Foundations of STEM Electronics

SAMPLER

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Foundations of STEM Electronics

Foundations of STEM: Electronics

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Electrical Engineering

INTRODUCTION

This unit focuses on building a foundational understanding of engineering, covering its definition, history, and key branches such as civil, mechanical, and electrical engineering. The exploration includes the roles engineers play in solving real-world challenges and the growing importance of careers related to computing. Core concepts of electrical circuits are introduced, including current, voltage, resistance, and power, alongside an examination of the differences between direct current (DC) and alternating current (AC). Ohm's law is applied to calculate relationships between voltage, current, and resistance. Through hands-on activities, circuit design and simulation are conducted using Multisim Live, providing a clear visualization of how electrical systems function without physical components. Practical tasks include connecting resistors, measuring electrical quantities, and troubleshooting circuits to understand their applications. The unit also covers analyzing circuit behavior, evaluating efficiency, and exploring the roles of components such as power sources, switches, and resistors in performance.

LEARNING OBJECTIVES

In this unit, you will:

- > define engineering and describe its purpose.
- > describe the fundamentals of engineering.
- > describe the history of engineering.
- understand the different fields of engineering.
- identify career opportunities in engineering.
- > understand how engineering can improve our quality of life.
- classify the differences between a computer engineer and a software engineer.

- > define electrical quantities and describe how they relate to the basic properties of electrical circuits.
- > distinguish between DC and AC electric currents.
- > understand how Ohm's law is applied to electrical circuits.
- understand how to connect resistors in an electrical circuit.
- > design electrical circuits.
- > simulate electrical circuits using Multisim Live.

TOOLS

> Multisim Live



LESSON 1 Introduction to Engineering

The Fundamentals of Engineering

The fundamental principle of **engineering** is the use of mathematics, science, and creative thinking in diverse professional settings to solve complex multidisciplinary problems to benefit people and society.

Almost all engineers need to have a good grasp of mathematics and physics. Depending on the engineering field, they may also need to have more specialized knowledge of chemistry, biology and medicine, electricity and magnetism, or computer science and Information Technology.

Apart from technical knowledge, engineers need to have good oral and written skills. A great amount of their time is spent explaining and promoting their ideas to their colleagues and superiors. Some of the greatest engineers in history have also been great communicators with excellent social skills.

Engineering

The application of science and math to solve problems.

The History of Engineering

Engineering, which is the process of using our brains to solve problems in our environment, has been a part of human life since the invention of agriculture. Before that time, humans lived in nomadic tribes of hunter-gatherers. Their problems included inventing new ways to hunt, clothe, and protect themselves from hazardous environments and violent wildlife. When humans began gathering and growing crops, many new problems were created. They needed to prepare the soil, provide water through irrigation, use livestock for more efficient work, harvest the grown crops, and store them in a secure site where they would be safe from the weather and thieves. These new problems created a new dimension in how people think and interact in their environment.



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The ancient era

A major turning point in human development occurred when people began using written language and arithmetic. Some of the earliest discovered writings that have been found are records and ledgers of supplies and provisions for towns and cities. People then started developing mathematics to better describe and process the new information created. After that, people wanted to address the problems they faced and the solutions they were designing. Hence, geometry was born, ushering in a new golden era of innovation in the Mediterranean and the Middle East. In 300 BC, in the region which is now modern Greece, Euclid wrote his book *Elements*, which is considered one of the most influential scientific textbooks of all time.



The middle Ages

In the European region, until the fall of the Roman Empire, engineering as a scientific methodology was further developed and was used to advance all aspects of life, from city planning to warfare.

At the start of the medieval period, most of Europe was declining into the Dark Ages. However, the situation in the Middle East was completely different.

Arab scientists and engineers made significant advances in math, physics, chemistry, and biology. As a result, a myriad of new devices and solutions to the most prominent problems of the time were invented by pioneering Arab engineers. Great feats of architecture and urban planning were made by pioneering Arab engineers, which can still be found and admired to this day.

The Arabic mathematician and engineer Ismail al-Jazari (1136-1206), best known for his mechanical devices, is considered the "father of robotics". He designed and built automated machines, clocks, and water-raising machines, in which the camshaft was used for the first time.

The renaissance-enlightenment era

While all this was happening in North Africa and the Middle East, engineers in the Far East and the Chinese kingdoms were also producing inventions that were slowly brought to the West along the Silk Road. The most important of these are often called The Four Great Inventions: the compass, papermaking, printing, and the invention of gunpowder, which would forever alter history when brought to the West.

With gunpowder, warfare was completely changed, and the compass and printing increased the movements of people and ideas across the globe. This ushered in the Renaissance Age,

where engineering and art were brought again to the forefront of human endeavor. The needs of war and trade pushed engineers of the time to invent new weapons and design better protection for cities, which led to significant advances in building architecture. One of the most prominent figures of the time was Leonardo da Vinci. While best known as an artist, he was also a brilliant engineer who designed many inventions and complex machines.





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He made a prototype for a helicopter, which testing has demonstrated to be capable of flight if manufactured with modern materials. During the same period, invasions carried out by the Mongol and Timurid empires blocked the Silk Road, so it could no longer bring goods and materials from India and China.

The industrial era

European engineers had to advance naval travel and navigation to find new routes to India and China to solve this problem. Great ships designed for long journeys were built, and expeditionary forces were sent to search for new trade routes. However, an unexpected event changed the course of history. In 1492, Christopher Columbus's voyage led to the European discovery of the Americas. Gold and silver mined from the Americas fueled further engineering advancements in Europe. This wealth enabled European engineers to develop more efficient weapons, providing European kingdoms with a significant technological edge over other parts of the world.

In 1776, James Watt invented the Watt steam engine, a machine which had a great capacity to produce motion through energy. This invention started what is now called the Industrial Revolution. Factories started being built, which created a new set of problems to solve. There were



constant innovations in **mechanical engineering**, **chemical engineering**, and **biomedical engineering**. Goods and medicine that were only used by royalty 100 years before were put in the hands of the common people. Industrialization started a chain reaction of technological and social changes occurring faster than ever before.

The modern era

The 20th century, although an era of global conflicts, brought advances in manufacturing, chemistry, and, most important of all, the advent of computing and **nuclear engineering**. Although Henry Ford didn't invent the automobile, he changed the manufacturing process forever by introducing the moving assembly line in 1913. The Space Race after World War II brought together scientists and engineers to build nuclear weapons and rockets to venture out into space. During these years, engineers laid the foundations for almost all the modern technologies that we use today. In the 90s, globalization started taking shape, and a new era of global cooperation between engineers began to reshape almost all aspects of life. Every decade, the quality of our lives in almost every part of the world has improved exponentially.



We now live in the Information Age. Artificial intelligence is processing big data to aid engineers in most fields.

However, they will need all the help they can get because, despite all the advances, the next generations face some of the greatest challenges to date, namely climate change and the energy crisis brought forth by the depletion of natural resources. As has always been the case throughout history, these modern problems require innovative solutions. It is a recurring cycle, with scientists and engineers right at the forefront, helping humanity confront new challenges.

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Engineering Fields

Chemical engineering

1. Biochemical engineering

Biochemical engineers work in the pharmaceutical, energy, and food and drink industries. They work to develop new drugs and treatments for pharmaceutical companies, they invent new methods to produce and preserve food and drinks, and they design new ways for fossil fuels to be refined into purer, cleaner, and more efficient gasoline to help reduce the emission of pollutants.

2. Environmental engineering

Environmental engineering is a highly relevant field today, because climate change has started taking its toll on the global population and natural resources are being depleted worldwide.

Environmental engineers specialize in finding optimal solutions to problems while minimizing their negative impact on the environment. Many companies and governments have started new projects with sustainable development in mind.

3. Nuclear engineering

Nuclear engineers are tasked with developing safe and efficient means of producing electricity through nuclear energy. With the rising cost of fossil fuels, nuclear energy presents a clean and powerful alternative. However, its military applications have historically had catastrophic consequences.

The new generation of nuclear power plants is designed to be safer, generate less hazardous waste, and prevent weaponization.

4. Process engineering

Process engineers are specialized in designing and optimizing the processes that take raw materials and energy and convert them into other materials and other forms of energy. The transmutation of materials and energy sources into suitable forms is one of the most fundamental elements of every engineering solution.



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Civil engineering

1. Construction engineering

Construction engineers are responsible for managing the construction of a building or a building complex, which could be anything from a simple warehouse to an international airport. They coordinate and manage large teams of other construction engineers, electrical engineers, and materials engineers. With their well-developed project management skills, they communicate information with clarity to their superiors and pass down the necessary information to their co-workers.

2. Geotechnical engineering

Geotechnical or geological engineers are responsible for analyzing construction projects and ensuring that they are developed safely and securely. They analyze and prepare the soil and rock surfaces where the main structures will be constructed. A geotechnical engineer may be responsible for deciding where to place the columns of a bridge so that it is as stable as possible in the event of an earthquake. They work closely with construction engineers to ensure that all operations run according to plan.

3. Municipal engineering

Municipal engineers are responsible for urban and city planning. They analyze the geographic locations and the needs of citizens, companies, and organizations and decide where to place a city's resources and services. For example, municipal engineers need to consider energy and water supply and waste disposal, as well as the distinction between residential, commercial, and industrial areas, all while following government policies and standards.

4. Transportation engineering

Transportation engineers are responsible for making sure that the inhabitants of small towns and major metropolitan areas are able to get to their destinations safely and quickly. They are the people who design road networks, bus routes, and underground metro systems. They are constantly analyzing traffic flow and trying to optimize it, because better traffic flow means fewer emissions and less money spent on fuel. They work closely with municipal and geotechnical engineers to coordinate their projects and figure out how their solutions fit into the overall picture.

5. Architectural engineering

Architectural engineers are responsible for applying engineering principles and creativity to design buildings that are resilient, sustainable, safe, and functional. They work alongside architects, who are responsible mainly for the visual elements of the construction.



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Electrical and computer engineering

1. Power engineering

Power engineering is a very specialized field tasked with optimizing how generated power is transmitted and distributed. Power engineers need to find ways to convert all kinds of energies, whether from renewable sources or fossil fuels, into electricity that is ready to use through power distribution grids. Engineers are now developing smart grids, a promising technology that will save energy and money for households and industry.

2. Electronics engineering

Electronics engineers research, design, develop, and test electronic components and systems for commercial or scientific applications. They create electronic circuits and components for telecommunications, aerospace guidance, acoustics, and instruments and controls.

3. Instrumentation engineering

Instrumentation engineers have one of the most important jobs in manufacturing production. They plan, design and monitor the automation systems in a manufacturing environment. This profession involves working with metering devices, instrumentation systems, and process control software.

4. Telecommunications engineering

With the ever-growing adoption of IoT technologies, telecommunications engineers are now at the forefront of technological progress. Telecommunications engineers design solutions that allow devices and systems to communicate and work together. Nowadays, with the advent of 5G networks, Edge AI, and neuromorphic chips, telecommunications engineers are faced with many opportunities to change our lives in the coming years.

5. Computer engineering

Computer engineering combines **electrical engineering**, electronics and computer science. Computer engineers are responsible for a wide range of computer technology like microchips and servers or even experimental technologies like quantum computers. They also work with almost every industry, from healthcare to manufacturing and transportation.

6. Software engineering

Software engineers provide solutions to real-world challenges through software development. The functionality of every digital device or network depends on mission critical software that is operating in the background. Today, **software engineering** is a crucial field.



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Mechanical engineering

1. Mechanical engineering

Mechanical engineers apply engineering principles and problem-solving techniques from design to manufacturing for any object. They use the principles of motion, energy, and force to find solutions to a problem, ensuring that their designs are efficient, reliable, and cost-effective.

2. Manufacturing engineering

Manufacturing engineers focus on the processes that create the products in a manufacturing unit. They aim to optimize cost, quality, and production capacity to create environmentally sustainable and commercially competitive products.

3. Industrial engineering

Industrial engineers are tasked with designing and optimizing complex industrial environments while considering ergonomics guidelines and manufacturing capacity. They must balance a wide variety of interconnected social, economic, and manufacturing variables to achieve optimal results.

4. Materials engineering

Materials engineering is one of the most important engineering professions. Materials engineers are responsible for designing and producing new materials with properties not normally found in nature. New materials mean new environments for experiments and devices that would not have been possible under normal circumstances.

Their research concerns materials and components like metals, plastics, ceramics, and nanomaterials.

5. Automotive engineering

Automotive engineering is the field that specializes in the design and production of vehicles. Through innovative research on smart roads and autonomous driving technologies, automotive engineers develop safer and more efficient vehicles. With renewable fuels and the rise of smart cities, transportation will be an integral part of city infrastructure modernization. Currently, automotive engineers are working on designing future transportation methods with sustainable development in mind.

6. Acoustical engineering

Acoustical engineers work in the arts industry, and they are responsible for handling sound equipment and designing the most efficient theaters, auditoriums, and concert halls to ensure the clearest possible sound can be heard by everyone present.

7. Aerospace engineering

Aerospace engineers are involved in building aircraft for sky and space missions. It is a profession that is in high demand nowadays, mainly because aviation companies are investing in hypersonic flight and low-consumption planes.



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Engineering Career Opportunities

Engineering provides an array of career opportunities. Engineers who work in the same field and specialty can have different job roles and daily activities. Below are the most common positions that you can pursue.

Research and development

When working in the research and development (R&D) department, you must take an idea and figure out how to make it into a tangible product. To accomplish this, you research potential new materials, improve existing processes, invent new ones, and make sure that the product is built and sold at competitive prices. Your finished product must be intuitive and appropriate for its purpose.

Design

As an engineer, you are tasked with taking the information derived from the R&D department and designing a product that serves its function and is financially sustainable and commercially competitive. You will produce schematics and prototype models made with Computer-Aided Design (CAD) and simulation tools.

Planning

Planning is the final step before the manufacturing of the product begins. You will be responsible for determining the necessary materials and manufacturing equipment, and you will plan all the steps needed to build a reliable and cost-effective product.

Production

As a production engineer, you use the work of your colleagues in R&D, design, and planning to implement the production stage. You need to ensure that the correct materials are provided, the schematics are correct, the appropriate tooling equipment is acquired, and that the product can be manufactured within the financial and time constraints.

Installation

In cases where the equipment or the system is very complex, as an installation engineer your work will be focused on its proper installation and setup. Machinery needs to be carefully integrated into an industrial or construction environment. You will manage this process and test and maintain the product's installation.

Quality control

Quality control or quality assurance is a critical part of a product or system life cycle. At every stage of product development, several tests are run. As a quality control engineer, you will inspect materials, check that dimensions and measurements are precise, and perform stress tests to record the product's behavior under unfavorable or extreme conditions. Furthermore, monitoring helps you analyze usage data and predict faults even after the product is sold. Quality control is a costly and time-consuming process, but it is financially beneficial because it saves the organization money and time spent on repairs.



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Marketing and sales

Whether the organization has an internal marketing department or marketing is outsourced, communication with the engineering department is paramount for an effective marketing and sales campaign. You will be tasked with explaining the product's qualities and the competitive advantages for potential customers to the marketing professionals.

Customer service and support

During the use of a product or system, damage and malfunctions may occur. Many products are complex machines that need to undergo maintenance operations at specific time intervals. Customers will need support to diagnose and fix issues. As an engineer who has an in-depth knowledge of the product or system, you will need to plan appropriate maintenance procedures and work with the technicians involved in this process.

Future Challenges

The main challenges that engineers will face in the coming years are multidisciplinary problems requiring innovative thinking and cooperation, as indicated below.

Key global engineering challenges and solutions

Global Challenges	Engineering Solutions
Climate change has started affecting the Earth in the recent decades.	Rising temperatures and sea levels are endangering coastal cities and threatening transportation networks. Engineers will need to work on solutions that halt the rate at which these problems are advancing and provide society with the necessary tools to adapt to changing conditions.
Natural resources are not infinite.	The use of renewable energy resources has proven to be effective, and some countries have achieved the target of covering energy consumption through renewable energy sources. Engineers need to invent energy-efficient systems and extend renewable energy infrastructure. The solutions to these problems also reduce emissions, which may slow down climate change.
Modern globalized society is vulnerable to pandemics that may affect all aspects of life.	Suitable medical units must be deployed rapidly, and laboratory devices must support innovative vaccine development. In both hospitals and laboratories, engineers will have to create solutions.
Securing cyberspace and protecting privacy.	Modern IT applications are interconnected and form systems that exchange critical and confidential data. Computer, network, and software engineers need to ensure that these systems are secure and not vulnerable to cybercriminals.
Food shortages occur due to overpopulation.	The global population is increasing at a steady rate, which creates a need to provide huge amounts of food at affordable costs. Chemical engineers need to contribute to improving food production and processing and ensure adequate food supply to all people.
Healthcare needs to be accessible to everyone.	While average life expectancy is rising, treatments for many illnesses and diseases are becoming more expensive, which may cause a divide in access to healthcare treatments. Engineers are tasked with inventing and developing medical equipment and treatments to provide accessible healthcare to people of all socioeconomic statuses.

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The Importance of Engineering

Problem-solving with engineering

We live in challenging times, where environmental and social changes are taking place faster than ever before. Engineering professions cover a wide spectrum of specialties, and engineers need to work together to find optimal solutions to complex problems. Throughout history, the greatest problems and challenges have led to advances in science and technology, and it was engineering that provided the solutions. Becoming an engineer is one of the best ways to positively impact communities, countries, and the whole of global society.

Improving quality of life with engineering

People's life has improved since we first started using engineering to solve small and large problems. However, the rate of progress has varied through the ages.

The advent of the Internet over the last 30 years has enabled global cooperation among scientists and engineers and increased the availability of knowledge, leading to the rapid creation of even more inventions.

A person living 100 years ago could never imagine the average person's quality of life today. Modern transportation has allowed the movement of people all around the world. A trip that used to take weeks or months is now completed in hours.

People can now live much more comfortably in countries with harsh winters or hot summers, with unfavorable conditions mitigated by temperature controlling devices. People can communicate with one another from anywhere in the world through chat or video calls. Many work remotely through advanced conferencing applications, bringing an evolution to the work environment.

Biotechnology could permit the production of abundant, high quality, sustainable food at low cost, allowing us to finally eradicate hunger worldwide.

Modern-day medical devices and telemedicine save lives. With the latest and upcoming advances in technology, our quality of life will only improve from now on.



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The importance of jobs related to computing

Technological advances in computing have created numerous jobs in engineering roles related to computers and computer networks. As computers are literally everywhere in our lives, the importance of these roles is significant. Some of the most common computer-related engineering jobs are:

- Telecommunications engineer
- Software engineer
- IoT engineer
- Cybersecurity engineer
- Systems architect
- Database administrator
- Systems engineer
- Technical support engineer

Some of these roles refer to hardware and some to software, but all of them require the skills and mindset of an engineer.

Computer Engineer Versus Software Engineer

There is an assumption that **computer** and **software engineers** do the same thing. Their studies may have a common basis in the key concepts of computer science, but their roles are different in practice.

Computer engineer

Computer engineers are mainly focused on designing hardware and planning computer infrastructure and communication processes.

Software engineer

Software engineers are tasked with the development and implementation of software applications and platforms.



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EXERCISES

- 1 Choose the correct answer.
 - **1.** Engineering is:
 - A. The application of science to solve problems.
 - **B.** A field solely focused on designing mechanical structures.
 - **C.** A process used only in building large infrastructure.
 - **D.** Unrelated to scientific principles.
 - 2. What is a basic principle of engineering?
 - A. Creative thinking alone
 - **B.** The use of science, mathematics, and creative thinking to solve complex problems
 - C. Solving problems only through trial and error
 - D. Avoiding multidisciplinary approaches
 - 3. What is a significant challenge for future engineers?
 - A. Overpopulation alone
 - B. Creating faster vehicles
 - **C.** Addressing climate change, the energy crisis, and vulnerability to pandemics
 - D. Managing artificial intelligence systems
 - Explain your understanding of the term "Engineering".
- 3 Describe and compare the fields of electrical engineering.
- 4 Create a table with the main challenges that engineers will face in the coming years.
- 5 What influence do you think the Industrial Revolution had on the evolution of engineering?
- 6 From what you have learned, name three occupations that are in danger of disappearing in the next few years, and three professions that you think will become more important.

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The Electrical Circuit

The Basics of Electricity

In this lesson, you will examine basic concepts that are used in the design of electrical circuits. You will also demonstrate the means by which you study their functions.

Current

The electric current in metallic conductors consists of electrons (e⁻), which are very small particles that carry the elementary negative (-) electric charge. Electrical signals move at very high speeds.

Amperes

To quantify the motion of electric charge, André-Marie Ampère created the concept of electric current, also called intensity of **current (I)**, which is measured in **amperes (A)**. The ampere can be understood as a measure of how many **electrons** — or how much electric charge, measured in coulombs — pass through a point in a circuit in one second.

 $1 A = \frac{1 \text{ coulomb}}{1 \text{ second}}$

Volt

In order for an electric current to move in a circuit, we must create a **potential difference**, also called a **voltage (V)**. This indicates how much energy is used in moving one **coulomb** of electric charge inside the circuit.

 $1 \text{ V} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$

Smart tip

The volt is the unit of electric voltage, and 1 volt is denoted as 1 V and is the measure of the potential difference when an electric current of 1 ampere (A) flows through an element of 1 ohm (Ω) resistance.

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Electrical quantities table

Electrical quantity	Unit of measurement
Electrical energy	Joule (J)
Electric charge Coulomb (C)	
Electric current	Ampere (A)
Voltage	Volt (V)
Resistance	Ohm (Ω)
Electric power	Watt (W)

The components of an electrical circuit are built from materials that facilitate the movement of electrons, which means electrical current can flow through them. These materials are called conductors. Metals are conductors, e.g., copper and aluminum.

Core Hardware Components of an Electrical Circuit

Power Source

We create a voltage between two points on the electrical circuit with a **power source**. The source works to transfer electrons from one point in the circuit to another. Two poles are created, one with an electron deficit (+) and the other with a surplus (-).

The balance in the quantities of electrons needs to be restored. To achieve this, electrons are drawn from the negative pole (-) to the positive pole (+). This movement generates electricity.

Alternating Current (AC) and Direct Current (DC)

The source is constructed so that the electric current either moves in constant direction from the negative to the positive pole (**DC**) or in an alternating direction back and forth between the poles (**AC**).

DC usually flows at low voltages and the electrons flow from (-) to (+), but we consider that the current flows from (+) to (-).

The electricity supply network of a city uses AC voltage for lights and home appliances. Electronic devices like computers and smartphones require low DC voltage. A DC power supply converts the AC voltage to a lower DC voltage.



The power source can be a battery or a generator.



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Resistor

As mentioned before, electrical current is the movement of electrons through an electrical wire. **Resistors** (R), as their name suggests, resist this movement. They do not stop it, they merely slow the movement down. The faster the electrons move, the greater the electrical energy of the system.

The energy carried by the electrons is converted into heat by resistors.

Resistance, measured in ohms, is defined in terms of the ratio of voltage to current. If a current of 1 A flows through a resistor when a voltage of 1 V is applied to it, its resistance is 1 ohm.

$$1 \text{ ohm} = \frac{1 \text{ V}}{1 \text{ A}}$$



If you have two or more resistors, then you give them names, such as R₁, R₂, R₃...





Switch

A switch (or circuit breaker) must be used in each circuit to control whether or not electricity flows through the circuit.



Information

Resistance is denoted by the Greek letter omega in capitals: Ω (ohm).

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Instruments for measuring Electrical Quantities

Various instruments have been invented for measuring the different electrical quantities. These include:

The **voltmeter**, which is connected in parallel with a conductor and measures the voltage across its ends.

The **ammeter**, which is connected in series with the conductor and measures the intensity of the current flowing through the conductor.

The **ohmmeter**, which measures the resistance of a conductor.

The **multimeter**, which is an instrument that can measure voltage, current, and resistance.

A multimeter is a tool that can measure the values of current, voltage, and resistance across various parts of an electrical circuit. It is mainly used for troubleshooting.



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What the colors on a resistor mean

Fixed resistors use standard color-coding rules to encode represent the basic properties of the resistor. The number of colored bands on a resistor indicates whether it is a standard or high precision resistor.

4 bands means a standard-precision resistor, whereas 5 bands means a high-precision resistor, and 6 bands is essentially a 5 band resistor but with an extra ring that denotes the temperature coefficient.

How to decode bands on a standard-precision resistor:

- The 1st, 2nd, 3rd, and 4th bands denote the resistor's value.
- The 5th band denotes the resistor's tolerance with a standard measurement error of within 5% to 10% of the real tolerance value of the resistor.

Let's examine the resistor color code:



Information

Not all resistors exert the same amount of resistance on the flow of electrons. The main rule is that the greater the resistance, the more the intensity of the electrical current is diminished.

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4-BAND	5-BAND	6-BAND
-010-	-0110-	-
1 2 x10 ⁵ ±5%	1 0 0 x10 ² ±1%	2 7 4 x10º ±2% 250
= 1,200 kΩ ± 5 %	= 10,000 $\Omega \pm 1 \%$	= 274 Ω ± 2%, 250 ppm/K

Resistor connections in Electrical circuits

In an electrical circuit, the resistors are connected as follows:

The total resistance is the resistance generated by all the resistors in a circuit.

Resistor connections	Description	Total resistance
In series R_1 R_2 $1 \ k\Omega$ $1 \ k\Omega$	Resistors R_1 and R_2 have one common end, the same current I flows through them and they have voltages V_1 and V_2 across their ends. $V_1 + V_2 = V_T$	$R_{T} = R_1 + R_2$
In parallel R_1 $1 k\Omega$ R_2 $1 k\Omega$	Resistors R_1 and R_2 have two common ends, have the same voltage V across their ends, and 2 different currents flow through them, I_1 and I_2 . $I_1 + I_2 = I_T$	$\frac{1}{R_{T}} = \frac{1}{R_{1}} + \frac{1}{R_{2}}$

Prefixes of units of measurement						
Name	nano	micro	milli	kilo	mega	giga
Symbol	n	μ	m	k	М	G
Factor	10 ⁻⁹	10 ⁻⁶	10 ⁻³	10 ³	10 ⁶	10 ⁹

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Electrical Circuit Connections

All components of a circuit offer some resistance to current depending on their use.

In the following circuit, you have:

- A lamp labeled X, operating normally at 12 V voltage.
- A switch labeled S.
- A 12 V power source.



Each device offers some resistance. For example, the wire in a lamp resists electron flow. The result of this is the conversion of electricity into heat and light.

The internal resistance of switches and power sources is negligible, so they aren't counted in the total resistance of the circuit. Example Open switch Lamp off S WW X 12 V V 12 V V12 V

The 12 V label on a lamp is the value of the voltage that must be applied to its ends for it to function properly.

The energy produced and the intensity of the electric current flowing through the lamp are related to the rated voltage of the connected battery. Low voltage results in reduced illumination or even insufficient output. Very high voltage may damage the lamp.



Information

Generally, DC sources are much safer than AC sources.

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Ohm's Law

In electrical circuits, it is important to know the relationship between the electric current flowing through a resistor and the voltage across its ends. The German physicist Georg Simon Ohm first explored this relationship in 1827.

He defined that a conductor which has a constant resistance R and a voltage V at its ends allows an electric current of intensity I to flow through the conductor. He found that the current I is proportional to the potential difference V. In mathematical notation, this relation is written as:

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

This law can also be applied to a circuit with more than one resistor. Essentially, you consider the complete electrical circuit as one resistor itself, by determining the total resistance of the entire circuit.

When studying electrical circuits and calculating the values of V, I, and R for each component of the circuit, you continuously apply Ohm's law.

Series and Parallel Circuit Connections

Series and Parallel connections of resistors are indicated below:

What is a Series Connection? All components in a series circuit are connected end to end, forming a single path for current to flow along. There is no branching of the electric current.

What is a Parallel Connection?

Components in a parallel circuit are connected so that there are two or more possible paths for the current, forming two sets of electrically common points. There is a branching of the electric current.



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Series Connections

Let's start with the series circuit.

You have the following values:

> R,= 30 kΩ

- $> R_2 = 60 \text{ k}\Omega$
- > Voltage V = 9 V supplied by the battery.





You will first calculate the total resistance R of the circuit: $R_{\rm T} = R_1 + R_2 = 90 \; k\Omega$

Next, you will calculate the current I flowing through the circuit:

$$I = \frac{V}{R_{T}} = \frac{9}{90 \text{ k}\Omega} = 0.1 \text{ mA}$$

Finally, you will calculate the voltages V at the ends of each resistor:

$$V_1 = I \times R_1 \Rightarrow 0.1 \text{ mA} \times 30 \text{ k}\Omega = (0.1 \times 10^{-3}) \times (30 \times 10^3) = 3 \text{ V}$$
$$V_2 = I \times R_2 \Rightarrow 0.1 \text{ mA} \times 60 \text{ k}\Omega = (0.1 \times 10^{-3}) \times (60 \times 10^3) = 6 \text{ V}$$

In a wire or cable, the resistance R depends on:

- the length: Longer wire means greater resistance.
- the thickness: Thicker wire means less resistance.
- the material that the cable is made from. For example, copper wires have low resistance.

Smart Tip

The lower the resistance of a conductor, the higher the intensity of the current flowing through it, for a given voltage.

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Node

A **node** is a point in a circuit where 2 or more conductors meet.

A circuit loop is a part of the circuit that starts at one point and ends at the same point following the path of current flow.



Ohm's law cannot be applied to devices in which the ohmic resistance does not remain constant. Examples include diodes, transistors, etc.

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Ohm's Law: Example Problem

In this example, we want to find the potential difference, or voltage, between points A and B.





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We can calculate the voltage between points A and B, if the current flowing through R_2 is $I_2=1A$.

So the voltage across the ends of R_2 will be:

$$V_2 = I_2 \times R_2 = 1 \times 18 = 18 V_2$$

Since the resistor $R_{3,4,5}$ is connected in parallel, with R_2 and therefore has a voltage of $V_{3,4,5}$ = 18V. So:

$$I_{3,4,5} = \frac{V_{3,4,5}}{R_{3,4,5}} = \frac{18}{18} = 1 A$$

The current flowing through the source and R, is: $I_{\rm T}=I_2+I_{\rm 3,4,5}=1+1=2~{\rm A}$

Thus, the voltage across A and B is:

$$V_{AB} = I_T \times R_T = 2 \times 20 = 40 V$$

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EXERCISES

- 1 Choose the correct answer.
 - **1.** A resistor is connected to the poles of a generator that has negligible internal resistance. If you connect another identical resistor in series with the first resistor, then the intensity of the current:
 - A. Will double.
 - B. Will remain constant.
 - C. Will drop to half.
 - D. Will quadruple.
 - 2. When two resistors, R₁ and R₂, with different resistances are connected in parallel:
 - **A.** They display the same voltage at their ends.
 - **B.** A current of equal intensity flows through each.
 - **C.** Their equivalent resistance is R_{τ} from the equation $R_{\tau} = R_1 + R_2$.
 - **D.** Currents of different intensities flow through each.
 - 3. What is the unit of voltage?
 - **A.** Ohms (Ω)
 - B. Volts (V)
 - C. Joules (J)
 - D. Watts (W)
 - 4. What is the formula for the total resistance in resistors connected in parallel?
 - **A.** $R_T = 1 / (R_1 + R_2 + R_3)$ **B.** $R_T = R_1 + R_2 + R_3 + ... + R_n$ **C.** $R_T = R_1 * R_2 / (R_1 + R_2)$ **D.** $R_T = 1 / R_1 + 1 / R_2 + 1 / R_3 + ... + 1 / R_n$
 - 5. What does a voltmeter measure?
 - A. The intensity of current
 - **B** The voltage
 - C. The resistance
 - D. The power output

- 2 On a piece of paper, draw a circuit consisting of two identical lamps X_1 and X_2 , the source V and the switch S in series. Closing the switch, electrical current begins flowing through the circuit. Determine whether the two lamps X_1 and X_2 will emit the same amount of light. Justify your answer.
 - Three resistors, $R_1 = 20 \Omega$, $R_2 = 5 \Omega$, and $R_3 = 4 \Omega$, are connected in parallel to a voltage V = 20 V. The resistor R_2 is connected to an ammeter in series which presents the current I_2 that flows through R_2 . The source is connected to a switch S and a second ammeter in series, which indicates the intensity of the current I, which flows through the source. The resistances of the power source and the ammeters are considered negligible.
 - **1.** Draw the circuit diagram. Find the total resistance R_{T} .
 - 2. Find the ammeter readings when switch S is closed.
 - In the circuit diagram, the source has voltage V. The power source and the two measurement instruments, the ammeter (A) and voltmeter (V), have negligible internal resistances.

The resistors have values $R_1 = 100 \Omega$, $R_2 = 50 \Omega$, $R_3 = 50 \Omega$, and the ammeter displays a reading of 0.8 A. Calculate the following:

- **1.** The total resistance of the circuit.
- 2. The intensity of the current flowing through each resistor.
- 3. The voltmeter reading.

Use the physics laboratory and try to make this circuit under the supervision of the teacher or the assistant, then explain how both the ammeter and the voltmeter are connected to the electrical circuit.



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PROJECT

Analyzing an Electrical Circuit



- Connect 2 lamps, X₁ and X₂, to this circuit, each of which operates normally at a voltage of 12 V and is damaged at a voltage greater than 15 V.
- 2. Connect 1 resistor in series with X_1 , with resistance R = 10 Ω .
- 3. Connect 3 switches, S_1 , S_2 , S_3 . These indicate very little resistance in the circuit, of the order of 10⁻⁷ Ω when closed, according to the program, and can therefore be considered negligible.
- 4. Connect 3 ammeters to measure the current in each branch of the circuit.

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Do the following:

Open switch S₃. What do you notice? Explain what you get.

With S_3 closed, and S_2 open, close S1. What do you notice? Explain what you observe.

With S_3 and S_1 closed, close S_2 . What do you notice? Explain what you observe.





X1

12V

Find the relationship of the current intensities I_{T} , I_{1} , and I_{2} from the readings of the ammeters.

Find the resistance R_1 from the voltage V_1 and the current I_1 , and the resistance R_2 from the voltage V_2 and the current I_2 , where R_1 is the resistance of lamp X_1 and R_2 is the resistance of lamp X_2 .

After stopping the simulation, change the source voltage from 10 V to 20 V and close switches S_1 and S_2 .

Then, close S_3 and write down what you notice about the bulbs X_1 and X_2 . Also, write what you notice about the values of current intensities I_T , I_4 , and I_2 .

X2

12V



With S_3 and S_1 open, close S_2 and write down what you notice about the bulbs X_1 and X_2 . Explain your observations.

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WRAD UD

THIS UNIT COVERED HOW TO:

- > understand what engineering is.
- recognize the fundamental principles, history, and different fields of engineering.
- > identify the opportunities, purposes, and challenges of engineering.
- acknowledge the importance of engineering for improving our quality of life.
- > differentiate the differences between a computer engineer and a software engineer.

- > distinguish between direct (DC) and alternating (AC) electrical currents.
- > read and draw simple circuits and explain how they work.
- > apply Ohm's law.
- > use Multisim Live to design and simulate electrical circuits.
- > use probes to measure voltage and current in simulations.

KEY TERMS

- Acoustical Engineering
- Aerospace Engineering
- Alternating current (AC)
- Ammeter
- Architectural Engineering
- Automotive Engineering
- Biochemical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Construction Engineering
- Current
- Direct current (DC)
- Electrical Engineering
- Electron
- Electronics Engineering
- Environmental Engineering
- Geotechnical Engineering

- Industrial Engineering
- Instrumentation Engineering
- Manufacturing Engineering
- Materials Engineering
- Mechanical Engineering
- Multimeter
- Municipal Engineering
- Node
- Nuclear Engineering
- Ohmmeter
- Power Engineering
- Process Engineering
- Resistor
- Software Engineering
- Source
- Telecommunications Engineering
- Transportation Engineering
- Voltmeter

Foundations of STEM Electronics

Engineer electric systems

Imagine designing and simulating electrical circuits that power the world around us. What if you could develop your own digital systems, troubleshoot real-life electronic circuits, and program microcontrollers to solve complex problems? This course guides you through the core concepts of electrical engineering, from basic circuit design to advanced simulations.

Foundations of STEM: You'll learn the essentials of digital circuits, master the art of circuit simulation with Tinkercad, and gain hands-on experience in programming microcontrollers for real-world applications. Discover the power of Karnaugh maps for circuit simplification, troubleshoot your designs, and explore practical applications that make a tangible impact.

By the end of this course, you'll have the expertise to design, simulate, and troubleshoot electrical systems with confidence, empowering you to create innovative solutions in the world of engineering.



