Electrons:** In conductive materials like copper, the single valence electron is so loosely held that it can easily break free from its atom with very little energy applied. These detached electrons, called **free electrons**, are then able to drift through the material's atomic structure. A solid piece of copper contains billions of these free electrons, forming a "sea of electrons." It is the collective, directed movement of these free electrons that we call electric current.
- **The Unit of Charge: The Coulomb (C)**
 - Because the charge on a single electron is incredibly small, we use a practical unit called the **Coulomb (C)** to measure electric charge.
 - Think of it like this: instead of counting individual grains of sand, we count bags of sand. The Coulomb is like a "bag" that contains a massive number of electron charges (approximately 6.24×10^{18} electrons!). When we talk about an electric current of 1 Ampere (A), it means that 1 Coulomb of charge (one "bag" of electrons) is flowing past a point in a wire every single second.

3. Coulomb's Law: The Rules of Attraction and Repulsion

Coulomb's Law is a fundamental principle that describes how charged objects interact with each other. This interaction happens through an invisible force field that surrounds every charged particle, called an **electric field**. You can think of this field like the gravitational field around the

Earth—you can't see it, but it exerts a force on other objects. The law is very simple and has two key parts:



1. Like charges REPEL.

- Two positive charges will push each other away.
- Two negative charges will also push each other away.
- *Example:* If you rub two balloons on your hair, they both get coated with extra electrons, giving them a negative charge. If you then try to bring them close together, their electric fields will interact and exert a force that pushes them apart.

2. Opposite charges ATTRACT.

- A positive charge and a negative charge will pull towards each other.
- *Example:* After rubbing a balloon on your hair, the balloon has a negative charge (it gained electrons). Your hair, having lost those electrons, now has a positive charge. The attraction between the positive hair and negative balloon is why the balloon will stick to your hair.

The strength of this force depends on two main factors:

- **The amount of charge:** The more charge an object has, the stronger its electric field and the greater the force of attraction or repulsion.
- **The distance between them:** The force gets weaker very quickly as the distance between the objects increases.

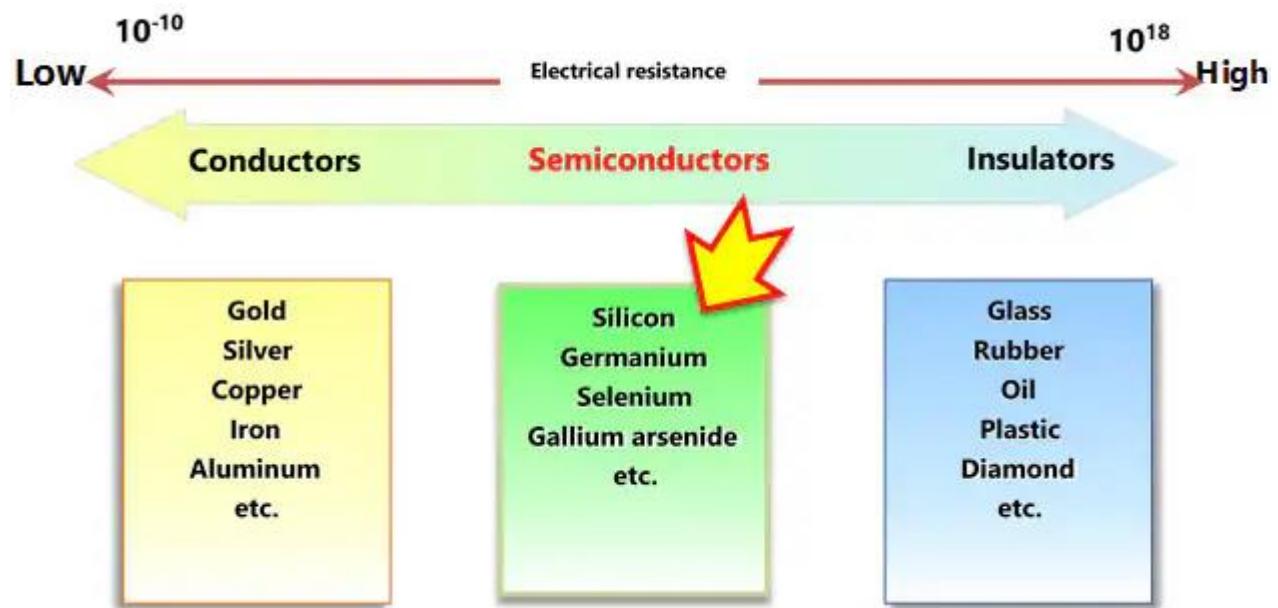
This fundamental force of attraction and repulsion is the engine of electricity. A battery, for example, works by creating a large surplus of negative charges at its negative terminal and a large deficit of electrons (making it positive) at its positive terminal. This separation of charge creates a powerful electric field and an "electrical pressure"—which we call **voltage**—that can push and pull free electrons through a wire, creating the flow of energy we call an electric current.

Materials, Current, and Voltage

This section moves from the theoretical world of the single atom to the practical world of real materials. Understanding how different materials behave electrically is fundamental to every aspect of electrical work. It answers the critical questions: Why does a copper wire carry current so well, while the plastic coating around it stops it completely? What exactly *is* this "flow" of electricity, what provides the "push" to make it happen, and how do we describe its direction? We will explore the distinct electrical personalities of conductors, insulators, and the "smart" materials known as semiconductors.

1. Conductors, Insulators, and Semiconductors

The single most important factor determining a material's electrical properties is its atomic structure, specifically how tightly its atoms hold onto their **valence electrons** (the electrons in the outermost shell). The ease with which these valence electrons can be freed from their atoms dictates whether a material will be a conductor, an insulator, or something in between.



- **Conductors: The "Highways" for Electrons:** A **conductor** is a material that allows electric current to flow through it easily, offering very little opposition. This is because the atoms in a conductor have very loosely held valence electrons.
 - **Structure:** Conductors typically have only 1 to 3 valence electrons. These electrons are so weakly attracted to their own nucleus that they can easily detach and drift throughout the material, forming a "sea of free electrons."
 - **Function:** When a voltage is applied across a conductor, this "sea" of free electrons is easily pushed along, creating a strong current.
 - **Examples:** Most metals are excellent conductors. The most common are:
 - **Copper:** The standard for electrical wiring due to its excellent conductivity and reasonable cost.

- **Silver:** The best electrical conductor, but too expensive for general use.
 - **Gold:** A very good conductor that doesn't corrode, making it ideal for coating electrical contacts and connectors.
 - **Aluminium:** Lighter and cheaper than copper, but not as good a conductor.
- **Insulators: The "Roadblocks" for Electrons** An **insulator** is a material that strongly resists the flow of electric current.
 - **Structure:** The atoms in an insulator have their valence electrons held very tightly. These materials typically have 5 to 8 valence electrons, meaning their outer shell is almost full. It takes a huge amount of energy to break these electrons free.
 - **Function:** Because there are virtually no free electrons to move, insulators can be used to block the flow of current. This is why they are used to coat electrical wires and make safety equipment.
 - **Examples:**
 - **Rubber, Plastic, and PVC:** Used to insulate wires and cables.
 - **Glass and Ceramics:** Used for high-voltage insulators on power lines.
 - **Air:** Dry air is a good insulator.
- **Semiconductors: The "Smart" Materials.** A **semiconductor** is a special material with electrical properties that fall between those of a conductor and an insulator.
 - **Structure:** Semiconductors have exactly 4 valence electrons. They are not good conductors, but they are not good insulators either.
 - **Function:** Their unique atomic structure allows them to be precisely controlled. By adding impurities (a process called "doping"), a semiconductor can be made to act more like a conductor or more like an insulator. This ability to control their conductivity makes them the foundation of all modern electronics.
 - **Examples:**
 - **Silicon (Si):** The most common semiconductor, used to make computer chips, transistors, diodes, and solar cells.
 - **Germanium (Ge):** Another common semiconductor material.

2. Electric Current (I): The Flow of Charge

Electric current is the organized, directed flow of free electrons (or charge) through a conductor.

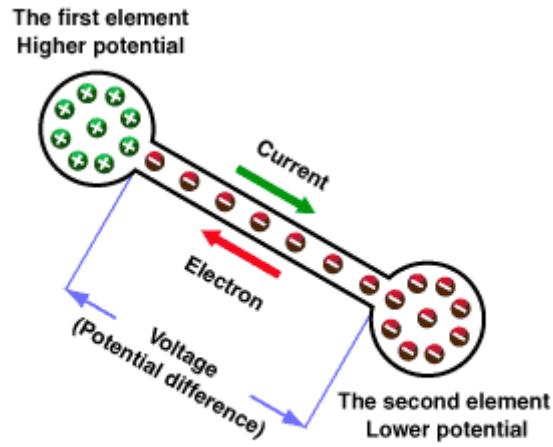
- **Analogy: Water in a Pipe:** Think of a conductor as a pipe filled with water (the free electrons). The electrons are always present, but they are moving randomly in all directions. Current only exists when a pressure (voltage) is applied to make them all flow in the **same direction**.
- **The Unit of Current: The Ampere (A)** The rate of this flow is measured in **Ampères (A)**, often shortened to "amps."

- **Definition:** 1 Ampere is equal to 1 Coulomb of charge flowing past a single point in a circuit in 1 second.
- So, if a current of 2 Amps is flowing through a wire, it means that 2 Coulombs' worth of electrons are passing any given point in that wire every second.

3. Voltage: The Driving Force (EMF and Potential Difference)

Current will not flow on its own; it needs a "push" or "pressure." This electrical pressure is known as **voltage**.

- **Electromotive Force (EMF): The Cause** Electromotive Force (EMF) is the total energy that a source (like a battery or generator) provides to create the electrical pressure. It is the force that "motivates" the electrons to move. EMF is the energy converted from another form (chemical, magnetic) into electrical energy.
- **Potential Difference (PD): The Effect** Potential Difference (PD), also called **voltage**, is the difference in electrical pressure between two points in a circuit. It is this difference in pressure that actually pushes the current through the components of the circuit.
- **Analogy: Water Tower:**
 - The **pump** that lifts water up into a water tower provides the **EMF**.
 - The **height difference** between the water in the tower and the ground creates the **water pressure**. This pressure is the **Potential Difference (Voltage)**. The greater the height difference, the greater the pressure.



Voltage and Current

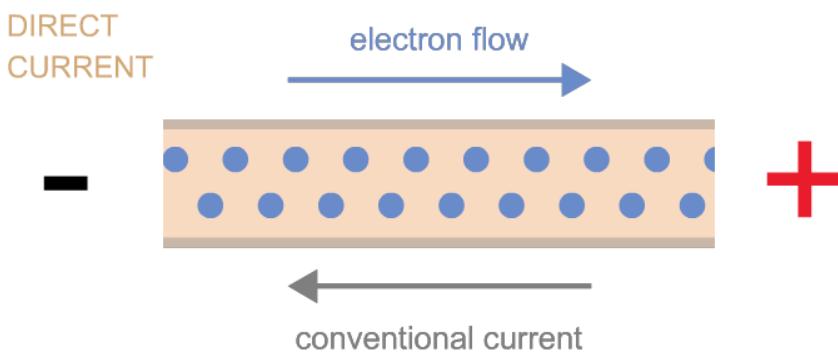
- **The Unit of Voltage: The Volt (V)** Both EMF and Potential Difference are measured in **Volts (V)**.
- **Main Sources of EMF:**
 - **Chemical (Cells/Batteries):** A chemical reaction inside a battery separates charges, creating a positive and negative terminal and thus a stable EMF.

- **Magnetic (Generators):** Moving a wire through a magnetic field (or a magnetic field past a wire) induces a voltage in the wire. This principle of electromagnetic induction is how power station generators produce electricity.
- **Thermal (Thermocouples):** When the junction of two different metals is heated, a small voltage is produced. This is used for temperature measurement.

4. Current Direction: A Tale of Two Flows

Historically, before the electron was discovered, scientists believed that electricity was the flow of some kind of positive fluid. This led to two different ways of describing current flow, both of which are still used today.

- **Electron Flow (Real Current)** This is what **actually happens** inside a metallic conductor. Electrons are negatively charged, so they are repelled from the negative terminal of a source and attracted to the positive terminal.
 - **Direction:** From Negative (-) to Positive (+).
- **Conventional Current Flow (The Industry Standard)** This is the original, historical model. It assumes that positive charges are moving.
 - **Direction:** From Positive (+) to Negative (-).
 - **Why it's still used:** When this standard was created, it was used to develop all the fundamental rules, formulas (like Ohm's Law), and symbols we use in electricity. All electronic component symbols (like the arrow on a diode) are drawn based on conventional current flow. To avoid confusion and the need to rewrite everything, the industry has stuck with it.



For all practical purposes in the electrical and electronics industry, you must always use CONVENTIONAL CURRENT FLOW for circuit diagrams and calculations.

The Electric Circuit and Resistance

Now that we understand materials, current, and voltage, we can bring them all together. This section explains how these elements form a complete electric circuit, introduces the concept of resistance (the opposition to current flow), and covers the essential graphical symbols used to draw circuit diagrams.

1. The Simple Electric Circuit: A Complete Path

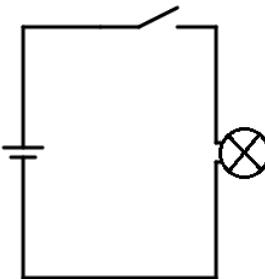
An **electric circuit** is a complete, closed-loop path through which electric current can flow. The term "closed-loop" is critical; it means the path starts at the energy source, travels through all the components, and returns to the source without any breaks. If this path is broken at any point, the entire flow of current stops immediately, much like a raised drawbridge stops all traffic. For a circuit to do useful work, it must contain four essential parts.

- **1. Source (of EMF):** This is the power supply that provides the voltage (EMF) to push the current around the circuit. The source's job is to create a potential difference, establishing a "high pressure" point and a "low pressure" point to motivate the electrons to move.
 - *Examples:* A **battery** provides Direct Current (DC) voltage through a chemical reaction. A **power generator** at a power station provides Alternating Current (AC) voltage through electromagnetism. A **solar panel** provides DC voltage by converting light energy.
- **2. Path (Conductor):** This provides the "motorway" for the current to travel from the source, to the device being powered, and back to the source. The path must be made of a conductive material (like copper) to ensure the energy is transported efficiently with minimal loss.
 - *Examples:* Copper wires in a household appliance or the thin, flat conductive tracks on a printed circuit board (PCB) inside a phone or computer.
- **3. Load:** This is the device or component that consumes the electrical energy and converts it into another, useful form of energy (like light, heat, or motion). The load is the entire reason for building the circuit; it's the part that does the work. Every load has some resistance.
 - *Examples:* A **lamp** (converts electricity to light and heat), a **motor** (to kinetic/mechanical energy), a **heater** or **toaster** (to thermal energy), a **speaker** (to sound energy).
- **4. Control:** This is a device that allows us to safely and intentionally open or close the circuit, starting or stopping the flow of current. It gives us command over the circuit's operation.
 - *Example:* A **switch** is the most common form. Other examples include **relays** (electrically operated switches) or **thermostats** (temperature-operated switches).

Analogy: A Central Heating System

- **Source:** The boiler's pump, which provides the pressure (EMF) to force water to circulate.
- **Path:** The copper pipes that carry the water to and from the boiler.
- **Load:** The radiators, which take the energy from the hot water and convert it to heat for the room. The water is colder after leaving the radiator, having done its work.

- **Control:** The valves on the radiators or the main thermostat, which can stop the flow of water to a specific radiator or the entire system.

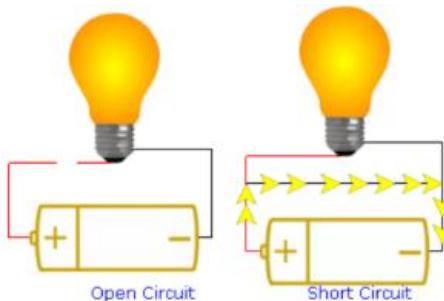


2. Resistance (R): The Opposition to Current Flow

While conductors allow current to flow easily, they don't offer a perfectly free path. **Resistance (R)** is the measure of a material's opposition to the flow of electric current. It's a fundamental property of all materials to some degree.

- **What Causes Resistance?** As free electrons are pushed through a conductor by voltage, they don't travel in a perfectly straight line. They continuously collide with the fixed atoms of the material's crystal lattice structure. Each collision slows the electron down and transfers some of its kinetic energy to the atom, causing the atom to vibrate more intensely.
 - **Analogy:** Imagine trying to run through a crowded hallway. You are the electron, and the people are the atoms. You can't run in a straight line; you keep bumping into people, which slows you down and creates a bit of chaos (heat). A good conductor is like a wide, empty hallway, while a poor conductor is like a narrow, crowded one.
- **The Effect of Resistance: Heat** This increased vibration of the atoms is what we experience as **heat**. Every component that has resistance will heat up when current flows through it. This can be a desired effect (like in an electric heater or toaster) or an undesired energy loss (like the heat from a computer's processor or a warm phone charger).
- **The Unit of Resistance: The Ohm (Ω)** Resistance is measured in **Ohms**, named after Georg Ohm. The symbol for the Ohm is the Greek letter omega (Ω). A material has a resistance of 1 Ohm if a voltage of 1 Volt is required to push a current of 1 Ampere through it.

3. Circuit Conditions: Open and Short Circuits



- **Open Circuit:** An **open circuit** occurs when there is an intentional or unintentional break in the path, preventing current from flowing. This is the normal condition when a switch is turned off. However, it can also be a fault, such as a broken wire, a loose connection, or a blown fuse. Because the path is incomplete, the resistance between the two broken points is

effectively infinite, and therefore the current is zero. The source voltage, however, still exists across the break.

- **Short Circuit:** A **short circuit** is a dangerous condition where the current finds an unintended, low-resistance path that bypasses the load. For example, if the insulation on two wires inside a power cord wears out and the bare copper conductors touch, the current will flow directly from the "hot" wire to the "neutral" wire, completely avoiding the appliance it's supposed to power.
 - **The Danger:** Because this "short" path has almost zero resistance, Ohm's Law ($I = V/R$) tells us that the current will become extremely high. This massive flow of current generates an intense amount of heat very quickly, which can melt wires, cause fires, and make batteries or power supplies explode. This is why circuits must always be protected by **fuses** (a thin wire designed to melt and break the circuit) or **circuit breakers** (a switch designed to trip open) when they detect this excessive current.

4. Graphical Symbols: The Language of Electricity

We use standard graphical symbols to draw circuit diagrams (schematics). This allows anyone, anywhere, to understand the layout and function of a circuit without language barriers.

Component	Symbol	Function
Cell		A circuit has to have a power source and that is often a cell.
Battery		A battery is a power source made from more than one cell.
Resistor		A component designed to have a specific amount of resistance to control the amount of current.
Lamp		A load that produces light when current flows through it.
Switch		A control device used to intentionally open or close a circuit path.
Voltmeter		A meter used to measure voltage (Potential Difference). It is connected <i>in parallel</i> (across) the component because it measures the <i>difference</i> in pressure between two points.
Ammeter		A meter used to measure current. It is connected <i>in series</i> (in line with) the circuit path because it must measure the entire flow of charge <i>through</i> it.
Ohmmeter		A meter used to measure resistance. It must only be used when the circuit is <i>powered off</i> , as it provides its own small voltage to perform the measurement.

Ohm's Law and Calculations

This section introduces the most important fundamental law in all of electricity and electronics: Ohm's Law. This law describes the precise mathematical relationship between the three key electrical quantities: Voltage, Current, and Resistance. It is the cornerstone of circuit analysis. Mastering Ohm's Law is not just beneficial; it is absolutely essential for analysing, designing, and troubleshooting any electrical circuit, from a simple flashlight to complex industrial machinery.

1. Ohm's Law: The Core Relationship

In the early 1800s, the German physicist Georg Ohm conducted countless experiments with circuits. He discovered a simple but profound relationship that forms the basis of our understanding of electricity. He stated that:

"The current flowing through a conductor is directly proportional to the voltage across its ends, provided the temperature and other physical conditions remain unchanged."

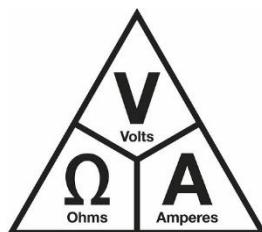
Let's break this down into its practical implications:

- **"Directly proportional to the voltage"**: This is the most intuitive part of the law. Voltage is the electrical "pressure." If you increase the pressure, you increase the flow. If you have a circuit with a constant resistance, and you double the voltage from 6V to 12V, the current flowing through that circuit will also exactly double.
- **"Inversely proportional to the resistance"**: Although not stated directly in that quote, the law also means that current is inversely proportional to resistance. If you keep the voltage constant but double the resistance, the current will be cut in half. Resistance opposes the flow, so more resistance means less current.
- **"Provided the temperature... remain[s] unchanged"**: This is a critical condition. As we learned, resistance in a conductor is caused by electrons colliding with atoms, which generates heat. For many common materials (like copper), as they get hotter, their atoms vibrate more vigorously, making it even harder for electrons to pass through. This means their resistance actually increases with temperature. Ohm's law is most accurate for components called **resistors**, which are specifically manufactured to have a stable resistance over a wide range of operating temperatures. Devices like filament light bulbs do *not* strictly follow Ohm's Law, because their resistance when hot is many times higher than their resistance when cold.

2. The Ohm's Law Formula: A Triangle of Power

Ohm's Law is expressed through a simple and powerful set of equations. The relationship between Voltage (V), Current (I), and Resistance (R) can be easily remembered using the Ohm's Law Triangle, a simple but invaluable memory aid.

The Ohm's Law Triangle:



To use the triangle, simply cover the quantity you want to find with your finger, and the remaining two variables will show you the correct formula:

- **To find Voltage (V):** Cover 'V'. You are left with I next to R, which means $I \times R$.
 - **Formula:** $V = I \times R$ (Voltage = Current multiplied by Resistance)
 - *This tells you how much electrical pressure is needed to push a certain amount of current through a certain resistance.*
- **To find Current (I):** Cover 'I'. You are left with V on top of R, which means V / R .
 - **Formula:** $I = V / R$ (Current = Voltage divided by Resistance)
 - *This is the most common use of Ohm's Law. It tells you how much current will flow if you apply a known voltage to a known resistance.*
- **To find Resistance (R):** Cover 'R'. You are left with V on top of I, which means V / I .
 - **Formula:** $R = V / I$ (Resistance = Voltage divided by Current)
 - *This is useful for finding the resistance of an unknown component by measuring the voltage across it and the current through it.*

Important Note on Units: For these formulas to work correctly, you must **always** convert your values to the base units before calculating:

- Voltage (V) in **Volts**
- Current (I) in **Amperes (Amps)**
- Resistance (R) in **Ohms (Ω)** *A common mistake is to calculate with milliamps (mA) or kilohms ($k\Omega$) directly. This will give you an incorrect answer.*

3. Calculations: Putting the Law into Practice

Working with Ohm's law often involves numbers that are very large or very small. We use metric prefixes to make them manageable.

Common Prefixes:

- **Mega (M):** 1,000,000 or $\times 10^6$ (e.g., $1 M\Omega = 1$ million Ohms)
- **kilo (k):** 1,000 or $\times 10^3$ (e.g., $1 kV = 1$ thousand Volts)
- **milli (m):** 0.001 or $\times 10^{-3}$ (e.g., $1 mA =$ one-thousandth of an Amp)
- **micro (μ):** 0.000001 or $\times 10^{-6}$ (e.g., $1 \mu A =$ one-millionth of an Amp)

Example Calculations:

- **Problem 1: Find the Current** A 12V battery is connected to a circuit with a 100Ω resistor. What current will flow?
 - **Formula:** $I = V / R$
 - **Calculation:** $I = 12V / 100\Omega = 0.12 A$
 - **Answer:** The current is 0.12 Amps (which is often expressed as 120 mA).

- **Problem 2: Find the Voltage** A current of 50 mA flows through a 1.2 kΩ resistor. What is the voltage drop across the resistor?
 - First, convert to base units: $50 \text{ mA} = 0.05 \text{ A}$; $1.2 \text{ k}\Omega = 1200 \Omega$.
 - Formula: $V = I \times R$
 - Calculation: $V = 0.05 \text{ A} \times 1200 \Omega = 60 \text{ V}$
 - Answer: The voltage is 60 Volts.
- **Problem 3: Find the Resistance** A circuit has a 9V supply, and you measure the current to be 300 μA. What is the total resistance of the circuit?
 - First, convert to base units: $300 \mu\text{A} = 0.0003 \text{ A}$.
 - Formula: $R = V / I$
 - Calculation: $R = 9\text{V} / 0.0003 \text{ A} = 30,000 \Omega$
 - Answer: The resistance is $30,000 \Omega$ (or $30 \text{ k}\Omega$).
- **Problem 4: Real-World Resistor Calculation.** A LED needs about 2V across it to light up and requires a current of 20 mA to be bright but not burn out. If you are using a 9V battery, what value of "current-limiting" resistor do you need to put in series with the LED?
 - First, find the voltage the resistor must "drop": The battery supplies 9V, but the LED only needs 2V. The resistor must handle the rest. $V_{\text{resistor}} = 9\text{V} - 2\text{V} = 7\text{V}$.
 - The current through the whole series circuit must be 20 mA. Convert to base units: $20 \text{ mA} = 0.02 \text{ A}$.
 - Now, find the required resistance: $R = V / I = 7\text{V} / 0.02\text{A} = 350 \Omega$.
 - Answer: You would need a 350Ω resistor.

4. Practical Verification: Proving the Law

One of the best ways to understand Ohm's Law is to prove it for yourself with a simple experiment. This also provides excellent practice in using multimeters correctly and safely.

Required Equipment:

- A variable DC power supply
- A multimeter (or two, for convenience)
- A resistor (e.g., 1 kΩ)
- Connecting leads

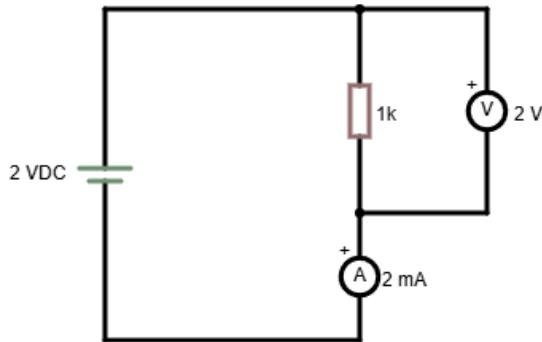
Procedure:

1. Measure the Resistance:

- Make sure the power supply is **OFF** and disconnected.
- Set your multimeter to the Ohmmeter (Ω) function.

- Connect the meter leads directly across the resistor. This isolates the component for a true reading.
- Record the actual resistance value. It may be slightly different from its rated value (e.g., a 1000Ω resistor might measure 995Ω). This is due to manufacturing tolerances.

2. Construct the Circuit:



- Connect the resistor in series with the power supply.
- Set the multimeter to the Ammeter (A) function (you may need to move the red lead to the Amps jack).
- **Break the circuit** and connect the ammeter **in series**. The ammeter acts like a flow meter for electricity, so the entire current must pass *through* it to be counted.

3. Measure Voltage and Current:

- Turn the power supply on and set it to a low voltage (e.g., 2V).
- Use a second multimeter (or reconfigure your first one) as a **Voltmeter (V)**. Connect it **in parallel** (across) the resistor. A voltmeter measures the *difference* in pressure between two points, so it must be connected on both sides of the component.
- Read and record the exact voltage from the voltmeter and the exact current from the ammeter.

4. Calculate and Compare:

- Using the voltage and current you just measured, use Ohm's Law to calculate the resistance: $R = V / I$.
- Compare this calculated resistance value to the resistance value you measured directly in Step 1. They should be very close! A small difference is expected due to the limited accuracy of the meters.

5. Repeat for Different Voltages and Interpret the Results:

- Increase the supply voltage (e.g., to 4V, 6V, 8V) and repeat the measurements and calculations.
- You will demonstrate that as the voltage increases, the current increases proportionally. The calculated resistance value should remain constant at each step.

- **Visual Proof:** If you plot your measured values on a graph with Voltage on the y-axis and Current on the x-axis, the points will form a straight line. The slope of this line is the resistance ($R = \Delta V / \Delta I$). This linear relationship is the visual proof of Ohm's Law.

Effects and Hazards of Electricity

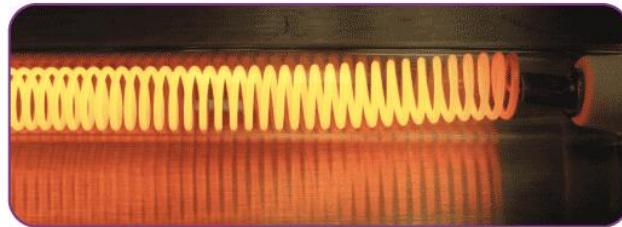
Understanding how to build and analyze circuits is only half the story. It is equally important to understand what electricity *does*—both intentionally and unintentionally. This section covers the three primary effects of electric current that we harness to do useful work, and the critical hazards that demand our constant respect and attention.

1. The Three Main Effects of Electric Current

Whenever current flows, it produces certain effects. We have engineered ways to harness these effects to our advantage.

- **1. The Heating Effect (Joule Heating)**

- **Principle:** As we learned, resistance is the opposition to current flow caused by electrons colliding with the atoms of a conductor. Each of these millions of collisions transfers energy, which manifests as heat. The amount of heat is governed by the formula for power, $P=I^2R$. This means the heat generated increases exponentially with the current. Doubling the current doesn't just double the heat; it quadruples it.

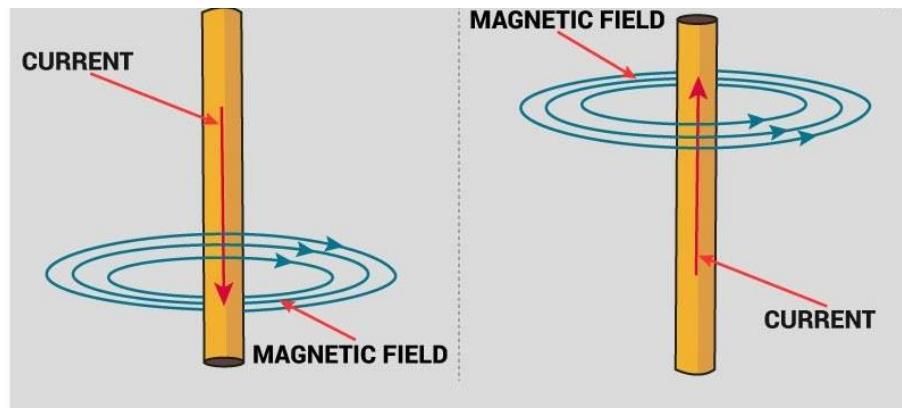


Electric coil

- **Useful Applications:** We use this effect directly in many devices.
 - **Electric Heaters & Toasters:** These use special wires made of high-resistance alloys (like nichrome) that are designed to get very hot without melting when current passes through them.
 - **Incandescent Light Bulbs:** These work by passing current through a very thin, high-resistance tungsten filament until it gets so hot that it glows white-hot, producing light (and a lot of waste heat).
 - **Fuses:** A fuse is a safety device that uses the heating effect. It contains a thin wire with a low melting point. If the current becomes dangerously high, the wire heats up, melts, and breaks the circuit.
 - **Unwanted Consequence:** The heating effect is also the cause of energy loss in power lines and the reason why electronic devices like computers need cooling fans. Overloaded wires can get hot enough to melt their insulation and start fires.

- **2. The Magnetic Effect (Electromagnetism)**

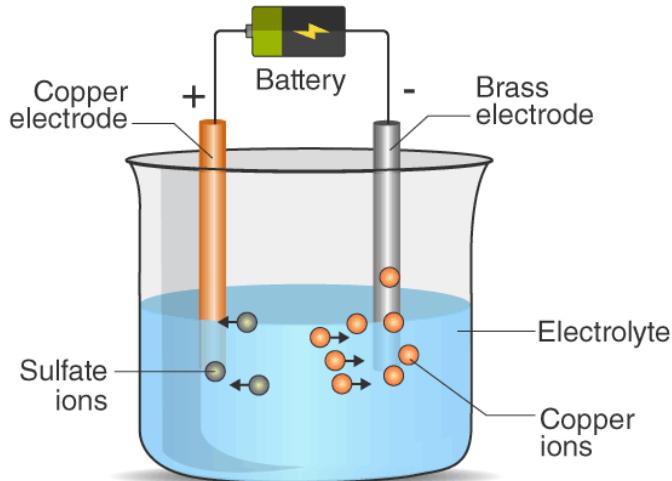
- **Principle:** This is one of the most profound discoveries in physics. Any wire carrying an electric current generates a magnetic field around it. The strength of this field is proportional to the current, and its direction can be found using the "Right-Hand Grip Rule." If you wrap the wire into a coil (a solenoid), this magnetic field becomes concentrated and much stronger.



- **Useful Applications:** This effect is the foundation of modern technology.
 - **Motors:** An electric motor works by creating powerful electromagnets that attract and repel permanent magnets, causing continuous rotation. This converts electrical energy into mechanical energy.
 - **Relays and Solenoids:** A solenoid is a coil that, when energized, pulls a metal plunger into its core. This linear motion can be used to open and close valves or, in a relay, to operate a switch in another, separate circuit.
 - **Transformers:** A transformer uses two coils to change AC voltage levels. The magnetic field created by the first coil induces a current in the second coil, allowing energy to be transferred without any physical connection.

- **3. The Chemical Effect (Electrolysis)**

- **Principle:** When an electric current is passed through certain liquids (called electrolytes), it can cause a chemical reaction. This process is known as electrolysis.



- **Useful Applications:**
 - **Battery Charging:** Charging a rechargeable battery involves forcing a current through it in the opposite direction of its normal discharge. This reverses the chemical reaction that occurred during use, restoring the battery's potential energy.

- **Electroplating:** This is a process used to coat an object with a thin layer of metal. For example, a piece of steel can be submerged in a solution containing copper salts. When current is passed through the solution, copper atoms are deposited onto the steel, giving it a protective or decorative copper coating.
- **Anodizing and Metal Refining:** The chemical effect is also used to create protective oxide layers on metals like aluminium (anodizing) and to purify raw metals like copper and aluminium from their ore.

2. Electrical Hazards: Respect the Power

Electricity is an indispensable tool, but it can be extremely dangerous if not handled with the proper knowledge and respect. You can't see, smell, or hear it until it's too late. Understanding the hazards is the first step to protecting yourself and others.

- **Electric Shock**

- **What it is:** An electric shock occurs when a person's body becomes part of an electric circuit, allowing current to pass through it. The severity depends primarily on the **amount of current** that flows, the **path** it takes through the body, and the **duration** of the flow.



- **Effects on the Body:**

- **1 mA (0.001 A):** Can usually be felt as a faint tingle.
- **5-10 mA (0.005 - 0.01 A):** "Let-go" current. Painful shock which can cause involuntary muscle contractions, making it impossible to let go of the energized object.
- **20-50 mA (0.02 - 0.05 A):** Extreme pain, respiratory arrest (breathing stops).
- **100-200 mA (0.1 - 0.2 A):** Ventricular fibrillation. The heart's rhythmic pumping is disrupted, and it just quivers ineffectively. This is often fatal. A current path across the chest is the most dangerous.

- **Burns**

- **Electrical Burns:** These are caused by the current flowing *through* tissues and organs. They are a form of internal heating and can cause severe damage deep inside the body, even if the surface wound looks small.



- **Thermal Burns:** These are caused by contact with an object that has been heated by electricity (like an overloaded wire) or by the intense energy of an arc flash.



- **Fire from Overheating**

- This is a common consequence of **short circuits** or **overloaded circuits**. When too much current flows, wires heat up rapidly. If they get hot enough, they can melt their plastic insulation and easily ignite nearby combustible materials like wood, paper, or insulation.



- **Arc Flash**

- This is arguably the most violent and dangerous electrical hazard. An arc flash is a high-current electrical explosion through the air. It can occur when there is a short circuit between two high-energy conductors.



- **The Effects:** An arc flash releases a massive amount of energy in fractions of a second, creating:
 - **Intense Light:** A blinding flash that can cause permanent eye damage.
 - **Extreme Heat:** Temperatures can reach up to 20,000°C, hotter than the surface of the sun, causing severe burns instantly.
 - **Pressure Wave (Arc Blast):** A powerful explosion that can throw a person across a room and send molten metal and shrapnel flying at high speeds.

3. Key Safety Principles

- **De-energize and LOTO:** Always assume a circuit is live until you have personally de-energized it and applied **Lock Out, Tag Out (LOTO)** procedures.
- **Use Proper PPE:** Use Personal Protective Equipment, including insulated gloves, safety glasses, and arc-rated clothing where required.
- **Maintain Insulation:** Never use tools or equipment with damaged insulation.
- **Use Circuit Protection:** Fuses, circuit breakers, and Residual Current Devices (RCDs) / Ground Fault Circuit Interrupters (GFCIs) are essential safety devices that must never be bypassed.