ELECTRICAL FUNDAMENTALS COMPETENCY

Industry Training Authority of BC

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Book: Electrical Fundamentals

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This text was compiled on 10/21/2023

TABLE OF CONTENTS

Acknowledgments

BCcampus would like to acknowledge the following individuals and organizations for their contributions in producing the Trades Access Common Core Open Textbook resources.

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- Matt Zeleny, Camosun Innovates, 3D imaging

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Licensing

*A detailed breakdown of this resource's licensing can be found in **Back Matter/Detailed Licensing**.*

Foreword

The BC Open Textbook Project began in 2012 with the goal of making post-secondary education in British Columbia more accessible by reducing student cost through the use of openly licensed textbooks. The BC Open Textbook Project is administered by BCcampus and is funded by the British Columbia Ministry of Advanced Education.

Open textbooks are open educational resources (OER); they are instructional resources created and shared in ways so that more people have access to them. This is a different model than traditionally copyrighted materials. OER are defined as teaching, learning, and research resources that reside in the public domain or have been released under an intellectual property licence that permits their free use and repurposing by others (Hewlett Foundation). Our open textbooks are openly licensed using a Creative Commons licence, and are offered in various e-book formats free of charge, or as printed books that are available at cost. For more information about this project, please contact opentext@bccampus.ca. If you are an instructor who is using this book for a course, please let us know.

Preface

The concept of identifying and creating resources for skills that are common to many trades has a long history in the Province of British Columbia. This collection of Trades Access Common Core (TACC) resources was adapted from the 15 Trades Common Core line modules co-published by the Industry Training and Apprenticeship Commission (ITAC) and the Centre for Curriculum Transfer and Technology (C2T2) in 2000-2002. Those modules were revisions of the original Common Core portion of the TRAC modules prepared by the Province of British Columbia Ministry of Post-Secondary Education in 1986. The TACC resources are still in use by a number of trades programs today and, with the permission from the Industry Training Authority (ITA), have been utilized in this project.

These open resources have been updated and realigned to match many of the line and competency titles found in the Province of BC's trades apprenticeship program outlines. A review was carried out to analyze the provincial program outlines of a number of trades, with the intent of finding common entry-level learning tasks that could be assembled into this package. This analysis provided the template for the outline used to update the existing modules. Many images found in ITA apprentice training modules were also incorporated into these resources to create books that are similar to what students will see when they continue their chosen trades training. The project team has also taken many new photographs for this project, which are available for use in other trades training resources.

The following list of lines and competencies was generated with the goal of creating an entry-level trades training resource, while still offering the flexibility for lines to be used as stand-alone books. This flexibility—in addition to the textbook content being openly licensed—allows these resources to be used within other contexts as well. For example, instructors or institutions may incorporate these resources into foundation-level trades training programming or within an online learning management system (LMS).

Line A – Safe Work Practices

- A-1 Control Workplace Hazards
- A-2 Describe WorkSafeBC Regulations
- A-3 Handle Hazardous Materials Safely
- A-4 Describe Personal Safety Practices
- A-5 Describe Fire Safety

Line B – Employability Skills

- B-1 Apply Study and Learning Skills
- B-2 Describe Expectations and Responsibilities of Employers and Employees
- B-3 Use Interpersonal Communication Skills
- B-4 Describe the Apprenticeship System

Line C – Tools and Equipment

- C-1 Describe Common Hand Tools and Their Uses
- C-2 Describe Common Power Tools and Their Uses
- C-3 Describe Rigging and Hoisting Equipment
- C-4 Describe Ladders and Platforms

Line D – Organizational Skills

- D-1 Solve Trades Mathematical Problems
- D-2 Apply Science Concepts to Trades Applications
- D-3 Read Drawings and Specifications
- D-4 Use Codes, Regulations, and Standards
- D-5 Use Manufacturer and Supplier Documentation
- D-6 Plan Projects

Line E – Electrical Fundamentals

- E-1 Describe the Basic Principles of Electricity
- E-2 Identify Common Circuit Components and Their Symbols
- E-3 Explain Wiring Connections
- E-4 Use Multimeters

All of the self-test questions are also available from BCcampus as separate data, if instructors would like to use the questions for online quizzes or competency testing.

Industry Training Authority of BC

The ITA works with employers, employees, industry, labour, training providers, and government to issue credentials, manage apprenticeships, set program standards, and increase opportunities in approximately 100 BC trades. Among its many functions are oversight of the development of training resources that align with program standards, outlines, and learning objectives, and authorizing permission to utilize these resources (text and images).

- Erin Johnston, Director of Training Delivery
- Cory Williams, Manager, Industry Relations
- Publishing Services, Queen’s Printer
- Spencer Tickner, Director of QP Publishing Services
- Dwayne Gordon, Manager, Electronic Publishing

Symbols Legend

Notes, cautions, and warnings are identified by special symbols. A list of those symbols is provided below.

Symbols Legend

 Important: This icon highlights important information.

 Poisonous: This icon is a reminder for a potentially toxic/poisonous situation.

 Resources: The resource icon highlights any required or optional resources.

 Flammable: This icon is a reminder for a potentially flammable situation.

 Self-test: This icon reminds you to complete a self-test.

 Explosive: This icon is a reminder for a possibly explosive situation.

 Safety gear: The safety gear icon is an important reminder to use protective equipment.

 Electric shock: This icon is a reminder for potential electric shock.

Safety Advisory

Be advised that references to the Workers' Compensation Board of British Columbia safety regulations contained within these materials do not/may not reflect the most recent Occupational Health and Safety Regulation. The current Standards and Regulation in BC can be obtained at the following website: http://www.worksafebc.com.

Please note that it is always the responsibility of any person using these materials to inform him/herself about the Occupational Health and Safety Regulation pertaining to his/her area of work.

BCcampus

January 2015

Disclaimer

The materials in the Trades Access Common Core Open Textbook project are for use by students and instructional staff and have been compiled from sources believed to be reliable and to represent best current opinions on these subjects. These manuals are intended to serve as a starting point for good practices and may not specify all minimum legal standards. No warranty, guarantee or representation is made by BCcampus as to the accuracy or sufficiency of the information contained in these publications. These manuals are intended to provide basic guidelines for trade practices. Do not assume, therefore, that all necessary warnings and safety precautionary measures are contained in this module and that other or additional measures may not be required.

SECTION OVERVIEW

1: Unit I - Basic Principles of Electricity

Learning Objectives

When you have completed the Learning Tasks in this Competency, you will be able to:

- describe the composition of matter and the structure of the atom
- describe the principles of electricity and the theory of current flow
- describe basic types of electrical circuits and their characteristics
- describe electromagnetism

You will use electricity daily. Vehicles and machinery are started and often operated by electricity. Electric tools make the performance of your job easier and more efficient. However, to use electricity safely and effectively, it is important to understand electricity's terminology and principles.

Thumbnail: Interior Communications Electrician 3rd Class Karla Martinez inspects wiring aboard the aircraft carrier USS Nimitz. (Public Domain; US Navy via Wikipedia)

CHAPTER OVERVIEW

1: Fundamentals of Electricity

Over the centuries scientists have discovered that electricity is predictable and measurable. Being familiar with the fundamentals of electricity will help you to understand how and why electrical circuits work.

1.1: Basic principles

Learning Task 1

Explain fundamentals of electricity

Over the centuries scientists have discovered that electricity is predictable and measurable. Being familiar with the fundamentals of electricity will help you to understand how and why electrical circuits work.

Basic principles

Electricity is a form of energy. To understand electricity, it is important that you first understand the structure of matter. Anything that occupies space and has weight is called matter. All liquids, gases, and solids are examples of matter in different forms. Matter is made of smaller units called atoms. Atoms can be grouped together in compounds to form molecules.

Atomic theory

Atoms are the most basic part of matter and differ in atomic structure from each other. The structure of the atom can be described in much the same way as the solar system. Instead of the Sun at the centre, there is a nucleus. This nucleus is made of two basic particles: protons and neutrons.

Neutrons make up the mass (or weight equivalency) of the atom, have no electrical charge, and are considered to be neutral. Protons are particles that have a positive (+) electrical charge and cannot be separated from the nucleus. Surrounding the nucleus in orbits are electrons. These are tiny particles with a negative (–) electrical charge. Figure 1 shows a model of a carbon atom.

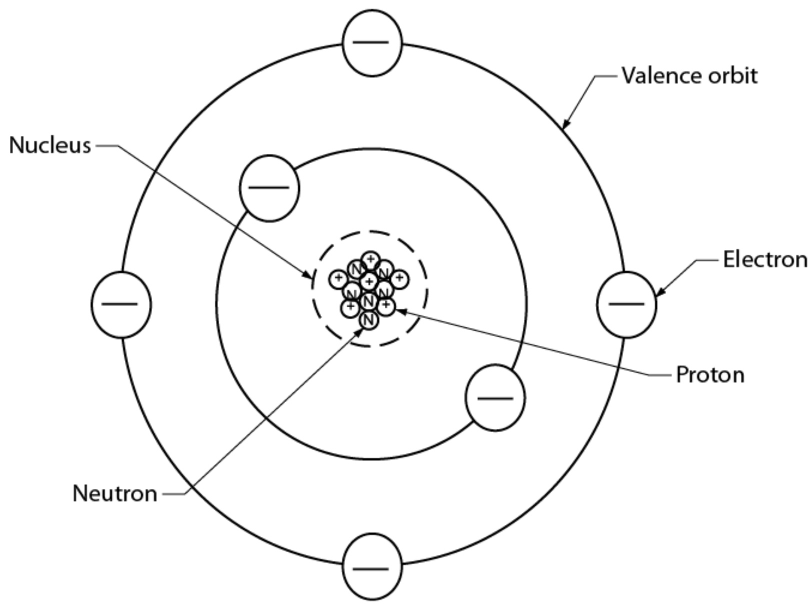
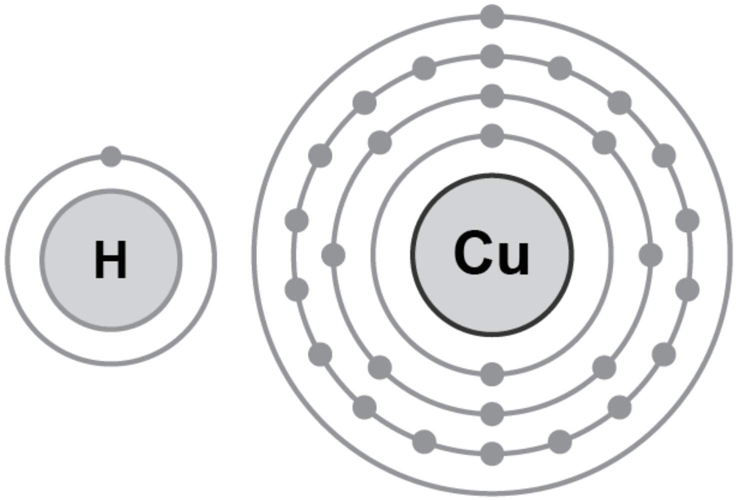


Figure 1.1.1: (CC BY-NC-SA; BC Industry Training Authority)

1. Carbon atom



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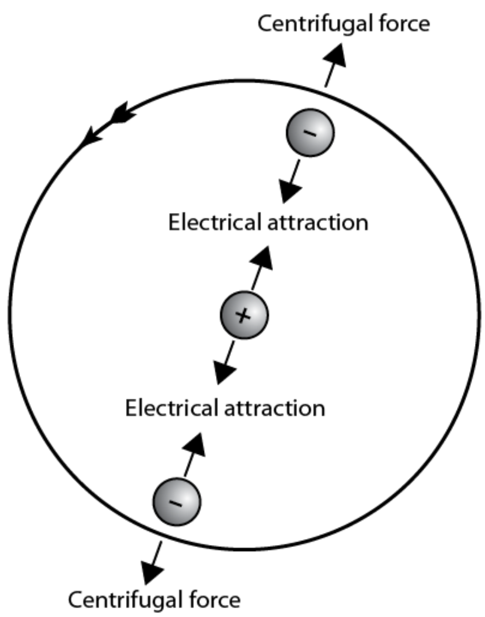
2. Hydrogen and copper atoms



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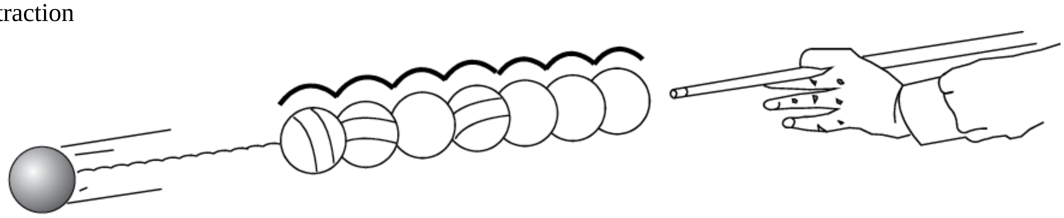
3. Electrical attraction



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4. Transmission of impulse

   Sources of electrical force

   You have just learned that if there is a surplus of electrons at one end of a conductor and a deficiency at the other end, a current flows in the conductor. There are devices that create this difference in charge so that a current will flow. These devices are referred to as sources of electromotive force. These sources include:

   - chemical
   - electromagnetic induction

- friction
- heat
- pressure
- light

Chemical

A battery is a source of electrical force due to the chemical reaction that takes place between plates and an electrolyte. This reaction causes a buildup of positive ions on one plate and negative ions on the other plate. This electrical difference between the plates is also known as potential difference.

Electromagnetic induction

Electric force can be generated by using a magnetic field. This is the method by which most of the electrical energy we use is produced. An example is an alternator or generator.

Friction

Friction can cause free electrons to move from one body to another and be stored there temporarily. When you walk across a carpet, electrons are transferred to the atoms in your body and you return them to other atoms when you touch a metallic object.

Heat

If two unlike metals are placed together and heated, they will produce electrical force. An example is the thermocouple in a furnace.

Pressure

Certain crystals will produce electricity if they are squeezed under extreme pressure. An example is a barbecue starter (also called piezoelectric generator).

Light

Some crystals and semiconductors will produce electrical force when they are exposed to light. An example is the photocell in a calculator.

All six of these sources of EMF achieve the same thing. They separate charge by:

- imparting energy to the electrons
- pushing them against an electrostatic field
- causing a surplus of electrons (negative charge) at one terminal of the source and a deficiency of electrons (positive charge) at the other terminal

In a sense, the process can be likened to compressing a spring. The energy stored in the compressed spring can be used later to do useful work. The same is true of the separated charges: they store energy that can be used to do useful work.

Electrical energy always comes from some other form of energy. The source of EMF is simply the device that makes the conversion from some other form of energy to electrical energy.

1.2: Electrical circuits and units of measurement

Electrical circuits and units of measurement

The term circuit refers to a circular journey or loop. In the case of an electrical circuit, it is the closed path or loop travelled by the electrons. The movement or flow of electrons (current) is predictable and measurable, depending on a number of variables within the circuit.

Polarity

Electrical polarity (positive and negative) is present in every electrical circuit. Electrons flow from the negative pole to the positive pole. In a direct current (DC) circuit, one pole is always negative, the other pole is always positive, and the electrons flow in one direction only. In an alternating current (AC) circuit, the two poles alternate between negative and positive, and the direction of the electron flow reverses.

Circuit components

A closed circuit provides a complete path for the flow of electrons through conductors. Included in this circuit there must be a resistance (or load), which will do the work and some form of control. For a circuit to be operational it must contain some basic components (Figure 5). These include:

- power source
- conductors
- controls
- load
- protection

Power source

In equipment, the power source is the battery when the engine is off and the generator when the engine is running. In most buildings, it is the power supplied by the local service provider.

Conductors

Conductors are wires or cables wrapped in insulation that carry the current in the circuit. A common ground circuit conductor could be the frame or body of the equipment or the frame on a vehicle.

Controls

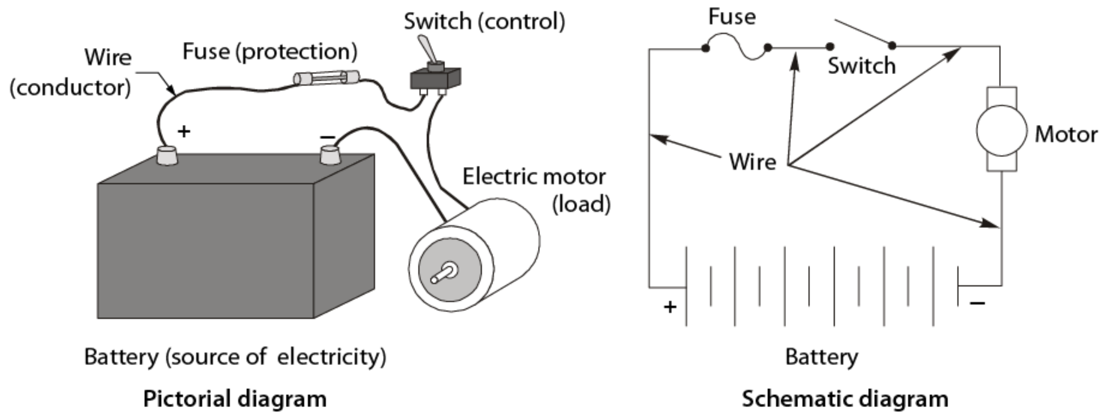
Switches are used to turn the current on and off or to regulate the flow of electricity. Switches can be operated mechanically by vacuum, pressure, or electricity.

Load

The load converts electrical energy to work, such as with electric motors, bulbs, heater coils, or horns.

Protection

Fuses, circuit breakers, or fusible links must be used to prevent damage to the source, load, and conductors.



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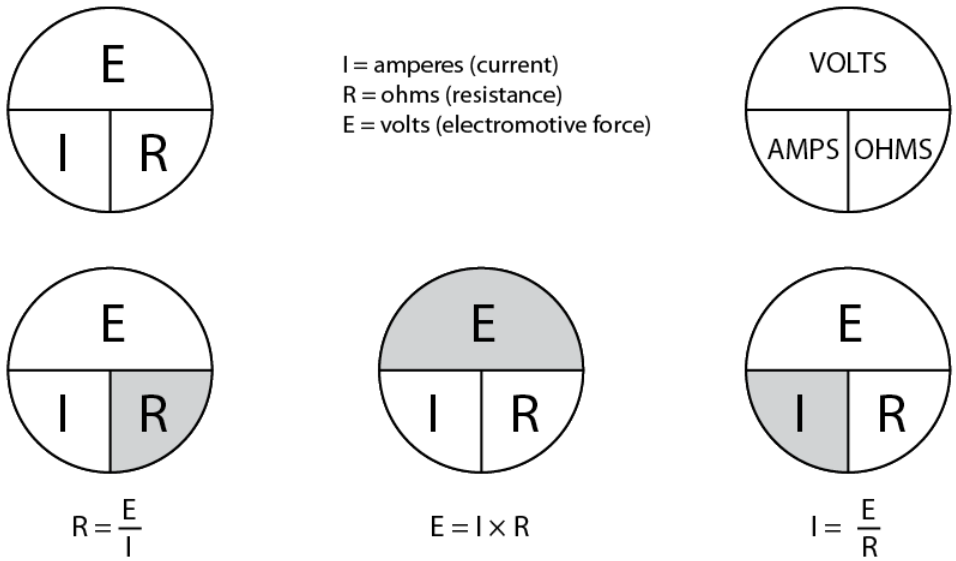
5. Basic circuit



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6. Ohm’s law circuit aid

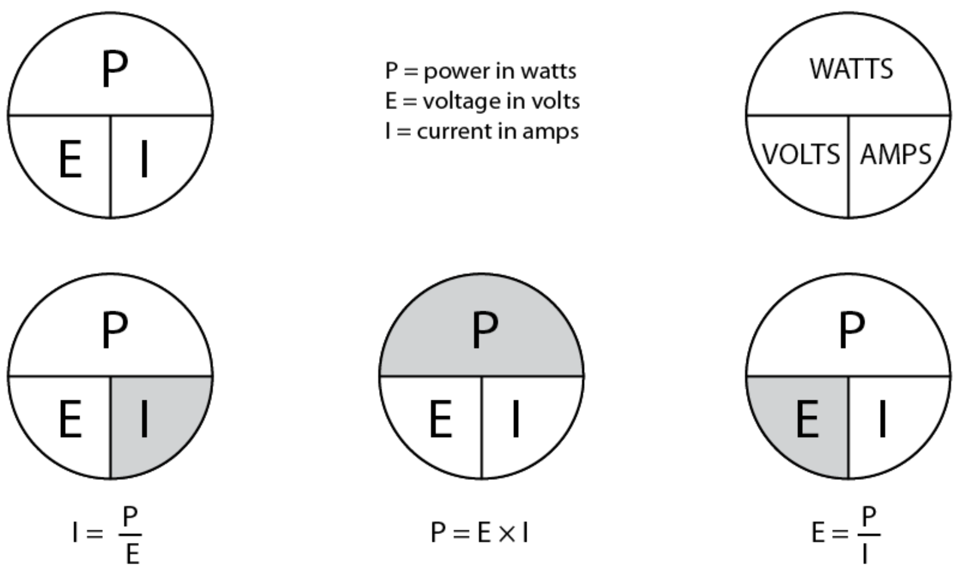

Figure 1.2.1: (CC BY-NC-SA; BC Industry Training Authority)

7. Power circuit aid

Try to solve the following questions for power, using Ohm's law calculations.

1. How many amps will flow through a 96 W headlight bulb in a 12 V system?

   The formula is I = P ÷ E.

   Therefore I = 96 W ÷ 12 V.

   The result is I = 8 A.

   This could be an important consideration in selecting the correct circuit protection device. A fuse with a rating of more than 8 A would have to be chosen in this situation.

2. How much power will a soldering gun produce if it uses 6 A in a 120 V electrical system?

The formula is P = E × I.

Therefore P = 120 V × 6 A.

The result is P = 720 W.

Soldering guns are rated in watts. The higher the wattage rating of the gun, the more heat it will produce.

Now complete the Learning Task Self-Test.

1.E: Self-Test 1

Self-Test 1

1. What are the tiny particles that matter is made of called?
    1. Compounds
    2. Atoms
    3. Ions
    4. Protons and neutrons
2. What are elements called that have atoms with electrons that are easily freed?
    1. Ions
    2. Conductors
    3. Insulators
    4. Elements
3. Which of the following best describes copper?
    1. Conductor
    2. Insulator
    3. Semiconductor
    4. Valence electron
4. Why are insulators useful?
    1. They transport an electrical charge.
    2. They do not transport an electrical charge.
    3. They readily release valence electrons.
    4. They will ionize easily when subjected to voltage.
5. In what units is current measured?
    1. Volts
    2. Amperes
    3. Ohms
    4. EMF
6. A source of electromotive force can be from a chemical reaction.
    1. True
    2. False
7. In a DC circuit the poles alternate from positive to negative.
    1. True
    2. False
8. What is the device called that is used to turn a circuit on and off?
    1. A control
    2. A conductor
    3. A load
    4. A protector
9. Which of the following best describes an electric motor?
    1. A control
    2. A load
    3. A fuse
    4. A conductor

Use Ohm's law for the following questions.

$E = I \times R$, where:

- Volts (V) is represented by "E" for electromotive force.

- Amperes (A) is represented by “I” for intensity of current.
- Ohms (Ω) is represented by “R” for resistance.

10. If resistance in a circuit is 6 Ω and the pressure is 24 V, what is the current flow?
    1. 2 A
    2. 4 A
    3. 6 A
    4. 8 A
11. If a circuit had a current flow of 8 A and the resistance is 20 Ω, what is the pressure in volts?
    1. 120 V
    2. 160 V
    3. 2.5 V
    4. 25 V
12. If a circuit has a current flow of 5 A and a pressure of 120 V, what is the resistance?
    1. 24 Ω
    2. 12 Ω
    3. 6 Ω
    4. 3 Ω

Use the power formula for the following questions.

watts = volts × amps or P = E × I

13. How much power will a heater produce if it uses 15 A in a 120 V electrical system?
    1. 1800 W
    2. 1500 W
    3. 900 W
    4. 1200 W
14. How many amps will flow through a 60 W headlight bulb in a 24 V system?
    1. 6 A
    2. 2.5 A
    3. 25 A
    4. 8 A
15. Use Ohm’s law to complete the following chart.

voltage	current	resistance
	500 mA	240
12		1000
12	8 A	
5		20 000
120	10	
	0.15 A	80
3	0.0002 A	

16. Use the power formula to complete the following chart.

power	voltage	current
1500 W		12.5 A
40 W	12 V	
	12 V	300 mA

200 W		10 A
96 W	12 V	
	12 V	40 A

CHAPTER OVERVIEW

2: Basic Circuit Concepts

2.1: Basic Electrical Circuits

Learning Task 2

Describe basic circuit concepts

You must understand how basic circuits function to properly diagnose and repair electrical problems. Now that you understand a simple circuit and how the basic components are connected, you can assemble more complex circuits and observe their characteristics.

Basic electrical circuits

A circuit must provide a complete path for current flow from the power source. The current must flow through a control device into an electrical load and back to the power source through a wire or through a vehicle chassis.

In equipment, wire is normally used only on the insulated side of the circuit, since the return circuit is the chassis. Some components may require a ground wire from the component to the frame This type of circuit is called the single wire system (Figure 1).

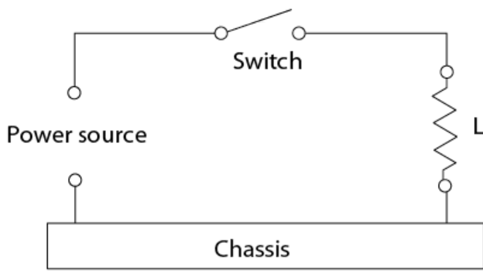

Figure 2.1.1: (CC BY-NC-SA; BC Industry Training Authority)

1. Single wire circuit

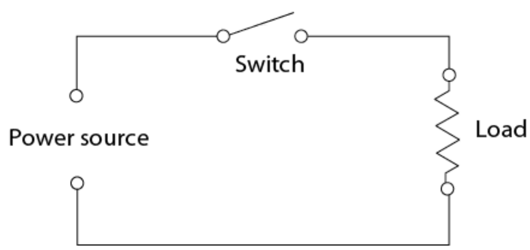

Figure 2.1.1: (CC BY-NC-SA; BC Industry Training Authority)

2. Two wire circuit

   There are three types of basic electrical circuits:

   - series circuits
   - parallel circuits
   - series-parallel (combination) circuits

2.2: Series Circuits

Series circuits

The electrical term in series refers to a circuit in which two or more components are connected one after another in order that the current can only flow through one path. The switch that controls the circuit is always in series with the loads. If more than one switch is used, both must be closed for the circuit to function. Circuit protectors (such as fuses) will also be in series. If any one of the components in a series circuit opens, the circuit will not function (Figure 3).

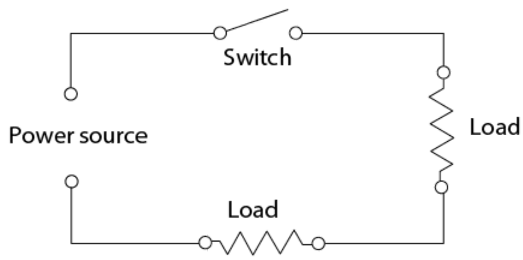

Figure 2.2.1: (CC BY-NC-SA; BC Industry Training Authority)

3. Series circuit

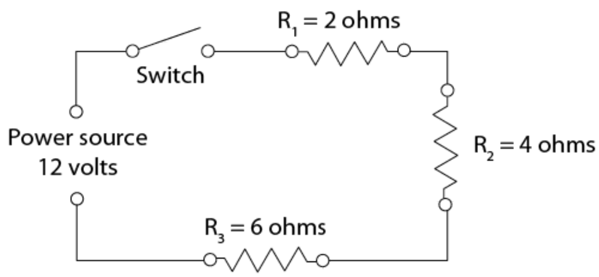

Figure 2.2.1: (CC BY-NC-SA; BC Industry Training Authority)

4. Series circuit

   Perform the following calculations:

   1. Total resistance or RT will equal the sum of the individual resistances.

      RT = R1 + R2 + R3

      RT = 2 Ω + 4 Ω + 6 Ω

      RT = 12 Ω

   2. Now apply Ohm’s law and calculate the current flow in the circuit.

      I = E ÷ R

      I = 12 V ÷ 12 Ω

      I = 1 A

   3. Current flow is the same throughout the circuit. By using Ohm’s law you can determine how much voltage will be used by each of the loads.

   The 2 ohm resistor will require:

   E = I × R

   E = 1 A × 2 Ω

   E = 2 V

   The 4 ohm resistor will require:

   E = I × R

   E = 1 A × 4 Ω

E = 4 V

The 6 ohm resistor will require:

E = I × R

E = 1 A × 6 Ω

E = 6 V

Add the individual voltages together and you will notice that they equal the original source voltage of 12 V.

ET = 2 V + 4 V + 6 V

ET = 12 V

The voltage that is used up in the circuit by the load is called voltage drop. This voltage drop is valuable in diagnosis as a measure of the resistance of a circuit. Some voltage may be lost in a circuit because of poor connections. If the voltage drop in connections (caused by high resistance) becomes too great, the load may not function properly or may not even work.

2.3: Parallel Circuits

The parallel circuit (Figure 2.3.1) has completely different characteristics. In a parallel circuit, two or more loads are connected side by side and are controlled by one or more switches. The different loads can each have their own switch, but the major difference is that each of the loads has access to the same amount of voltage and can operate independently of the others. There is more than one path through which the current can flow.

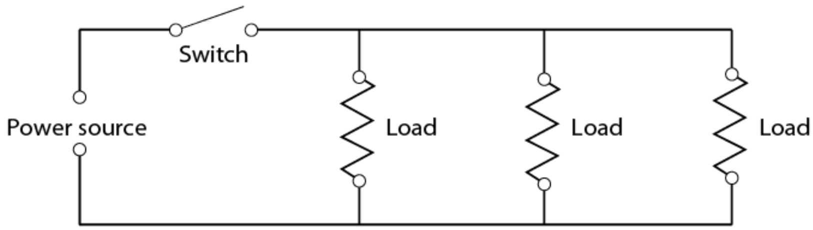

Figure 2.3.1: Parallel circuit (CC BY-NC-SA; BC Industry Training Authority)

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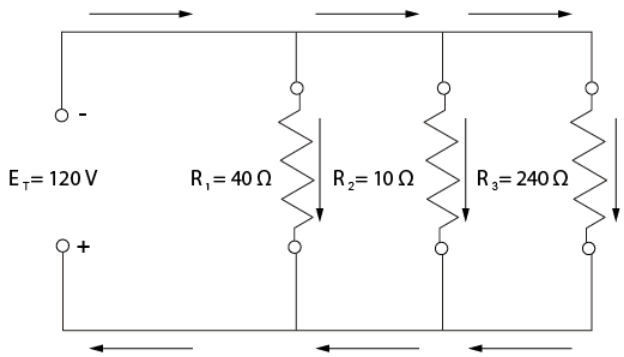


Figure 2.3.2: Parallel circuit (CC BY-NC-SA; BC Industry Training Authority)

$$\begin{aligned} \mathrm{I}_1 &= \frac{\mathrm{E}_1}{\mathrm{R}_1} = \frac{120}{40} = 3\text{amps} \\ \mathrm{I}_2 &= \frac{\mathrm{E}_2}{\mathrm{R}_2} = \frac{120}{10} = 12\text{amps} \\ \mathrm{I}_3 &= \frac{\mathrm{E}_3}{\mathrm{R}_3} = \frac{120}{240} = 0.5\text{amp} \end{aligned} \tag{2.3.1}$$

$$R_T = \frac{E_T}{I_T} = \frac{120}{15.5} = 7.7 \text{ ohms} \tag{2.3.2}$$

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots} \tag{2.3.3}$$

$$\begin{aligned} R_T &= \frac{1}{\frac{1}{40} + \frac{1}{10} + \frac{1}{240}} = 7.7 \text{ ohms} \\ R_T &= \frac{1}{\frac{6}{240} + \frac{24}{240} + \frac{1}{240}} \\ R_T &= \frac{\frac{240}{240}}{31} \\ R_T &= 7.7 \text{ ohms} \end{aligned}$$

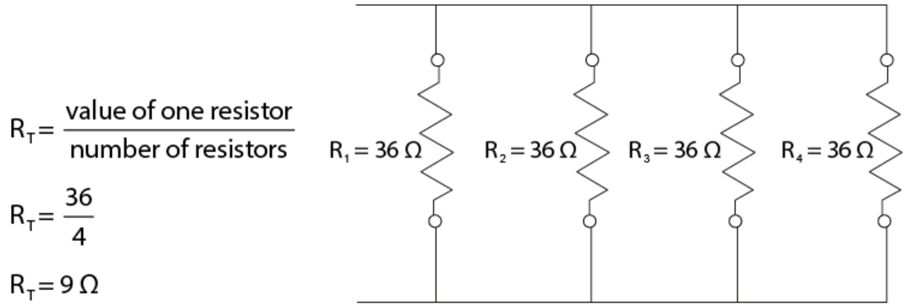


Figure 2.3.3: Parallel circuit with four resistors (CC BY-NC-SA; BC Industry Training Authority)

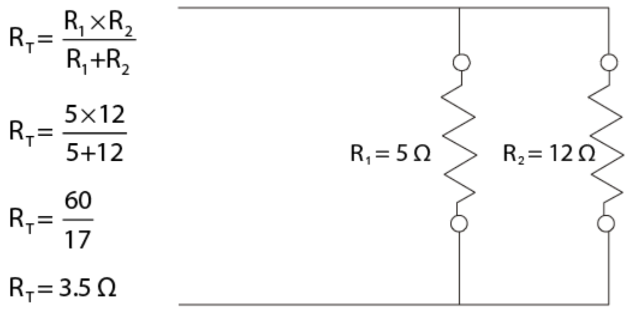


Figure 2.3.4: Parallel circuit with two resistors (CC BY-NC-SA; BC Industry Training Authority)

2.4: Series-parallel Circuits

Series-parallel circuits

The series-parallel circuit combines the two previously described types of circuits into one operating system with some distinct advantages. By introducing a load or resistor in series with a parallel circuit, the current flow through the circuit can be controlled (Figure 9).

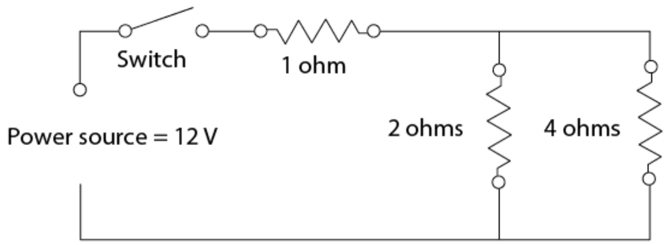


Figure 2.4.1: (CC BY-NC-SA; BC Industry Training Authority)

9. Series-parallel circuit

$$R_T = \frac{2\,\Omega \times 4\,\Omega}{2\,\Omega + 4\,\Omega}$$

$$R_T = \frac{8\,\Omega}{6\,\Omega}$$

$$R_T = 1.3\,\Omega$$

Figure 2.4.1: (CC BY-NC-SA; BC Industry Training Authority)

$$R_T = 1.3\,\Omega + 1\,\Omega$$

$$R_T = 2.3\,\Omega$$

Figure 2.4.1: (CC BY-NC-SA; BC Industry Training Authority)

Using Ohm’s law you can calculate total current flow.

I = E ÷ R

I = 12 V ÷ 2.3 Ω

I = 5.15 mA

2.5: Polarity and direction of current flow

Polarity and direction of current flow

Earlier you learned about the term polarity, referring to the charge at one point with respect to another. When working with electrical circuits, we often refer to the polarity between different points in the circuit. Understanding polarity is important for connecting the leads of polarity-dependent devices such as some meters and motors. Polarity is also important for determining the direction of current flow. In Figure 10 the current leaves the source at the negative terminal, travels around the circuit in a clockwise direction, and re-enters the source at the positive terminal.

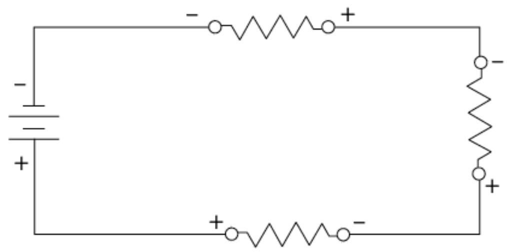


Figure 2.5.1: (CC BY-NC-SA; BC Industry Training Authority)

10. Polarity

    It is important to notice that current flows through loads from negative to positive, and current flows through sources from positive to negative. A more precise way of stating this is that outside the source, current flows from negative to positive, but inside the source current flows from positive to negative.

    Now complete the Learning Task Self-Test.

2.E: Self-Test 2

Self-Test 2

1. What takes the place of a ground return wire in a single wire system?
   1. Fuse
   2. Case ground
   3. Circuit breaker
   4. Chassis
2. How many paths does a series circuit have for current flow?
   1. 1
   2. 2
   3. 3
   4. 4
3. What is a circuit called that has more than one path for current flow?
   1. Series circuit
   2. Complex circuit
   3. Compound circuit
   4. Parallel circuit
4. What must the total voltage drop in a circuit be equal to?
   1. The source voltage
   2. The first voltage drop
   3. Half the source voltage
   4. Twice the source voltage
5. A 12 V circuit with a 4 ohm resistor will have a current of 6 A.
   1. True
   2. False
6. A 120 V circuit with a current of 10 A will have a load with what resistance?
   1. 12 Ω
   2. 24 Ω
   3. 6 Ω
   4. 10 Ω
7. If one load fails in a parallel circuit, all other loads will fail.
   1. True
   2. False
8. What is the total resistance in a series circuit with four resistors rated at 2 Ω each?
   1. 2 Ω
   2. 4 Ω
   3. 6 Ω
   4. 8 Ω
9. A 120 V parallel circuit has three resistors: 20 Ω, 12 Ω, and 24 Ω. What is the current?
   1. 6 A
   2. 18 A
   3. 21 A
   4. 24 A
10. What is the total resistance for a 120 V circuit with three resistors of 20 Ω, 12 Ω, and 24 Ω in parallel?
    1. 6 Ω
    2. 8 Ω
    3. 12 Ω

4. 24 Ω

CHAPTER OVERVIEW

3: Electromagnetism

A magnet attracts ferrous metals and some alloys. Magnets can take three forms:

- natural
- artificial
- electric

Natural magnets (i.e., magnetite) are very weak. Artificial magnets are made from magnetic materials (such as iron, nickel, and cobalt) and are given a strong magnetic force during construction. These are permanent magnets and have some limited use. Electromagnets can be easily turned on and off and are in common use because they are not permanent. They are called temporary magnets.

3.1: Magnetic Fields

If a magnet is suspended in the air, it will always turn and align with Earth's north and south poles. The two ends, called the magnetic poles, are where the force is strongest.

A magnetic field of force is set up between the two poles. You can think of it as invisible lines of force traveling from one pole to the other. The magnetic lines (flux lines) are continuous and always form loops. These invisible lines can be seen if you sprinkle iron filings on a piece of paper placed over a bar magnet (Figure $3.1.1$).

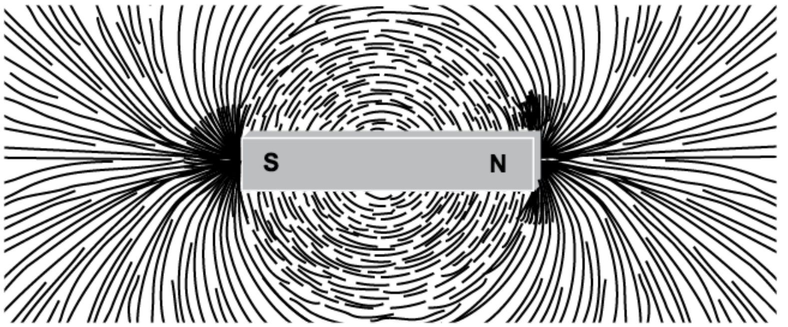


Figure $3.1.1$: Magnetic lines of force (CC BY-NC-SA; BC Industry Training Authority)

Characteristics of magnetic lines of force

Magnets have some specific rules governing their operation.

Magnetic lines of force possess direction

These lines are continuous and extend from the north pole to the south pole of the magnet (Figure $3.1.2$).

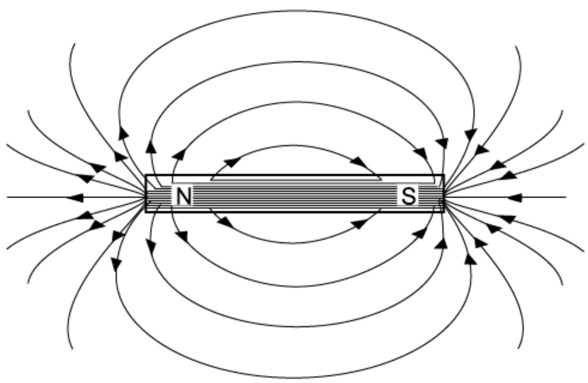


Figure $3.1.2$: Flux line direction (CC BY-NC-SA; BC Industry Training Authority)

Magnetic lines of force always form complete loops

The lines do not begin and end at the poles but rather pass through the magnet to form complete loops. If you were to cut a magnet in half, you could observe the magnetic field between the two pieces of the magnet (Figure $3.1.3$).

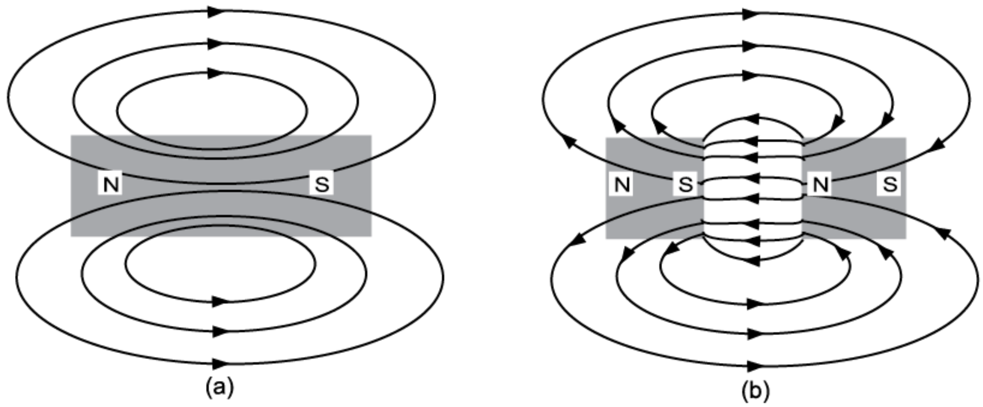


Figure 3.1.3: Magnetic loops (CC BY-NC-SA; BC Industry Training Authority)

Magnetic lines of force always form tight loops

This rule explains the idea of attraction. The flux lines attempt to pull in as close to the magnet as possible, just like rubber bands. They also try to concentrate at each pole. If you place two unlike poles together, they try to become one big magnet and shorten the lines of force (Figure 3.1.4).

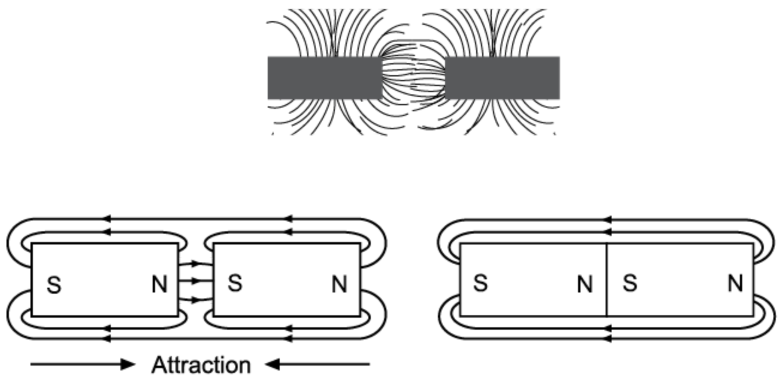


Figure 3.1.4: Magnetic attraction (CC BY-NC-SA; BC Industry Training Authority)

Magnetic lines of force repel each other

If magnetic lines of force act like rubber bands, why don't they collapse into the center? The reason is that they repel each other. Look back at Figure 3; notice that the lines tend to diverge as they move away from the poles, rather than converge or even remain parallel. This results from their mutual repulsion.

Magnetic lines of force never cross, but must always form individual loops

The mutual repulsion of each magnetic line accounts for this effect. This explains why like poles repel each other. If the lines cannot cross each other, then they must exert a force against each other. If you could see the lines of force, they would look like the diagram in (Figure 3.1.5).

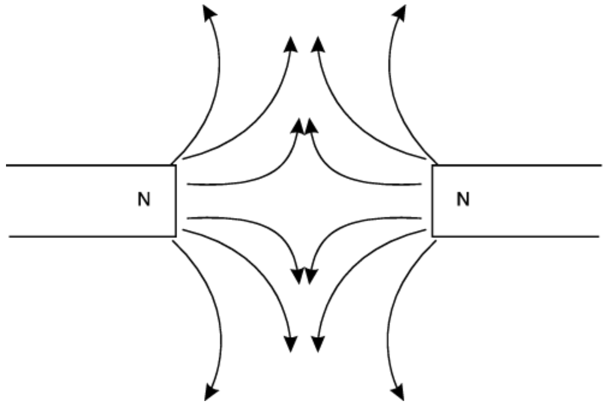


Figure 3.1.5: Repulsion (CC BY-NC-SA; BC Industry Training Authority)

Magnetic lines of force can pass more easily through material that can be magnetized

The magnetic lines of force will distort to include a piece of iron in the field. This will have the effect of turning the iron into a temporary magnet. Then the opposite poles of the two magnets will attract each other and try to shorten the flux lines. This accounts for the attraction of unmagnetized ferromagnetic objects (Figure 3.1.6).

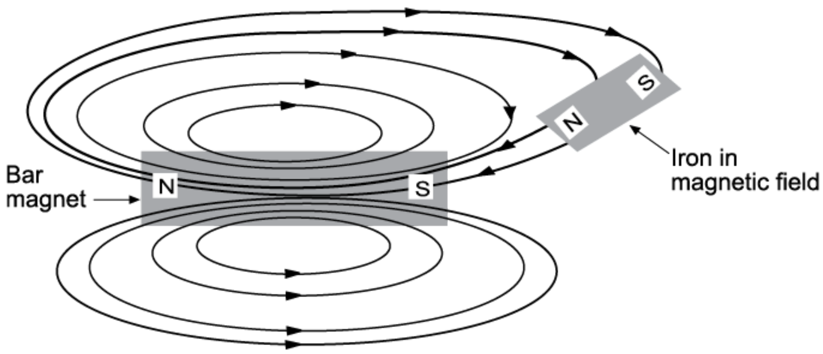


Figure 3.1.6: Iron easily magnetized (CC BY-NC-SA; BC Industry Training Authority)

There is no insulation against magnetic lines of force

All magnetic field lines must terminate on the opposite pole, which means there is no way to stop them. Nature must find a way to return the magnetic field lines back to an opposite pole. However, magnetic fields can be rerouted around objects. This is a form of magnetic shielding. By surrounding an object with a material that can “conduct” magnetic flux better than the materials around it, the magnetic field will tend to flow along this material and avoid the objects inside. This allows the field lines to terminate on the opposite poles, but just gives them a different route to follow (Figure 3.1.7).

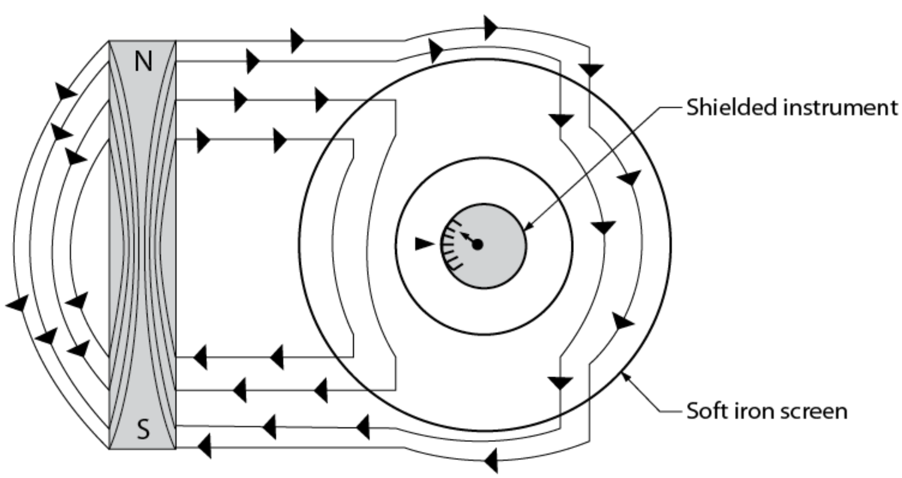


Figure 3.1.7: Magnetic shielding (CC BY-NC-SA; BC Industry Training Authority)

Alignment of the atoms

If you took a permanent magnet and cut it in half, you would have two permanent magnets, each with a north and south pole. If you continued cutting each in half, you would have more magnets. This suggests that if you could cut right down to the atom, it would also be a perfect permanent magnet.

This theory can be extended to non-magnetic material as well. Each of the atoms is a magnet, but they are all pointing in different directions. If you can get enough atoms pointing in the same direction, you will have a magnet. All you have to do is expose the piece of metal to flux lines, and the atoms will align.

These atoms tend to form in groups called domains. When the domain becomes large enough, the entire piece of metal becomes the domain and exerts force. When all of the atoms become aligned, the piece has become saturated and cannot get any stronger.

3.2: Electricity and Magnetism

Electricity and magnetism

There is a direct relationship between electricity and magnetism. If there is current flow in a conductor there will be lines of force created around the conductor. If you could look at the magnetic field formed around a current-carrying conductor, it would look like Figure 3.2.1.

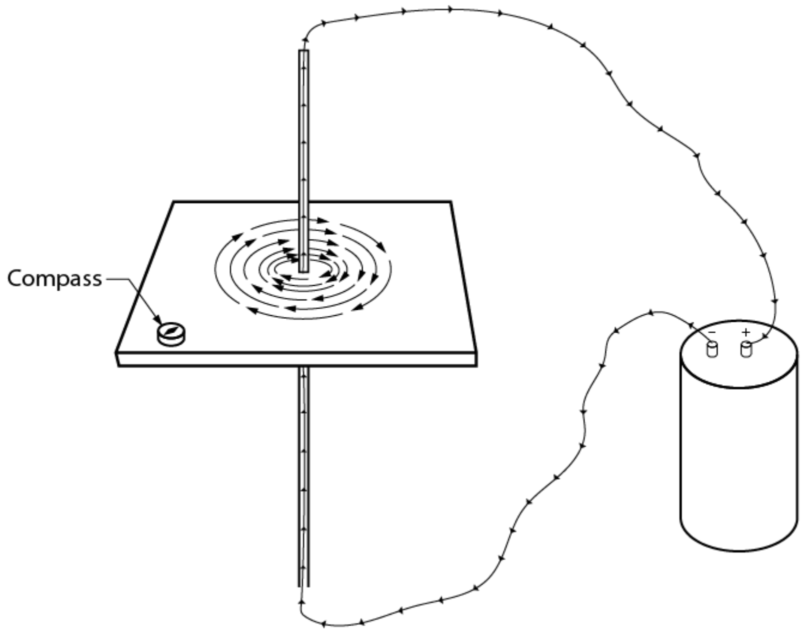


Figure 3.2.1: Electromagnetic field (CC BY-NC-SA; BC Industry Training Authority)

Note that the lines of force circle the conductor in rings and have direction. The direction of the lines of force depends on the direction of electron flow. If you know the direction of electron flow, you can determine the direction of the lines of force by using your left hand.

The "left-hand rule" says that if you hold the conductor in your left hand with your thumb pointing in the direction of the electron current flow, your fingers will curl in the direction of the lines of force. You will sometimes find this referenced as the "right-hand rule" from those using convention flow notation.

Interaction of fields

Magnetic fields around a current-carrying conductor act in the same way as the fields around a permanent magnet. In Figure 3.2.2, two conductors have been moved close together. The current is going in opposite directions, as indicated by the symbol in the end of the conductor. An X indicates electron flow in; a dot indicates electron flow out. The magnetic lines of force try to push the two conductors apart because they are in opposite directions. The arrows indicate the direction of the magnetic force.

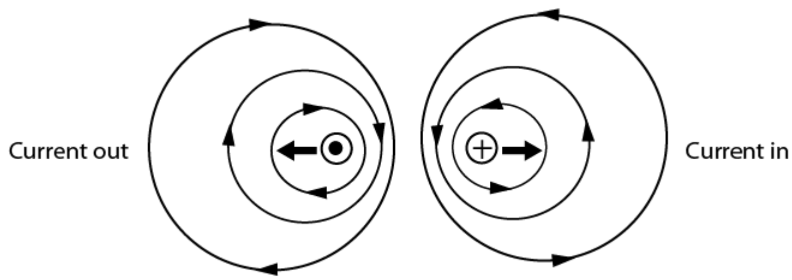


Figure 3.2.2: Opposite currents repel (CC BY-NC-SA; BC Industry Training Authority)

If one of the conductors has the current reversed, then the magnetic lines of force travel in the same directions. When this occurs the lines of force try to contract and pull tight, just as they did with a permanent magnet. The resulting force will try to pull the two conductors together (Figure 3.2.3).

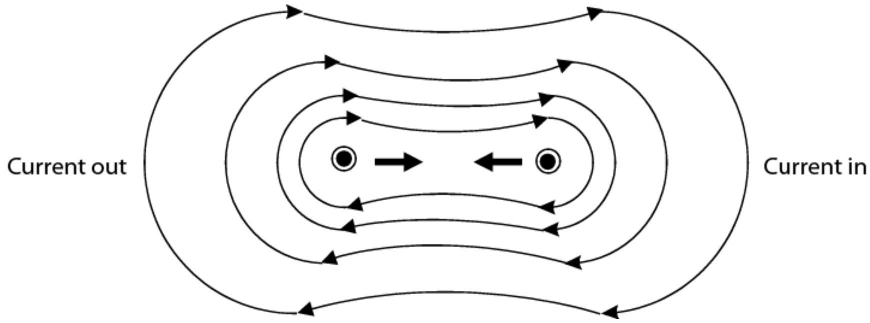


Figure 3.2.3: Like currents attract (CC BY-NC-SA; BC Industry Training Authority)

Conductors in loops

If a conductor carrying a current is formed into a loop, the magnetic field will be arranged differently. It will form looped lines of force with a north pole on one side of the loop and a south pole on the other. The magnetic flux lines add to each other and produce a much denser magnetic field in the center of the coil (Figure 3.2.4).

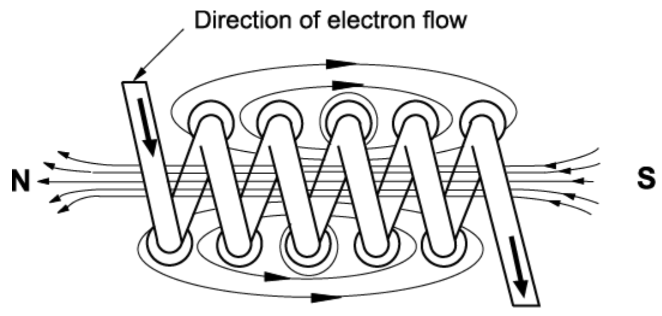


Figure 3.2.4: Flux in a loop (CC BY-NC-SA; BC Industry Training Authority)

Electromagnets

If a piece of soft iron is placed in the coil and a current is passed through the coil in one direction, the magnetic field of the coil causes the domains to align in the iron. This causes poles to form in the iron and creates an electromagnet, as shown in 3.2.5.

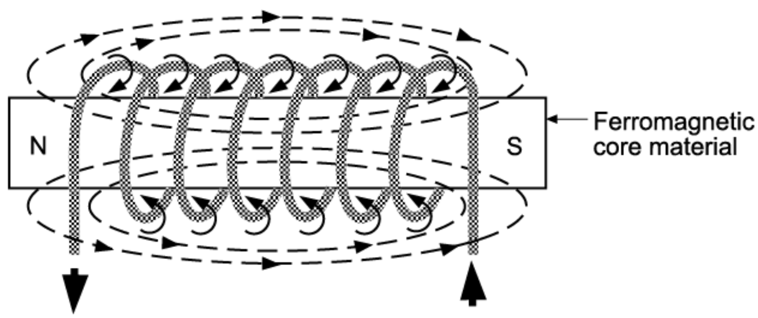


Figure 3.2.5: Electromagnet (CC BY-NC-SA; BC Industry Training Authority)

The strength of the electromagnet varies with the number of loops formed, the strength of the electric current, and the type of core in the winding. Because the iron core has a low magnetic retention, the magnetic field collapses when the current stops flowing. The iron core is no longer magnetized and will release whatever it was being used to hold or pull inward.

Electric motors and generators

Electromagnets are probably most commonly used in motors and generators. We have seen that magnetism can be caused by electricity. Electric motors use the force of electromagnets to produce rotation. On the other hand, electricity can be produced by magnetism. When a conductor is moved through a magnetic field or a magnet is moved past a conductor, the movement will induce a voltage in the conductor. Most electricity is generated in this way.

To generate a voltage, three elements must be combined (Figure 3.2.6:

1. a conductor

2. a magnetic field
3. movement by either the conductor or the magnetic field

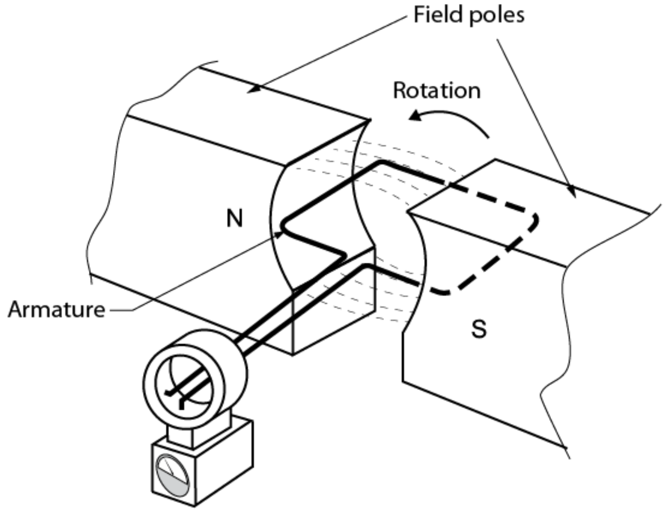


Figure $3.2.6$: Simple generator (CC BY-NC-SA; BC Industry Training Authority)

The amount of voltage produced will depend on the strength of the magnetic field and the speed at which the conductor or the field moves. A conductor that moves through a magnetic field quickly will generate a higher voltage than one that moves more slowly.

A conductor that moves through a strong magnetic field will generate a higher voltage than one moved through a weak magnetic field.

Alternating current

Electric current that flows in one direction for a split second then changes direction in another split second is called alternating current (AC). In an alternating voltage, the polarity reverses direction periodically. The spinning mechanical motion of an electric generator produces AC voltage and current.

AC waveform and hertz

Hertz is the unit used to describe the frequency of AC direction change. Figure $3.2.7$ is a graphic illustration using a curved line with arrows to indicate a change of direction in AC electron flow. Starting at point A, the current flows in one direction, and then at 120 volts it changes direction, drops to 0 volts, and continues to 120 volts, where it changes direction again back to point B at 0 volts.

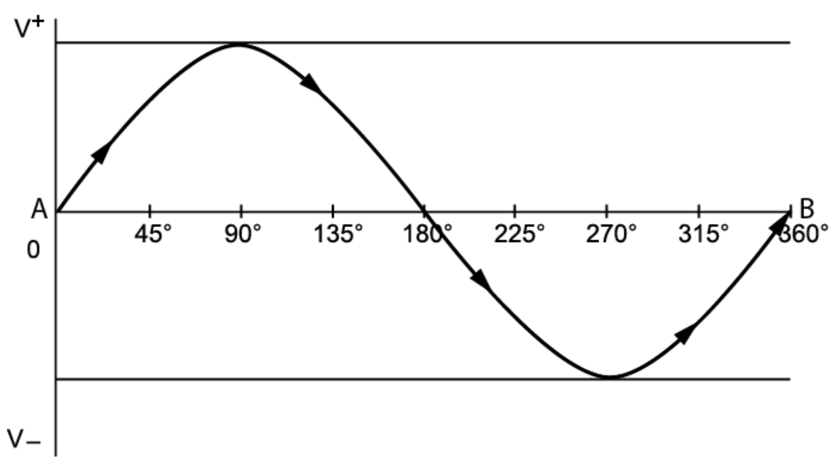


Figure $3.2.7$: AC sine wave (CC BY-NC-SA; BC Industry Training Authority)

If it takes one second to complete the cycle from A to B, we would say the frequency is 1 hertz. Household utility AC current is supplied to the customer at 60 hertz, meaning 60 cycles per second.

Single-phase power supply

Single-phase electric power refers to the distribution of alternating current electric power using a system in which all the voltages of the supply vary in unison. Single-phase distribution is used when loads are mostly lighting and heating, and with a few large electric motors. Single-phase power typically comprises one voltage that is carried between two separate conductors. The two hot lines are called Line 1 and Line 2. In some systems, a grounded neutral, often labeled N, is provided that reduces the referenced voltage in half. These systems are typically found in residential and small commercial applications.

Three-phase AC power supply

Three-phase electrical power refers to a type of electrical power distribution in which three or more energized electrical conductors are carrying alternating currents. Examples of three-phase power systems are industrial applications and power transmission. Three-phase power supplies are used to power large motors and other heavy loads. A three-phase system is generally more economical than equivalent single-phase or two-phase (an uncommon power supply) systems at the same voltage.

Three-phase power comprises three independent voltages that are carried on three separate conductors. The three hot lines are called Line 1, Line 2, and Line 3. Three-phase power is typically found in commercial and industrial buildings.

Now complete the Learning Task Self-Test.

3.E: Self-Test 3

Self-Test 3

1. There are three types of magnets: natural, artificial, and electric.
    1. True
    2. False
2. Natural magnets have the strongest force.
    1. True
    2. False
3. If the south poles of two magnets are brought together, what they will do?
    1. Conduct
    2. Relate
    3. Saturate
    4. Repel
4. Changing which of the following will also change the strength of an electromagnet?
    1. Direction of current flow
    2. Size of wires
    3. The length of the core
    4. Amount of current flow
5. What is the core of an electromagnet usually made from?
    1. Air
    2. Soft iron
    3. Aluminum
    4. Copper
6. What two elements must be combined with a conductor to generate a voltage?
    1. Magnetic field and a current
    2. Current and movement
    3. Coil and a magnet
    4. Magnetic field and movement
7. Magnetic lines of force never cross.
    1. True
    2. False

4: Answer Key

Answer Key

Self-Test 1

1. b. Atoms
2. b. Conductors
3. a. Conductor
4. b. They do not transport an electrical charge.
5. b. Amperes
6. a. True
7. b. False
8. a. A control
9. d. A load
10. b. 4 A
11. b. 160 V
12. a. 24 Ω
13. a. 1800 W
14. b. 2.5 A
15.

voltage	current	resistance
120	500 mA	240
12	0.012 A	1000
12	8 A	1.5
5	0.00025 A	20 000
120	10	12
12	0.15 A	80
3	0.0002 A	15 000

16.

power	voltage	current
1500 W	120 V	12.5 A
40 W	12 V	4 A
3.6 W	12 V	300 mA
200 W	20 V	10 A
96 W	12 V	8 A
480 W	12 V	40 A

Self-Test 2

1. d. Chassis
2. a. 1
3. d. Parallel circuit
4. a. The source voltage
5. b. False
6. a. 12 Ω
7. b. False
8. d. 8 Ω
9. c. 21 A
10. a. 6 Ω

Self-Test 3

1. a. True
2. b. False
3. d. Repel
4. d. Amount of current flow
5. b. Soft iron
6. d. Magnetic field and movement
7. a. True

SECTION OVERVIEW

2: Unit II- Common Circuit Components and Their Symbols

Learning Objectives

- When you have completed the Learning Tasks in this Competency you should be able to:
- describe the components of a circuit
- identify common electrical components
- describe solid state devices
- identify wiring connectors
- describe the composition of simple wiring diagrams

Many types of electric devices are used in almost every trade. Mechanical trades will find electrical devices in every motor-driven vehicle. Construction trades will encounter them in most construction projects. To be able to recognize or troubleshoot electrical devices, you must be familiar with the correct terminology and symbols used to identify them.

CHAPTER OVERVIEW

5: Circuit Components and their Schematic Symbols

All electrical components are rated with different current, voltage, and other values, depending on their use. Replacing an electrical component with one of a different value could present a serious safety hazard to the person using the equipment. Should you have to replace an electrical component at any time, always be sure that the current, voltage, and other electrical ratings of the replacement match those of the original.

In addition, to ensure public safety from electrical and fire hazards, the Canadian Standards Association (CSA) approves electrical components. Each component is tested before it can be sold on the Canadian market. Always use only CSA-approved equipment. The CSA approval should be clearly visible on the component or the package.

You may have to assemble devices in a circuit from plans or drawings in which symbols are used to represent basic electrical devices and components. Although some plans use pictures of the devices instead of symbols, you should be familiar with the symbols so that you can identify each individual device. Not all electrical symbols are standard, but most symbols can be easily recognized.

5.1: Electrical systems

Electrical systems

An electrical system has two main conditions: it is closed or it is open. Closed means the circuit is complete and conducting. Open means the circuit is incomplete and no current flows.

There are different electrical systems, identified by voltage. The term low voltage is relative and its definition varies by context. The Canadian Electrical Code defines low voltage as from 31 V to 750 V and systems operating at 30 volts or less.

Automotive systems normally use direct current and are rated up to 24 volts. Residential alternating current voltage may be 120 or 240 volts. Lighting and small appliances normally use 120 volts. Clothes dryers, stoves, and ovens use 240 volts. Shop equipment also uses either 120 or 240 volts. Most hand-held electric tools and many shop tools use 120 volts or battery power. Some equipment, such as electric welders, use 240 volts.

5.2: Conductors

Conductors are required to create a circuit and carry the current that will operate different devices or loads. Conductors are normally made of copper with a plastic or fiber insulating coating covering them so that they do not contact anything. Exposed wires are not only a safety concern, they are a problem in the circuit if they contact each other.

Conductors are rated according to the American Wire Gauge (AWG) system, which designates different gauges for wires of different thicknesses. Most conductors found in vehicles and equipment are braided multi-strand conductors because they can withstand vibration and motion better than solid conductors. Most wiring found in residential and industrial applications is solid conductors. Special measuring gauges (Figure 5.2.1) are used to determine the actual physical wire size.

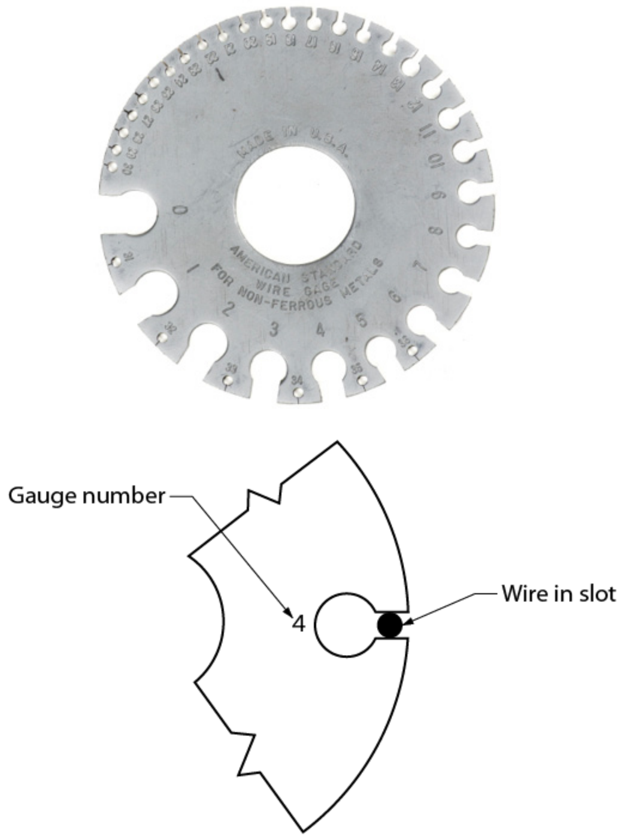


Figure 5.2.1: Wire gauge (CC BY-NC-SA; BC Industry Training Authority)

A conductor is normally shown on a wiring diagram by a straight line with a color notation and often a gauge or size notation.

A power cord is a flexible conductor used to supply electrical energy to electrical equipment. With plugs attached, these cords are used to attach appliances such as dryers and ranges to their receptacles. In industry, they are used to connect portable electrical equipment or machinery to receptacles. Conductors are covered with insulating material to prevent the unwanted flow of electric current. Various conditions of use dictate the type of insulating material:

- voltage rating
- temperature rating
- location (e.g., wet or dry or potential mechanical damage)

5.3: Receptacles

Receptacles (Figure 5.3.1) are one-half of a two-piece multi-contact connector. The other half is the plug. Receptacles vary in shape, size, and application. Most 120 volt residential applications use the duplex U-ground receptacle. In addition, dryer and range receptacles are used in higher-voltage applications. The correct receptacle must be used with the correct plug for each application.

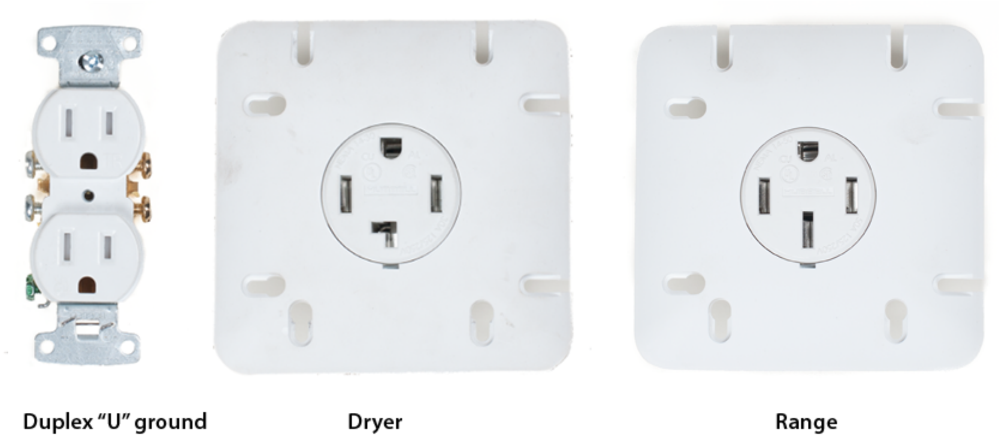


Figure 5.3.1: Receptacles (CC BY-NC-SA; BC Industry Training Authority)

5.4: Circuit Protection Devices

Protection is required to prevent damage to expensive components and all the equipment wiring if a circuit should overload due to excessive current flow. Protection can be provided by:

- fuses
- fusible links
- circuit breakers
- thermal limiters

Fuses

The fuse is the most common circuit protection device. Fuses are available in different shapes and sizes and are rated to burn out or blow out at a specific amount of current flow. The material within the fuse provides excellent conductivity as long as the current flow stays below the rating of the fuse.

Once the current flow exceeds the rating, the material will melt and open the circuit. Blown fuses indicate a circuit fault that must be located and repaired. Simply replacing a burned fuse will not correct the problem. A burned fuse should never be replaced with another fuse with a higher rating than what is recommended by the manufacturer.

Fuses can be located in a fuse box or in-line in a special holder. Small fuses, such as the glass tube fuse, are available in different lengths and sizes and have the amps rating printed on their end. Bayonet-type fuses are colour coded and have the amperage rating printed on the case. Larger cartridge fuses are used in high-voltage industrial applications. Plug or screw-type fuses have a clear window on the face to check them. Figure 5.4.1 shows these four types of fuses.

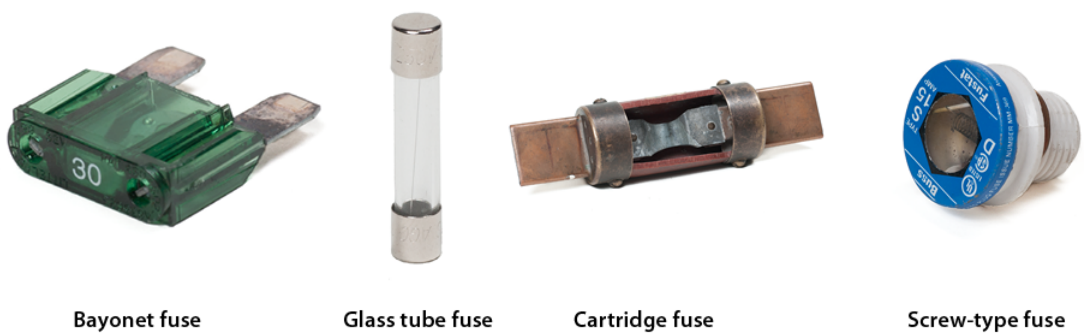


Figure 5.4.1: Fuses (CC BY-NC-SA; BC Industry Training Authority)

Fusible links

Fusible links (Figure 5.4.2) are special wires designed to burn out and open the circuit if the current flow exceeds the rated amount. These links are normally crimped into sealed connectors within the circuit. There should be a four-gauge difference between the conductors they protect. If the conductor is 16 gauge, the fusible link must be 20 gauge. Fusible links can be identified by a colour code or by a large insulation block with the gauge cast into the surface. They cannot be replaced with regular conductors.

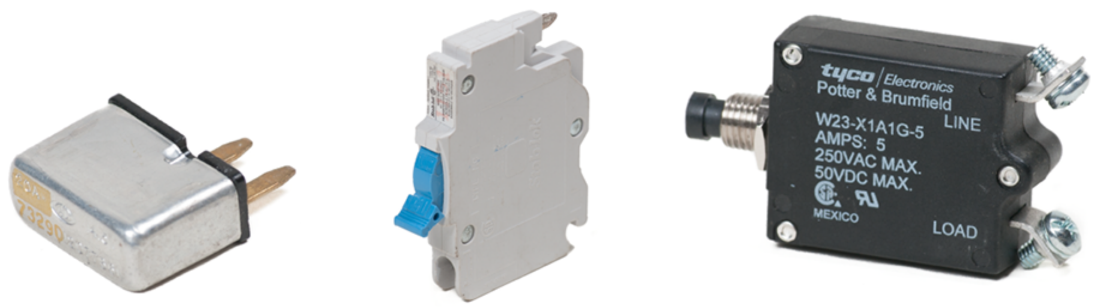
Figure 5.4.2: Fusible link and ratings (CC BY-NC-SA; BC Industry Training Authority)

Fuse link wire size	Color code
20 GA	Blue
18 GA	Brown or red
16 GA	Black or orange

Fuse link wire size	Color code
14 GA	Green

Circuit Breakers

Circuit breakers (Figure 5.4.3) are used in circuits that may have temporary overloads and must be restored to service quickly without permanent disruption. Headlight circuits are a typical low-voltage circuit that use a circuit breaker. Residential wiring for 120 and 240 volt systems also use circuit breakers.



Automotive **Residential** **Electrical**

Figure 5.4.3: Circuit breakers (CC BY-NC-SA; BC Industry Training Authority)

There are three different types of circuit breakers:

- cycling
- non-cycling
- manual reset

Cycling circuit breaker

Cycling circuit breakers contain an arm constructed of two different types of metal: one that expands quickly when heated and one that expands more slowly. This allows the circuit breaker to cycle from open to closed automatically.

A contact point is attached to one end of the arm that provides a closed circuit when it touches a fixed contact. If the current is too high for the circuit, the arm will heat and begin to bend, lifting the movable contact away from the fixed contact to open the circuit. When the arm cools, it will straighten out and touch the fixed contact again, closing the circuit. This is the type of circuit breaker that is used in automobile lighting systems.

Non-cycling circuit breaker

Non-cycling circuit breakers use a high-resistance wire around the arm to carry current when the contact points open. This provides heat that prevents the circuit breaker from cycling. To reset this type of circuit breaker, it must be disconnected from the power source so that the arm can cool.

Manual reset circuit breaker

Manual reset circuit breakers must be reset by pushing a button or reset bar. They will not cycle automatically. This type of circuit breaker is used in residential wiring.

Thermal limiters

Thermal limiters are designed to melt if the device they are protecting exceeds a pre-set temperature. For example, the heating elements in a 120-volt portable electric heater are protected by a thermal limiter. If a thermal limiter melts, it must be replaced, just like a fuse.

5.5: Circuit Control Devices

Controlling a circuit is an essential part of the electrical system. The control devices will turn circuits on and off and limit the conditions within the circuit, including amperage and voltage.

Circuit control devices include:

- resistors
- switches
- relays
- solenoids

Resistors

Resistors are used in circuits where full current flow may not be required. One side effect of resistors is that they produce heat. There are three common resistors found in most circuits:

- fixed
- stepped
- variable

Fixed resistors

Fixed resistors (Figure $5.5.1$) restrict current flow or voltage and are connected into the circuit or built right into a component. In some cases, this resistance is provided by wires. These special wires can be identified by markings that state "resistor wire—do not cut or splice."

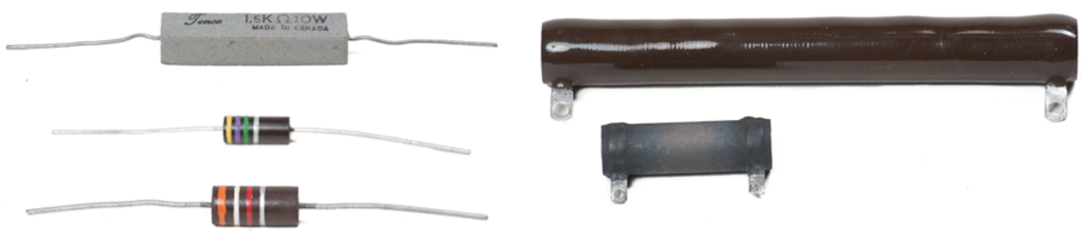


Figure 5.5.1: Fixed resistors (CC BY-NC-SA; BC Industry Training Authority)

Stepped resistors

Stepped or tapped resistors (Figure $5.5.2$) have more than one fixed value and are connected by wiring and a switch into the circuit. The control system on a fan is a good example of one use for this type of resistor. The current will flow through different resistances and provide different fan motor speeds by selecting different fan speeds with the switch.

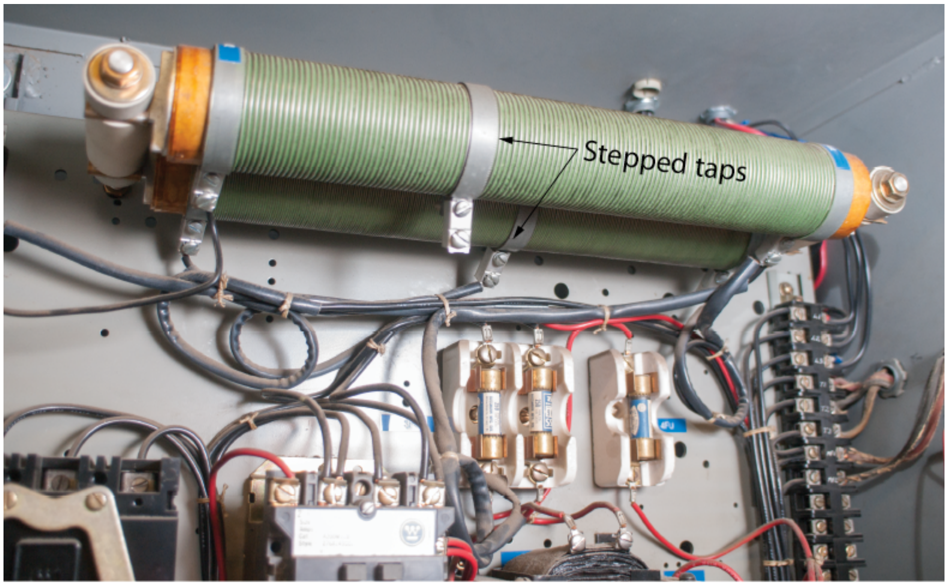


Figure 5.5.2: Stepped resistor (CC BY-NC-SA; BC Industry Training Authority)

Variable resistors

Variable resistors (Figure 8) include potentiometers and rheostats. A variable resistor is called a potentiometer when it is used to control voltage or is called a rheostat when it is used to control current.

A rheostat has two connections and a movable wiper that contacts a winding. If the wiper is close to the power connection, there is a high current flow, and as the wiper is moved away from the power connection, the resistance in the circuit increases, and the current drops.

A potentiometer has a winding that is in series rather than being open ended. Each end of the winding has a terminal for connection into a circuit, as does the movable arm. The movable arm provides an output voltage that varies from full source voltage to zero voltage as it moves along the winding.

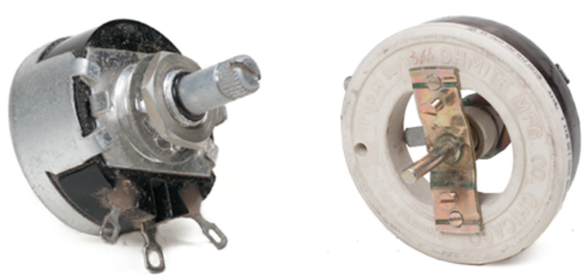


Figure 5.5.3: Variable resistors (CC BY-NC-SA; BC Industry Training Authority)

Switches

Switches are the most common control device for electrical circuits. Switches operate a circuit by opening or closing the circuit. Switches are operated manually, hydraulically, electrically, or pneumatically.

Switches have different numbers of inputs, called poles, and different numbers of outputs, called throws. The most common switch is the single-pole, single-throw switch (SPST).

A switch that can make more than one contact is called a single-pole, double-throw switch (SPDT). A slide switch, rocker switch, and a toggle are shown in Figure 5.5.4.

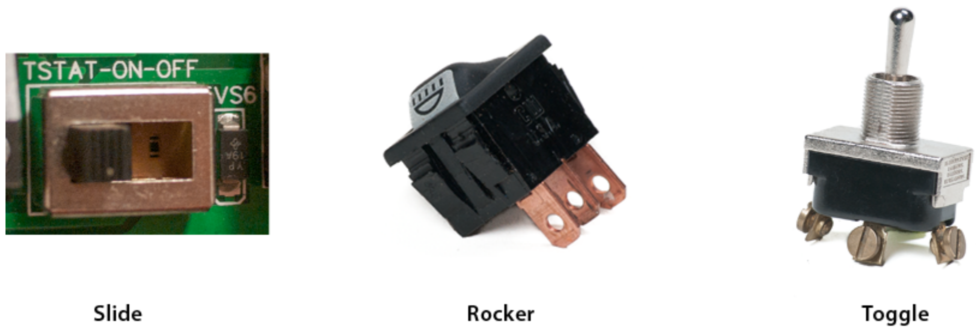


Figure 5.5.4: Slide, rocker, and toggle switches (CC BY-NC-SA; BC Industry Training Authority)

If the same control operates more than one switch, it is called a gang switch. The arrangement of the fixed contact positions (called throws) and the moving contact (the pole), can be seen in the schematic symbol (Figure 5.5.5). It is called a double-pole, double-throw switch (DPDT).

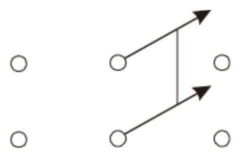


Figure 5.5.5: Double pole double throw switch (CC BY-NC-SA; BC Industry Training Authority)

Another type of switch is the pushbutton switch. This type of switch can be used in different configurations, including SPST, SPDT, and DPDT.

A rotary switch, shown in Figure 5.5.6, has a single pole and two positions.

Figure 5.5.6: Rotary switch (CC BY-NC-SA; BC Industry Training Authority)

Momentary contact switches (Figure 5.5.7) require the operator to maintain pressure to keep the circuit open or closed, because the operating button is spring-loaded and will return to its at-rest position when released. A typical application is a horn switch or blower door safety on a furnace.

Figure 5.5.7: Momentary contact switch (CC BY-NC-SA; BC Industry Training Authority)

Temperature, pressure, and motion switches

A temperature-sensitive switch operates on the same principle as a cycling circuit breaker to make and break an electrical connection. These switches are called flashers and can be used to operate turn signals or emergency lights. In this type of switch, the heater is included as part of the switch.

Other temperature-sensitive switches can be used to turn current flow on or off for operations such as cooling fans or electric defrosters. They sense the temperature of the engine or outside air and control the circuit by using a bimetal strip and contacts (Figure 5.5.8).

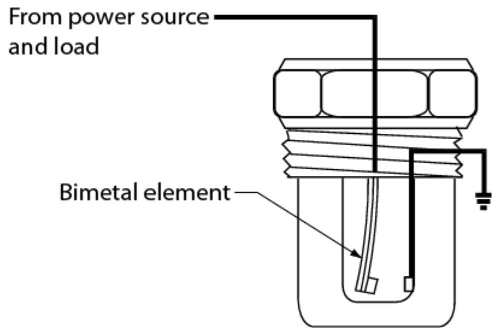


Figure 5.5.8: Temperature-sensitive switch (CC BY-NC-SA; BC Industry Training Authority)

Pressure-sensitive switches can sense the pressure in a pneumatic or hydraulic system and turn electrical devices on and off. These are used for electrical clutches in air conditioning, air pumps, and other similar systems.

Relays and Contactors

Relays and Contactors are electrically activated switches that allow a small current flow to control a large current flow. Every relay and contactor has a power circuit and a control circuit. An external switch energizes the control circuit. The control circuit consists of a soft iron core with a wire winding, called a coil or solenoid.

When current flows through the coil, an electromagnetic field is created that pulls an armature down to close contacts in the circuit. A typical application is a starter relay (Figure 5.5.9:) on a car or contactor that starts an AC compressor.

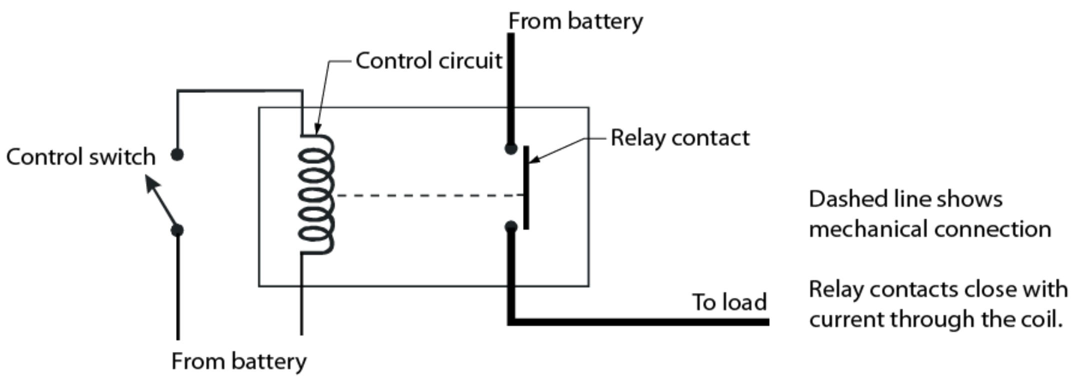


Figure 5.5.9: Relay (CC BY-NC-SA; BC Industry Training Authority)

Solenoids

A solenoid (Figure 5.5.10) is an electromagnet with a movable core that changes electrical energy into mechanical force. Some solenoids may activate contacts and act as a relay, such as in a starter solenoid, or they can be connected to valves to shut of the flow of fluids.

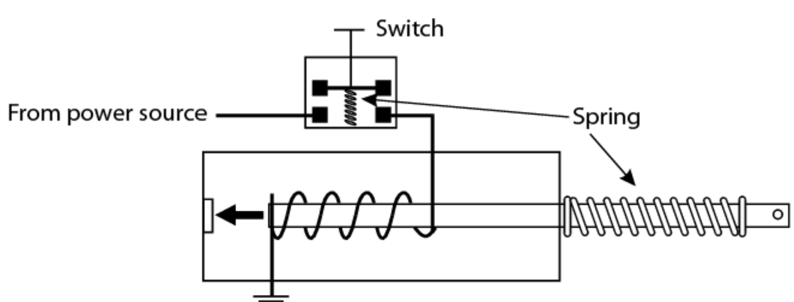


Figure 5.5.10: Solenoid (CC BY-NC-SA; BC Industry Training Authority)

5.6: Lamps

Lamps turn electrical energy into light. There are many different types and styles of lamps. Some are used in small applications, while others are used in residential or industrial sites. Light symbols vary with application and manufacturer. Typical residential incandescent and fluorescent lights are shown in Figure 5.6.1. The incandescent lamp is available in different watt ratings. The fluorescent lamp is available in different lengths, wattages, and types of illumination. It is easily recognizable by its long tube shape.

Figure 5.6.1: Lamps (CC BY-NC-SA; BC Industry Training Authority)

Light-duty incandescent lamps

Light-duty incandescent lamps most commonly have bases that are either the screw-type or the bayonet type Figure 5.6.2.

Figure 5.6.2: Incandescent lamps (CC BY-NC-SA; BC Industry Training Authority)

The amount of illumination from the neon lamp (Figure 5.6.3) is small. The neon lamp uses minimal current but needs higher voltage.

Figure 5.6.3: Decorative neon lamp (CC BY-NC-SA; BC Industry Training Authority)

Lamp holders

Lamp holders (Figure 5.6.4) are used to hold lamps and provide a means of connecting the lamp to the electrical circuit. Incandescent lamps use a screw-type attachment. This may be housed in a plastic or porcelain body. Some lamp holders have built-in switches. Fluorescent lamp holders are available in different styles and sizes.

Figure 5.6.4: Lamp holders (CC BY-NC-SA; BC Industry Training Authority)

5.7: Transformers

The transformer shown in Figure 5.7.1 is used to increase or decrease the voltage in an electric circuit. Transformers are rated in volts and amps for specific applications. A typical application is a doorbell circuit or control circuit on AC equipment, transforming 120 volts AC to 24 volts AC.

Figure 5.7.1: Transformer (CC BY-NC-SA; BC Industry Training Authority)

5.8: Solid state components

Solid-state components are made of semiconductor material. These are joined at a junction and can provide different types of control without mechanical movement, depending on how they are connected in a circuit.

5.9: Capacitors

Capacitors (Figure 5.9.1) are devices used to absorb and store electric current to prevent damage to components. These components are made of two-conductor plates with a non-conducting material between them. Capacitors will store energy if the circuit is broken and will remain charged until the circuit is restored.

Figure 5.9.1: (CC BY-NC-SA; BC Industry Training Authority)

Capacitors are useful for absorbing stray currents and preventing arcing across opening contacts. Variable capacitors are called trimmers or tuners and are used only in very sensitive circuits with low current flow.

Capacitors are also used to shift the phasing inside electric motors. Depending upon their application, this can give electric motors greater starting torque (Figure 5.9.2), increased efficiency, or both.

Figure 5.9.2: Start Capacitor (Elcap, CC0, via Wikimedia Commons)

5.10: Light-emitting diodes (LEDs)

Light-emitting diodes (LEDs) produce light from electricity using semiconductor materials. They operate from a low DC voltage and produce little heat because there is no incandescent filament. They are available in a range of colours, with red, green, and yellow being the most common.

Figure 5.10.1: Individual LED (CC BY-NC-SA; BC Industry Training Authority)

The seven-segment number display (Figure 5.10.2) uses one LED for each section to create different numbers from 0 to 9.

Figure 5.10.2: Seven-segment display (CC BY-NC-SA; BC Industry Training Authority)

5.11: Sealed Components

These components must not be opened. They can be found in applications such as engine controls, charging systems, electronic dash displays, and message modules. They are normally constructed in such a manner as to make entry difficult, if not impossible.

5.12: Cells and Batteries

Cells and batteries convert chemical energy to electrical energy. They are used to provide power to portable electronic equipment. They may also be used for backup power in the event of a power failure.

The single cells shown in Figure 24 can produce 1 to 4 volts, depending on their compositions. For example, cells may be carbon-zinc, alkaline-manganese, nickel-cadmium, silver oxide, or lithium types.

Figure 5.12.1: Cells (CC BY-NC-SA; BC Industry Training Authority)

Note the polarity of the symbol for a cell shown in Figure Figure 5.12.2.

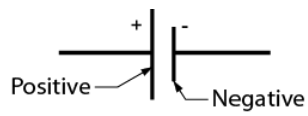


Figure 5.12.2: Symbol for a cell (CC BY-NC-SA; BC Industry Training Authority)

Cells may be connected in series within a case to make up a battery. Both the 12-volt automotive battery and the 9-volt clip-in battery (Figure 5.12.3) have multiple cells inside the case. The symbol for a battery is composed of the number of symbols for cells corresponding to the number of cells in the battery (Figure 5.12.4).

Figure 5.12.3: Batteries (CC BY-NC-SA; BC Industry Training Authority)

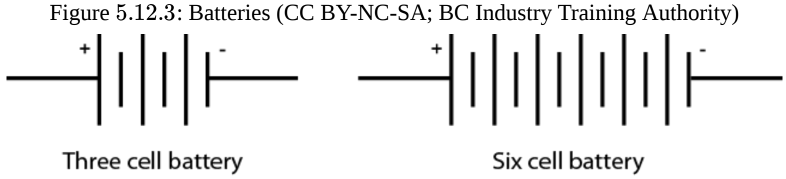


Figure 5.12.4: Symbols for batteries (CC BY-NC-SA; BC Industry Training Authority)

Now complete the Learning Task Self-Test.

5.E: Self Test 1

Self-Test 1

1. Match the device on the left with its purpose on the right.
    1. Circuit breaker 1. Protects circuits
    2. Relay 2. Electric switch
    3. Solenoid 3. Variable control
    4. Rheostat 4. Movable core
2. What best describes tapped or stepped resistors?
    1. They have two or more fixed values.
    2. They have only one unchangeable rating.
    3. They have a variable range of resistance.
    4. They are used to control charging systems.
3. How is a fuse different from a circuit breaker?
    1. A fuse acts like a diode.
    2. A circuit breaker doesn’t need a ground.
    3. A fuse can be reset and a circuit breaker cannot.
    4. A circuit breaker can be reset and a fuse cannot.
4. 6 gauge wire is smaller than 18 gauge.
    1. True
    2. False
5. What are conductors normally made from?
    1. Steel
    2. Copper
    3. Soft iron
    4. Aluminum
6. Receptacles are one-half of a two-piece multi-contact connector.
    1. True
    2. False
7. What are circuit breakers, fuses, and thermal limiters all examples of?
    1. Relays
    2. Switches
    3. Receptacles
    4. Protection devices
8. How many gauges of difference must there be between a fusible link and a conductor?
    1. 2
    2. 4
    3. 6
    4. 8
9. Relays require a power circuit and a control circuit.
    1. True
    2. False
10. What are transformers used for?
    1. To act like a relay
    2. To increase amperage
    3. To increase or decrease voltage
    4. To change the current from DC to AC
11. Who is responsible for testing all electrical components?

1. ITA
2. NSA
3. CSA
4. DNA

12. Closed means the circuit is complete and conducting.
    1. True
    2. False
13. What voltage other than 120 V does a residential system use?
    1. 180 V
    2. 200 V
    3. 240 V
    4. 280 V

CHAPTER OVERVIEW

6: Wiring Diagrams

The ability to read and understand a wiring diagram is important for any tradesperson. You may need to repair a power tool, install a heat pump, or try to find a fuse in a car. Any of these situations requires an ability to read and understand a wiring diagram.

6.1: Symbols Used in Schematic Diagrams

Electrical symbols may be different for each manufacturer, but in most cases they are standard. Every manufacturer's diagram should have a symbol identification chart or "key" located in the wiring book. Some examples of electrical symbols are shown in Figure \(\PageIndex{1}\).

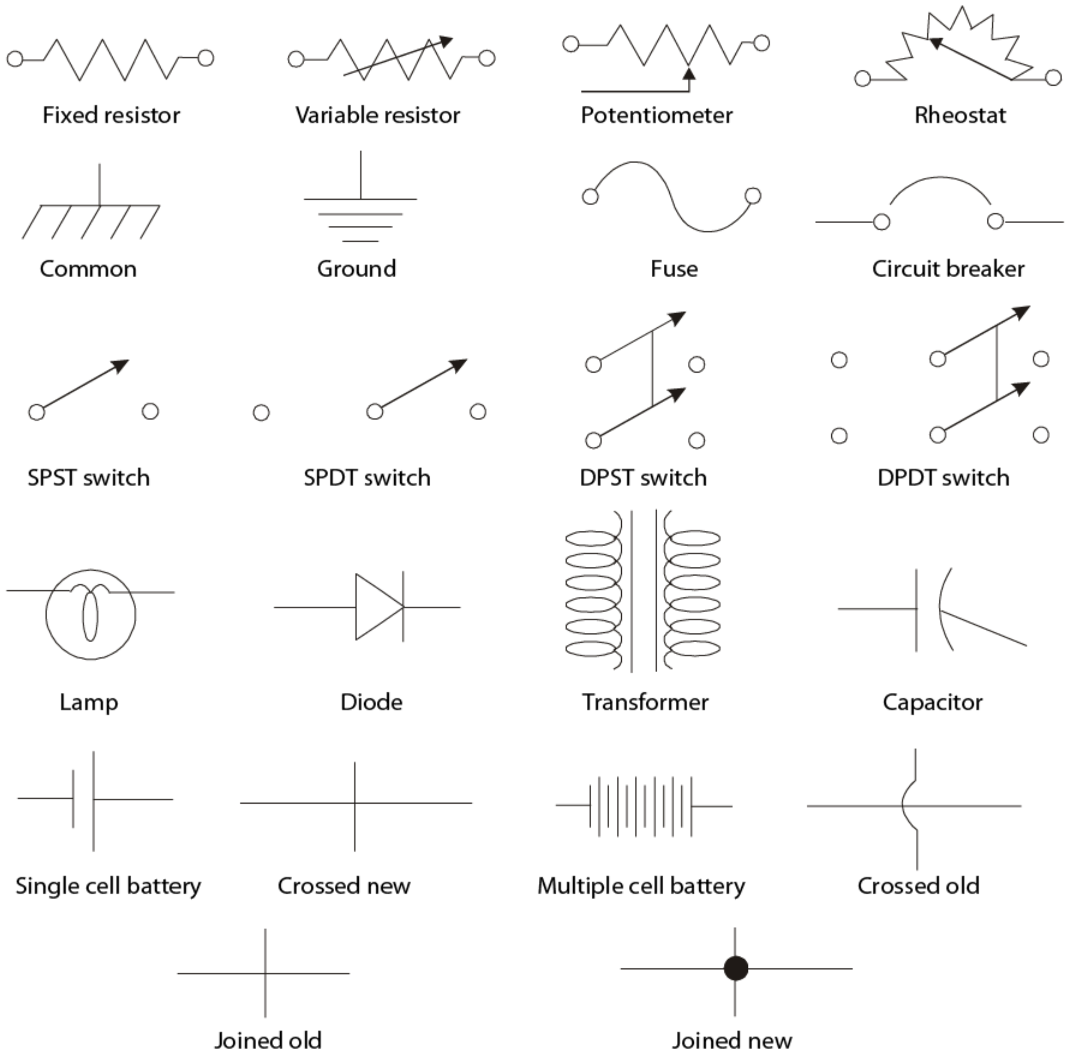


Figure 6.1.1: Common electrical symbols (CC BY-NC-SA; BC Industry Training Authority)

6.2: Types of Electrical Diagrams

There are four basic types of electrical diagrams:

- schematic
- wiring
- block
- pictorial

Schematic Diagrams

The schematic diagram (Figure 6.2.1), often called a ladder diagram, is intended to be the simplest form of an electrical circuit. This diagram shows the circuit components on horizontal lines without regard to their physical location. It is used for troubleshooting because it is easy to understand the operation of the circuit. The loads are located on the far right of the diagram, and the controls for each load are located to the left. To understand the sequence of operation, the drawing is read from the upper left corner and then from left to right, and from top to bottom.

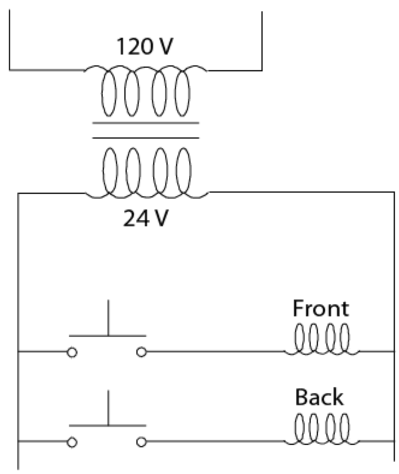


Figure 6.2.1: Schematic of a doorbell system (CC BY-NC-SA; BC Industry Training Authority)

Wiring diagrams

The wiring diagram (Figure 6.2.2) shows the relative layout of the circuit components using the appropriate symbols and the wire connections. Although a wiring diagram is the easiest to use for wiring an installation, it is sometimes difficult to understand circuit operation and is not as applicable for troubleshooting.

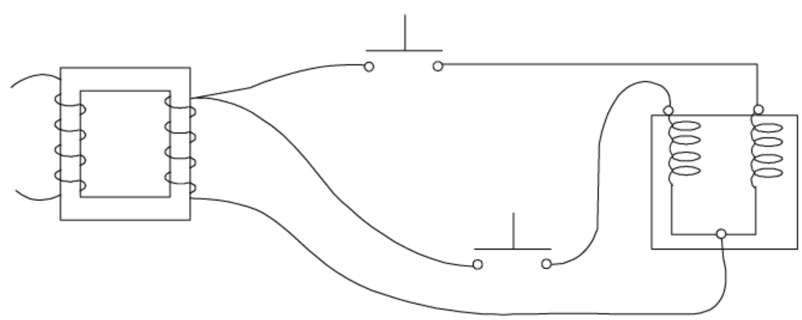


Figure 6.2.2: Wiring diagram (CC BY-NC-SA; BC Industry Training Authority)

Block diagrams

The block diagram (Figure 6.2.3), also called a *functional block diagram*, is used to describe the sequence of circuit operations. This diagram indicates by functional descriptions, showing which components must operate first in order to get a final outcome. They do not refer to specifics like device symbols or related wire connections.

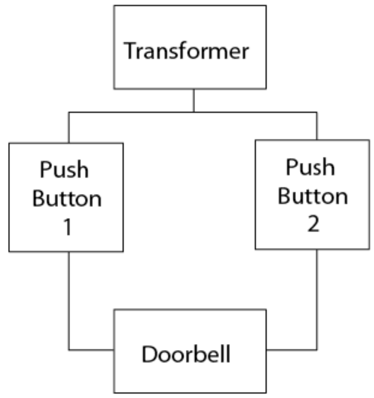


Figure 6.2.3: Block diagram (CC BY-NC-SA; BC Industry Training Authority)

Pictorial diagrams

A pictorial diagram (Figure 6.2.4) shows the circuit components in more detail, as they really look, and indicates how the wiring is attached. These diagrams can be used to locate components in a complex system.

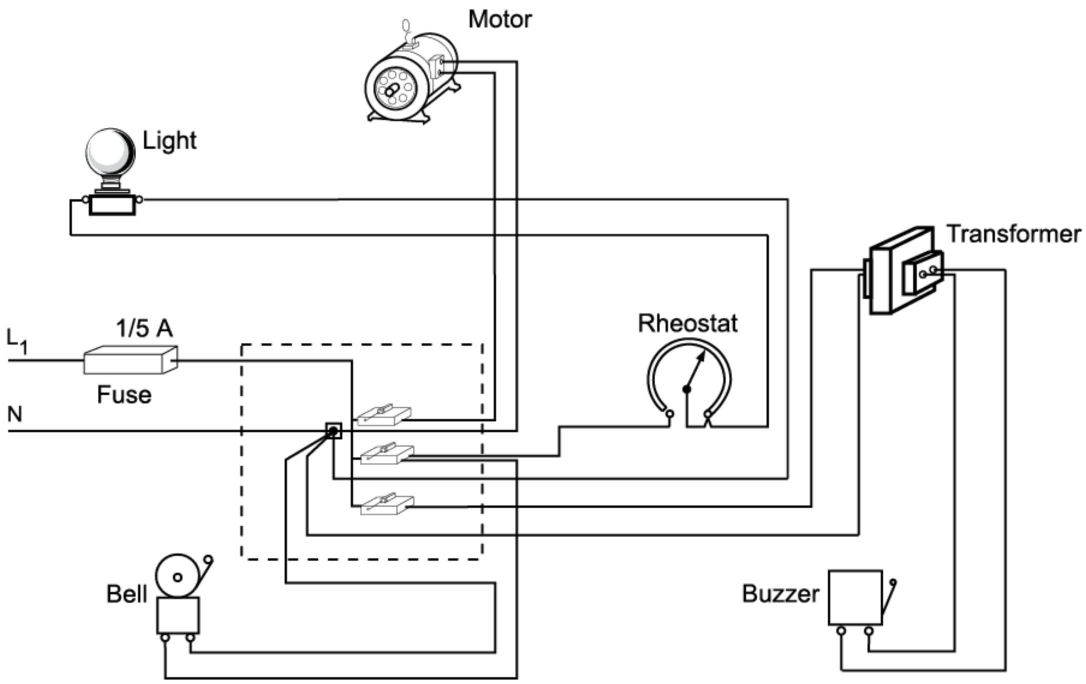


Figure 6.2.4: Pictorial diagram (CC BY-NC-SA; BC Industry Training Authority)

Now complete the Learning Task Self-Test.

6.E: Self Test 2

Self-Test 2

1. A schematic diagram is often called a ladder diagram.
   1. True
   2. False
2. What is the fourth type of wiring diagram, in addition to schematic, wiring, and block diagrams?
   1. Line
   2. Oblique
   3. Pictorial
   4. Isometric
3. A schematic diagram shows all physical locations of components.
   1. True
   2. False
4. For which operations is a wiring diagram best suited?
   1. Diagnosing
   2. Sequencing
   3. Installation
   4. Troubleshooting
5. A pictorial diagram is used to locate components in complex systems.
   1. True
   2. False
6. A block diagram includes symbols.
   1. True
   2. False

CHAPTER OVERVIEW

7: Common Circuit Characteristics

Electrical components can be connected in different configurations to form circuits for different power outputs and applications.

7.1: Series Circuits

A series circuit is constructed by connecting all of the circuit components in line with one another. The schematic diagram in Figure 7.1.1 is an example of a simple series circuit. In this case, a battery (source) is connected through a switch to three resistors (load devices), all of which are in line with one another.

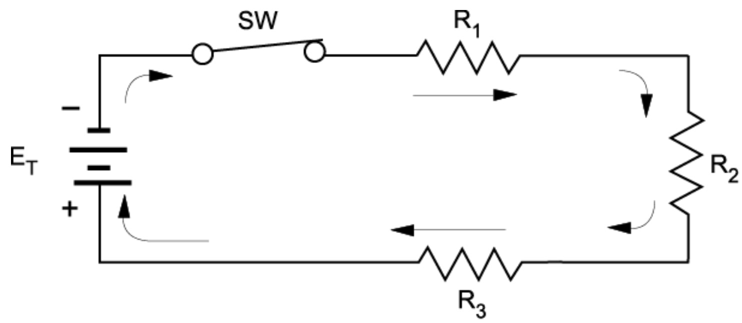


Figure 7.1.1: A simple series circuit (CC BY-NC-SA; BC Industry Training Authority)

When the switch is closed, there is only one path for current flow. Any circuit that provides only one path for current flow is categorized as a series circuit.

If any part of a series circuit is opened, the current cannot flow and none of the components will operate. The circuit may be opened by the switch or by the failure of a component in the circuit. For example, some decorative lights have clusters within the string that are connected as a series circuit. If one lamp burns out (or opens), all the other lamps go out. You then have to test each lamp individually to find the failed bulb, and this gets very challenging if two bulbs happen to be damaged.

Application of series circuits

Electrical components or devices are generally connected in series whenever it is necessary to:

- control the amount of current flow in a circuit
- divide the total voltage of a supply

For example:

- Switches are connected in series with loads so that you can energize or de-energize different loads.
- Protective devices such as fuses and overload relays are connected in series with line conductors.
- By connecting equal values of resistance in series, the same voltage drop can be obtained across each resistance. Twenty Christmas tree lights connected in series to a 120 V supply would have a voltage rating of 6 V per light.

Disadvantages of series circuits

When designing a series circuit, consider these points:

- An open in any one device will also interrupt current flow to all remaining devices.
- A short in one device will cause an increase in current through all the devices.
- Changing the resistance value of one device will change the current, voltage, and power values of all remaining devices.

7.2: Parallel Circuits

The parallel circuit is probably the most common type of circuit you will encounter. Loads in power distribution systems are usually connected in parallel with each other in one way or another. A parallel circuit is constructed by connecting the terminals of all the individual load devices so that the same value of voltage appears across each component. In Figure $7.2.1$, you can see that each of the three resistors receives the same voltage from the source.

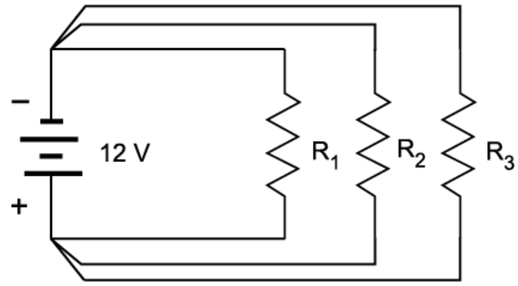


Figure $7.2.1$: A parallel circuit (CC BY-NC-SA; BC Industry Training Authority)

Figure $7.2.2$ shows the more traditional schematic of the same circuit. Notice that:

- The total supply voltage appears across each of the three resistors.
- There are three separate paths (or branches) for current flow, each leaving the negative terminal of the supply and returning to the positive terminal.

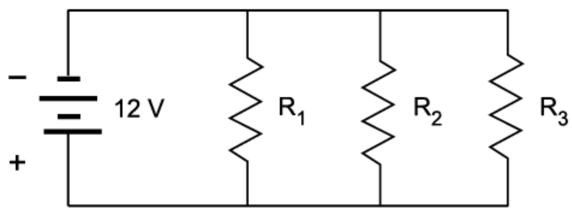


Figure $7.2.2$: Schematic of a parallel circuit (CC BY-NC-SA; BC Industry Training Authority)

The two fundamental characteristics of any parallel circuit are that:

- The voltage across each branch is the same.
- There is more than one path for the current to flow through.

In contrast to a series circuit, current still flows to the remaining devices in the circuit if any one branch or component in a parallel circuit is opened.

7.3: Voltage Source Circuits

Multiple power sources can be connected in series or parallel in order to meet the different voltage or current output requirements for various applications:

- Power sources are connected in series to increase the voltage output.
- Power sources are connected in parallel to increase the current capacity

Series Sources

Voltage sources are sometimes connected in series to produce a higher voltage value. This is common in devices such as flashlights and portable transistor radios, in which 1.5 V battery cells are used.

To obtain a higher voltage output from series-connected sources, you must observe correct polarity. In Figure $7.3.1$, a net voltage of 6 V is obtained if the individual 1.5 V cells are acting in the same direction. This is called series aiding.

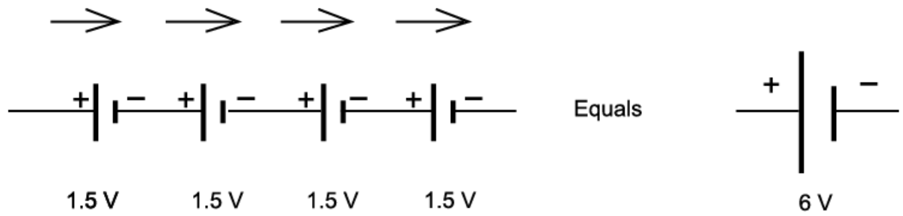


Figure $7.3.1$: Battery cells connected in series aiding (CC BY-NC-SA; BC Industry Training Authority)

For the voltages to accumulate, the negative terminal of one source connects in series with the positive terminal of the next source, and so on.

When voltage sources are connected in series opposing, the net voltage value is derived by subtraction. This is illustrated in Figure $7.3.2$.

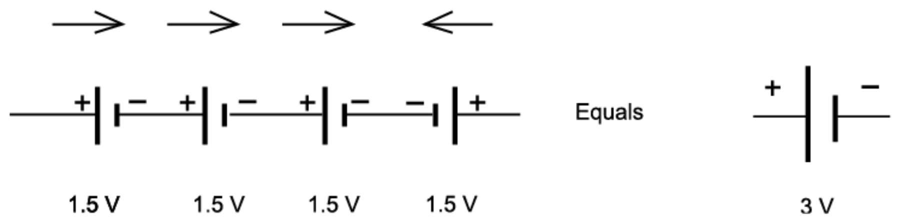


Figure $7.3.2$: Battery cells connected in series opposing (CC BY-NC-SA; BC Industry Training Authority)

- Three of the cells are connected series aiding to produce 4.5 V.
- One cell is connected with opposite polarity of 1.5 V.
- The net voltage is 4.5 V – 1.5 V = 3 V.
- Overall polarity acts in the direction of the largest cell.

Parallel sources

Voltage sources are connected in parallel whenever it is necessary to deliver a current output greater than the current output that a single source of supply can provide, without increasing voltage across a load.

An advantage of parallel-connected power sources is that one source can be removed for maintenance or repairs while reduced power to the load is maintained. This is common in RVs that have dual batteries. For parallel batteries, current capacity is equal to that of one battery multiplied by the number of parallel batteries. If a 6 V battery has a maximum current output of 1 amp, and if it is necessary to supply a load requiring 2 amps, then you can connect a second 6 V battery in parallel with the first, as shown in Figure $7.3.3$.

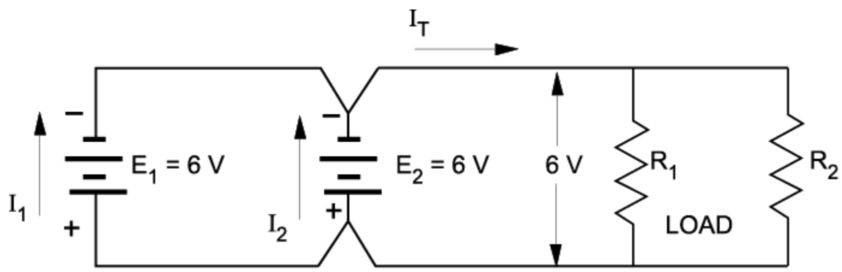


Figure 7.3.3: Two batteries in parallel (CC BY-NC-SA; BC Industry Training Authority)

Whenever batteries or other power sources such as transformers or generators are to be connected in parallel, it is very important that the power sources have the following:

- The same terminal voltages

  A lower voltage source connected to a higher one acts as a load itself, rather than helping share the real load current with the other sources of supply.

- Properly connected polarity.

  Like terminals of the power sources must be connected together; that is, positive-to-positive and negative-to-negative.

7.4: Three-wire Power Supply System

Electrical energy to most individual and small commercial buildings in North America is distributed through a 120 V/240 V AC, single-phase, three-wire system.

Several advantages are gained by using this method of distribution:

- Copper conductor current requirements can be reduced.
- Two different voltages (120 V and 240 V) are available.
- Improved safety is established through grounding the neutral.

Source connections

A three-wire circuit is accomplished by connecting two 120 V sources in a series-aiding configuration. The conductor taken from the common point between the two sources is called the neutral conductor. Conductors taken from the two outer points are called the line or hot conductors.

As shown in Figure 7.4.1:

- Voltage measured line-to-line is 240 V.
- Voltage measured from either line to neutral is 120 V.

This allows connection to either 120 V loads (such as lighting) or 240 V loads (such as ranges or clothes dryers). See Figure 7.4.2.

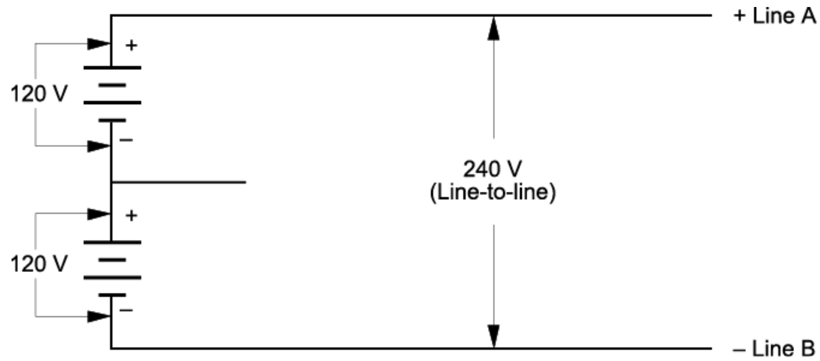


Figure 7.4.1: Three-wire circuit (CC BY-NC-SA; BC Industry Training Authority)

Note that polarities shown in Figure 7.4.1 change every 120th of a second for a 60 hertz AC power supply.

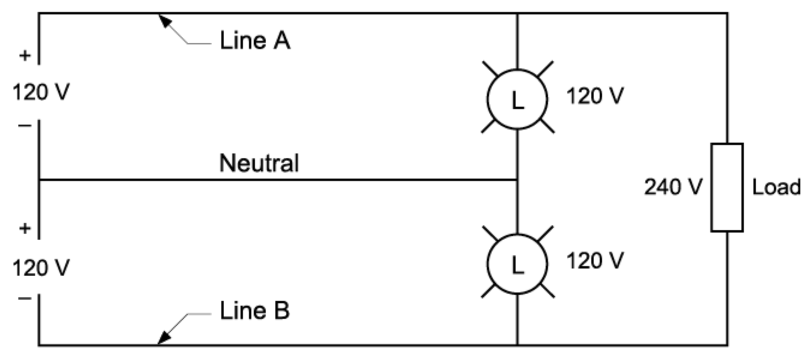


Figure 7.4.2: Three-wire distribution (CC BY-NC-SA; BC Industry Training Authority)

For safety reasons, it is important that circuit conductors are identified by colour:

- Insulation on the two-line conductors is usually black (or sometimes one is black and one is red).
- The neutral always has white insulation.

The neutral is also grounded (directly connected to earth) at the source of supply.

Grounding the neutral conductor

Earth is a conductor of electricity. Therefore, to reduce the hazards of electrical shock and improve safety, electrical distribution systems usually have one of the circuit conductors connected to Earth, or as we say, grounded.

In most electrical systems, the neutral conductor is grounded at the supply by directly connecting it to Earth by another conductor (called the system grounding conductor) or by an electrode. Although grounding electrical distribution systems is an elaborate topic, consider the following simplified example.

Example

The fundamental purpose of grounding is to guard against electrical shocks and fire hazards. But what makes a grounded electrical system safer? Consider an ungrounded 120 V/240 V wiring system with a fault, as shown in Figure 7.4.3. Theoretically, if an insulation fault occurs at a piece of equipment (so that a line conductor makes accidental contact with the metal frame), nothing should happen. However, if an accidental ground should occur and a person comes in contact with the faulty equipment and ground, that person will experience a shock of 240 V (the line-to-line voltage).

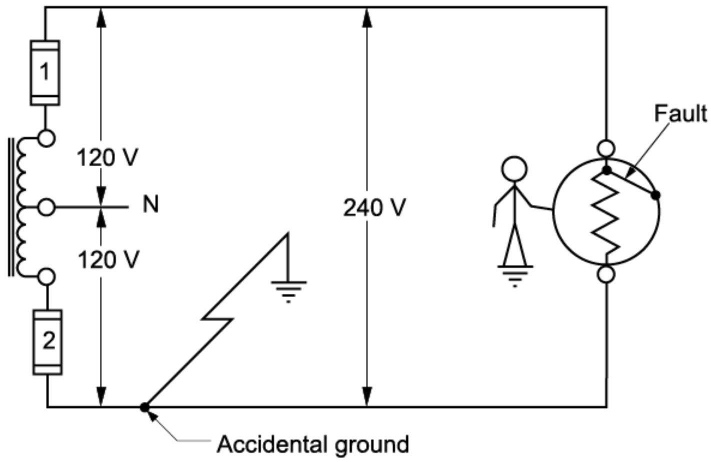


Figure 7.4.3: Accidental fault in an ungrounded wiring system (CC BY-NC-SA; BC Industry Training Authority)

Now look at the same wiring system with the neutral purposely grounded, as shown in Figure 7.4.4.

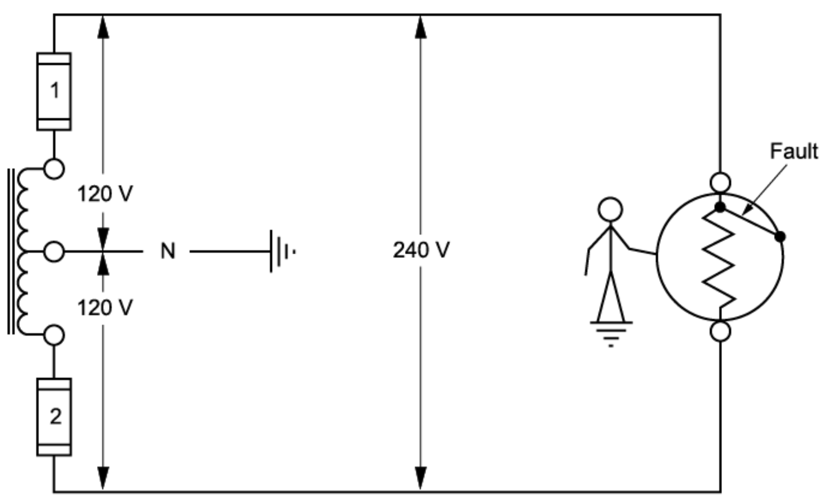


Figure 7.4.4: Accidental fault in a grounded neutral writing system (CC BY-NC-SA; BC Industry Training Authority)

With the neutral grounded and the same equipment fault as previously described, the person coming in contact with both the metal frame of the equipment and the Earth would experience a shock of only 120 V (which is the line-to-neutral voltage). The shock voltage has been reduced by 50%.

To further minimize shock hazard, not only is the wiring system grounded but also all metallic, non-current-carrying parts of the equipment are grounded by using a bonding conductor. This is an important step if maximum safety is to be achieved.

As shown in Figure 7.4.5, if the equipment is also grounded intentionally, then a line-to-frame fault condition offers a low-resistance path for current flow back to the system neutral. Essentially this is a line-to-neutral short circuit, which causes the circuit overcurrent device to trip, thus eliminating the shock hazard from the system.

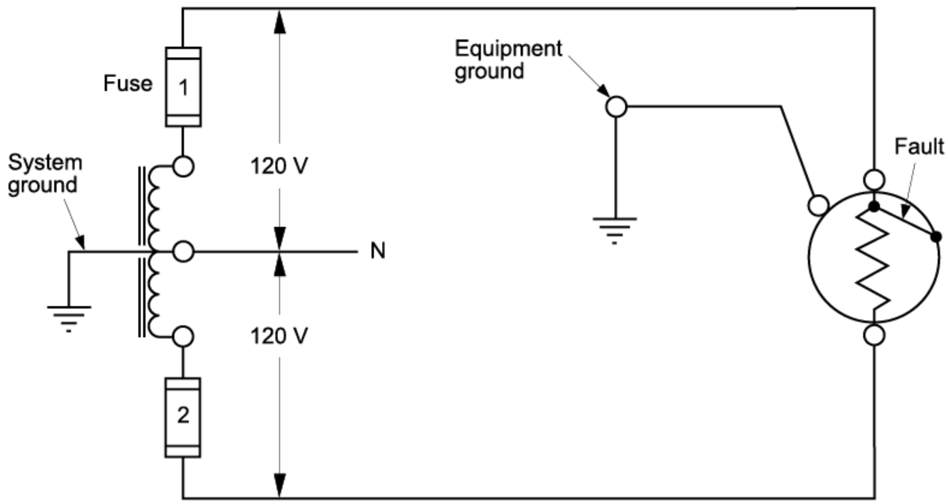


Figure 7.4.5: A properly grounded wiring system (CC BY-NC-SA; BC Industry Training Authority)

Although properly grounded wiring systems do not eliminate shock hazard, they certainly lower the odds of being shocked!

Now complete the Learning Task Self-Test.

7.E: Self-Test 3

Self-Test 3

1. Typical house wiring is an example of a series circuit.
    1. True
    2. False
2. If one load fails in a series circuit, what happens to the other loads?
    1. They will all fail.
    2. A fuse will blow.
    3. Nothing happens.
    4. The rest remain working.
3. As more resistors are added in series, what increases?
    1. Power
    2. Voltage
    3. Current
    4. Resistance
4. A series circuit allows the control of current flow.
    1. True
    2. False
5. Which of the following is true about a parallel circuit?
    1. Voltage will be different at each load.
    2. Voltage will be the same at each load.
    3. Current will be the same at each load.
    4. Resistance will be the same at each load.
6. The three-wire circuit is an example of which of the following?
    1. Hot jumping
    2. Series aiding
    3. Parallel aiding
    4. Backpacking circuit
7. For what purpose is a circuit grounded?
    1. Safety
    2. Series aiding
    3. Circuit protection
    4. Easier installation
8. What is the result of connecting three 6 V batteries in series?
    1. 12 volts are produced.
    2. 18 volts are produced.
    3. 24 volts are produced.
    4. The voltage doesn’t change.
9. Which of the following must apply to power sources connected in parallel?
    1. Unlike terminals must be connected.
    2. They must be connected with a fuse.
    3. Like terminals must be connected.
    4. They must have a transformer between them.
10. For voltages to accumulate in series aiding, what must occur?
    1. Correct polarity
    2. Circuit protection
    3. Similar amperages

4. Dissimilar amperage

11. If two 12 V batteries are connected in parallel, what will the voltage be across any load?
    1. 6 V
    2. 12 V
    3. 24 V
    4. 48 V

8: Answer Key

Answer Key

Self-Test 1

1. Match the device on the left with its purpose on the right.
    1. Circuit breaker (1. Protects circuits)
    2. Rheostat (3. Variable control)
    3. Relay (2. Electric switch)
    4. Solenoid (4. Movable core)
2. a. They have two or more fixed values.
3. d. A circuit breaker can be reset and a fuse cannot.
4. b. False
5. b. Copper
6. a. True
7. d. Protection devices
8. b. 4
9. a. True
10. c. To increase or decrease voltage
11. c. CSA
12. a. True
13. c. 240 V

Self-Test 2

1. a. True
2. c. Pictorial
3. b. False
4. c. Installations
5. a. True
6. b. False

Self-Test 3

1. b. False
2. a. They will all fail.
3. d. Resistance
4. a. True
5. b. Voltage will be the same at each load.
6. b. Series aiding
7. a. Safety
8. b. 18 volts are produced.
9. c. Like terminals must be connected.
10. a. Correct polarity
11. b. 12 V

SECTION OVERVIEW

3: Unit III- Wiring Connections

Learning Objectives

When you have completed the Learning Tasks in this Competency, you will be able to:

- define the terms used and explain the principles of soldering
- describe the methods for making properly soldered connections
- maintain soldering equipment
- use wireless connectors

It is important for you to be familiar with techniques for soldering electrical connections and how to use wireless connectors. For example, the ends of the finely stranded wires used for power supply cords on most portable power tools are soldered to permit a long-lasting, troublefree connection. Solder also produces secure, durable electrical connections for switches, plugs, and tools. Wireless connectors are commonly used in many electrical applications because they are quick and easy to use.

CHAPTER OVERVIEW

9: Wiring Connections

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Making tight electrical connections is critical to a safe wiring job. If wires come loose, you could get arcing and overheating, which could lead to a fire. The right connector is determined by a number of variables.

9.1: Conductors

A material that allows energy to flow with relative ease is known as a conductor. The most common form of electrical conductor used is the wire. Most electrical wires are made from copper or aluminum and are in one of two forms: solid or stranded.

The term electrical cable usually refers to multiple insulated wires grouped in a common sheathing (Figure 9.1.1).

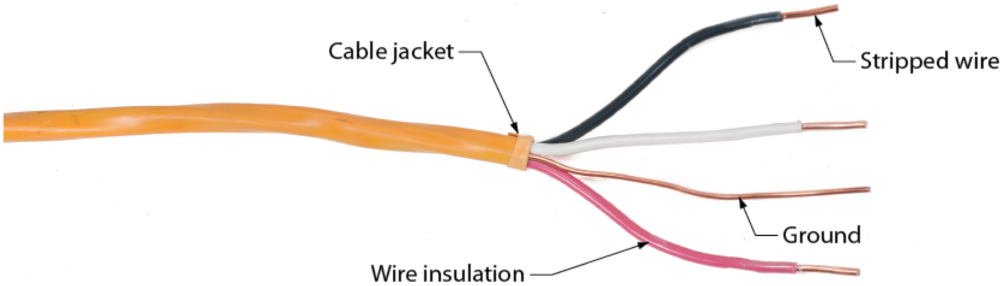

Figure 9.1.1: Electrical cable components (CC BY-NC-SA; BC Industry Training Authority)

Stranded conductors

Stranded wire is a collection of solid wires twisted or braided together, commonly around a central core (Figure 9.1.2).

Figure 9.1.2: Stranded flexible conductor (CC BY-NC-SA; BC Industry Training Authority)

The current carrying capacity of a stranded wire is close to the current carrying ability of a single strand. Stranded wires act as a single conductor and carry a single electrical current. Stranded conductors are normally used in a thin wire that requires flexibility, such as speaker wire. Ordinarily, a stranded conductor has wires all the same size. The size of the strands used depends on the flexibility required. For example, #00 gauge cable may be made up of seven strands of #7 gauge wire, or 19 strands of #12 gauge, or 37 strands of #24 gauge, the last one being rated “extra flexible.”

Solid conductors

Solid wire consists of one strand of copper metal wire, bare or surrounded by an insulator. Solid wire is normally found in smaller sizes only. Solid wire is cheaper to manufacture than stranded wire and is used where there is little need for flexibility in the wire.

Insulating materials

The purpose of conductor insulation is to prevent unwanted flow of electrical current, such as ground faults, short circuits, or electric shock. There are various methods used to insulate conductors to satisfy the many conditions encountered in electrical installations, such as temperature, moisture, and different voltage
ratings. Insulating materials include:

- enamel coating
- rubber
- thermoplastics
- minerals

Stripping insulation

To make any type of electrical connection, you will need to expose the base wire from the insulated covering. You can do this with wire strippers (Figure 9.1.3).

Figure 9.1.3: Wire strippers (CC BY-NC-SA; BC Industry Training Authority)

With wire strippers, you can strip the amount of wire required for the type of connection being made. It is important to avoid damaging the copper wire by nicking the copper or cutting into it. Nicked wires can lead to overheating and eventually could cause an electrical fire.

Colour coding

Most electrical wiring circuits look complicated because several wires are found at any one point in the circuit. To make it easier to know exactly which is which, wires are identified by colour or labeled.

For building construction, the Canadian Electrical Code reserves two colours for specific applications:

When this system of colour coding is followed, at any point in any circuit, a white wire always indicates a neutral conductor. A green wire always indicates an equipment grounding conductor. Any other colour wires, such as red, black, or blue, can be assumed to be live or hot, meaning that they will have a voltage on the conductor and are therefore dangerous.

Wire size

Wires are manufactured in sizes according to the American Wire Gauge (AWG) system. The cross-sectional area of each gauge is an important factor for determining the current carrying capacity of a wire (ampacity). Increasing gauge numbers denote decreasing wire diameters, ranging from the largest 0000 (4/0) to the smallest, 44.

- White or natural grey covering is reserved for insulated, identified conductors, identified common conductors, and identified neutral conductors.
- Green covering is reserved for the equipment grounding conductor.

9.2: Soldered Connections

A variety of joints are used to prepare wires for soldering. These include:

- Western Union splice
- tap joint
- twist joint

Western Union splice

This splice joins the ends of two wires inline (compared to the twist joint below). Strip the wires for a length of 2.5 to 8 cm (1" to 3"), as shown in Figure 9.2.1. Clean the wire, then twist the ends of the wire tightly together as shown.

Figure 9.2.1: Western Union splice (CC BY-NC-SA; BC Industry Training Authority)

Tap joint

The tap joint (Figure 9.2.2) connects a stranded wire to an intermediate point along the length of a second wire. Wrap the wire at least six times.

Figure 9.2.2: Tap joint (CC BY-NC-SA; BC Industry Training Authority)

Twist joint

The twist joint (Figure 9.2.3) is used to join parallel wires, whereas the Western Union splice is used to connect wires that are in line. Strip the insulation, clean the wires, and twist them together tightly for a length of 2.5 cm (1 in.).

Figure 9.2.3: Twist joint (CC BY-NC-SA; BC Industry Training Authority)

Tinning stranded wire

In a general sense, tinning is the process of applying a thin layer of solder to something and will be discussed in more detail in Learning Task 2. In the case of stranded wire, you should tin the stripped ends of the wire to prevent the strands from separating while bending or connecting. Use only enough solder to make the stripped portion of the wire solid. The strands of the wire should be visible through the solder. Avoid solder from wicking in a wire underneath
the insulation because it will make the wire solid and cause it to break more easily.

Figure 9.2.4: Tinning stranded wire before bending it (CC BY-NC-SA; BC Industry Training Authority)

9.3: Solderless connectors

Soldering is the recommended way to splice, tap, or join wires to make a rigid, permanent, weather-resistant connection. The process of soldering can be time-consuming, awkward, restrictive, and expensive.

In many applications, soldering has been replaced by special connecting devices that simplify wire joining procedures. Solderless connectors are used on both wire and cable connections. Types of solderless connectors include:

- looped-end
- twist-on
- set-screw
- crimp-on

Looped-end connectors

The most common solderless connection has the looped end of a wire (Figure 9.3.1) held in place by a set-screw at an electrical terminal (Figure 9). Note that the direction of the loop is the same as the direction the screw is turned when it is tightened (clockwise). The screw and washer should be made of corrosion-resistant materials such as copper or brass.

Figure 9.3.1: Good loop (also known as a hook) (CC BY-NC-SA; BC Industry Training Authority)

Figure 9.3.2: Proper installation under terminal screw (CC BY-NC-SA; BC Industry Training Authority)

Twist-on connectors

The twist-on connector is a one-piece connecting device designed to splice aluminum or copper wires. Twist-on connectors are also known as wire nuts, wire connectors, cone connectors, thimble connectors, or Marrettes. Inside the blunt, bullet-like cover of the twist-on connector is a cone-shaped spring insert that threads itself onto conductors when the connector is twisted. When the connector is twisted onto the stripped ends of wires, the wires are drawn, twisted, and squeezed into the connector's metal insert. Electrical continuity is maintained both by the direct twisted wire-to-wire contact and by contact with the metal insert.

Figure 9.3.3: Exposed wires twisted together (CC BY-NC-SA; BC Industry Training Authority)

Figure 9.3.4: Completed connection (CC BY-NC-SA; BC Industry Training Authority)

Wing-like extensions (Figure 9.3.5) are molded into some makes of connectors to reduce operator muscle fatigue when installing a large number of the connectors.

Figure 9.3.5: Winged connector (CC BY-NC-SA; BC Industry Training Authority)

The shell of the twist-on connector provides sufficient insulation to allow these connectors to be used in circuits carrying up to 600 V.

Twist-on wire connectors are commonly colour-coded to indicate the connector size and, hence, their capacity (Figure 9.3.6). They are commonly used as an alternative to soldering conductors since they are quicker to install and allow easy removal for future modifications, unlike soldered connections.

Figure 9.3.6: Twist-on connectors end view showing metal inserts (CC BY-NC-SA; BC Industry Training Authority)

Twist-on connectors are not often used on wire gauges thicker than AWG #10 (5.26 mm²) because such solid wires are too stiff to be reliably connected with this method. Instead, set screw connectors, clamps, or crimp connectors are used.

Set-screw connectors

Set-screw connectors (Figure 13) consist of two parts:

- a brass connector body into which wires are inserted
- an insulated cone-shaped cap that is screwed onto the brass connector

Figure 9.3.7: Set-screw connector (CC BY-NC-SA; BC Industry Training Authority)

The set-screw connector is most often used as a splice inside a protected electrical box and lighting fixtures. Although set-screws are more time-consuming to install and are more expensive than twist-ons, they may offer a more secure connection than twist-on connectors.

Crimp-on connectors

A crimp-on connector is used for a permanent tight splice. The crimp-on connector (compression connection) can have one or two parts.

The two-part connector (Figure 9.3.8) has a conductor retaining sleeve that is compressed by using special crimping pliers and an insulated screw cap into which the crimped retainer is inserted.

The sleeve is composed of copper or zinc-plated steel, while the cap is a high dielectric substance. The zinc-plated steel retaining sleeve should not be used with aluminum conductors, as electrolysis can occur between the metals.

Figure 9.3.8: Two-part crimp-on connector (CC BY-NC-SA; BC Industry Training Authority)

These devices are available in many sizes. As with other solderless connectors, each application must carefully select the correct size two-piece crimp-on connector.

The one-part crimp-on connector (Figure $9.3.9$) is commonly used as a terminal lug. Both the fork and the ring-type greatly simplify connecting stranded conductors to terminal screws. The crimp-on connector sometimes has a soft, hose-like tube that is molded to the connector. The connector and the insulation are crimped together. After crimping, the insulation returns to its original form.

Figure $9.3.9$: One-part crimp-on connectors (CC BY-NC-SA; BC Industry Training Authority)

Now complete the Learning Task Self-Test.

9.E: Self-Test 1

Self-Test 1

1. Which term best describes a material that allows electrical energy to pass through it?
    1. Resister
    2. Insulator
    3. Conductor
    4. Connector
2. Which of the following best describes the term electrical cable?
    1. Any wire
    2. Any insulated wire
    3. Multiple wires grouped together in a common insulation
    4. Multiple insulated wires grouped together in a common sheathing
3. What is the primary purpose of insulation on wires?
    1. To protect the wire
    2. To make installation easier
    3. To prevent unwanted current flow
    4. So the wire can be colour coded
4. When is stranded wire used?
    1. On short wires
    2. When cost is a factor
    3. On straight runs of wire
    4. When flexibility is needed
5. Wire is sized by gauge: the higher the number, the larger the wire.
    1. True
    2. False
6. What should be done to stranded wire prior to bending?
    1. It should be curled.
    2. It should be tinned.
    3. It should be wound.
    4. It should be twisted.
7. Solderless connections are more costly than soldering.
    1. True
    2. False
8. What is one advantage to a twist-on connector?
    1. It is permanent.
    2. One size fits all.
    3. It will not come apart.
    4. It can be removed easily.
9. It doesn't matter what material the conductor is made from when making a connection.
    1. True
    2. False
10. What type of connector should be used to create a permanent splice?
    1. Twist
    2. Winged
    3. Crimp-on
    4. Set screw

CHAPTER OVERVIEW

10: Soldering Techniques

Most components are fitted with leads, pins, lugs, or some other means of interconnecting them electrically. Most soldering involves bonding these leads to other leads, circuit wires, copper pads, or other circuit parts. The primary purpose of soldering an electrical connection is to ensure an efficient flow of current between the joined parts.

Soldering properly is an important skill. Correct operation of electric circuitry depends on correct soldering. Poor soldering will often lead to poor operation of the circuit.

Safety

Your safety must always be a concern while you are soldering. There is a risk of inhaling fumes from soldering operations that can irritate the nose, throat, and lungs. Studies show that prolonged exposure to certain fumes may result in occupational asthma and contribute to chronic lung disease. In addition, fumes that you breathe may contain invisible particles, such as lead and zinc, that could cause poisoning. Always complete soldering operations in well-ventilated spaces. You should also carefully wash your hands before eating, drinking, or smoking. You should wear safety glasses with side shields to protect yourself from splashing solder.

10.1: Solder Bonding

The soldering process depends on molten solder flowing into all the microscopic surface imperfections of the metals to be soldered and even penetrating very slightly below their surface. In this process, a chemical reaction occurs in which the solder actually melts some of the metals and alloys with them. Upon cooling, this combination of penetration and alloying results in a very strong bond between the solder and metal. When two pieces of metal are soldered together, a thin layer of solder adheres between them and completes the connection.

The process of surface penetration and alloying is known as wetting of the host metals (Figure 1). Some metals are very receptive to wetting and can readily be soldered, while others are non-receptive and cannot be soldered at all. Copper is very receptive to wetting by tin/lead solders. Tin also wets readily, as do silver and gold, but to a lesser extent. Solder wetting is displayed by a smooth, shiny flow of solder onto the metal surface. The process is often called tinning. Metals such as aluminum and iron will not wet properly. The solder forms stubborn flecks and balls and fails to penetrate or adhere. Effective solder bonding of these metals is not possible.

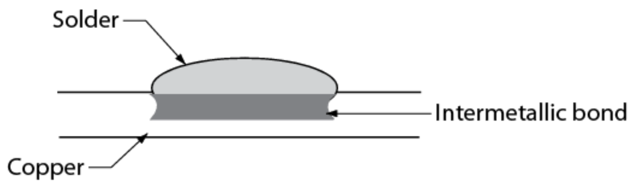

Figure 10.1.1: (CC BY-NC-SA; BC Industry Training Authority)

1. Wetting action

   Solder flux

   Solder wetting of metal is severely curtailed by the presence of surface oxides. This is one of the reasons aluminum cannot be tinned and soldered. Its surface is oxidized almost instantly by the presence of atmospheric oxygen. A clean, oxide-free surface cannot be obtained for soldering. Oxidization also restricts wetting of copper, so any copper parts to be soldered should be as clean as possible. Fortunately, copper oxidizes rather slowly, so surfaces cleaned by scraping or sanding will remain pure copper for some time before a tarnishing film of copper oxide reforms.

   Unfortunately, oxidization is hastened by heat. Application of a heated soldering iron or molten solder will start surface oxidation, even on a freshly cleaned surface. For this reason, it is very hard to solder even clean copper without applying a soldering flux.

   The primary function of a soldering flux is to eliminate oxidation during the soldering process. Flux melts and flows when heated, effectively sealing the surfaces against the entry of oxygen. Flux also lowers the surface tension of the molten solder, allowing it to flow and spread more easily. Flux contains a small quantity of an active antioxidant material, which serves as a mild cleaner to remove any surface tarnish.

   Historically, soldering flux has been caustic liquids or pastes containing acids. This is because part of their function has been to scour and roughen the surfaces. The problem with acid flux is that it never completely vaporizes during heating and continues to corrode the metal surfaces indefinitely.

   The flux most commonly used in electric soldering is rosin. Rosin is an organic material derived from certain tree saps. It is non-corrosive, reasonably non-toxic, and readily liquefied by heat. Its residues are also easily removed after soldering. Rosin flux is usually a continuous single or multiple core inside the wire solder (Figure 2). Because it melts at a much lower temperature than solder, rosin is readily dispersed onto the job both before and during the melting of the solder. Low-odour solder and solders without flux are available.

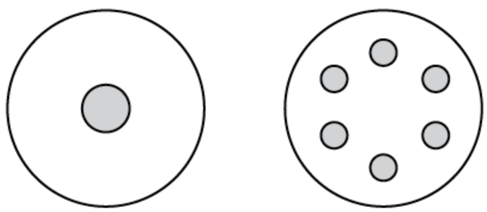

Figure 10.1.1: (CC BY-NC-SA; BC Industry Training Authority)

2. Flux-cored solder wire

Rosin core solder is the only kind you should use in electric work. Never use acid core or other solder containing corrosive flux. Never use any form of paste or liquid flux containing acid. Not only will the ongoing corrosion eventually cause mechanical deterioration, it will rapidly destroy the connection's ability to conduct current.

Composition of solder

Solder is an alloy of different metals, commonly tin and lead, that have a lower melting point than the base metal. Both metals are reasonably good electrical conductors. The ratio of tin to lead has a great deal to do with the melting point and hardness of solder and also with its conductivity. Tin melts at about 327°C (620°F) and lead at about 232°C (450°F). When these metals are combined, the melting point of the mixture goes down. The melting point varies with the ratio of tin to lead, with the lowest occurring at about 183°C (360°F) for a 63/37 tin-lead mixture.

This lowest melting temperature is called the eutectic point. It marks the temperature at which the solder changes directly from solid to liquid with no semi-liquid or plastic state in between. Since a narrow plastic state is desirable in soldering operations, a 60/40 mix is very common. This raises the melting point slightly to about 188°C (370°F) and gives a temperature range for plasticity of about 4°C to 6°C (40°F to 43°F). It also produces optimum conduction characteristics and hardness for electronics soldering.

Note that the ratios for solder composition always state the tin content first.
60/40 solder is composed of 60% tin and 40% lead (by weight).

Wire solder is available in a variety of diameters. Which to use depends on the sizes of the component leads and terminals to be soldered. Diameters of 0.75 mm (1/16ø) and 0.38 mm (1/32ø) are the most commonly used sizes.

10.2: Soldering Tools

Soldering tools

Historically, heating the host metals and melting the solder was done by firing in a forge or by pouring molten solder onto the metals and wiping it into place with leather pads. Later, heat was applied by means of an iron bit that was heated in the forge. The name soldering iron has carried forward to this day. Today, heat is applied by various electrically heated soldering tools called irons or pencils or guns. Figure 3 shows two examples. The majority of electronic soldering done during electronic repair, for example, is completed with a low-wattage soldering pencil.

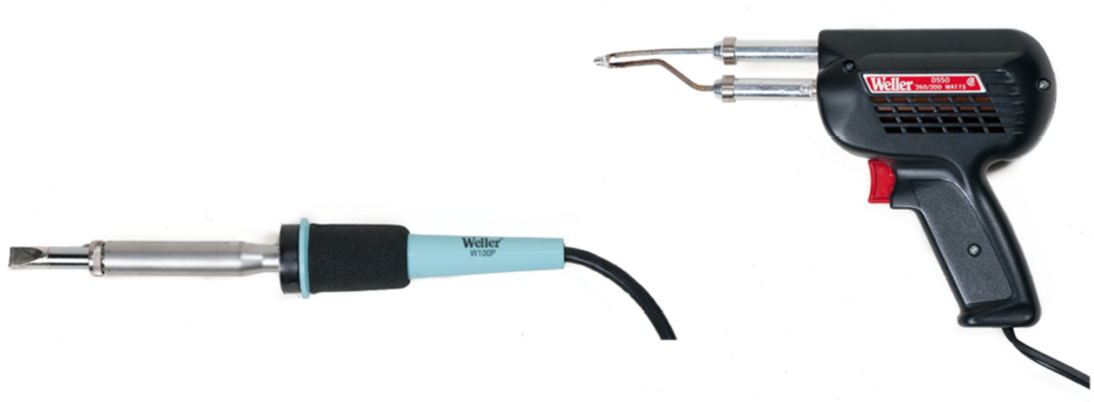

Figure 10.2.1: (CC BY-NC-SA; BC Industry Training Authority)

3. Some common soldering tools

Figure 10.2.1: (CC BY-NC-SA; BC Industry Training Authority)

4. Soldering tip shapes

   Regardless of the shape, size, or design of the iron, the tip must be tinned. Tinning the tip is the process of applying a thin layer of solder to the tip to keep atmospheric oxygen and other contaminants off the soldering surface and help with the flow of the solder. A poorly tinned tip will make it virtually impossible to achieve a sound solder joint.

   Soldering iron manufacturers specify an operating temperature range for each type of tip. This requires mating the heating capability of iron and tip. Insufficient iron capability will result in tip temperatures that are lower than needed for quality solder work or in rapid drop in tip temperature during soldering. Excessive heat will quickly deteriorate the tip and may possibly damage the components and printed circuit board being soldered.

   You can estimate tip temperature by following this two-step process:

   - Apply a small amount of solder to the flat surface of the tip and immediately wipe the tip with a damp cellulose sponge or paper towel.
   - Observe tip colour immediately after wiping.
     - If the color of the surface is silver, the temperature is between 315°C and 370°C (600°F and 698°F).
     - If the tip shows gold streaks, the temperature is approaching 425°C (797°F).

The copper tips of irons and pencils are progressively dissolved by solder, and they soon become pitted and corroded. This is particularly true of the continuous-heat types. It is virtually impossible to do quality soldering with a corroded tip. Corroding can be slowed down by keeping the tip clean and well tinned.

Clean the tip by wiping it frequently with a damp cloth or cellulose sponge. The damp wipe will shock the built-up burned flux from the tip. Immediately re-tin the tip and leave a thin coating to keep atmospheric oxygen off the soldering surface. Wipe the excess solder off the tip before the next use. Reclean and recoat with solder when you finish each soldering task.

When pitting becomes significant, you should dress the tip and reshape it to clean metal with a fine file. This can be done with the tip hot so that the refreshed tip can immediately be re-tinned. Excess solder should be wiped away after re-tinning. Steel-clad tips suffer much less corrosion and should never be dressed with a file. Like copper tips, however, they should be cleaned frequently when hot.

10.3: Soldering techniques

Soldering techniques

To avoid soldering problems, it is extremely important to work with clean materials and the correct amount of heat. Soldering problems can normally be avoided by bringing the metals to soldering temperature quickly and completing the solder application in a short period of time. You know you have the proper heat when a joint can be completed in about two seconds. The heat will transfer most effectively to the work if a clean tip is lightly tinned with a film of solder. The film of solder will create a bridge between the iron and soldering surfaces by flowing into all gaps. Sometimes a small amount of solder must be added to help form this bridge by applying a small drop to the iron's tip before applying it to the work surfaces.

Although learning the theories of good soldering is important in developing soldering skills, good soldering is primarily learned through practice. Holding the iron and applying it and the solder to the work surface must be done using techniques that are comfortable and natural to each individual. How you do the job is unimportant as long as the end result is a quality soldered joint with no damage to the surrounding components and materials. At every opportunity, you should experiment with different techniques, always making certain that your soldering meets the requirements of effective soldering listed earlier.

Procedures

To solder effectively, follow these procedures:

1. Follow safety precautions.
   Always wear safety glasses with side shields when soldering. Ensure adequate ventilation or use solder fume extraction hoods to prevent accumulation of solder fumes. Wear closed-toed shoes and clothing made of natural fibres, with long sleeves and long trouser legs to protect against burns from solder splashes.

   Avoid touching the solder pencil tip or freshly soldered joints. Use an iron holder and allow the iron to cool completely before putting it away. Never solder on equipment that has power supplied to it. Before eating, drinking, or smoking, always wash your hands to avoid accidentally ingesting lead.

2. Clean and tin host materials.

The materials to be soldered (leads, pads, terminals, etc.) must be clean and tinned. Inspect all host metals and clean them to remove contaminants such as oxides, machine oil, hand lotion, and skin oils. Avoid touching cleaned surfaces.

Most component leads and hookup wires are factory tinned. Copper parts and solder pads that are untinned should be cleaned and tinned separately.

To tin a surface, clean it and then heat the surface with a soldering tip. Apply the solder to the surface and allow a thin coating to form on the surface. Allow the surface to cool.

When tinning stranded insulated wires, strip the wire to the appropriate length for the joint being made. Tin the wire, using only enough solder to make the stripped wire solid. The strands of wire should be visible through the solder. Avoid solder from wicking in the wire underneath the insulation.

When tinning and soldering, make a solder bridge to increase the linkage area and speed heating of the surface or joint (Figure 5).

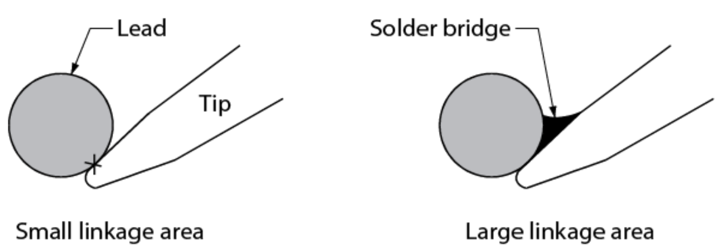

Figure 10.3.1: (CC BY-NC-SA; BC Industry Training Authority)

5. Cross-section view of iron tip on a round lead - "X" shows point of contact

   3. Form a mechanical joint between the host metals.

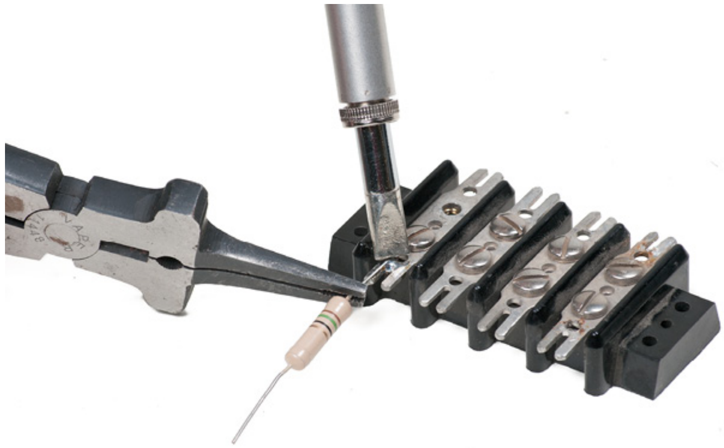

Figure 10.3.1: (CC BY-NC-SA; BC Industry Training Authority)

4. Needle-nose pliers used as a heat sink
   5. Allow the connection to cool undisturbed.

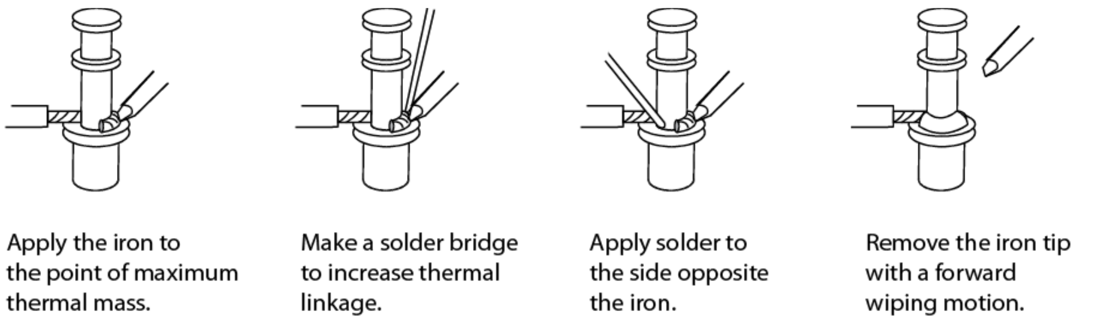

Figure 10.3.1: (CC BY-NC-SA; BC Industry Training Authority)

5. Steps to solder conductors to turret terminals

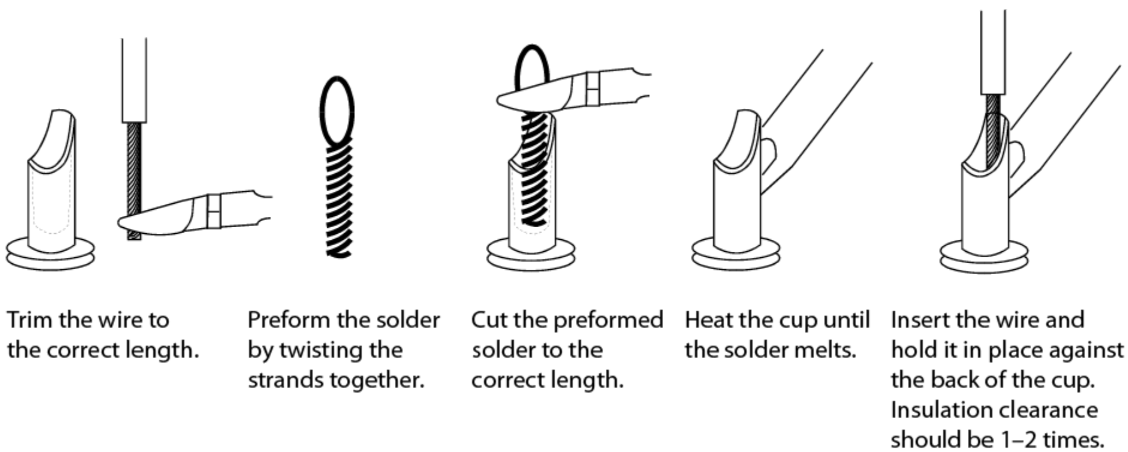

Figure 10.3.1: (CC BY-NC-SA; BC Industry Training Authority)

6. Soldering procedures for cup terminals

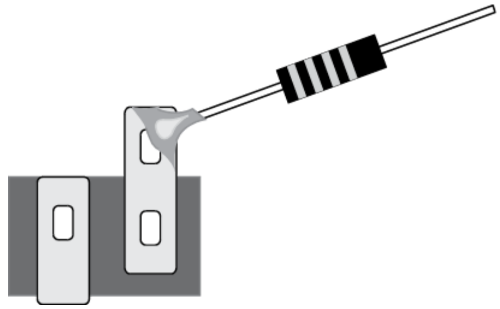

Figure 10.3.1: (CC BY-NC-SA; BC Industry Training Authority)

7. Correctly soldered connection

   Soldering defects

   The following characteristics are unacceptable in a solder joint:

   - charred, burned, or melted insulation or parts
   - excessive solder, including peaks, icicles, and bridging
   - flux residue, solder splatter, or other foreign materials on circuitry of adjacent areas
   - insufficient solder
   - pits, holes, or voids or exposed base metal in the soldered connection
   - fractured or cracked solder connection or evidence of grain change
   - cut, nicked, gouged, or scraped conductors
   - improper conductor length

   During the soldering process, you must be very careful to avoid defects in the solder joint itself. Soldering defects primarily reduce the efficiency of the electrical connection between the metals to be joined.

   Cold solder joint

   A cold solder joint occurs when the component leads have not been heated sufficiently. A lack of heat in the metals to be joined will reduce or eliminate proper wetting of the surfaces, as described earlier. Insufficient wetting will cause the solder to pile up on the joint surface rather than flow smoothly through the joint. An efficient electrical connection between the metals to be joined will not be made, resulting in resistance to current flow through the joint.

   Cold joints commonly result from applying solder to the soldering iron's tip rather than to the joint to be soldered. When the solder is touched to the iron rather than to the joint, the solder will melt before the joint has heated sufficiently. The melted solder will flow over the joint, but will not properly wet it. Unless heat is maintained well after the solder flows over the joint, a cold solder joint will usually occur.

   The major indicator of a cold solder joint is a frosty appearance to the surface of the solder. In some instances, reheating the joint adequately will correct a cold joint. If the surface stays frosty, the used solder must be removed and the joint resoldered using correct procedures.

   Fractured joint

   A fractured joint occurs during the cooling process when the soldered joint is moved while the solder is in its plastic state. Movement during the plastic state will have a crystallizing effect on the solder and a very rough, inefficient joint will result.

   The usual cause of a fractured joint is a poor mechanical connection of the metals before soldering begins. Components must be mounted firmly before soldering begins.

   Reheating usually cures a fractured joint, but the addition of a small amount of fresh solder may be needed to reflux the exposed metals.

   Rosin joint

   A rosin joint occurs when part of the joint has been heated enough to melt the flux and coat the metals, but not enough to cause the solder to flow. The covering of flux acts as an insulator and consequently provides a very poor electrical connection or no connection at all.

Reheating and applying a small drop of fresh solder will often cure a rosin joint.

Now complete the Learning Task Self-Test.

10.E: Self-Test 2

Self-Test 2

1. Safety factors such as toxic fumes and splashing flux should always be addressed when soldering.
    1. True
    2. False
2. Which of the following best describes the process of surface penetration?
    1. Bonding
    2. Wetting
    3. Soldering
    4. Prepping
3. Which of the following should apply when tinning stranded wire?
    1. The strands should be thickly coated.
    2. The strands should be visible under the solder.
    3. The solder should wick up underneath the insulation.
    4. A large blob of solder should form at the end of the wire.
4. Metals like aluminum and iron wet easily.
    1. True
    2. False
5. What is the purpose of flux?
    1. To remove oxides
    2. To clean the metal
    3. To assist with heating
    4. To remove the solder
6. What is the most common alloy used for solder?
    1. Tin-lead
    2. Lead-silver
    3. Tin-copper
    4. Lead-copper
7. Soldering pencils are used for heavy-duty applications.
    1. True
    2. False
8. What must be done to a soldering tip prior to soldering?
    1. Tin it.
    2. Wash it.
    3. Wire brush it.
    4. Heat it red hot.
9. What should be done to an overly corroded soldering tip?
    1. Nothing.
    2. Re-tin it.
    3. Throw it away.
    4. Dress it with a fine file.
10. What is the purpose of a heatsink?
    1. To protect the solder
    2. To pull flux to the joint
    3. To pull heat to the area for soldering
    4. To pull heat away from certain components
11. What would cause a solder joint to be piled up and lumpy in appearance?

1. Insufficient heat
2. Lack of flux
3. Poor tinning
4. A corroded tip

11: Answer Key

Answer Key

Self-Test 1

1. c. Conductor
2. d. Multiple insulated wires grouped together in a common sheathing
3. c. To prevent unwanted current flow
4. d. When flexibility is needed
5. b. False
6. b. It should be tinned.
7. b. False
8. d. It can be removed easily.
9. b. False
10. c. Crimp-on

Self-Test 2

1. a. True
2. b. Wetting
3. b. The strands should be visible under the solder.
4. b. False
5. a. To remove oxides
6. a. Tin-lead
7. b. False
8. a. Tin it.
9. d. Dress it with a fine file.
10. d. To pull heat away from certain components
11. a. Insufficient heat

SECTION OVERVIEW

4: Unit IV- Using Multimeters

Learning Objectives

When you have completed the Learning Tasks in this Competency, you will be able to:

- describe the proper handling, use, and storage of electric meters
- describe the procedures for connecting meters to measure voltage, current, and resistance
- describe how to use meters to analyze electric circuits

This Competency will introduce you to three basic meters for measuring voltage, current, and resistance. You must have a basic understanding of the purpose and operation of each type of meter before you attempt to use one. If you connect a meter incorrectly, you not only risk damaging the instrument, but more importantly, you or some innocent bystander could receive a serious electrical shock.

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12.1: Prelude to Describe the use and storage of meters

Learning Task 1

Describe the use and storage of meters

A technician is only as accurate as the measurement equipment being used. If the equipment is misused or is faulty, then the measurements will be inaccurate. If the measurements are inaccurate, then the technician will draw the wrong conclusions. To avoid getting inaccurate readings, you need to handle, use, and store meters properly.

The two major types of meters are digital and analog (Figure 1). Although both meters perform the same functions, they look different. As you can see, the difference is in the display unit. Digital meters are usually simpler to use and are more accurate than analog meters, and therefore have become more popular. We will focus on the digital multimeter (DMM), as it is the most common type in use, although analog multimeters may still be preferable in some cases, for example, when monitoring a rapidly varying value.

Figure 12.1.1: Digital and analog multimeters (CC BY-NC-SA; BC Industry Training Authority)

12.2: Meter safety precautions

The proper care of test equipment and instruments is of utmost importance, whether they are analog or digital. The length of time an instrument retains its original usefulness and accuracy depends largely on the care it receives in the hands of the user.

Note

Improper connection can cause damage to the circuit or the test instrument, or cause personal injury.

Precautions in handling and using a meter

These precautions apply equally to digital and analog meters.

- Do not drop any meter.
- Do not overload any meter. When in doubt, use a high range that you know will not be overloaded. You can always switch to a lower range if necessary.
- Do not tamper with precision instruments. Let a competent instrument repair person service precision instruments.
- Before connecting a meter to a circuit, ensure that the range switch is set to an appropriate position.
- Carefully check circuit connections before applying power to meters.
- Be careful not to touch any other electronic components within the equipment.
- Be careful not to touch the probe tips to each other while connected to anything else.

12.3: Digital Multimeters

All digital multimeters combine the features of an ammeter, a voltmeter, and an ohmmeter. Since a DMM is an important tool, you will want to learn how to use one correctly. Figure 12.3.1 shows a typical DMM, although different models may have a different number of digits in the display unit, and the input/output jacks may be in slightly different places.

Figure 12.3.1: Typical DMM (CC BY-NC-SA; BC Industry Training Authority)

The upper portion of the DMM houses the display unit. The middle portion of the DMM houses the function switch, and the bottom portion contains the jacks for test leads.

The function switch normally has positions that allow a technician to measure AC volts, DC volts, DC amps, and resistance. In addition, some DMMs have function switch positions that will allow a technician to measure AC amps, test diodes, and capacitors. Some DMMs require manual setting of ranges; others have an autoranging feature.

All DMMs may be used to measure voltage, current, and resistance. More advanced DMMs may measure frequency, relative power differences, or other important circuit parameters. Each measurement function has similarities and differences that you need to learn about.

Many meters will use symbols on the display, switch, and connections. Figure 12.3.2 lists some of the common symbols you may see.

~	AC	[battery]	Low battery
⎓	DC	⊡	Manual range or automatic touch hold
Ω	Ohms	·)))	Continuity beeper
≂	AC or DC	⊳|—	Diode
Hz	Hertz	⏚	Ground
+	Positive	⊟	Fuse
–	Negative	⧈	Double insulation
μF	MicroFarad	⊣(	Capacitor
m	Milli	OL	Overload
M	Mega		

Figure 12.3.2: Common DMM symbols (CC BY-NC-SA; BC Industry Training Authority)

12.4: Introduction to voltage measurements

Voltage measurements are very easy to make with a DMM. On meters with manual range selection, start with a value one setting higher than expected. An autorange DMM will automatically select the range based on the voltage present. Figure 12.4.1 shows the process.

$$\begin{gathered}\frac{1}{1000}V = 1\mathrm{mV} \\ 1000\mathrm{V} = 1\mathrm{kV}\end{gathered} \tag{12.4.1}$$

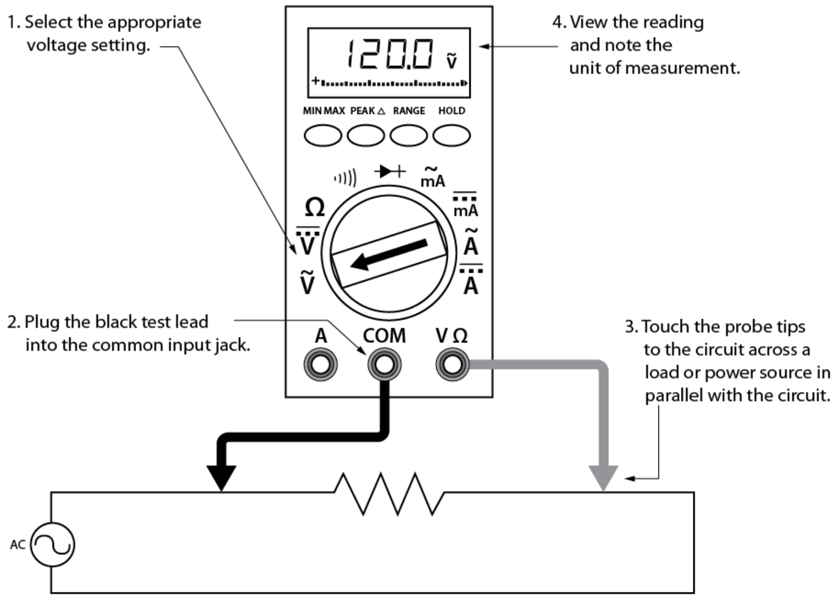

Figure 12.4.1: Using a DMM to measure voltage (CC BY-NC-SA; BC Industry Training Authority)

Follow these steps to measure voltage:

1. Select the DC or AC volts function by turning the function switch to DC or AC volts.
2. Plug the test probes into the appropriate probe jacks.
3. Connect the tips of the probes across the source or load.
4. View the reading on the display unit. Be sure to note the unit of measurement. If you are testing DC voltage and a negative sign appears in the display, the polarity of your probes is incorrect and needs to be reversed.

> Use the one-hand technique. Attach test leads one at a time using only one hand. Put your other hand in a pocket or behind your back. Whatever you choose to do with your other hand, keep it well away from a live circuit or associated equipment. Avoid holding test leads in both hands. The one-hand technique decreases the possibility of a dangerous electrical shock by reducing the chance of current flowing through your body across your chest.

Autoranging units display the unit of measurement in the top right corner (annunciator). In manual ranging units, the meter will use the range selected. Autorange will determine the highest setting and automatically display that unit.

12.5: Introduction to current measurements

As you have seen, the placement of meter leads for voltage measurements is straightforward. The leads are simply connected across, or in parallel with, the points of voltage to be measured.

For current measurements, however, the process is slightly more complex. First, the circuit must be opened at the test points and the meter inserted in series at that opening (Figure 12.5.1). The total current must flow through the meter. To allow the measurement to be made without disturbing the circuit itself, the current meter must have very little internal resistance.

This is where the beginner must be particularly alert. If the meter is inadvertently connected across a P.D. (potential difference) or in parallel with a component instead of in series, the small internal resistance will permit a very large current to flow through the meter. This will most certainly damage the meter severely and perhaps the circuit as well.

> With current measurements, shutting off the power before connecting the meter is essential. You will be disconnecting one end of a wire or component in order to connect the meter in series. If you leave the power on, you could easily receive a dangerous shock or do damage to the circuit.

On meters with manual range selection, start with the highest current setting and work your way down.

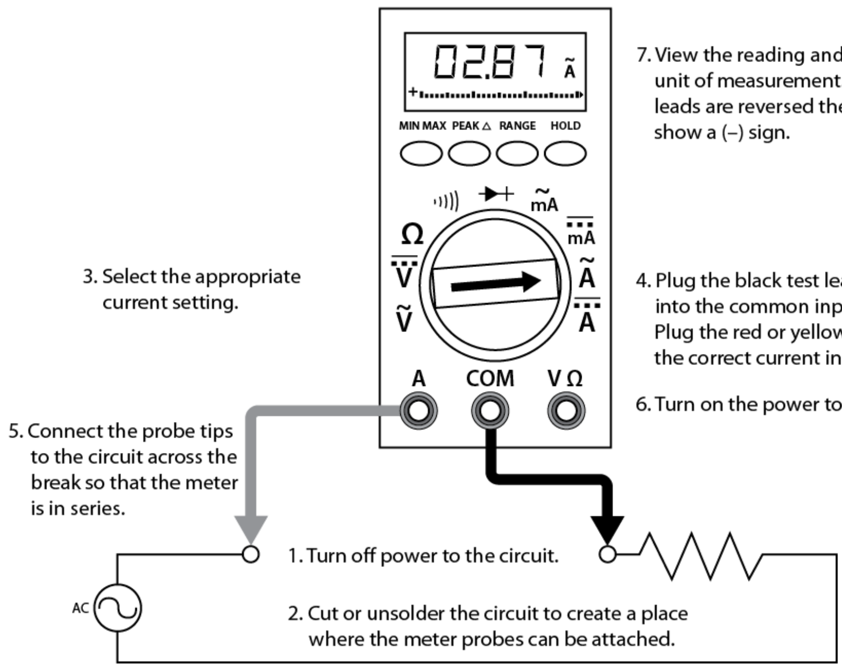

Figure 12.5.1: Using a DMM to measure current (CC BY-NC-SA; BC Industry Training Authority)

Current Measurement Procedures

Follow the steps below to measure current:

1. Turn off the power to the circuit that will be measured.
2. Open the circuit by disconnecting or unsoldering a connection at a point where you wish to measure current.
3. Select the DC or AC amps function by turning the function switch to DC or AC amps.
4. Plug the test probes into the appropriate probe jacks. Note that the jacks used may not be the same ones used to measure volts.
5. Connect the tips of the probes across the break in the circuit as shown in Figure 12.5.2so that the current to be measured flows through the meter. Note that this is a series connection. Never connect the ammeter in parallel with the source or load, as this will cause a short circuit and damage the meter

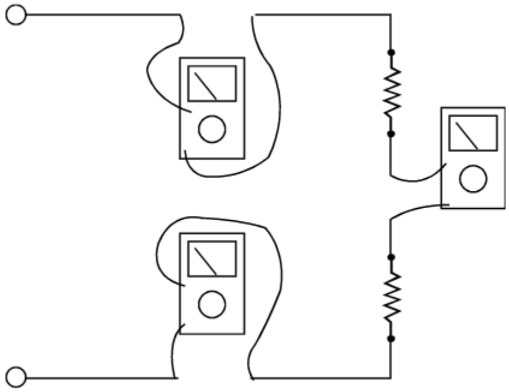

Figure 12.5.2: Ammeter connections to measure the same current at different points in a circuit (CC BY-NC-SA; BC Industry Training Authority)

6. Turn the circuit power back on.
7. View the reading on the display unit. Be sure to note the unit of measurement.
8. Switch power off and disconnect meter leads from the circuit.
9. If testing is finished at this test point, restore the circuit by reclosing the connection. When current measurements are complete, turn the function switch to the OFF position and remove the test leads.

Some types of DMMs have a clamp-on ammeter or tong tester. These ammeters have two springloaded expandable jaws that allow you to clamp around a single conductor (Figure 12.5.3). This feature allows you to measure the magnetic field created by the current flowing through the wire to give an ampere reading without having to make physical contact or disconnect the circuit.

Figure 12.5.3: Using clamp-on ammeter (CC BY-NC-SA; BC Industry Training Authority).

12.6: Introduction to resistance measurements

You have studied voltage and current measurements, but you will find resistance measurements different in several ways. Resistance is measured with the circuit's power turned off. The ohmmeter applies its own voltage to the unknown resistance and then measures the current it produces to calculate a resistance value readout.

Role of the battery

Even though it reads out resistance, the ohmmeter is still a current-measuring device at heart. The ohmmeter is created from a DC meter by adding a group of resistors (called multiplier resistors) and an internal battery. The battery supplies the current flow that is eventually measured by the meter. For this reason, use an ohmmeter only on dead circuits.

In the process of measuring resistance, the test leads are inserted in the meter jacks. The leads are then attached to the ends of whatever resistance is to be measured. Since current can flow either way through a pure resistance, there is no polarity requirement for attaching the meter leads. The meter's battery sends a current flow through the unknown resistance, the meter's internal resistors, and the current meter.

The ohmmeter is designed to display 0 Ω when the test leads are clipped together (zero external resistance). When the leads are left open, the meter reads infinite (I) resistance or over-limit (OL) resistance. When a resistance is placed between the leads, the readout increases according to how much current that resistance allows to flow.

An ohmmeter should never be left on the ohms function when not in use to conserve its battery. Since the current available from the meter depends on the battery's state of charge, the DMM should be zero adjusted to start. This may require no more than a test of touching the two probes together.

Figure $12.6.1$shows how resistance measurements are taken.

> **Note**
>
> **1 000 Ω = 1 kΩ**
>
> **1 000 000 Ω = 1 MΩ**

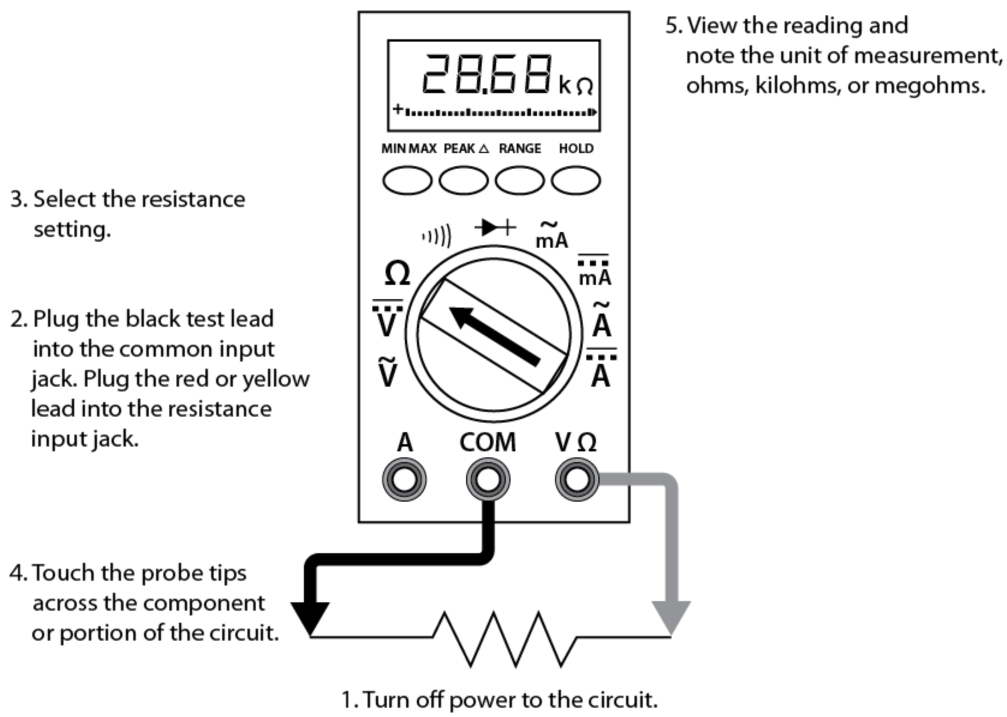

Figure 12.6.1: Using a DMM to measure resistance (CC BY-NC-SA; BC Industry Training Authority)

Resistance measurement procedures

Follow the steps below to measure resistance:

1. Turn off the power to the circuit. Remove or isolate the component to be tested.
2. Plug the test probes into the appropriate probe jacks. Note that the jacks used may be the same ones used to measure volts.
3. Select the ohms function by turning the function switch to ohms. Start with the lowest setting.
4. Touch the probes together to check the leads, connections, and battery life. The meter should display zero or a minimal amount of resistance for the test leads. With the leads apart, the meter should display OL or I, depending on the manufacturer.
5. Connect the tips of the probes across the break in the component or portion of the circuit for which you want to determine resistance. If you get an OL (over limit), move to the next level.
6. View the reading on the display unit. Be sure to note the unit of measurement.
7. After all the resistance readings are complete, turn the DMM off to prevent the battery from draining

To measure the resistance of components in a circuit, disconnect all but one load. This prevents loss of correct orientation when reconnecting.

You can use the same connection procedure to verify that a circuit, wire, fuse, or switch is complete with no open. This is called a continuity test, and most DMMs will have an audible continuity setting ( ). If there is no audible alarm, then the circuit is broken, or there is too much resistance. A good example is testing a heating element when the element is burned out.

Now complete the Learning Task Self-Test.

12.E: Self-Test 1

Self-Test 1

1. What are multimeters used to test, in addition to amperage and voltage?
    1. Pressure
    2. Humidity
    3. Resistance
    4. Temperature
2. Analog meters are more popular than digital.
    1. True
    2. False
3. How many volts are in 2200 mV?
    1. 0.22 V
    2. 2.2 V
    3. 22 V
    4. 220 V
4. It is important to turn the circuit off before checking voltage.
    1. True
    2. False
5. What would happen if you connected the probes backwards when checking voltage?
    1. Damage to the DDM would occur.
    2. Damage to the circuit would occur.
    3. A negative voltage would be read.
    4. It doesn’t matter which way they go.
6. What is one important safety technique when testing electrical circuits?
    1. Wearing gloves
    2. Wearing safety glasses
    3. Using the one-hand technique
    4. Using the two-hand technique
7. The first step when using an autorange DDM is to select the range required.
    1. True
    2. False
8. A circuit must be broken to test current.
    1. True
    2. False
9. Is an amperage test done in series or parallel?
    1. Series
    2. Parallel
10. When is it important to turn off a DDM to extend battery life?
    1. After checking voltage
    2. After checking amperage
    3. After checking resistance
    4. Never; it turns off automatically
11. When the probes are touched together in a resistance test, what should the meter read?
    1. 0
    2. Infinity
    3. OL
    4. Nothing

12. How many ohms are in 2.125 kΩ?
    1. 21.25 Ω
    2. 212.5 Ω
    3. 2125 Ω
    4. 21 250 Ω
13. What is the name of the test used when testing a circuit for an open?
    1. Infinity test
    2. Overload test
    3. Continuity test
    4. This test cannot be done.

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13.1: Use meters to analyze simple circuits

The trick to effective troubleshooting electrical equipment and circuits is to zero in as quickly as possible on the problem. Using an electric meter will allow you to effectively test the components that are most likely to cause the problem before you unnecessarily dismantle the equipment and replace parts.

Safety

Even though you may normally deal with small voltages and currents, the values are never far away from lethal levels. You can receive a shock or burn from any common electrical circuit. The severity of the electrical shock depends on several factors:

- the amount of current that passes through the body
- the path that the current takes through the body
- type of voltage—AC or DC
- voltage strength
- the length of time that the current flows within the body
- condition of the skin and the body's chemical makeup
- area of contact

A circuit breaker generally limits normal household light circuits 15 amperes and plug circuits of 20 amperes. This 15 amp device has been designed to trip and open a circuit if the 15-ampere value is exceeded, and it is designed to protect against property damage. It is possible to cause a fatal injury with a current flow of only 50 milliamperes (mA) or five one-hundredths of an ampere. The body is sensitive to relatively small values of current. In comparison, a 100-watt lightbulb draws approximately 0.85 amperes (850 mA) of current when connected to a 120-volt source. Remember, there are 15 amperes available in each standard house circuit.

Electrical shocks, electric burns, and other related injuries occur far too often and, in most cases, go unrecorded. If an accident happens:

- Don't touch the person and use a conductive tool to free the person that may be electrically energized.
- Shut off the power or pull the plug if it is safe to do so. If you are not able to, get help.
- Remove the person from the contact point using a non-conductive object such as a dry piece of wood or a leather belt.
- Call 911 for help if the person is obviously injured (loss of consciousness, significant trauma, etc.)
- Seek medical attention (first aid) in any case of injury, such as an altered mental state (confusion, slow/slurred speech) or other obvious injuries (laceration, burn, etc.).

When performing maintenance or doing repair work, or when a machine is in an unsafe state, it is vital to eliminate the possibility of the machine being energized unexpectedly. Workers need to guard against contact with electrical voltages and control electrical currents to create a safe work environment.

Make the environment safer by doing the following:

- Protect portable electrical equipment with an approved ground-fault circuit interrupter (GFI) when using the equipment outdoors.
- Ensure all the cords are in good condition, with the caps and plugs well secured on the cables. Ensure the proper U-ground plug is in good working condition.
- Use cords of sufficient gauge for the amount of current used by the tools they are powering. Each tool is labeled with the power that it draws.
- Treat all conductors and bare wires—even apparently de-energized ones—as if they are energized until they are locked out and tagged.
- Do not make any electrical measurements without specific instructions from a qualified person.
- When servicing equipment, be sure it is "locked out," meaning the electrical service is shut off at a disconnect panel whenever possible, the panel is locked, and the only key is kept by the person working on the equipment.
- When replacing components on mobile equipment, disconnect the battery.

13.2: Troubleshooting principles

There are really only two rules for troubleshooting using a voltmeter. They are simple and always true:

1. If you measure a voltage across a switch, the switch is open.
2. If you measure a correct voltage across a load and the load doesn't work, the load has failed.

With digital meters, voltage readings that are considered as zero will often indicate minimal voltage readings. For example, a minimal reading could indicate a very slight resistance across the switch contacts or even a meter inaccuracy when reading across a closed switch.

Notice that the first rule does not say that the switch is closed if you read zero volts across a switch. There are many situations in which you might read zero volts across an open switch.

The second rule indicates that the load has failed. This only means that the problem is with the load, and you don't have to look anywhere else for the problem. The actual remedy still has to be determined. This may require a replacement of the load, but there may be other possibilities. For example, there may be an overload that needs resetting.

Always look for the easy fix first. Check components that are easily accessible first that might explain the symptom that you have observed. For example, one of the first checks is to verify the power supply.

Voltage tests

You can troubleshoot a problem using either volt or ohms tests. It is most practical to choose voltage testing. With a resistance test, you have to first disconnect the component being tested from the circuit. In other words, you may not really find the problem. While removing the wiring, you could jostle things and possibly change the circuit, which may temporarily remedy the problem.

When you use your voltmeter to troubleshoot, you will find either an open switch or a load that has failed. You may then remove the device and double-check it with your ohmmeter. You can do this without moving any wires and without changing the circuit in any way.

Voltage drops in series circuits

Consider the simple series circuit in Figure 13.2.1. In series circuits, the total voltage is the sum of the individual voltage drops in the circuit, and the equation E = IR is used to calculate the voltage drop across each resistor. Since the current is the same through each resistor, the voltage drop across each resistor is directly proportional to the resistance value. In other words, the greater the value of a resistor in a series circuit, the higher the voltage drop.

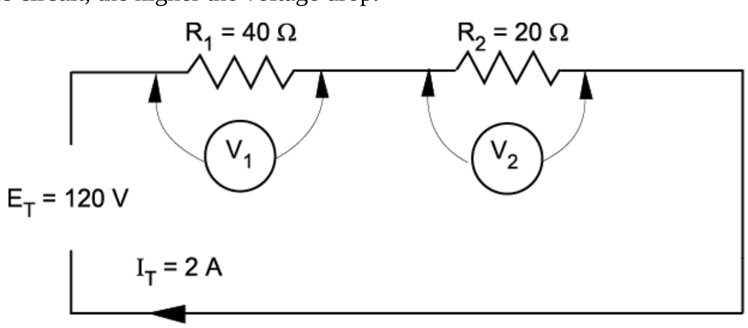

Figure 13.2.1: (CC BY-NC-SA; BC Industry Training Authority)

Example 13.2.1

From the values given above, you can easily calculate the voltage drop across each resistor by:

Solution

E1 = I1 × R1 = 2 A × 40 Ω = 80 V

E2 = I2 × R2 = 2 A × 20 Ω = 40 V

The voltage drop of 80 V across the 40 Ω resistor is twice the voltage drop across the 20 Ω resistor.

Refer to Figure 13.2.2 If an open is introduced between resistors R1 and R2 (for example, by disconnecting a lead), current flow through the circuit is, of course, interrupted. If there is no current flow, the voltage drop across each resistive element is zero (since E = I × R).

However, the potential difference of the source still exists across the open. If a voltmeter is connected across the open, the reading is the same as if it were connected directly across the terminals of the supply source.

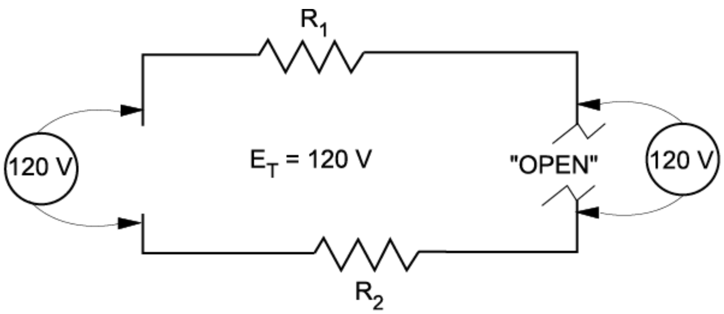

Figure 13.2.2: Voltage across an open (CC BY-NC-SA; BC Industry Training Authority)

In a series lighting circuit, you could easily determine which lamp was burnt open simply by measuring the voltage across the lamp-holder terminals, in succession, until you have measured the total source voltage.

Caution!

Since the source voltage still exists across the open in a series circuit, this represents a shock hazard. Be careful not to touch the live parts of the circuit!

Similarly, if a switch is opened, the full-source voltage will appear across the switch contacts. Even though the voltage across the load devices may be zero, if any of those loads are ahead of the switch, they will be energized with full voltage to ground.

Troubleshooting series components

Sometimes you will be required to troubleshoot a piece of equipment that has stopped working. The first thing you would check for is power. Is the breaker off? Is the switch off? Is there a general power outage?

Once you have determined that power is still available, you can use the multimeter to locate the problem. Starting with the first component or the easiest one to check, work your way through the circuit until you reach the component that shows no voltage reading. This is known as hopscotch voltage readings. Figure 3 illustrates this process. The dashed line indicates where the probe has already been placed and removed.

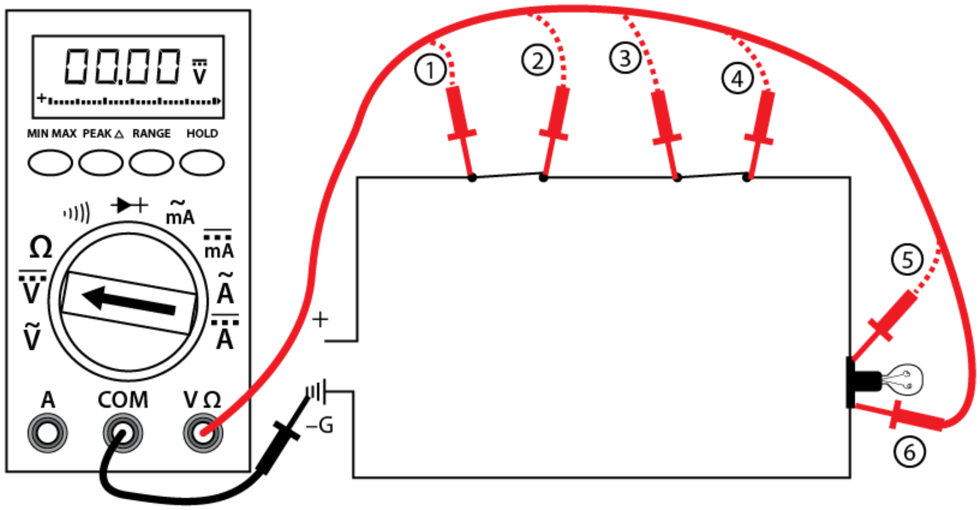

Figure 13.2.3: Hopscotch troubleshooting (CC BY-NC-SA; BC Industry Training Authority)

Follow these steps to complete the voltage test procedures with an autorange meter:

- Set the selector dial to the type of current to be tested: AC or DC.
- Once you have determined that the load (shown as a lightbulb) is not working, check for voltage across the light first to verify rule #2 (i.e., if you measure a correct voltage across a load and the load doesn't work, the load has failed.).
- If you have voltage across the light, then the light has failed. If there are zero volts across the light, then one of the switches or wiring connections in the circuit has failed. If you have a zero reading across the light, continue with the next steps.
- Place the black probe at a grounded component.
- Place the red probe and check for a voltage reading at each test point, starting at test point 1, verifying the power supply.
- Continue working your way through the circuit until you get a zero reading, which would indicate a break in the circuit just before that point.
  - Reading at 2 = switch #1 closed, zero at 2 = switch #1 open
  - Reading at 3 = wiring to switch #2 good, zero at 3 = wiring to switch #2 open
  - Reading at 4 = switch #2 closed, zero at 4 = switch #2 open
  - Reading at 5 = wiring to light good, zero at 5 = wiring to light open
  - Reading at 6 = load is energized, zero at 6 = the load is open (although you have already checked the load in your first test). If you get to this stage and the load is energized, the only component left that must be faulty is the final wiring from the load to ground.
- Once the open in the circuit has been identified, you can de-energize the circuit,
- remove the component, and double-check the component with your ohmmeter.
- If this is the last test you are doing, turn the meter to "off" and store it in a safe place.

Testing resistance (ohms) with a digital multimeter

This test, using a digital multimeter, determines whether:

- an electrical circuit is complete or broken
- the resistance of a component matches the manufacturer's specification

Follow these steps to complete the resistance test procedure:

- Make sure all power is off on the circuit you are testing.
- Make sure that the component that you are testing is isolated from the complete circuit. Either remove the component from the circuit or isolate it with an open switch.
- Set the selector dial to Ω.

- Connect the test lead and probes to the component terminals as shown (Figure 4).
- Observe the readout window to obtain the Ω reading.
- Compare the results to the manufacturer's Ω specifications. If the readings match the component, then resistance is not a problem.
  - If the component is a load, there should be resistance that matches the manufacturer's specs.
  - If the reading is infinite (I) or overloaded (OL), the component is open.
  - If the reading is zero, then the component is closed (if it is a load, this is an internal short).
- If this is the last test you are doing, turn the meter to "off" and store it in a safe place.

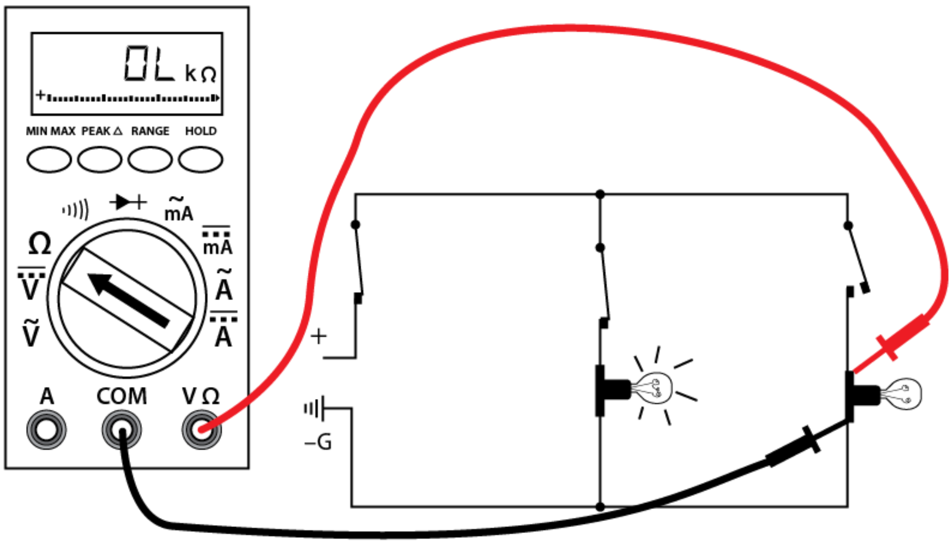

Figure 13.2.4: Ohm test of a load (CC BY-NC-SA; BC Industry Training Authority)

Note

There may be other energized circuits even though the circuit you are working on is not energized. DO NOT TOUCH THE METER PROBES TO ANY ENERGIZED COMPONENTS WHEN TESTING FOR CONTINUITY. YOU MAY DAMAGE THE METER.

Continuity test

This is a quick audible alarm test using a digital multimeter to determine whether an electrical circuit or wire is complete or broken.

This test can be applied to a circuit as a whole or in sections—on individual components or sections of wiring. A break in continuity can be caused by mechanical damage, corrosion of components, or simply a switch being left open.

Follow these steps to complete the continuity test procedure with an autorange digital meter:

- Make sure all power is off in the circuit you are testing.
- Set the selector dial to Ω (audible alarm symbol).
- Connect the test lead and probes on the load terminals as shown (Figure 13.2.5). The audible alarm will indicate continuity without a need for taking your eyes off the work.
- Touch the probes together to check the leads, connections, and battery life. The audible alarm should sound. With the leads apart, the meter should display OL or I, depending on the manufacturer.
- If this is the last test you are doing, turn the meter to "off" and store it in a safe place.

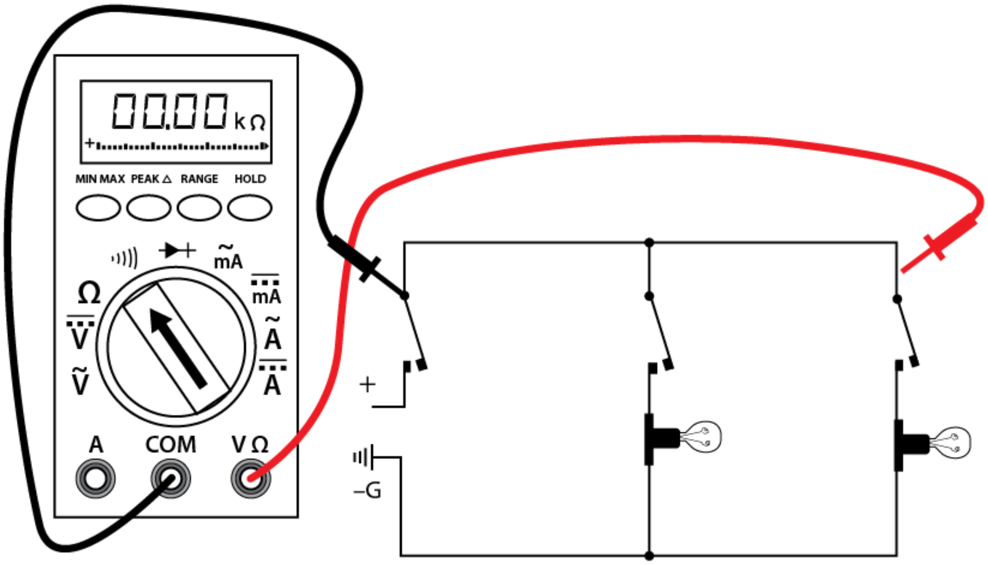

Figure 13.2.5: Wiring for a continuity test (CC BY-NC-SA; BC Industry Training Authority)

Note

There may be other energized circuits even though the circuit you are working on is not energized. DO NOT TOUCH THE METER PROBES TO ANY ENERGIZED COMPONENTS WHEN TESTING FOR Ω (RESISTANCE). YOU MAY DAMAGE THE METER.

13.3: Polarity in a parallel circuit

Just as in series circuits, electrical current flows “from negative to positive” through each of the load components in a parallel circuit. As illustrated in Figure 13.3.1, electrons leave the negative terminal of the source and flow from negative to positive through each of the load resistors. Note that the polarity of each of the resistors is the same as the polarity of the source.

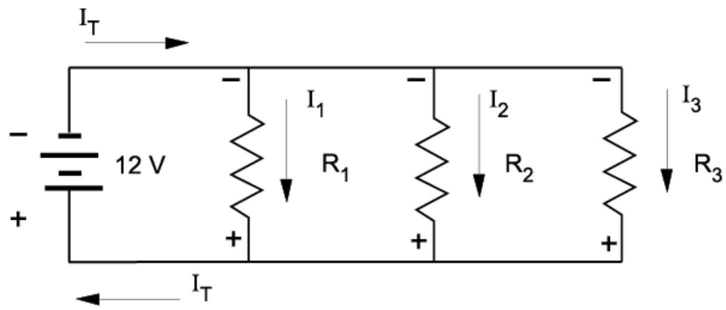

Figure 13.3.1: Polarity in a parallel circuit (CC BY-NC-SA; BC Industry Training Authority)

Polarity is always expressed from one point of a circuit relative to another point with a different electrical potential. Note that in Figure 6 the top side of each resistor, which is marked negative, is in effect the same point. No difference in potential exists between any of these like terminals.

Also notice that the individual currents through each resistor (I_1, I_2, I_3) together constitute the total current (I_T) drawn from the source. When the total current required to operate each of these parallel loads exceeds the current output rating of the one source, you will need to increase the source output.

Polarity test for parallel voltage sources

Voltage sources are connected in parallel whenever it is necessary to deliver a current output greater than the current output a single source of supply can provide, without increasing voltage across a load.

- Power sources are connected *in series* to increase the *voltage output*.
- Conversely, power sources are connected *in parallel* to increase the *current capacity*.

An advantage of parallel-connected power sources is that one source can be removed for maintenance or repairs while reduced power to the load is maintained. If a 6 V battery has a maximum current output of 1 A, and if it is necessary to supply a load requiring 2 A, then you can connect a second 6 V battery in parallel with the first.

If there is any doubt about the polarity of the two batteries, then you can do a simple voltmeter test for correct polarity.

1. Tie one side of the power sources together.
2. Before connecting the paralleling jumper between the remaining two terminals, insert a voltmeter between these two points. See Figure 13.3.2
3. If the polarity is incorrect (Figure 13.3.2b), the voltmeter indicates two times the source voltage, because the equal EMFs aid each other. Do NOT connect across these terminals.

Caution!

Since there is a difference in potential between these two points, connecting a paralleling jumper between them would result in a short circuit!

If the polarity is correct (Figure 13.3.2a), then the voltmeter indicates 0 V because the EMFs oppose each other. You may connect a paralleling jumper between these two points.

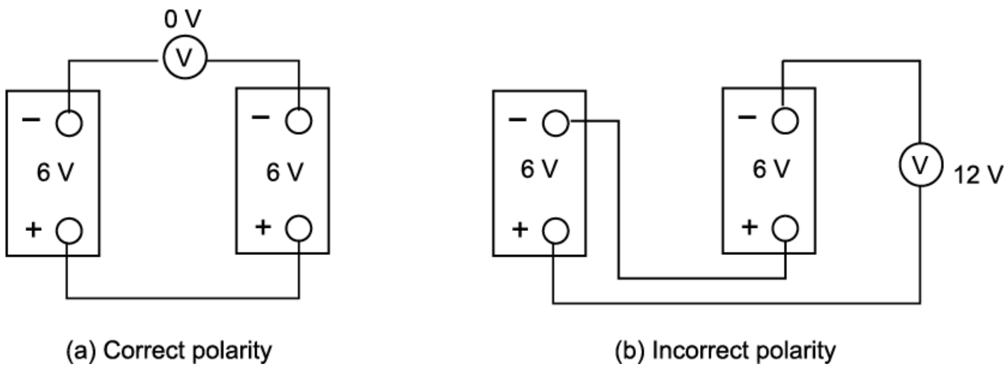

Figure 13.3.2: Polarity test (CC BY-NC-SA; BC Industry Training Authority)

Now complete the Learning Task Self-Test.

13.E: Self Test 2

Self-Test 2

1. What is the lowest amperage at which fatal injury can occur in a human?
   1. 15 A
   2. 0.15 A
   3. 50 mA
   4. 15 mA
2. If you measure voltage across a switch, what state is it in?
   1. Open
   2. Closed
3. If you measure correct voltage across a load but the load doesn't work, what is wrong?
   1. There is no power.
   2. There is no current.
   3. A switch is open.
   4. The load has failed.
4. Refer to Figure 1. If you have a reading at point 4, but not at 5, what is the problem?
   1. The load has failed.
   2. The switch is open.
   3. The wiring has failed.
   4. The ground has failed.

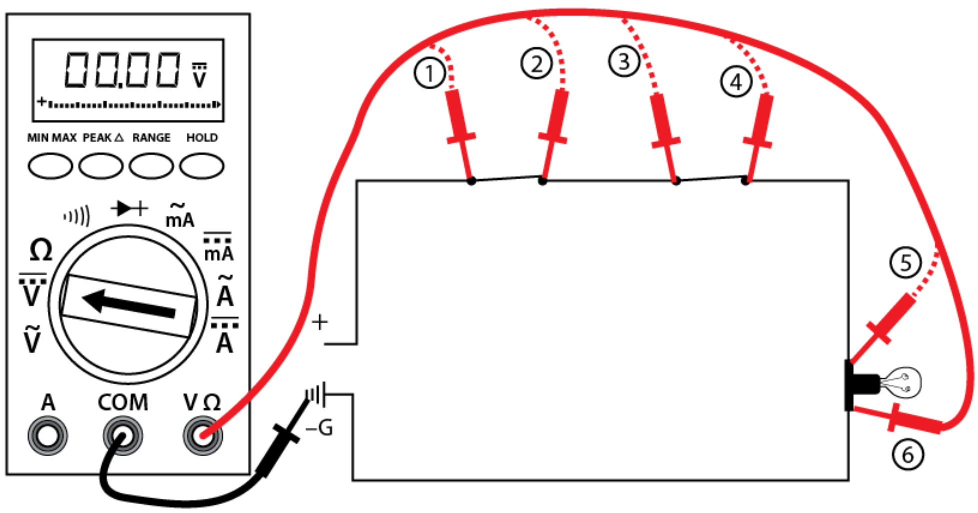

Figure 13.E.1: (CC BY-NC-SA; BC Industry Training Authority)

1. 5. Refer to Figure 1. If you have a reading at 5 and zero at 6, what is the problem?
   1. The load has failed.
   2. The switch is open.
   3. The wiring has failed.
   4. The ground has failed.

   6. What is always the first step when testing for resistance?
   1. Check the load.
   2. Remove the component.
   3. Turn the circuit power on.
   4. Turn the circuit power off.

   7. What is the best test for checking if a heating element is faulty?

1. Voltage test
2. Continuity test
3. Amperage test
4. They cannot be tested.

8. What will increase when power sources are connected in series?

1. Voltage
2. Current
3. Resistance
4. Continuity

14: Answer Key

Answer Key

Self-Test 1

1. c. Resistance
2. b. False
3. b. 2.2 V
4. b. False
5. c. A negative voltage would be read.
6. c. Using the one-hand technique
7. b. False
8. b. False
9. a. Series
10. c. After checking resistance
11. a. 0
12. c. 2125 Ω
13. c. Continuity test

Self-Test 2

1. c. 50 mA
2. a. Open
3. d. The load has failed.
4. c. The wiring has failed.
5. a. The load has failed.
6. d. Turn the circuit power off.
7. b. Continuity test
8. a. Voltage

Index

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Glossary

Sample Word 1 | Sample Definition 1

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      - 2.1: Basic Electrical Circuits - *CC BY 4.0*
      - 2.2: Series Circuits - *CC BY 4.0*
      - 2.3: Parallel Circuits - *CC BY 4.0*
      - 2.4: Series-parallel Circuits - *CC BY 4.0*
      - 2.5: Polarity and direction of current flow - *CC BY 4.0*
      - 2.E: Self-Test 2 - *CC BY 4.0*
    - 3: Electromagnetism - *CC BY 4.0*
      - 3.1: Magnetic Fields - *CC BY 4.0*
      - 3.2: Electricity and Magnetism - *CC BY 4.0*
      - 3.E: Self-Test 3 - *CC BY 4.0*
    - 4: Answer Key - *CC BY 4.0*
  - 2: Unit II- Common Circuit Components and Their Symbols - *CC BY 4.0*
    - 5: Circuit Components and their Schematic Symbols - *CC BY 4.0*
      - 5.1: Electrical systems - *CC BY 4.0*
      - 5.2: Conductors - *CC BY 4.0*
      - 5.3: Receptacles - *CC BY 4.0*
      - 5.4: Circuit Protection Devices - *CC BY 4.0*
      - 5.5: Circuit Control Devices - *CC BY 4.0*
      - 5.6: Lamps - *CC BY 4.0*
      - 5.7: Transformers - *CC BY 4.0*
      - 5.8: Solid state components - *CC BY 4.0*
      - 5.9: Capacitors - *CC BY 4.0*
      - 5.10: Light-emitting diodes (LEDs) - *CC BY 4.0*
      - 5.11: Sealed Components - *CC BY 4.0*
      - 5.12: Cells and Batteries - *CC BY 4.0*
      - 5.E: Self Test 1 - *CC BY 4.0*
    - 6: Wiring Diagrams - *CC BY 4.0*
      - 6.1: Symbols Used in Schematic Diagrams - *CC BY 4.0*
      - 6.2: Types of Electrical Diagrams - *CC BY 4.0*
      - 6.E: Self Test 2 - *CC BY 4.0*
    - 7: Common Circuit Characteristics - *CC BY 4.0*
      - 7.1: Series Circuits - *CC BY 4.0*
      - 7.2: Parallel Circuits - *CC BY 4.0*
      - 7.3: Voltage Source Circuits - *CC BY 4.0*
      - 7.4: Three-wire Power Supply System - *CC BY 4.0*
      - 7.E: Self-Test 3 - *CC BY 4.0*
    - 8: Answer Key - *CC BY 4.0*
  - 3: Unit III- Wiring Connections - *CC BY 4.0*
    - 9: Wiring Connections - *CC BY 4.0*
      - 9.1: Conductors - *CC BY 4.0*
      - 9.2: Soldered Connections - *CC BY 4.0*
      - 9.3: Solderless connectors - *CC BY 4.0*
      - 9.E: Self-Test 1 - *CC BY 4.0*
    - 10: Soldering Techniques - *CC BY 4.0*
      - 10.1: Solder Bonding - *CC BY 4.0*
      - 10.2: Soldering Tools - *CC BY 4.0*
      - 10.3: Soldering techniques - *CC BY 4.0*
      - 10.E: Self-Test 2 - *CC BY 4.0*
    - 11: Answer Key - *CC BY 4.0*
  - 4: Unit IV- Using Multimeters - *CC BY 4.0*