Block C: Routine Trade Activities and Electrical Concepts

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Plumbing Apprenticeship Program Level 1 Series

Block C: Routine Trade Activities and Electrical Concepts

BC Plumbing Apprenticeship, Level 1

SKILLEDTRADESBC

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Block C: Routine Trade Activities and Electrical Concepts of the Plumbing Apprenticeship Program Level 1 Series features Skilled Trades BC industry-authority content on the routine trade activities and foundational electrical concepts that support accurate, efficient, and code-compliant plumbing work. This block emphasizes the knowledge apprentices rely on to interpret information, apply standards, and make informed decisions on the job site.

In Block C, apprentices develop core skills in mathematics and science as they apply to the trades, build an understanding of basic electrical concepts and principles of electricity, and learn how to read and interpret drawings and specifications. The block also introduces codes, regulations, and standards, along with the effective use of manufacturer and supplier documentation. Together, these competencies help apprentices work safely, communicate clearly with other trades, and ensure installations meet required technical and regulatory expectations.

Plumbing Apprenticeship Program Level 1 Series

The *Plumbing Apprenticeship Program Level 1 Series* offers comprehensive training materials designed to build on foundational skills and knowledge. The series is divided into four main blocks, each focusing on critical areas of plumbing systems and installations.

Block A: Safety Related Functions

A-1: Workplace Hazards
A-2: WorkSafeBC Regulations
A-3: Safe Handling of Hazardous Materials
A-4: Personal Safety Practices
A-5: Fire Safety

Block B: Tools and Equipment

B-1: Use Hand Tools and Measuring Tools
B-2: Use Portable Power Tools and Use
B-3: Use Access Equipment
B-4: Use Rigging, Hoisting, Lifting and Positioning Equipment, and Rigging
B-5: Use Soldering and Brazing Equipment and Oxy-Fuel Cutting Equipment
B-6: Use Welding Equipment

Block C: Routine Trade Activities and Electrical Concepts

C-1: Mathematics and Science
C-2: Electrical Concepts and Principles of Electricity
C-3: Drawings and Specifications

C-4: Codes, Regulations and Standards
C-5: Manufacturer and Supplier Documentation

Block D: Piping and Components

D-1: Install Pipe and Tubing
D-2: Install Valves
D-3: Install Fittings
D-4: Penetrate Structures

Plumbing Apprenticeship Program Overview and Upcoming Resources

- **Plumbing Apprenticeship Program Level 1 Series** can be found in the TRU Open Press Collection.
- **Plumbing Apprenticeship Program Level 2 Series** can be found in the TRU Open Press Collection.
- **Plumbing Apprenticeship Program Level 3 Series** can be found in the BCCampus Open Collection.
- **Plumbing Apprenticeship Program Level 4 Series** can be found in the BCCampus Open Collection. (Block F: Commission and Service will be available soon.)

Disclaimer

The materials in these Learning Guides are intended for use by students and instructional staff. They have been compiled from sources believed to be reliable and to represent the best current opinions on these subjects. These manuals are designed to serve as a starting point for good practices and may not cover all minimum legal standards. No warranty, guarantee, or representation is made by the BC Piping Trades Articulation Committee, the Skilled Trades BC authority, or the King’s Printer of British Columbia regarding the accuracy or sufficiency of the information contained in these publications. These manuals aim to provide basic guidelines for piping trades practices. Therefore, do not assume that all necessary warnings and safety precautions are included, and additional measures may be required.

Safety Advisory

The current Standards and Regulation in BC can be obtained at the WorkSafeBC website: http://www.worksafebc.com

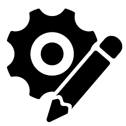
Please note that it is always the responsibility of any person using these materials to inform themselves about the Occupational Health and Safety Regulation pertaining to their areas of work.

[From previous 2021 book – confirm this message with Skilled Trades]

Symbol Legend


Important Information

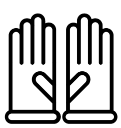

Potentially Toxic/ Poisonous Situation


Required or Optional Resources


Potentially Flammable Situation


Complete a Self-Test


Possibly Explosive Situation


Use Protective Equipment


Potential Electric Shock

Acknowledgements

The development of the *Plumbing Apprenticeship Level 1* learning resources was a collaborative effort driven by a commitment to excellence in trades education. These resources were created to support apprentices and journeypersons in mastering the skills and knowledge essential to the piping trades. This achievement would not have been possible without the dedication and expertise of *Skilled Trades BC* and the *Piping Trades Articulation Committee*, whose contributions, leadership, and guidance have been instrumental in shaping high-quality, industry-aligned training resources. We extend our sincere gratitude for their contributions and ongoing stewardship in advancing the piping trades.

The content for *Block C: Routine Trade Activities and Electrical Concepts* is adapted from the Piping Trades Apprenticeship Program from SkilledTradesBC (2019 Harmonized) and the Trades Access Common Core (TACC) resources developed by Camosun College, created in 2015 and revised in 2019, and made available through BCcampus:

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

The original materials were produced in collaboration with industry partners and aligned with the Industry Training Authority (ITA)/SkilledTradesBC harmonized program outlines for Plumbing, Steamfitting/Pipefitting, and Sprinkler Fitting. These works were released under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence, except where otherwise noted.

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This adapted version has been reformatted and integrated into the current Thompson Rivers University/TRU Open Press open educational resource in collaboration with the BC Piping Articulation and Curriculum Subcommittee and SkilledTradesBC, in support of open, accessible, and up-to-date apprenticeship training.

The Open Press

The Open Press combines TRU's open platforms and expertise in learning design and open resource development to support the creation and reuse of open educational resources, while encouraging open scholarship and research.

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Resources

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- Open School BC
- Camosun College
- Trades Training BC

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To order printed copies of Program Outlines or learning resources (where available) for BC Trades, contact:

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Land Acknowledgement

Thompson Rivers University (TRU) campuses are situated on the ancestral lands of the Tk'emlúps te Secwépemc and the T'exelc within Secwepemcúl'ecw, the ancestral and unceded territory of the Secwépemc. The rich tapestry of this land also encompasses the territories of the St'át'imc, Nlaka'pamux, Tŝilhqot'in, Nuxalk, and Dakelh. Recognizing the deep histories and ongoing presence of these Indigenous peoples, we express gratitude for the wisdom held by this land. TRU is dedicated to fostering an inclusive and respectful environment, valuing education as a shared journey. TRU Open Press, inspired by collaborative learning on this land, upholds open principles and accessible education, nurturing respectful, reciprocal relationships through the shared exchange of knowledge across generations and communities.

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If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video: Introducing SkilledTradesBC

Starting December 1, 2022, Industry Training Authority was officially renamed to SkilledTradesBC. Hear more in this video from SkilledTradesBC CEO, Shelley Gray, on what this means for the trades industry and British Columbians. Closed captioning and transcripts are available with this video, Introducing Skilled Trades BC (2022) on YouTube.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2618

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References

Camosun College. (n.d.). *Line D: Organizational Skills*. BCcampus. https://collection.bccampus.ca/textbook/qFKGAJ78/

SkilledTradesBC. (2025). Plumber program outline (Implementation date: August 18, 2025; Last revised: December 16, 2025) [PDF]. Province of British Columbia. https://skilledtradesbc.ca/media/2776/download

SkilledTradesBC. (2022, December 1). Introducing Skilled Trades BC. YouTube. https://www.youtube.com/watch?v=OQgwdP0rNog

Accessibility

The web version of *Block C: Routine Trade Activities and Electrical Concepts* has been designed to meet Web Content Accessibility Guidelines 2.0, level AA. In addition, it follows all guidelines in Appendix A: Checklist for Accessibility of the Accessibility Toolkit – 2nd Edition.

Includes:

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Links	Links do not open new windows or tabs. If they do, a textual reference is included in the link text.	
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H5P	All H5P activities that include images, videos, and/or audio content meet the accessibility requirements for those media types.	
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- Some tables may use merged cells, but they have been structured to work properly with screen readers and there may be long descriptions included in each section if readers prefer to see the table data in a bulleted list.
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Other Formats Available

- In addition to the web version, this book is available in a number of file formats, including PDF. The Print PDF has passed our Accessibility Check.

C-2 ELECTRICAL CONCEPTS AND PRINCIPLES OF ELECTRICITY

Plumber Apprenticeship Program – Level 1

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C-2 Electrical Concepts and Principles of Electricity Introduction

Understanding the basic principles of electricity is important for working safely and effectively in the trades. In this section, you will learn how electricity behaves, how circuits work, and how to read and use electrical information in practical situations.

Learning Objectives

After completing this section, you should be able to:

- Describe electron theory and the causes of electricity.
- Explain how electrical circuits work.
- Interpret basic wiring diagrams and electrical symbols.
- Measure electrical quantities using appropriate tools.
- Apply the principles of electricity to trade-related tasks.
- Use mathematics and science to help you solve trade-related problems.

Topic areas covered in this publication are in alignment with SkilledTradesBC Harmonized 2018 Program Outlines.

You will be required to reference publications and videos available online at WorkSafeBC.

Supplementary Resources

- Trades Access Common Core Line C: Tools and Equipment Videos – BCcampus by Camosun College.

Terminology

The following terms may be used throughout this section. Note that some glossary terms may be in italics throughout the section content but are not included in this list. A complete list of terms for Section C-2 can be found in the **Glossary.**

- **AC generator:** A machine that makes electricity by spinning a coil or magnet, producing alternating current (AC). (Section C-2.1)
- **alternating current (AC):** Electricity that flows back and forth in a circuit many times per second. (Section C-2.1)
- **American wire gauge (AWG) system:** A standard way to measure how thick electrical wires are. Smaller numbers mean thicker wires. (Section C-2.1)
- **ammeter:** A tool used to measure how much electrical current is flowing in a circuit. (Section C-2.1)
- **Ampere's Force Law:** A law that explains how electricity flowing through a wire creates a magnetic force that can act on other wires carrying current. (Section C-2.1)
- **anode:** The electrode where electric current leaves a device or where oxidation happens in a chemical reaction. (Section C-2.1 and Section C-2.2)
- **block diagram (functional block diagram; block and line diagram)**: A diagram that shows how parts of a system work together in steps. (Section C-2.3)
- **cathode:** The electrode where electric current enters a device or where reduction happens in a chemical reaction. (Section C-2.1)
- **cation:** A positively charged ion (an atom that has lost electrons). (Section C-2.1)
- **circuit breaker:** A safety device that automatically shuts off electricity when too much current flows. (Section C-2.1)
- **clamp-on ammeter**: A tool that measures current by clamping around a wire without touching it directly. (Section C-2.4)
- **closed circuit:** A complete path that allows electricity to flow. (Section C-2.1)
- **conductor:** A material, usually metal, that allows electricity to flow easily. (Section C-2.1)
- **continuity**: When electricity can flow through a circuit without a break. (Section C-2.4)
- **coulomb:** A unit used to measure electric charge. (Section C-2.1)
- **current (amperage):** The flow of electrical charge through a circuit. (Section C-2.1)
- **direct current (DC):** Electricity that flows in one direction only. (Section C-2.1)
- **electrical symbols:** Simple drawings used to represent electrical parts in a diagram. (Section C-2.3)
- **electrical circuit:** A complete path that allows electricity to travel from a source, through components, and back again. (Section C-2.1)
- **electricity:** The flow of tiny particles called electrons through a material, usually a wire. (Section C-2.1)
- **electromagnetism:** The force created by electricity and magnetism working together, such as when electric current makes a magnet. (Section C-2.1)
- **electromotive force (EMF):** Another name for voltage; the force that pushes electricity through a circuit. (Section C-2.2)
- **fuse:** A safety device that melts and breaks a circuit if too much current flows. (Section C-2.1)
- **induction:** The process of creating electrical current using a changing magnetic field. (Section C-2.1)
- **in series**: A way of connecting a meter so that electricity must flow through the meter as part of the circuit, allowing all the electrical current to flow through it before moving on. (Section C-2.4)
- **load:** A device that uses electrical energy to do work, such as producing heat, light, or motion. (Section C-2.1)
- **magnetic field:** An invisible area around a magnet or electrical current where magnetic forces can be felt.

(Section C-2.1)

- **milliamps (mA):** A unit used to measure small electrical currents; 1 milliamp equals 0.001 amps; small amounts of electrical current measured by a meter, where one milliamp equals one-thousandth of an amp. (Section C-2.4)
- **multimeter:** A tool that can measure voltage, current, and resistance in a circuit. (Section C-2.3; Section C-2.4)
- **Ohm's law:** A rule that shows the relationship between voltage, current, and resistance in a circuit. (Section C-2.1)
- **open circuit:** A broken path that prevents electricity from flowing. (Section C-2.1)
- **parallel circuit:** A circuit with more than one path for electricity to flow. (Section C-2.1)
- **pictorial diagram (or schematic):** A diagram that shows electrical parts as they actually look in real life. (Section C-2.3)
- **polarity:** The arrangement of positive and negative connections in a circuit, which determines the direction electricity flows; the correct way to connect meter leads to positive (+) and negative (−) points so the meter reads properly. (Section C-2.4)
- **power:** The rate at which electrical energy is used or converted into other forms of energy. (Section C-2.1)
- **relay:** An electrically controlled switch that uses a small current to control a larger one. (Section C-2.1)
- **resistance:** The opposition to the flow of electrical current in a circuit. (Section C-2.1)
- **schematic diagram (ladder diagram):** A diagram that uses symbols to show how an electrical circuit works. (Section C-2.3)
- **series circuit:** A circuit with only one path for electricity to follow. (Section C-2.1)
- **single-phase power:** A type of electrical power that uses one alternating voltage supply, commonly found in homes. (Section C-2.1)
- **solenoid valve:** A valve that opens or closes using an electric current and a magnetic coil. (Section C-2.1)
- **switch:** A device used to open or close a circuit to control the flow of electricity. (Section C-2.1)
- **thermocouple:** A device made of two different metals that produces a small voltage when heated, used to measure temperature. (Section C-2.1)
- **thermoelectricity (thermoelectric effect):** The creation of electricity from heat differences between two materials. (Section C-2.1)
- **three-phase power:** A type of electrical power that uses three alternating voltages, commonly used in commercial and industrial settings. (Section C-2.1)
- **transformer:** A device that increases or decreases voltage in an alternating current (AC) circuit. (Section C-2.1)
- **voltage:** The electrical pressure that pushes current through a circuit. (Section C-2.1)
- **voltage drop:** The loss of voltage as electricity moves through a circuit or component. (Section C-2.1)
- **voltmeter:** A tool used to measure the voltage between two points in a circuit. (Section C-2.3)
- **wiring diagram:** A drawing that shows how wires and components are connected in a circuit. (Section C-2.3)
- **watt (W):** The unit used to measure electrical power. (Section C-2.1)

C-2.1 Electron Theory and Causes of Electricity

Electricity

Electricity is a form of energy that has the ability to do work. Energy cannot be created or destroyed; it merely changes from one form to another. Electricity is the movement of ***electrons***, and it can be converted to ***light energy***, ***mechanical energy***, and ***heat energy***. These electrons can be harnessed, stored and put to work. To understand how this is done, the theory of the electron must be examined.

Pipe trades workers are required to use electricity daily and require a basic understanding of the predictable and measurable nature of electricity and ***electrical circuits***. Understanding electricity is crucial for the following:

- Using, troubleshooting, and maintaining electrical power tools
- Installing, troubleshooting, and servicing electrical appliances like hot water storage tanks, boilers and pumps
- Installing and troubleshooting electrical control systems like those found in heating and cooling
- Using multimeters safely

Matter

All *matter*, whether it is solid, liquid, or gas (Figure 1), is composed of tiny particles called ***atoms***. Millions of these atoms could be placed on the head of a pin and still not be seen. Atoms are composed of three even smaller particles: *electrons*, ***proton****s*, and ***neutron****s* (Figure 2).

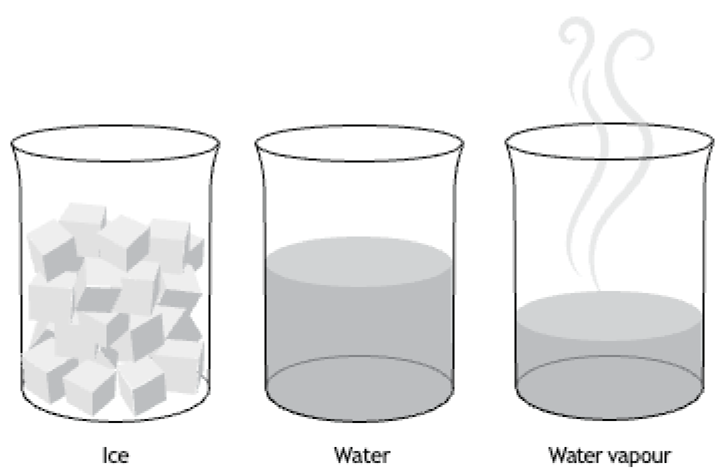

Figure 1 *States of matter (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

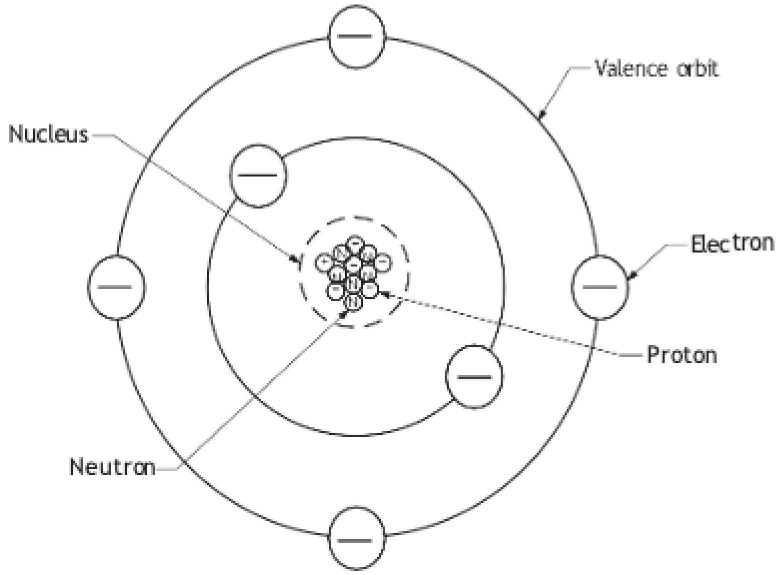

Figure 2 *The atom (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Atoms look very much like miniature solar systems. The sun is the core of the solar system; within the atom, the core is the *nucleus*, consisting of protons and neutrons tightly bound together. The sun has planets revolving around it; the atom's "planets" are its electrons, which revolve around it at extremely high speeds (approximately 299,792 km/s or 186,000 miles/s).

In the solar system, the gravitational pull of the sun (its nucleus) holds its planets in orbit around it. The atom differs in that the protons and electrons are ***charged particles*** that attract one another, holding the atom together. Electrons have a negative (−) charge, and protons have a positive (+) charge. Neutrons are neutral and have no charge. Since opposite charges attract and like charges repel, the oppositely charged protons and electrons attract one another, holding electrons in orbit around the nucleus.

Electron orbits, called *shells* (Figure 3), vary in their distance from the nucleus. The electrons farthest from the nucleus are not bound as strongly to the atom. Atoms with one to three electrons in their outermost, or ***valence shell***, are considered to be ***conductor***s. Under certain conditions, electrons in the valence shell can be knocked out of their orbits and become "free" electrons.

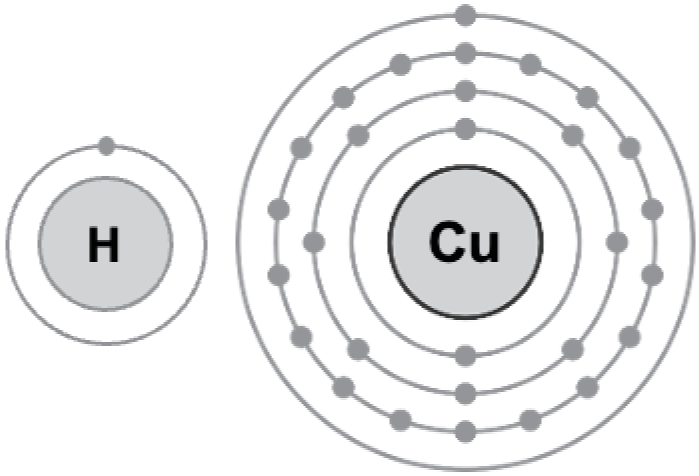

Figure 3 *Orbital shells of hydrogen and copper (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

When this happens, an atom has more protons than electrons and is said to be *ionized*. In this condition, the atom has a positive charge and is called a ***cation***. Since atoms normally have an equal number of protons and electrons, the positively charged atom would then try to pick up a stray electron to balance itself. This new electron might come from an atom nearby that may be experiencing the same condition that excited its atoms, and the process would repeat. Thus, there is a flow of electrons from atom to atom, and this is called ***electricity***.

Fundamentals of Magnetism

A basic understanding of ***magnetism*** will help in your understanding of electricity. There are three classes of magnets: natural, artificial, and electric. Natural magnets, such as ***magnetite***, are very weak and are not commonly used in the trades.

Artificial magnets are made from magnetic material such as iron, nickel, or cobalt and are permanently induced with magnetic force (magnetized) during their construction. They are used in devices such as electric motors, credit cards, and speakers.

The ***electromagnet*** is created by pushing a current through a coiled conductor and can be turned on and off.

All magnets have specific rules that govern their operation:

1. Magnets have two poles, north and south. Like poles will repel, and unlike poles will attract. This rule highlights the magnetic force associated with magnets and explains the science behind a compass.
2. Magnetic lines of force (flux lines) are continuous and form loops from the north pole to the south pole.

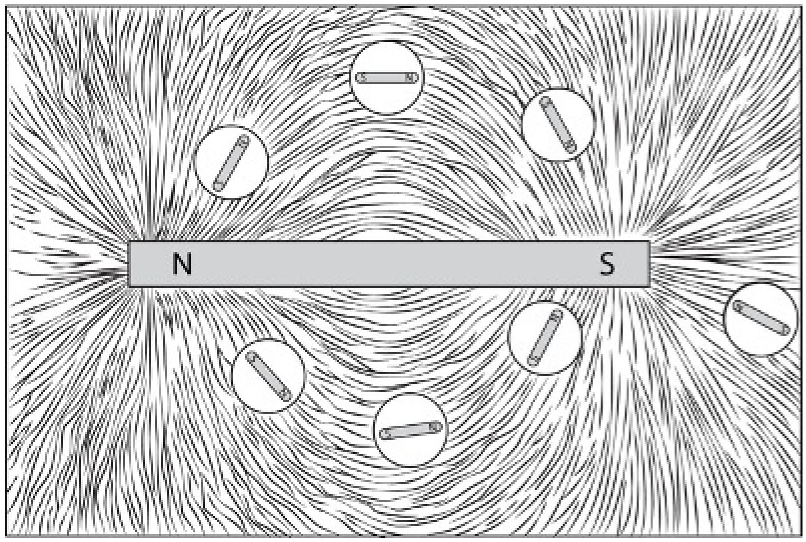

Figure 4 *Magnetic lines form loops (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

3. Magnetic lines of force never cross. This is illustrated in Rule 1: like poles repel. As these lines cannot cross, they must act against each other.

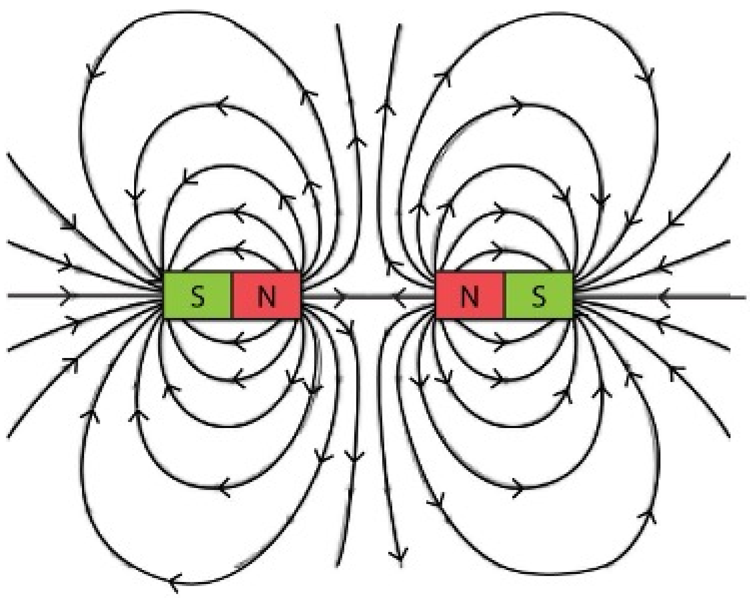

Figure 5 *Magnetic lines never cross (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

4. Lines of flux form tight loops when unlike poles attract. This is illustrated in Rule 1: unlike poles attract. These tight loops act like rubber bands constricting, forcing two magnets to become one.

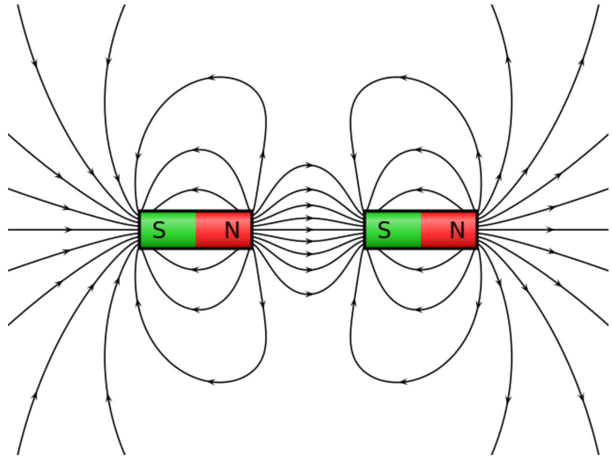

Figure 6 *Lines of flux form tight loops (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

5. Magnetic lines of force can pass more easily though materials that can be magnetized. This property is called *permeability*, the measure of response to a magnetic field of force.
6. There is NO insulation against magnetic lines of force.

Electricity and Magnetism

Electricity and magnetism are directly related. If a current is pushed through a ***conductor***, magnetic lines of force, or magnetic force, are created around it. If a conductor moves through a magnetic field, or a magnet moves through a coiled conductor, the moving magnetic field will induce a ***voltage*** potential. The faster the magnet moves, the stronger the voltage.

We see this phenomenon of ***electromagnetism*** in the generation of AC current, where kinetic energy, like falling water through a hydro dam, turns a conductor through a magnetic field called an ***AC generator***, producing *voltage* potential. We see it in equipment such as a ***solenoid valve***, where a current flow actuates a *valve stem* to control flow of fluid through the valve or a current pushed through a coil around a magnet moves an electrical motor. In each, the higher the voltage potential, the stronger the magnetic force, and vice versa.

We see the relationship between electricity and magnetism in ***Ampere's Force Law*** that explains the magnetic force of attraction and repulsion by two wires carrying current. Taken further, this law explains what happens when a conductor is formed into a loop (see Transformers in C-2.2 Electrical Circuits).

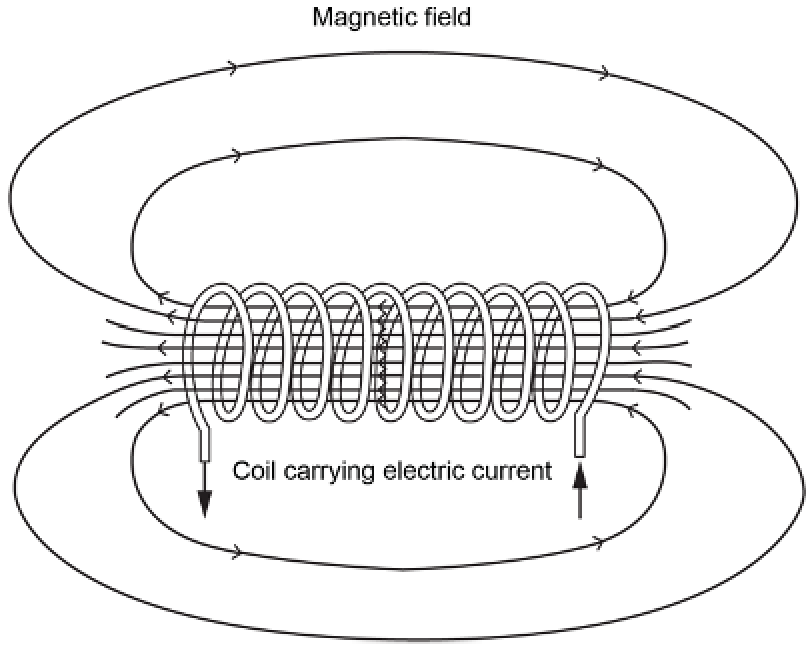

Figure 7 *Conductor formed into a loop (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

Conductors

To use electrons (electricity) to do work, they must be transported from one place to another. Electrons can be made to flow in all matter; however, this flow is much easier in some kinds of matter than others. The atoms of some matter tend to hold on to their valence electrons very tightly, while other forms of matter easily lose their valence electrons. To transport electrons, select material that permits easy flow. These materials are called ***conductor***s. Examples of good conductors are silver, copper, aluminum and mercury. Conductive material is usually formed into wire. Wire permits easy transportation of electrons over great distances.

Conductors in the form of wires are one of the four basic components of an electric circuit. Conductors are not all equal in composition, and there are possible dangerous consequences of choosing the wrong size or type of conductor.

The quantity of electrons that can be safely transferred by a conductor depends upon the diameter of the conductor (Figure 8). If too many electrons flow through a small conductor, large amounts of heat are generated and, as the undersized conductor heats up, the wire's ***resistance*** tends to rise, creating a feedback loop that has the potential for fire. Therefore, the cross-sectional area of a conductor is the basis for sizing conductors or wire. Conductors are sized according to gauge numbers. In the ***American wire gauge* (AWG)** system of wire sizing, the lower the gauge number, the larger the cross-sectional area and the greater the flow of electrons (simplified: "lower number = thicker wire"). AWG, along with wire material selection, factors in the choosing of an appropriate conductor in a given system. Actual conductor selection goes beyond the scope of this material.

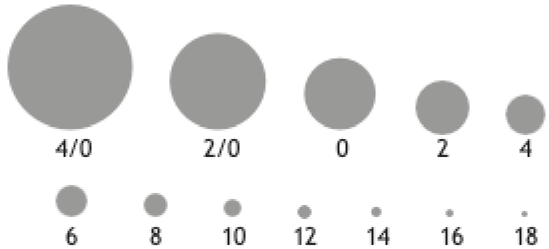

Figure 8 *Conductor wire sizes (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Insulators are materials with extremely low conductivity (Figure 9). They have five to seven electrons in their ***valence shell*** and cling tightly to their valence electrons. Some examples of good insulators are rubber, wood, glass, and cork. The properties of conductors and insulators are essential in utilizing electricity. Conductors put electricity where it is needed, while insulators isolate the flow of electricity.

Figure 9 *Insulators (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Sources of Electromotive Force

It is necessary to have a force or pressure to make electricity flow through a path called a ***circuit***. Electrical pressure, like most other pressures, is a force. It is this force that creates the action and keeps the electrons moving in a circuit. This electrical pressure is called ***electromotive force (EMF)*** and is measured in units called ***volts***. Voltage is the potential pressure difference measured between two points in an electrical circuit, and 6.24 quintillion (6.24 × 1018) electrons gathered at one point are known as a ***coulomb*** of potential. Voltage potential describes the source in a circuit, such as a storage battery or an AC source, and is one of the four basic components of an electric circuit.

There are six principal causes of electromotive force or potential:

- Heat
- Magnetism
- Chemicals

- Pressure
- Friction
- Light

Heat

When heat is applied to two dissimilar metals at the point where they are joined, electrons move from one metal to the other, and electricity is produced. This method is known as ***thermoelectricity*** and is called the ***thermoelectric effect***.

The more heat applied, the greater the amount of electric charge produced. The electric charge created is a result of differences in temperatures within the hot and cold junctions of the metals and the different ability that each metal has in holding on to its electrons. Each of the metals responds to the difference in temperature in different ways. Electrons will flow from the material that gives up its electrons easily (the ***anode***) to the other material, which has a greater tendency to hold on to its electrons (the ***cathode***).

A good example of this method of generating electricity used in the heating trade is a ***thermocouple*** (Figure 10). A thermocouple is made of two dissimilar metals welded together at the tip. When a pilot flame is directed at the tip of a thermocouple, a charge of electricity is created at the thermocouple's ***cold junctions***. The connection of the cold junctions to a safety shutoff valve causes current to flow through a coil of wire within the valve, energizes an electromagnet that holds the valve in the open position, and allows gas to flow to the appliance.

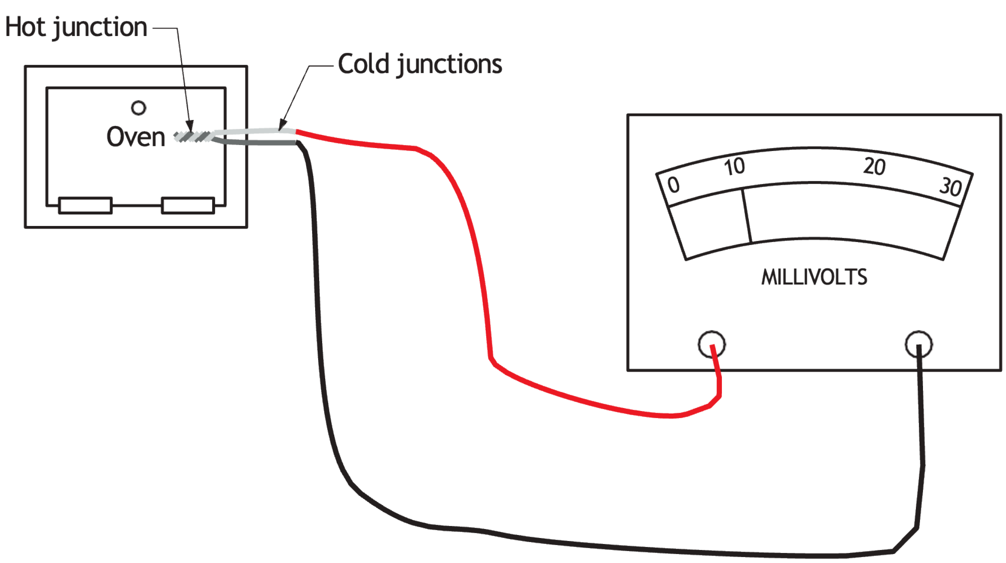

Figure 10 *Heat used to generate electricity (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Magnetism

Moving a ***conductor*** through a *magnetic field*, or moving a magnetic field across a conductor, induces a ***voltage*** and causes an electric current to flow. This process, known as ***electromagnetic induction***, is a key principle of *electromagnetism*, and is used to generate alternating current (AC) electricity using permanent magnets.

The pressure of water or steam, as found in a nuclear or natural gas power plant, is used to rotate a coil of wire between the north and south poles of a magnetic field (Figure 11). The movement of the coil within the magnetic field induces current and voltage within the coil.

Watch the following video by Science ABC (2024) on YouTube titled "Electromagnetism Explained in Simple words" [4:13].

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2411#oembed-1

If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video: Electromagnetism Explained in Simple Words

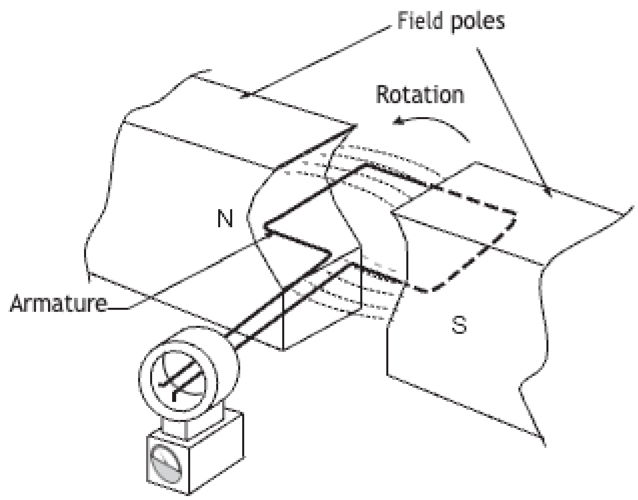

Figure 11 *Electricity created through magnetism (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Split-ring commutators, brushes and other devices are used to harness this energy, which is called ***alternating current (AC)***. In North American–generated voltage, current and voltage build up and drop off in a positive cycle, then build up and drop off in the opposite direction 60 times every second, a frequency of 60 ***hertz (Hz)***. In Europe, the generators are turned at slightly slower speeds, causing AC electricity to be generated at a frequency of 50 cycles per second, or 50 Hertz.

Chemicals

Batteries produce electricity through ***electrochemical reactions***. Each battery (or cell) contains electrodes and an electrolyte that allow charged particles to move. This process, called ***electrochemistry***, produces ***direct current (DC)*** electricity.

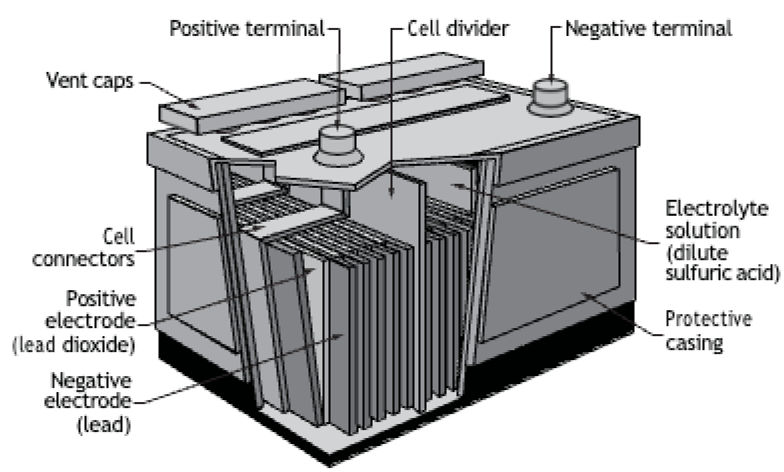

Figure 12 *Automobile battery (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

All batteries contain one or more cells, but people often use the terms battery and cell interchangeably. A cell is just the working chemical unit inside a battery; one battery can contain any number of cells. A cell has three main parts: a positive electrode (cathode), a negative electrode (anode), and a liquid or paste in contact with them called the ***electrolyte*** (Figure 12). When a battery is externally connected to an electric circuit, a chemical reaction takes place in the electrolyte. This causes ions (in this case, atoms with a positive electrical charge) to flow through the electrolyte in one direction, with electrons (particles with a negative charge) flowing through the outer circuit in the other direction. This movement of electric charge makes an electric current flow through the cell and through the circuit it is connected to.

It's important to note that **the electrodes in a battery are always made from two dissimilar materials.** This is the key to how and why a battery works: one of the materials, the anode, readily gives up electrons; the second material, the cathode, readily receives electrons. If both electrodes were made from the same material, there would be no exchange of electrons and no current would flow. This phenomenon is seen in a serious nuisance condition called ***electrolysis***, occurs naturally in metal systems such as underground pipelines, and causes material corrosion.

Pressure

Applying pressure to certain materials produces electricity. This is called ***piezoelectricity***. The force of the pressure passes through the material to its atoms and drives the electrons out of orbit toward the force. Positive and negative charges are built up on opposite sides of the material.

The effect is most noticeable in crystal materials. Piezoelectricity can be seen clearly in an ordinary spark igniter used to light a gas barbecue (Figure 13).

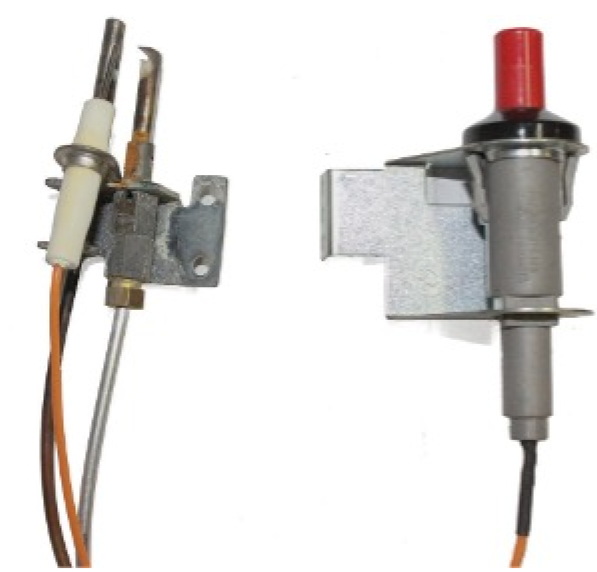

Figure 13 *Piezo igniter assembly (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Friction

If you walk across a carpet and get a shock when you touch a metal doorknob, or get a jolt from the door handle of a car, you have experienced the creation of electricity through ***friction***, which is known as ***triboelectricity or static electricity***. This occurs when two dissimilar materials are rubbed together, causing electrons to migrate to one of the materials. A path for the electrons to get to ground is completed when you touch the energized material and are in contact with the earth or ground through your feet. Large trucks carrying gasoline drag chains to constantly discharge any buildup of static electricity so that there cannot be any spark created once the truck stops moving. Lightning is an extreme effect of static discharge.

Light

Light is another form of energy and is thought to consist of small particles of energy called ***photons***. When a light beam strikes certain materials (including potassium and sodium), the energy from the photons causes the atoms to release electrons. This is called ***photoelectricity*** or the *photoelectric effect* (Figure 14). The best example of this is using the sun to generate electricity. Also known as ***photovoltaics***, using solar panels to generate electricity has become common these days.

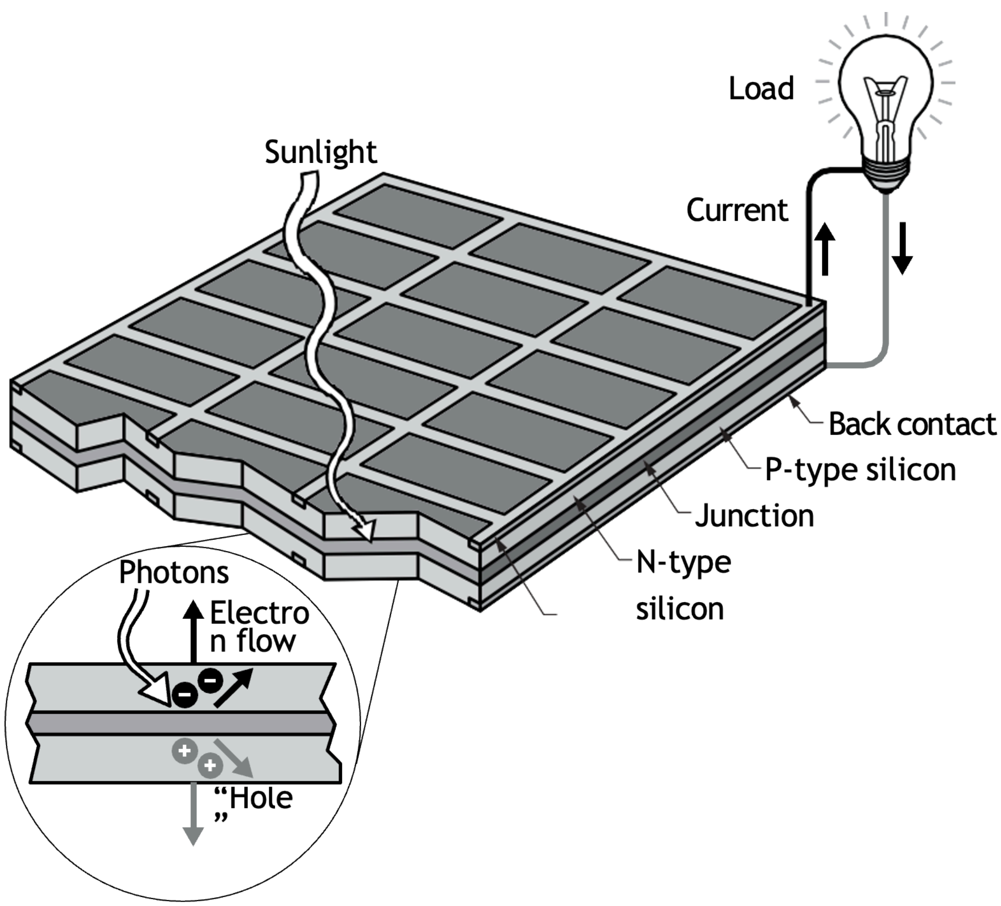

Figure 14 *Photoelectricity (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

Of these six causes of electricity, all but magnetism cause direct current (DC) voltage; magnetism or *electromagnetic induction* causes alternating current or (AC) voltage.

Self-Test C-2.1: Electron Theory and Causes of Electricity

Complete Self-Test C-2.1 and check your answers.

If you are using a printed copy, please find Self-Test C-2.1 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2411#h5p-29

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- Sprinkler Fitter: Competency C-1 Use Mathematics and Science

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Media Attributions

C-2.2 Electrical Circuits

Electrical circuits operate using three fundamental concepts: ***voltage***, ***current***, and ***resistance***. These concepts describe how electrical energy is supplied, how it flows, and how it is controlled within a ***circuit***. Understanding these three ideas is essential before working with any powered equipment or electrical components in the piping trades.

Voltage, Amperage and Resistance

To illustrate the three concepts involving an electrical circuit, consider a tank filled with water to a certain level as an analogy. At the bottom of this tank, there is a hose. If the hose is capped off, there will be head pressure available due to gravity but no flow will occur unless the cap is removed. This available pressure can be compared to ***voltage*** in an electrical circuit (Figure 1).

Voltage

Voltage is the electrical pressure or potential created by one of the six methods mentioned earlier: friction, pressure (piezoelectricity), heat (thermoelectric effect), light (photoelectric effect), chemical action, and magnetism (electromagnetic induction). This pressure is needed to push electrons through a circuit. One ***coulomb*** of electrical charge is defined as 6.28 quintillion (6.28×10^{18}) electrons, and 1 ***volt*** is defined as the electrical pressure needed to force 1 coulomb of charge through 1 ohm of resistance in 1 second. Voltage is the difference in potential between two points in a circuit, and without a source of voltage there can be no current flow.

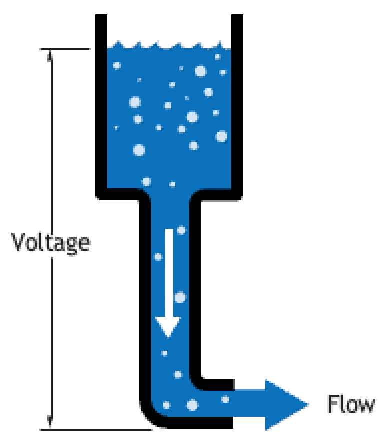

Figure 1 *Voltage (electrical pressure) (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

Amperage

As electrons flow through a ***conductor***, their quantity can be measured. One method of measuring electron flow would be to select a single point on a conductor and count the electrons that pass that point. Since electrons are extremely small, it would be impractical. Instead, electron flow (or ***current***) is measured in large units called ***amperes (or amps)***. One ampere is 1 coulomb of charge passing a given point in a circuit in 1 second. It is the flow of current (amperage) that produces work in a circuit. Current must flow in order for lights to light or motors to turn.

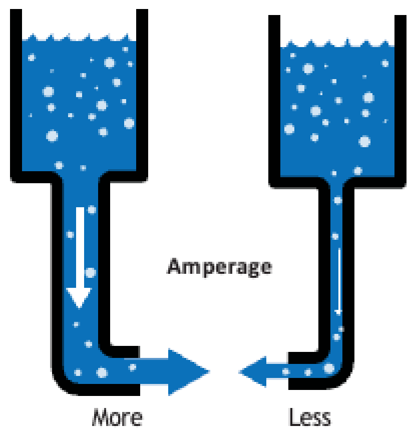

Figure 2 *Amperage (current flow) (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

In our illustration, the amount of water flowing through the hose from the tank can be compared to ***current*** (Figure 2). The higher the water level, the higher the pressure and the higher the flow rate of water through the hose. A larger hose also allows a higher flow rate. With water, we measure flow as volume of water flowing through the hose over a certain period of time, usually expressed in gallons per minute or litres per second. Conductors (wires) in an electrical circuit are sized on their ability to carry amperage without causing excessive heat build-up.

Resistance

Resistance is generally associated with a ***load***, a basic component of an electric circuit that converts electricity into work. As electrons flow through a conductor, they have a tendency to crowd and push other atoms and electrons. This crowding is minimal and causes little resistance in the conductor. However, a load acts much like a funnel, in that it causes a greater crowding of the electrons and restricts flow. This resistance to flow creates heat as a byproduct, and in the case of a toaster or electric kettle this heat is desirable (Figure 3). However, when electricity is converted to light or mechanical energy (such as in a light bulb or motor), heat is an undesirable byproduct. Conductors must be sized to minimize this heat buildup. Resistance to current flow is measured in units called ***ohms***. In an AC circuit, an additional factor called ***impedance*** opposes electron flow. Impedance is also measured in ohms. For the sake of ease, we will use the term *resistance* to describe impedance in an AC circuit.

Figure 3 *Glowing filaments of a modern toaster (Nick Carson/en.wikipedia)*

Consider two water tanks: one with a narrow pipe and one with a wide pipe. A wider pipe can transport more volume than a narrow pipe under the same pressure. The narrow pipe "resists" the flow of water through it even though the water is at the same pressure as in the tank with the wider pipe (Figure 4).

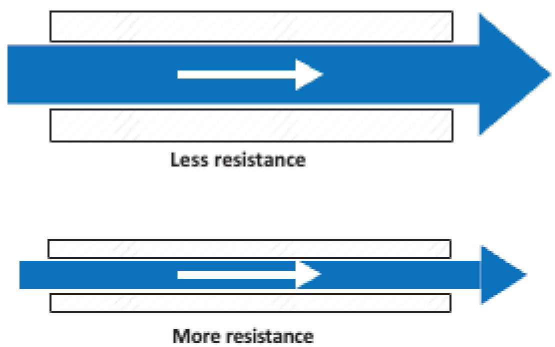

Figure 4 *Resistance in narrower pipe (BC Industry Training Authority, 2019).*

Ohm's Law

In 1827, German physicist Georg Simon Ohm discovered that there is a calculable relationship between electrical pressure, resistance, and current flow in any circuit, and his published theory is called ***Ohm's law***. Stated as an equation, depending on which value is unknown, Ohm's law can be expressed in three variations:

$$E = I \times R \quad R = \frac{E}{I} \quad I = \frac{E}{R}$$

where

$$E = \text{electromotive force (EMF) measured in volts}$$

I = intensity of current measured in amperes or amps

R = resistance measured in ohms

The abbreviations for each are V for volts, A for amps and the Greek symbol Ω (omega) for ohms. The omega symbol is used instead of the letter O, which could cause confusion if numbers precede the symbol.

Ohm's law is commonly presented as a learning triangle (Figure 5) in order to make the relationship between the three electrical entities easier to understand.

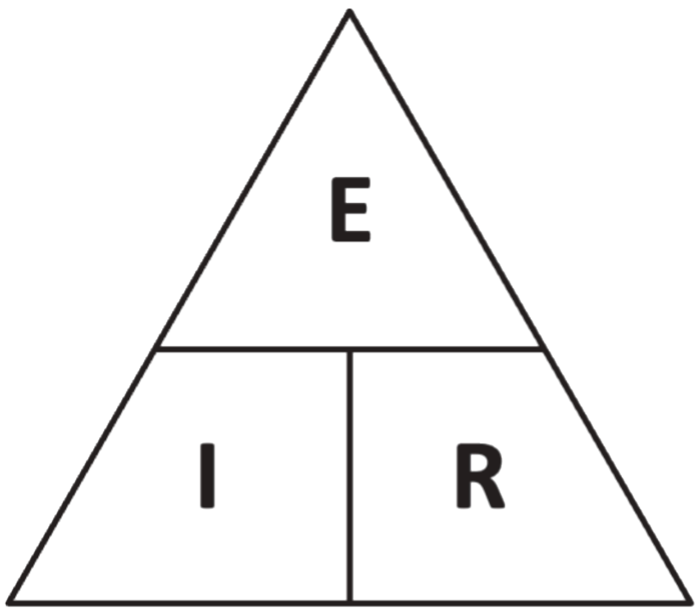

Figure 5 *Ohm's law triangle (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

Ohm's law states that it takes 1 volt to push 1 ampere through 1 ohm of resistance and is a useful tool to assess a circuit and find unknown values.

Watch the following video by Tradestutor (2020) on YouTube titled *Ohms law quick and easy* [4:17].

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2457#oembed-1

If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video:

Ohms law quick and easy

Ohm's Law Put to Use

Example 1.

A 12 V battery pushes 3 A of current through a circuit. What is the resistance found in this circuit?

Solution.

The unknown value is R, resistance.

Therefore $R = \frac{E}{I}$

$R = \frac{12V}{3A}$

Resistance $= 4\ \Omega$

Example 2.

Given a circuit with a resistance of 10 Ω, an EMF of 24 V, what is the current flow?

Solution.

The unknown value is I, amperage.

$$I = \frac{E}{R} \quad I = \frac{24\ V}{10\ \Omega} \quad I = 2.4\ A$$

Example 3.

If a circuit has a current flow of 2 amps and the resistance is 20 Ω, what is the pressure in volts?

Solution.

The unknown value is E, voltage.

$$E = I \times R \quad E = 2\ A \times 20\ \Omega \quad E = 40\ V$$

Power

Voltage potential pushes electron flow though a load that changes electrical energy into other forms of energy, such as ***kinetic energy*** (in a motor) or heat and light (in a lamp). This work performed by the load is described as ***power* (P)** and measured in ***watts* (W)**.

Power can be expressed as:

$$P = E \times I \quad E = \frac{P}{I} \quad I = \frac{P}{E}$$

Where:

$$E = \text{electromotive force, volts} \quad I = \text{intensity of current, amps} \quad P = \text{power, watts}$$

These relationships are often shown using a *Watt's law triangle* (Figure 6), which helps visualize the relationship between voltage, current, and power, and makes it easier to determine unknown values.

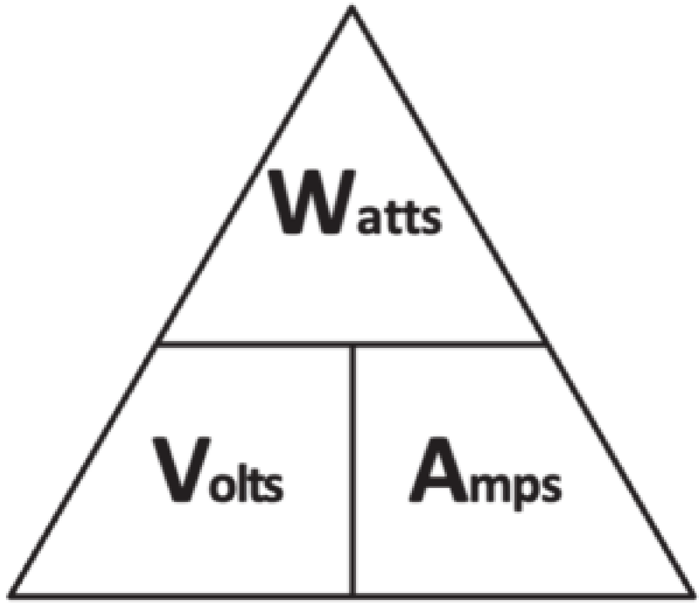

Figure 6 *Watt's law triangle* (*BC Industry Training Authority*, 2019). CC BY-NC-SA 4.0

Power Calculation Put to Use

Example 1.

\quad\text{What size [pb_glossary id="5466"]fuse[/pb_glossary] is appropriate for a 96 W bulb in a 12 V DC system?}

$$\mathrm{I} = \frac{\mathrm{P}}{\mathrm{E}} \quad \mathrm{I} = \frac{96\ \mathrm{W}}{12\ \mathrm{V}} \quad \mathrm{I} = 8\ \mathrm{A}$$

The fuse would need to be rated for more than 8 amps.

Example 2.

How much power would a soldering gun produce if it uses 6 A in a 120 VAC circuit?

$$\mathrm{P} = \mathrm{E} \times \mathrm{I} \quad \mathrm{P} = 120\ \mathrm{V} \times 6\ \mathrm{A} \quad \mathrm{P} = 720\ \mathrm{W}$$

Example 3.

Here we see how Ohm's law and the power calculation can be used together.

What is the correct theoretical resistance of a hot water tank element with a power rating of 4,500 W in a 240 VAC system? Note: this info, Watts and VAC, is given on the name plate of an element.

$$\mathrm{I} = \frac{\mathrm{P}}{\mathrm{E}} \quad \mathrm{I} = \frac{4,500\ \mathrm{W}}{240\ \mathrm{V}} \quad \mathrm{I} = 18.75\ \mathrm{A} \quad \mathrm{R} = \frac{\mathrm{E}}{\mathrm{I}} \quad \mathrm{R} = \frac{240\ \mathrm{V}}{18.75\ \mathrm{A}} \quad \mathrm{R} = 12.8\ \Omega$$

Summary

Electricity flowing through a conductor can be compared to water flowing through a hose. The voltage that forces electrons to flow through the conductor is comparable to the water pressure or ***psi*** that forces water through the hose. The amperage is the number of electrons that pass through the conductor and compares to the number of gallons of water that pass any given point over time. Resistance is similar to the friction between the water and the walls of the hose. In any electrical circuit, it is the electrical pressure or voltage from the source that causes electrons to flow, and in most circuits, this voltage is kept fairly constant. The amount of electron flow or amperage depends upon the resistance in the circuit. If the total resistance in the circuit is high, then the amperage will be low, and vice versa. If at any time the resistance of a given circuit is changed, then the amperage will also change.

Using Electric Current

For electric current to be usable, it must be able to travel from the source through the conductor to the load and then back to the source. As mentioned earlier, the source produces one of two basic types of electric current: *alternating current* (AC) or *direct current* (DC). Each has unique properties that make it more desirable than the other under certain circumstances.

Direct current (DC)

As mentioned earlier, chemicals, heat, pressure, light, and friction are all causes of direct current or DC voltage.

A battery is a common source of ***direct current (DC)*** (Figure 7). A battery will always have two poles or terminals: one negative and one positive. A chemical reaction inside the battery between the anode and the cathode causes electrons to move through an *electrolyte* (acid or alkali) to the negative terminal, giving it a negative (−) electrical charge (creating electrical flow). The other terminal has a corresponding lack of electrons, making its charge positive (+). If a wire is connected from a negative terminal to a light bulb and then to a positive terminal, electrons will flow through the conductors from the negative terminal to the positive terminal through the bulb, and the bulb will light.

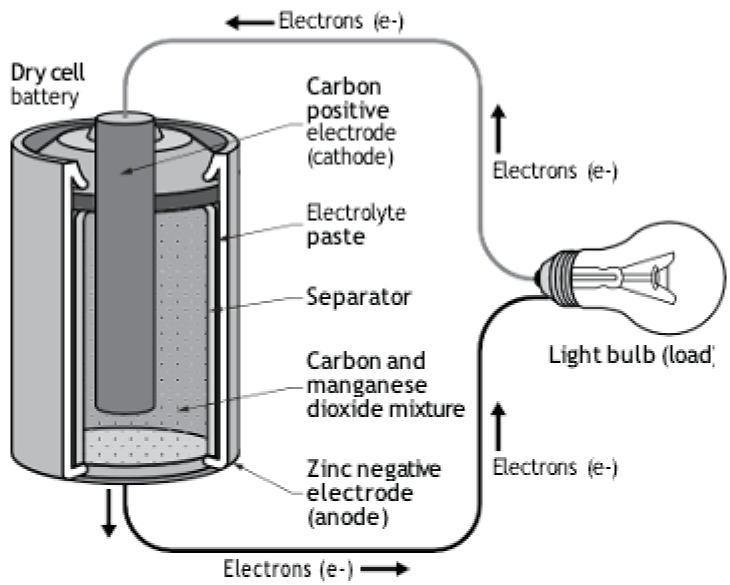

Figure 7 *A cell creating electricity (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Although there are conflicting theories in the field, the most popular theory is that electron flow in a DC circuit is always negative-to-positive, and this direct current flows constantly in one direction until the circuit is broken or the source stops supplying electrons.

Another characteristic of any electron flow can be demonstrated using a DC power source, a square piece of cardboard, and some iron filings (Figure 8). A hole is cut through the centre of the cardboard. A wire is run from one terminal of a battery, through the hole in the cardboard, and back to the other battery terminal. Iron filings are lightly scattered on the cardboard, and the cardboard is gently tapped. The filings will arrange themselves in concentric circles on the cardboard around the conductor. This illustrates the presence of a magnetic field around the conductor whenever current flows through it. The iron filings align themselves with the magnetic field that exists while current flows. If the wires are disconnected, the magnetic field collapses and disappears, and the filings will no longer be arranged in any pattern. This illustrates the concept that a magnetic field is associated with any movement of electrons.

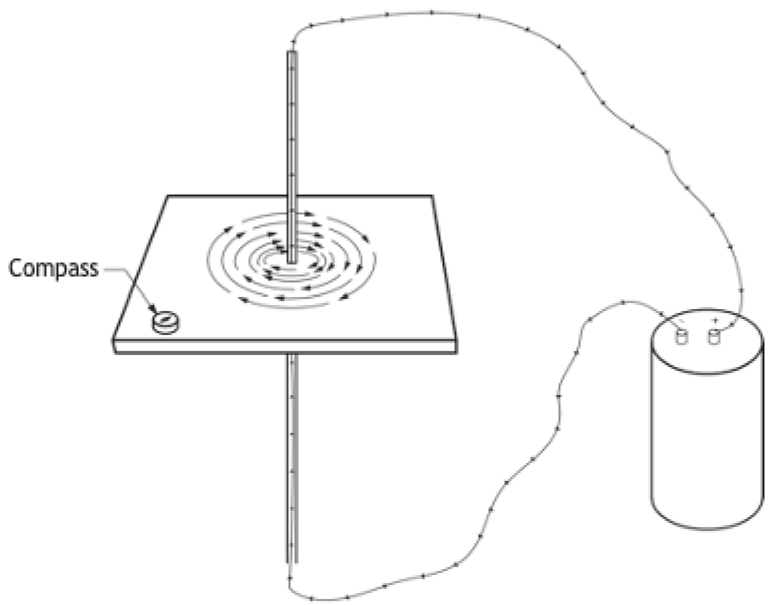

Figure 8 *Current flow in a conductor* (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0

Alternating Current (AC) and Electromagnetic Induction

Alternating current (AC) is a current that flows through a conductor in one direction for a split second and then in the opposite direction for a split second. Current alternates because of the generation techniques used at the power plant. The power of steam or water spins a loop of wire within an external magnetic field. Current is produced in a conductor when it is moved through a magnetic field because the magnetic lines of force are applying a force on the free electrons in the conductor and causing them to move (Figure 9). This process of generating current in a conductor by placing the conductor in a changing magnetic field is called ***induction***. It is called induction because there is no physical connection between the conductor and the magnet. The current is said to be ***induced*** in the conductor by the magnetic field.

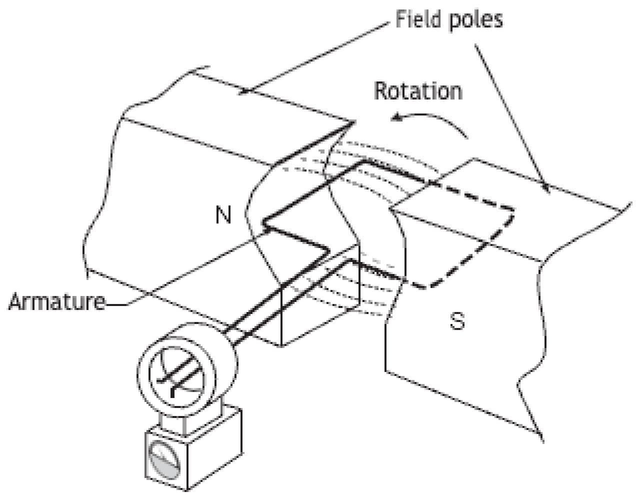

Figure 9 *Spinning a loop of wire within a magnetic field produces current and voltage (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

One requirement for this ***electromagnetic induction*** to take place is that the conductor, which is often a piece of wire, be perpendicular to the magnetic lines of force to produce the maximum force on the free electrons. The direction in which the induced current flows is determined by the direction of the lines of force and by the direction in which the wire is moving in the field. If an AC current is fed through a piece of wire, the electromagnetic field that is produced is constantly growing and shrinking due to the constantly changing current in the wire.

This growing and shrinking magnetic field can induce electrical current in another wire that is held close to the first wire. The current in the second wire will also be AC and, in fact, will look very similar to the current flowing in the first wire. It is common to wrap the wire into a coil to concentrate the strength of the magnetic field at the ends of the coil. Wrapping the coil around an iron bar will further concentrate the magnetic field in the iron bar. The magnetic field will be strongest inside the bar and at its ends (poles).

Here in North America, the generators that create alternating current might spin at a rate of 3,600 rpm (revolutions per minute), whereas in Europe it's slightly slower, perhaps 3,000 rpm.

As the coil moves through its rotation, it will experience a buildup and dropoff of current in a positive polarity through 180 degrees and then a buildup and dropoff in the other half-rotation but in a negative polarity. In North America, AC typically operates at 60 hertz (Hz), meaning the current changes direction 60 times per second, whereas in Europe, the frequency is 50 Hertz. An estimated 95% of all electricity generated and distributed in North America is alternating current.

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 comprises two independent voltages that are carried on two separate conductors or hot lines.

The two hot lines are called *Line 1* and *Line 2*. Single phase is typically found in residential and small commercial applications. Single-phase AC supply voltage is commonly stepped from three-phase distribution to 120 or 240 VAC at point of use.

Three-Phase AC Power Supply

Three-phase AC 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 supply is used to power large motors and other heavy loads. A three-phase system is generally more economical than equivalent single-phase 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. Like single phase AC, three phase AC uses ***transformers***, described as delta and/or wye windings that provide multiple step-up or -down options. Three-phase power is typically found in commercial and industrial applications. Three phase AC supply is commonly stepped to 208 VAC at point of use.

Advantages of Using Alternating Current

For generating and distributing large quantities of electrical energy, alternating current is used rather than direct current. There are several reasons for this:

- Alternators can be manufactured with much higher voltage and power ratings than DC generators. In North America, large alternators commonly generate electrical voltages as high as 13,800 volts. The output windings called the armature can be mounted on the stationary part of the machine, and the magnetic field can be made to rotate by mounting it on the rotor. The current produced by an AC generator (alternator) need not pass through a set of commutators and brushes. It is the commutator and brushes in a DC generator that limit the maximum voltage and power rating of the machine.
- Alternating voltages can be easily stepped up and down. Transformers allow the alternating voltages to be stepped up at the source so that they can be transmitted long distances at higher voltages with lower currents. This reduces both line drop and line loss. At the load end, the transformers can step down the voltage to a lower, safer voltage for utilization. These transformers have efficiencies in the range of 95% to 99%. With DC voltages, this process is much more difficult and much less efficient.
- AC motors and controls are generally smaller, simpler, cheaper and more reliable than DC motors with similar ratings. Because AC induction motors do not require brushes, they are much more reliable. The brushes required in a DC motor need a lot of maintenance. Also, the initial cost of an AC induction motor is lower than that of a comparable DC motor.

Advantages of Using Direct Current

It is easy to understand how these advantages make alternating current a less expensive, more efficient and more reliable way of transmitting energy over long distances. However, there are some situations in which the use of direct current is a better choice. Sometimes it is the only choice.

- Direct current is required to produce the magnetic fields for alternators and synchronous motors. An alternating

current would produce a field with poles that constantly reverse.
- Electrochemical processes such as electroplating and battery charging require DC voltages.
- High-intensity light sources that use carbon arcs require direct current.
- Many manufacturing processes require very precise speed control of motors. In the past, it was not possible to get the same speed accuracy with AC motors as with DC motors. However, with the advent of variable-frequency drives, this is changing. Many applications that once required DC motors and controls are now using AC motors and variable-frequency drives.
- The use of DC traction motors on such equipment as electric trains and mining rock-trucks eliminates the need for transmissions, clutches and drive shafts.

A Simple Circuit

A ***simple circuit*** (Figure 10) contains four basic components:

1. **A power source**: Provides the voltage needed to push current through the circuit.
2. **Conductors:** Wires or pathways that allow current to flow.
3. **A control device:** Usually a switch that opens or closes the circuit.
4. **A load**: A device with resistance that performs work, such as producing heat, light, or motion.

In this type of circuit, the electrical energy supplied by the power source is used by the load and converted into useful work—for example, heating a toaster, lighting a bulb, or turning a motor.

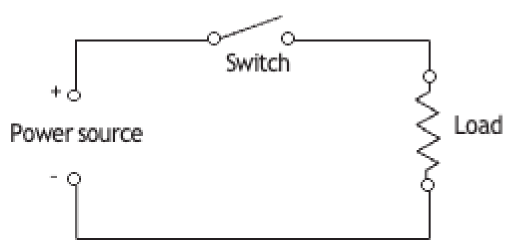

Figure 10 *A basic circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Switches

Switches are used to control a load in a circuit. A ***switch*** is a device that simply opens or closes an electrical circuit. A switch has at least two positions: open or closed. When a switch is open, no electricity can flow through it. An open switch will de-energize the load. When a switch is closed, electricity can flow through the circuit and energize the load. Circuits are called ***open*** or ***closed*** in conjunction with switches being opened or closed. Open means OFF, and closed means ON.

Most switches have two parts: a ***throw*** and a ***pole*** (Figure 11). The throw is the part of a switch that remains stationary. The pole is the part of the switch that moves to open or close the switch. When the pole is touching the throw, the switch is closed. Switches are described by the number of poles and throws they have. To throw a switch, the pole is moved to another position. Thus, a throw is a position of the pole. The simplest switch is a single pole, single throw (SPST) switch. This means it has one pole (moving mechanism) and one throw (position) that the pole can make contact with. An example of an SPST switch would be the switch that turns your bedroom light on or off.

Figure 11 *Single pole switch configurations (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

If another contact is added to an SPST switch, it becomes a single pole, double throw (SPDT) switch. The pole can be thrown to one of two positions to energize one of two different circuits or loads. An example of an SPDT switch would be a three-way switch that operates a hallway light fixture. One of these switches at either end of the hallway can turn the light on or off.

Some household appliances such as electric ranges and water heaters require 240 volts AC. In this case, two circuits are connected to the two "***busbars***" within an electrical panel, each with 120 volts of potential but each being 180 degrees "***out of phase***" from each other. Electrical panels are designed so that two breakers installed side-by-side will each make contact with the different busbars (Figure 12). In this method, the voltages are added together and fed to the same piece of equipment through a cable that will have each of these voltages carried by a different-coloured insulated conductor, think a range fed with Lines 1 and 2 for 240 VAC. Typically, the colours of these two "*hot*" wires are red and black. The two breakers supplying the circuit will have their poles tied together for safety. This is to prevent one circuit from being de-energized without interrupting voltage to the other. Because the two switches are operated simultaneously and are either open or closed, the breaker would be categorized as double pole, single throw (DPST) (Figure 13).

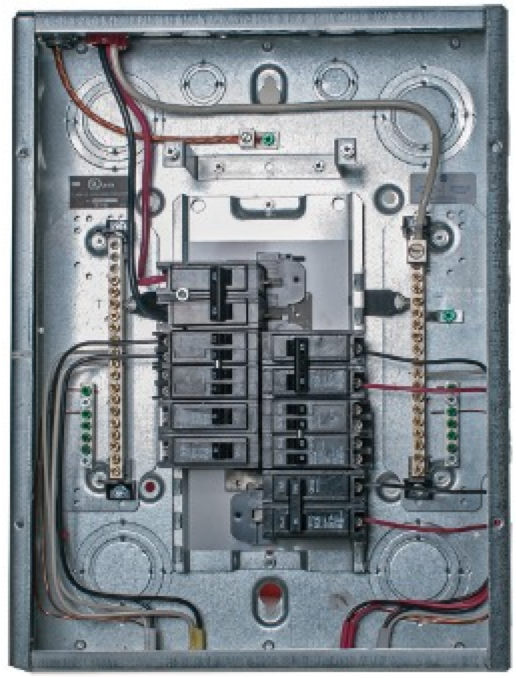

Figure 12 *Residential panel (BC Industry Training Authority, 2019/BCcampus [modified]).* CC BY-NC-SA 4.0

Figure 13 *Double pole switch configurations*

If another throw is added to the DPST switch, it becomes a double pole, double throw (DPDT) switch. Now the poles can make contact in two positions, such as might be found in a circuit that has a forward/reverse operation of a 240 volt piece of equipment.

If a single pole can be thrown so that it will make contact with any one of a number of contacts, it is called a ***rotary switch*** (Figure 14). An example of a rotary switch might be one that is used in an audio store to enable one set of speakers at a time to be listened to.

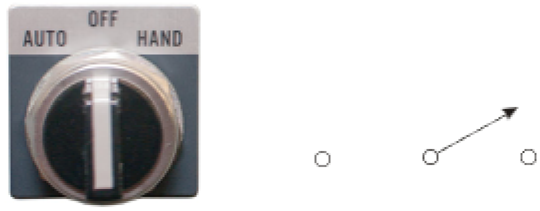

Figure 14 Rotary switch (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0

Disconnect switches (Figure 15) should always be placed in the "hot" leg of a circuit and should be the first electrical device in the path from the source. All loads in the circuit can be de-energized by opening the disconnect switch. Only the contacts of the switch will have electrical potential when the switch is open, and the rest of the circuit can then be worked on safely.

Figure 15 *A utility disconnect switch to control power to a building. It controls 3-phase 120/208 V, 200A service to a commercial building. (Rsparks3/Wikimedia Commons)* CC0 1.0

Figure 15 *Disconnect switch (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Excessive current flowing through a circuit can be dangerous for both people and property. To protect against overheating of circuit components, especially wiring buried in walls and ceilings, something must be placed in the circuit to sense excessive current and open before danger arises. This protection is provided by circuit protectors. There are two main types of circuit protectors: fuses and circuit breakers.

Fuses

A ***fuse*** is used in a circuit to protect against wiring overloads (Figure 16). An overload occurs whenever there is too much current for the size of the wire. This could happen if too many loads are plugged into the same circuit. Because they would be wired in parallel to each other (covered later in this section), the amperage would increase and cause overheating of the conductors.

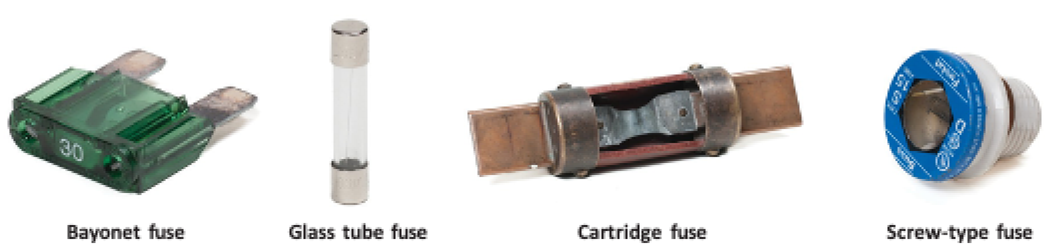

Figure 16 *Fuses (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Another example of an overload would be if a piece of metal fell across the bare wires of a circuit, in effect bypassing the load. This is known as a ***short circuit*** or *simply short* (Figure 17). This means that current has an unrestricted path from the source out and back, without encountering a load. If there is no load in the circuit, there is nothing to limit the amount of current that is being pushed by the source voltage and, consequently the amperage will shoot up to an unsafe point, where it will cause overheating of conductors and possibly a fire.

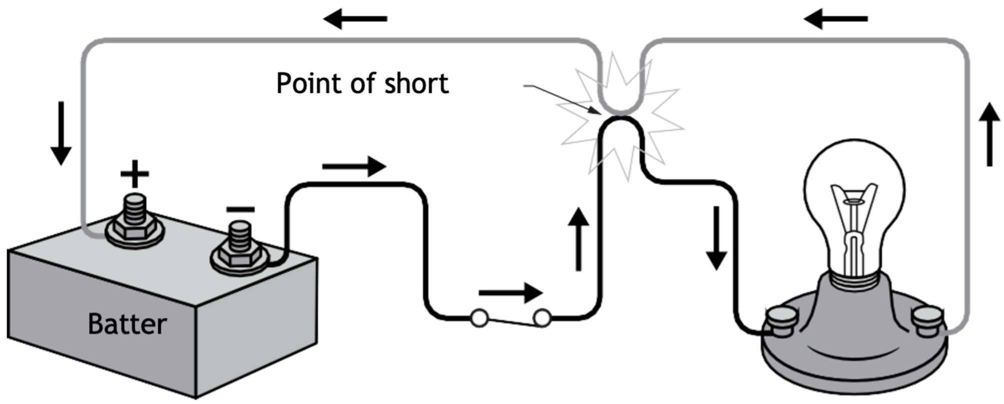

Figure 17 *Short circuit (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

A short could also occur if there is a malfunction in the load, such as the windings in a motor coming in contact with its ground connection. In these cases, the current will always take the path of least resistance, and electrons will surge through the short circuit back to the source. Since the wires in the circuit are sized for the normal operating amperage of the circuit, they are much too small to handle the high amperage cause by the short, so something must be installed in the circuit that will open it whenever current flow gets to an unsafe level.

Time-Delay Fuses

Time-delay fuses are designed and built to withstand the initial current load caused by the starting of electric motors. A motor will take several seconds to come up to speed after starting. This start takes more current than when the motor is up to its operating speed. If a fuse were sized for start-up, it would be too large to protect the wire in the circuit under normal operation, and if it were sized for normal operating amperage, it would blow each time the motor started.

A time-delay fuse has a metal fuse strip that has one end attached to the case of the fuse and the other end attached to a pin held under spring tension (Figure 18). The end of the pin is embedded in solder. If the solder gets hot enough to melt, the pin pulls out of the solder, breaking the circuit.

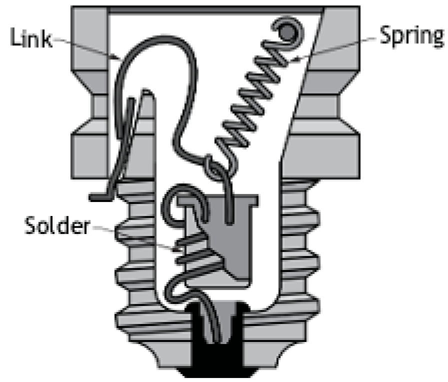

Figure 18 *Time-delay fuse (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

This solder will withstand a momentary overload (such as at motor start-up) without melting. If the heat from the overload is continuous, the solder melts and the circuit breaks. This might take several seconds. If a direct short should occur, the metal fuse strip melts instantly and opens the circuit.

Circuit Breakers

The other type of circuit protector is the ***circuit breaker*** (Figure 19). The advantage of circuit breakers over fuses is that the breakers can be reset whereas a fuse must be replaced.

Figure 19 *Circuit breakers (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Some circuit breakers look very much like a switch. They usually have a lever with "on" and "off" positions. When the switch is in the "on" position, current flows through a thermal device within the breaker. If excessive current flows through this device, which is simply a bimetal element that will warp when it gets hot, it "***trips***" the breaker and opens the circuit. When the breaker is tripped, the lever moves into a position that is indicated as neither "on" nor "off" to the observer, but the circuit is open. After the thermal element has cooled sufficiently, the breaker can be manually reset by cycling the lever to the "off" position and then "on." If the condition that caused the breaker to trip is still there, the breaker won't allow itself to stay in the "on" position.

Another type of circuit breaker looks like a regular strip fuse with a button protruding from the top. When this breaker trips, it can be manually reset by pushing the button.

Whenever a fuse blows or a breaker trips, the cause should be determined and corrected before replacing or resetting. In a 120 V household circuit, the fuses or circuit breakers are always placed in the energized portion of the circuit. In a 240 V circuit, both energized portions are fused.

Circuits

Before looking at the different ways electrical components can be connected, it is important to understand that a circuit is simply a complete path that allows current to flow. Circuits can be arranged in different ways depending on how we want the loads to behave. The two most common types are:

- *Series circuits* (one path)
- ***Parallel circuits*** (multiple paths)

Each type has different characteristics and uses.

Series Circuits

A ***series circuit*** is one in which electrons have only one path they may follow. Loads and switches are wired together end-to-end so that the electricity must pass through the first load to get to the second one, in much the same way as in a series loop hot water heating system (Figure 20). If three light bulbs with equal resistance are wired in series, electricity passing through one of the light bulbs must also pass through the other two in order for the bulb to light up. If one of the bulbs is removed, the path or circuit is broken and none of the bulbs will light. Old-fashioned Christmas lights were wired in series, and if one bulb went out, they all went out. Each bulb had to be tested one at a time until the bad bulb was found. A break in any part of a series circuit ends the flow of electricity throughout the circuit.

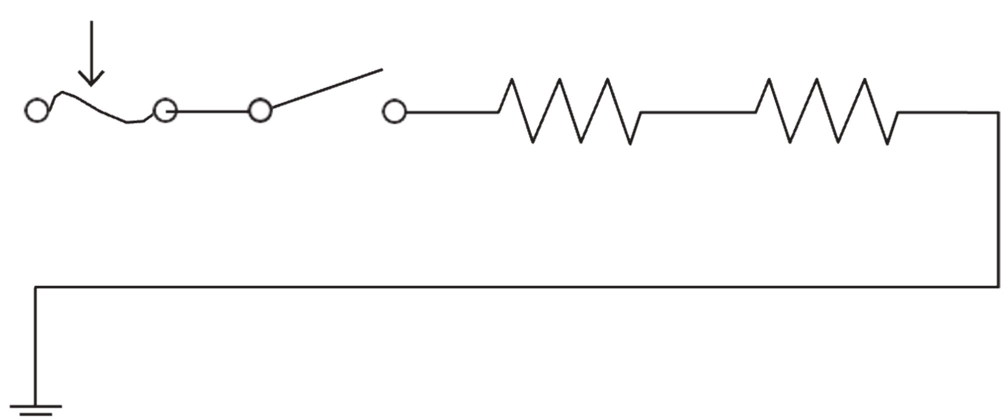

Figure 20 *Series circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

For Ohm's law calculations, the one constant is that the total resistance in a series circuit will be the sum of all individual resistances in the circuit. For example, if two 20 ohm loads are wired in series, the total resistance of the circuit is 40 ohms (Figure 21).

Watch the following video by Tradestutor (2020) on YouTube titled "Series circuit Explanation (quick and easy)" [4:25].

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2457#oembed-2

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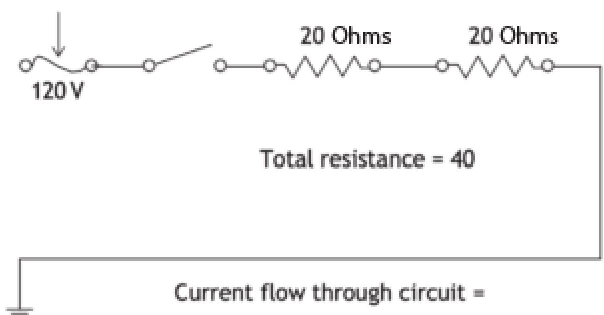

Figure 21 *Resistance in a series circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

The amperage or current flow everywhere in a series circuit is equal. If an ammeter (an instrument that measures amperage) is placed at any point in the circuit, the amperage will be the same.

Amperage is determined by the total resistance in the circuit. If at any time the resistance in the circuit is changed, the rate of electron flow will be altered. If the total resistance goes up, then the amperage will decrease. If the total resistance drops, the amperage will increase.

The total resistance in a series circuit can be determined by using a ***voltmeter*** (an instrument that measures voltage difference between two points) to measure the voltage drop across each load. ***Voltage drop*** is the amount of voltage used at each load. The total circuit voltage will be the sum of the individual voltage drops. For example, the voltage drop across the two loads in the circuit shown in Figure 22 will be 60 volts each. This phenomenon is known as ***Kirchhoff's law*** and is seen in all series circuits. Not all circuits have loads of equal resistance, but Kirchhoff's law still applies: the sum of the voltage drop across each individual load will equal the supply voltage.

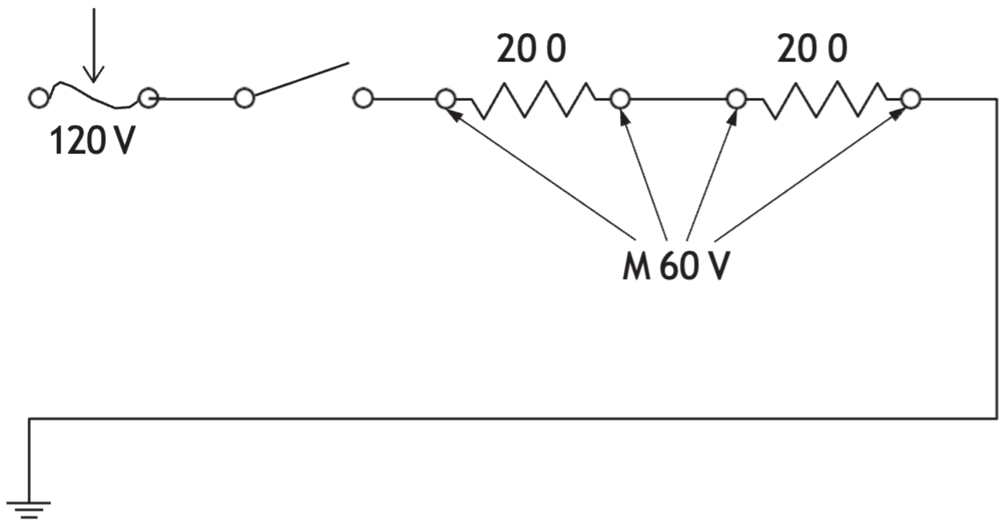

Figure 22 *Voltage drop across loads (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

A series circuit will exhibit the following characteristics:

1. The total resistance of the circuit is equal to the sum of the resistances of the individual loads of the circuit.
2. The amperage or current is the same through all parts of the circuit.
3. Kirchhoff's law states the total voltage applied to the circuit is equal to the sum of the voltage across the individual loads. The voltage drops that occur in a series circuit are proportional to the resistances of the various loads. The load with the greatest resistance will have the largest voltage drop. The load with the least resistance will have the smallest voltage drop. If all loads have the same resistance, then the source voltage divides evenly among the loads.

Parallel Circuits

A ***parallel circuit*** is one in which electricity has two or more paths to follow. If three light bulbs are wired in parallel, electricity can pass through any one of the bulbs without passing through the other two (Figure 23). If one of the bulbs is removed, electricity still reaches the other two and they remain lighted.

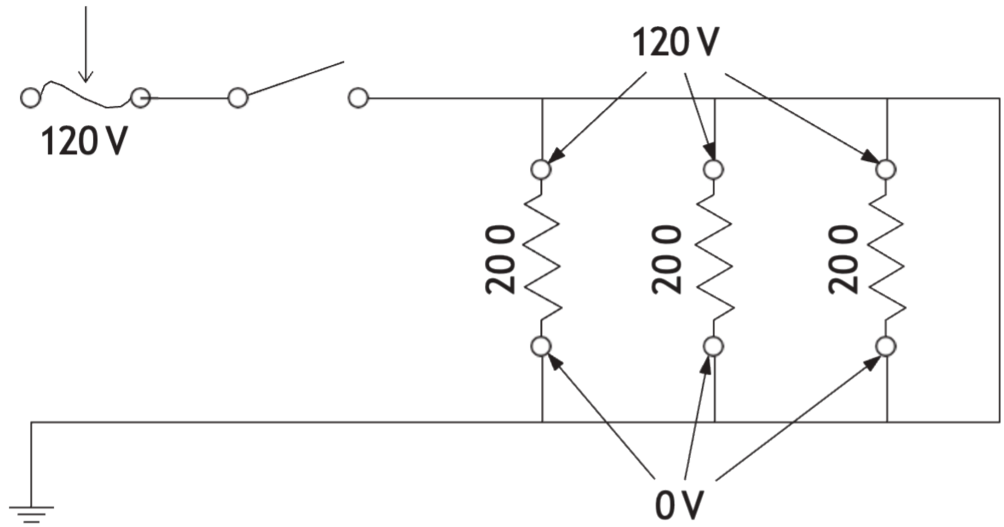

Figure 23 *Parallel circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

In Figure 23, the voltage potential between the 120 V, also known as the hot (H) terminal, and the 0 V grounded or neutral terminal (N) is 120 V. Since loads A, B and C are wired across H and N, the voltage across each load is also 120 V. In a parallel circuit, the voltage is equal in each path. If loads A, B and C are equal in resistance and also have the same voltage across each, the current (amperage) passing through each of the loads is equal. The total amperage of a parallel circuit can be determined by adding the amperage of all the loads in that circuit.

Watch the following video by Tradestutor (2020) on YouTube titled “Parallel circuit calculations (quick and easy)” [4:46].

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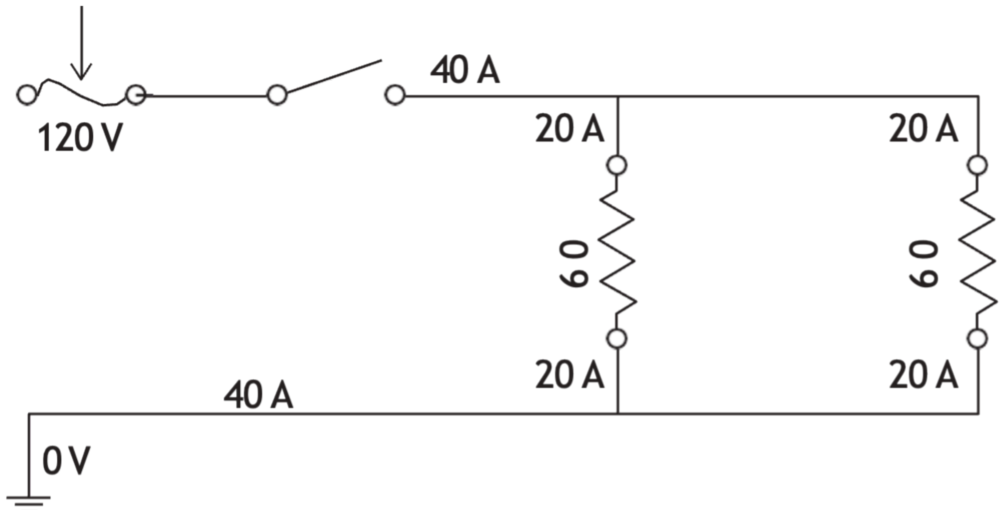

Figure 24 *Amperage in a parallel circuit with equal loads (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

In Figure 24, the total amperage of the circuit is found by adding the amperage draw of load A (20 amps) and the amperage draw of load B (20 amps) to equal a total circuit amperage of 40 amps $(20\text{ A} + 20\text{ A} = 40\text{ A})$. This can be proven by measuring the amperage at H or N with an ammeter and comparing to the sum of the two individual amperage draws.

In Figure 25, if the resistance of load A is 60 ohms and the resistance of load B is 10 ohms, then load A has six times the resistance to current flow as load B does. Since load A has more resistance to current flow than load B, more amperes will flow through load B (remember, the voltage is the same across both loads). In fact, six times as many amps will flow across load B than load A.

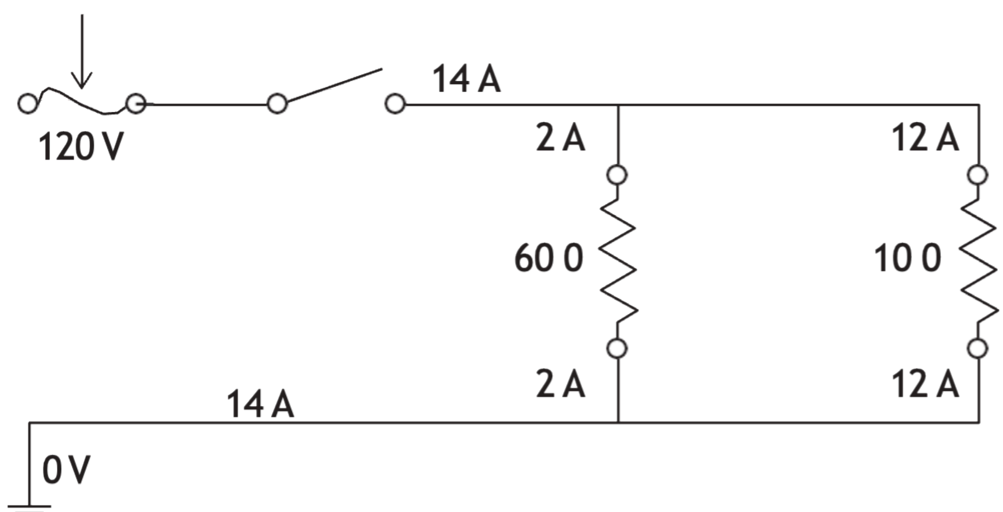

Figure 25 *Amperage in a parallel circuit with unequal loads (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

For example, the 60 Ω resistor (load A) draws 2 amperes $(\frac{120\text{ V}}{60\ \Omega} = 2\text{ A})$ and the 10 Ω resistor (load B) draws

12 amperes $(\frac{120\text{ V}}{10\ \Omega} = 12\text{ A})$. To arrive at total amperage for the entire circuit, add A's amperage (2 A) and B's amperage (12 A) for a total amperage of 14 amps.

The total resistance in a parallel circuit is not as it is in a series circuit. The total resistance of a parallel circuit is always less than the resistance of the smallest of the individual resistances. For example, if two 20-ohm loads are wired in parallel in a 120 V circuit, as shown in Figure 26, the total amperage of the circuit is 12 A. The total resistance, therefore, can be calculated as $\frac{120\text{ V}}{12\text{ A}} = 10\ \Omega$, which is smaller than the smallest individual resistance of 20 Ω.

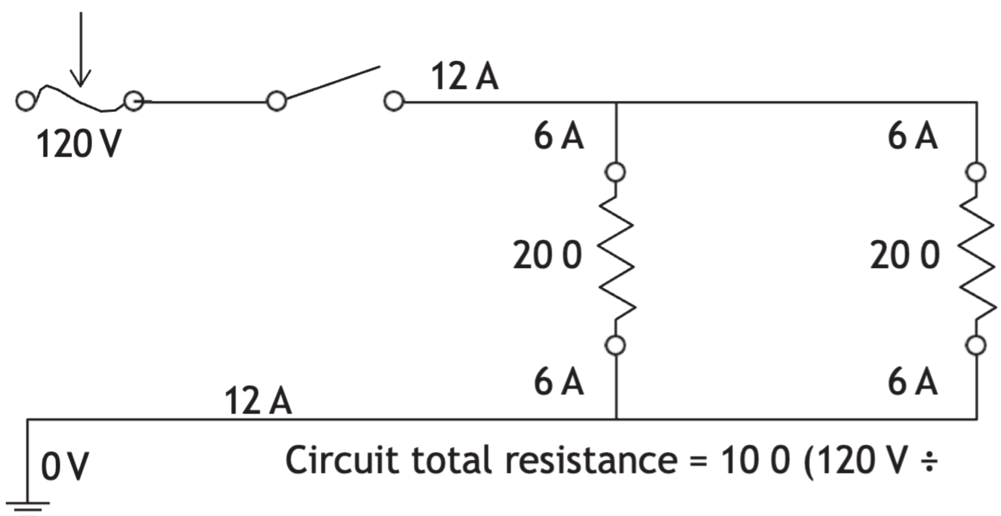

Figure 26 *Resistance in a parallel circuit with equal loads* (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0

The important thing to remember is that **total resistance decreases as more loads are added to a parallel circuit.** If too many loads are plugged into an electrical circuit, resistance will decrease and amperage will increase, eventually causing the fuse or circuit breaker to open the circuit.

A parallel circuit will always exhibit these three characteristics:

1. The voltage across each path in the circuit is the same as that of the source.
2. The total amperage flowing into the circuit is equal to the sum of the amperes flowing through the separate paths. The amperage in the separate paths is inversely proportional to the amount of resistance of the loads in these paths. The path with the greatest resistance will have the least amperage. The path with the smallest resistance will have the most amperage.
3. The total resistance of the circuit is always less than the resistance of the smallest of the individual resistances. Total resistance decreases as more loads are added to the parallel circuit.

Series-Parallel Circuits

Series-parallel circuits are merely combinations of series and parallel circuits. Figure 27 is an example of a series-parallel circuit. Loads A, B, C and D are all in the circuit. When working with series-parallel circuits, divide the overall circuit into sub-circuits. This will result in several series and/or parallel sub-circuits that can then be analyzed by using the fundamentals of series and parallel circuits discussed earlier.

For instance, loads B (5 Ω) and C (10 Ω) in Figure 27 comprise a parallel sub-circuit. That parallel sub-circuit is in series with loads A and D. The characteristics of parallel circuits can be used to analyze sub-circuits B and C. Then, by considering sub-circuit B/C as a single load in series with A and D, the characteristics of series circuits can be used to analyze the larger parent circuit.

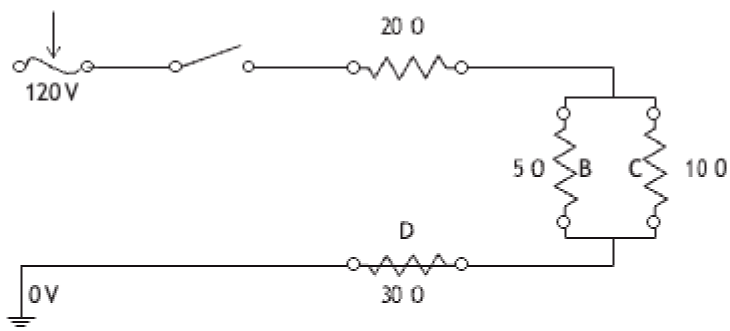

Figure 27 *Series-parallel circuit (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

The resistance of two loads in parallel can be calculated using the following formula:

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$

For sub-circuit B/C, the resistance would be:

$$R = \frac{5 \times 10}{5 + 10} \quad = \frac{50}{15} \quad = 3.33$$

When the resistance of B/C (3.33 Ω) is added to the two other resistances of 20 Ω and 30 Ω, the total resistance of the circuit can be calculated to be 53.33 Ω. The amperage flowing through the circuit can then be calculated by dividing the total resistance into the source voltage, to get 2.25 amps $(\frac{120\ \text{V}}{53.33\ \Omega} = 2.25\ \text{A})$.

Any electrical circuit can be reduced to (1) a source, (2) a path, conductors, and (3) a single resistance, a load.

Transformers

A *transformer* is an electrical device used to change alternating current (AC) voltage to either a higher or lower level. Transformers only work with AC because they rely on a changing magnetic field. If a transformer changes 120 VAC to 24 VAC, it is called a ***step-down transformer*** (Figure 28). If it increases voltage (for example, from 120 VAC to 12,000 VAC), it is called a ***step-up transformer***. An ***isolation transformer*** does not change voltage but provides protection from electrical shock by separating circuits. An isolation transformer neither steps up or down but, rather, provides galvanic protection from electric shock to sensitive equipment. Transformers are available in a variety of capacities for isolation, stepping up or stepping down AC voltages. A transformer is considered to be a load on the primary side and a source on the secondary side.

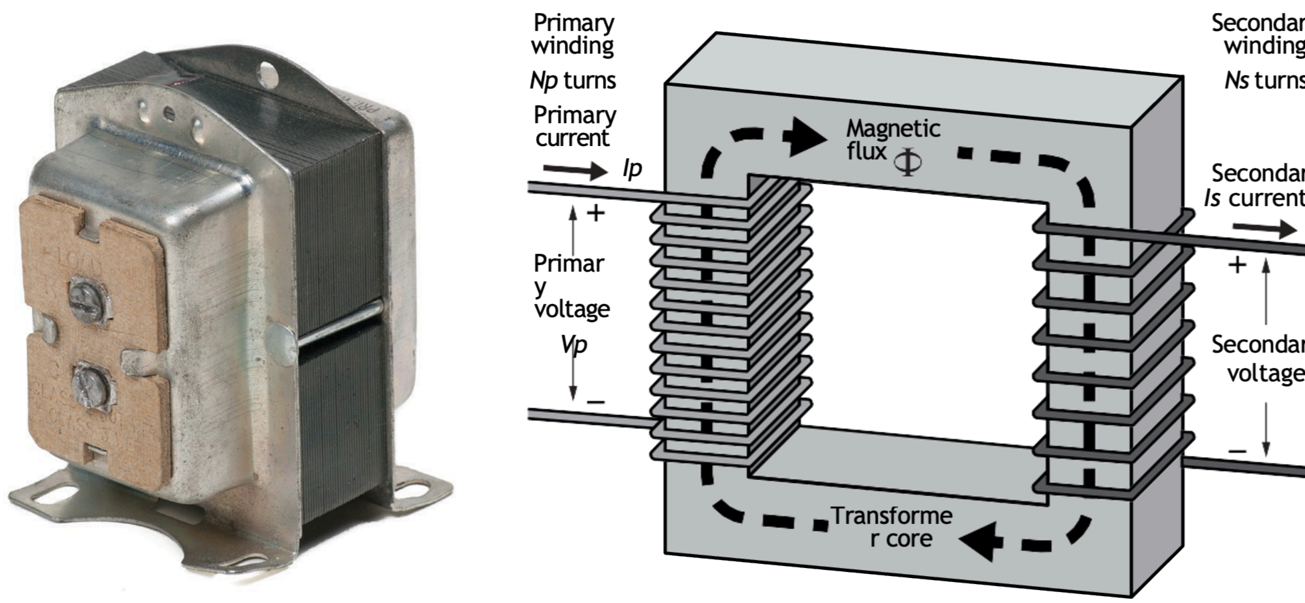

Figure 28 *Step-down transformer (BC Industry Training Authority, 2019).*

Construction and Operation

The construction of a transformer is relatively simple. It consists of two coils of wire, called ***windings***. Windings or wire are placed around one side of an iron ring:

- The ***primary winding*** is connected to the power source.
- The ***secondary winding*** delivers the output voltage.

There is no direct electrical connection between the primary and secondary windings. Instead, energy is transferred through ***magnetic induction***.

Two important principles explain how transformers work:

- When electric current flows through a conductor, it creates a magnetic field (Figure 29).
- When a conductor moves through a magnetic field, a voltage is induced in that conductor (Figure 30).

In an AC circuit, current is constantly changing direction. This causes the magnetic field around the primary winding to continually grow and collapse. This changing magnetic field induces a voltage in the secondary winding.

Because direct current (DC) flows in only one direction and does not continuously change, DC cannot be used to operate a transformer.

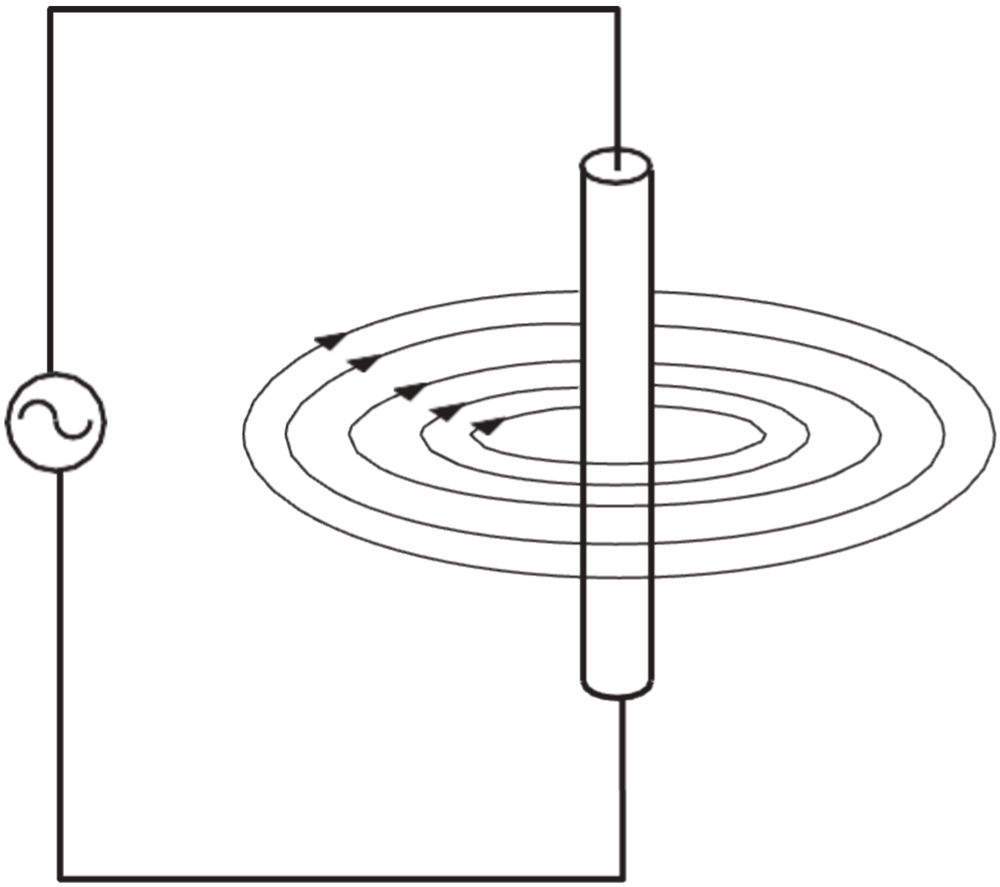

Figure 29 *Magnetic field produced by current flow through a conductor (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

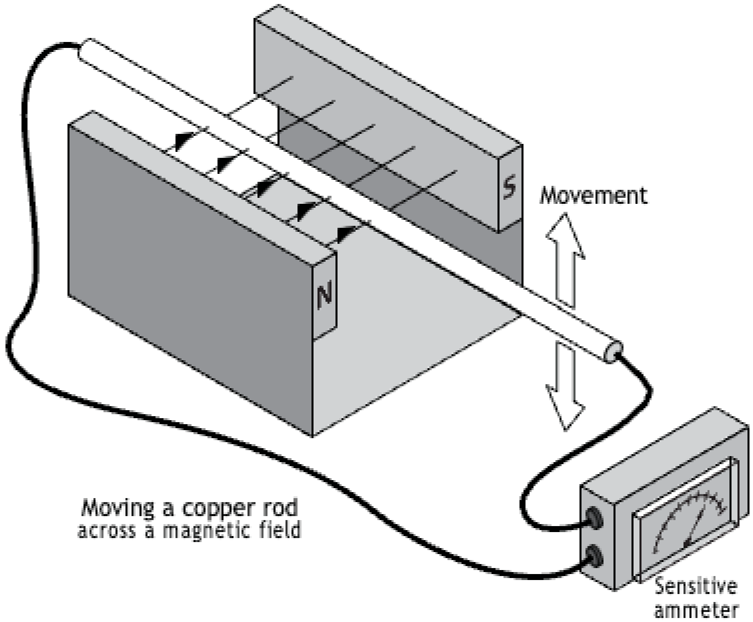

Figure 30 *Current flow generated in a conductor (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Voltage Transformation

The output voltage of a transformer depends on the ratio of turns (loops of wire) in the windings:

- If the secondary winding has **more turns** than the primary, the voltage increases.
- If the secondary winding has **fewer turns**, the voltage decreases.

Power Rating (VA)

Transformers are rated based on the amount of power they can handle. This is expressed in *volt-amperes* (VA).

For example:

$$24\ \mathrm{V} \times 2\ \mathrm{A} = 48\ \mathrm{VA}$$

The unit VA is equivalent to *watts*, since power is calculated as voltage multiplied by current.

When replacing a transformer, if one with an identical wattage cannot be obtained, use one with a higher VA rating. If one of a lower rating is used and the original had been sized close to its capacity, the new transformer will burn out in time due to excessive heat created by an undersized secondary winding.

Sensitive Ammeter

A magnetic field must remain in motion if a continuous voltage is to be induced in the secondary windings. The magnetic lines of force must continually cut the conductor. In AC current, electrons flow in one direction, then stop and flow in the opposite direction. This occurs 60 times a second. This means that as electrons flow in the primary winding, the magnetic field builds up in intensity. When electron flow stops, the magnetic field collapses. As the electron flow changes direction, the magnetic field again builds up, this time in the opposite direction. It is this pulsating magnetic field moving in and out of the secondary windings that induces voltage. Because a DC source produces current flowing in one direction at a constant level, it cannot be used with a transformer.

The AC voltage output of the secondary winding of the transformer is determined by the ratio of the number of windings in the secondary to the number of windings in the primary. If the number of windings in the secondary is greater than in the primary, more electrons are excited and the voltage produced will be higher than in the primary. If there are fewer windings in the secondary than in the primary, fewer electrons are excited and a lower voltage is produced.

Solenoids

A ***solenoid*** consists of a coil of insulated conductor wire and a movable iron rod (Figure 31).

A solenoid may also be called an ***electromagnet***. The tip of the iron rod is positioned just inside the entrance of the coil opening. When the coil is electrically energized and current flows through it, the resulting intensified magnetic field of the coil pulls the iron rod into the centre of the coil. The iron rod will remain in this position until the coil is de-energized. Normally, gravity allows the iron core to return to its original position, although some solenoids, particularly those used in pressurized water systems, use a spring on the return. Solenoids are used for such things as valves, doorbells, locking devices and many other types of electromechanical equipment.

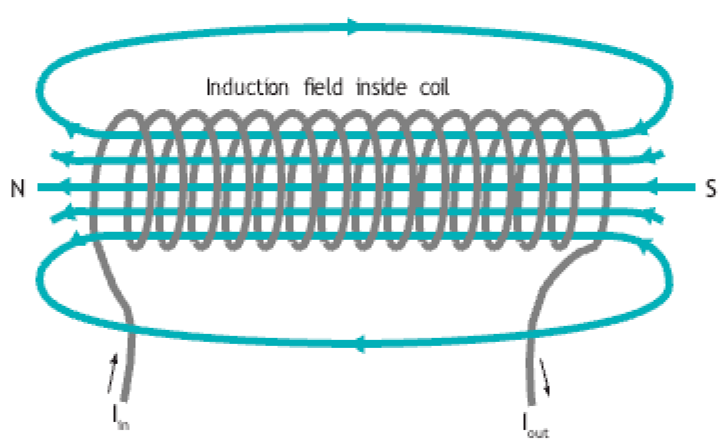

Figure 31 *Solenoid (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Relays

Electrical ***relays*** use the principle of the electromagnet. A relay consists of a coil of insulated wire with an iron core fixed within it (Figure 32). A movable metal armature is located nearby the end of the iron core. The armature has an electrical contact on one end. Another contact is stationary. When the relay becomes electrically energized, the iron core becomes magnetized and attracts the metal armature toward it. When the armature moves to the magnet, the armature contact closes against the stationary contact. When the relay is de-energized, the core is de-magnetized. A spring returns the armature to its original position and the contacts separate.

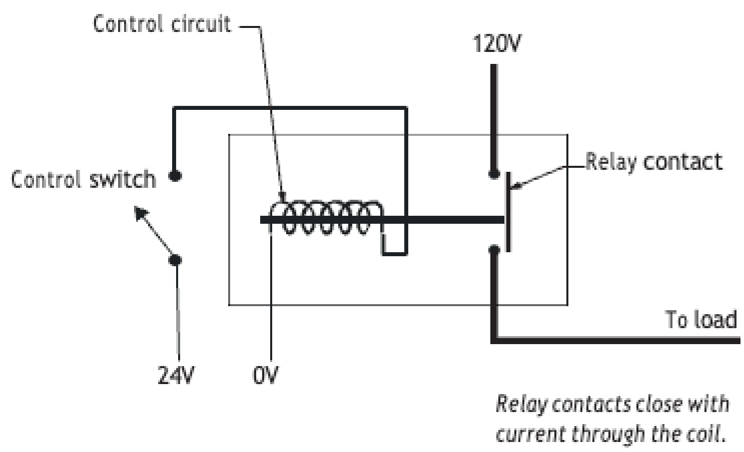

Figure 32 *Relay (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

A relay is used when it is necessary to control an electrical device that operates on, for instance, 120 VAC by using a control voltage of another value, for instance, 24 VAC. If the 24 V were to be directly interconnected with the 120 V, the 24 V components would likely burn out. This strategy is used quite successfully in hydronic heating and air conditioning, where 120 V or 240 V motors are switched on and off by a 24 V control circuit. The relay would be identified as a load on the 24 V side and a switch on the 120 or 240 V side.

Another reason to use a relay might be to operate a piece of large equipment from a remote location. For instance, a large electric motor operating on 600 VAC and drawing many amps needs to be controlled from a location that is 10 storeys above it (Figure 33). To do this, heavy wires would have to be routed from the source in the basement up to the 10th floor, through a heavy switch, then back down to the motor and subsequently back to the power panel. If a relay were used, a 24 VAC source (step-down transformer) located in the basement close to the motor could supply a light wire with voltage right up to the 10th floor, through a light-duty switch, back down to the coil in the relay. The normally open relay contacts would have the 600 V wired through it to the motor. When the switch on the 10th floor is closed, 24 V is sent to the relay coil, which pulls in the armature and closes the normally open contacts, sending the 600 V to the motor. The addition of an inexpensive relay is more than offset by the cost savings realized by not having to run very much heavy, expensive wire.

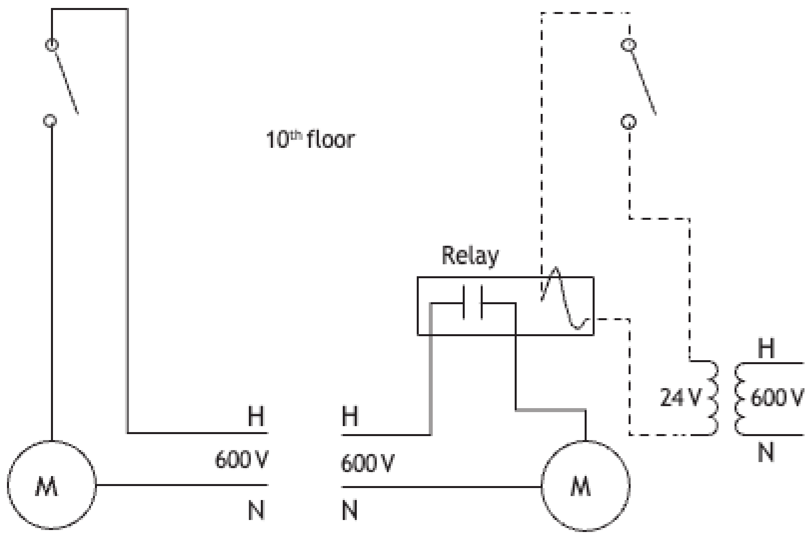

Figure 33 *Sample application of a relay (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

There are several types of relays. The relay described in the previous examples is used to close or complete a circuit. This type of relay contains a set of normally open (NO) contacts. This means that the contacts are open when the relay is not energized and closed when the relay is energized. Another type of relay is used to open a circuit. This relay contains a set of normally closed (NC) contacts. This means that the contacts are closed when the relay is not energized and opened when the relay is energized.

Some relays are also capable of opening or closing several circuits at the same time.

The description of this switching action is the same for relays as it is for manual switches. Figure 34 shows a typical relay capable of opening and closing several circuits.

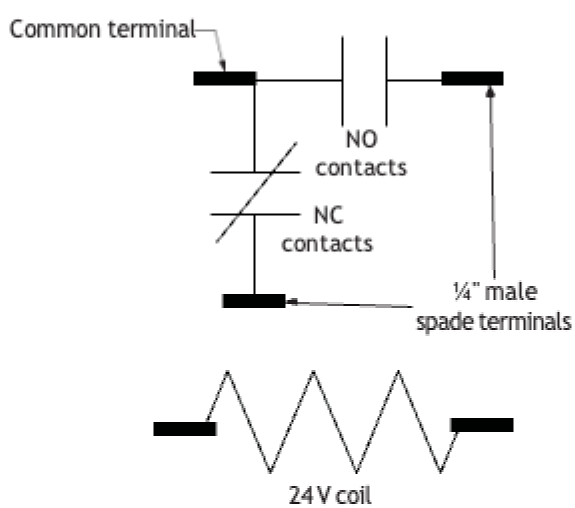

Figure 34 *SPDT (single pole, double throw) relay for multiple circuits (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Capacitors

A ***capacitor*** is an electrical component composed of two metal plates separated by an insulator that stores a charge to help equipment such as motors and compressors run more efficiently.

When a capacitive motor starts up, there is a large current draw on the system that is bolstered by the stored charge captured in the capacitor, supporting smooth motor start and run.

Capacitance, measured in the SI system in ***farads (F)***, describes how efficiently a capacitor stores a charge.

Ampacity

Ampacity is an electrical rating used to properly size conductors used for electrical wiring circuits. This rating is based on a few variables such as type of conductor, size of conductor and insulation that covers the conductor. Manufacturers put ampacity ratings on the nameplates of their electrical equipment. When selecting wire size for equipment, take the ampacity rating shown on the equipment and apply this to the ampacity tables found in the Canadian Electrical Code. Normally, conductors that supply electricity to any equipment that has a motor have to be rated at 125% of the equipment's rated ampacity. For example, if a motor's rated current draw is 5 amps, the conductors will have to be capable of 125% of 5 amps, or 6.25 amps. The extra 25% is to make sure that the wiring will not catch fire in the event of an electrical overload. If the circuit is properly fused, an overload will blow the fuse or trip the breaker before the wire gets hot enough to ignite its coating of insulation.

Supplementary Videos

To better understand motors and electrical principles, check out the excellent information in some of "The Engineering Mindset" videos:

- Alternating Current Basics: *How does an Electric Motor work? (DC Motor)* [4:49]
- AC and DC Electricity: *AC and DC Electricity basics* [2:56]
- How DC Motors Work: *How does an Electric Motor work? (DC Motor)* [4:49]
- Induction Motors: *Induction Motor Basics* [8:38]
- How 3-phase Electricity Works: *How Three Phase Electricity works – The basics explained* [7:52] (originally linked: *AC and DC Electricity basics* [2:56])
- Main electrical panel explained: *Main electrical panel explained – Load center – service panel* [10:18]

Self-Test C-2.2: Electrical Circuits

Complete Self-Test C-2.2 and check your answers.

If you are using a printed copy, please find Self-Test C-2.2 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2457#h5p-30

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BC Industry Training Authority. (2019). *Piping trades apprenticeship program: Use Tools and Equipment—Level 1 harmonized* [Binder]. Crown Publications, Queen's Printer for British Columbia. https://www.crownpub.bc.ca/Product/Details/7960000261_S

- Plumber: Competency O-1 Use the Principles of Electricity
- Steamfitter: Level 2 Competency K-1 Use the Principles of Electricity
- Sprinkler Fitter: Competency C-1 Use Mathematics and Science

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The Engineering Mindset. (2022, November 8). *How does an electric motor work? (DC motor)* [Video]. YouTube. https://www.youtube.com/watch?v=1AaUK6pT_cE&list=RDCMUCk0fGHsCEzGig-rSzkfCjMw&index=7

The Engineering Mindset. (2022, November 8). *How three-phase electricity works – The basics explained* [Video]. YouTube. https://www.youtube.com/watch?v=4oRT7PoXSS0

The Engineering Mindset. (2022, November 8). *Induction motor basics* [Video]. YouTube. https://www.youtube.com/watch?v=AOC7uTnxmTI

The Engineering Mindset. (2022, November 8). *Main electrical panel explained – Load center – service panel* [Video]. YouTube. https://www.youtube.com/watch?v=UBERduCp3Wo

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Media Attributions

C-2.3 Wiring Diagrams and Symbols

Wiring Diagrams

A ***wiring diagram*** is a roadmap of an electrical circuit. Using it, a service technician can analyze the circuit. Diagrams are also used to systematically troubleshoot problems in a circuit. There are four main types of wiring diagrams:

- Pictorial
- Block and line
- Wiring
- Schematic

Pictorial Diagrams

A ***pictorial diagram*** shows the circuit components in detail as they really look and indicates how the wiring is attached (Figure 1). These diagrams can be used to locate components in a complex system. A pictorial diagram is best suited for individuals with little knowledge of wiring, as the diagram can be followed easily because the components can be recognized.

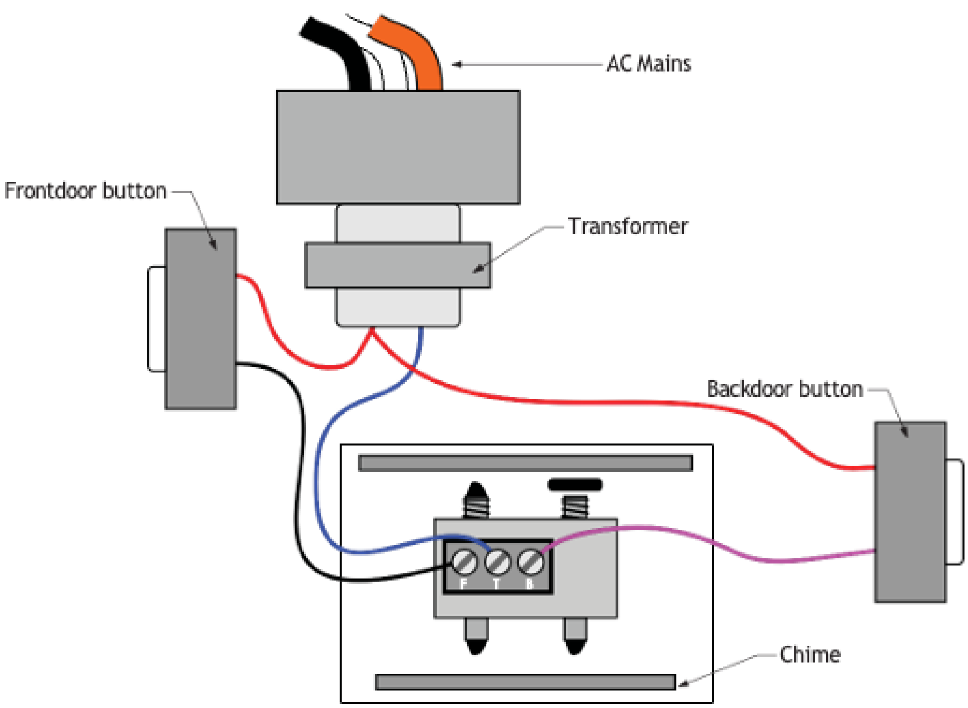


Figure 1 *Pictorial diagram of a doorbell circuit (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Block and Line Diagrams

The ***block diagram***, also called a *functional block diagram* or *block and line diagram* (Figure 2), is used to describe the sequence of circuit operation. This diagram indicates, by functional descriptions, which components must operate first in order to get a final outcome. It does not make reference to specifics, like device symbols or related wire connections. These types of diagrams are used widely for troubleshooting as they relate directly to a sequence of operation.

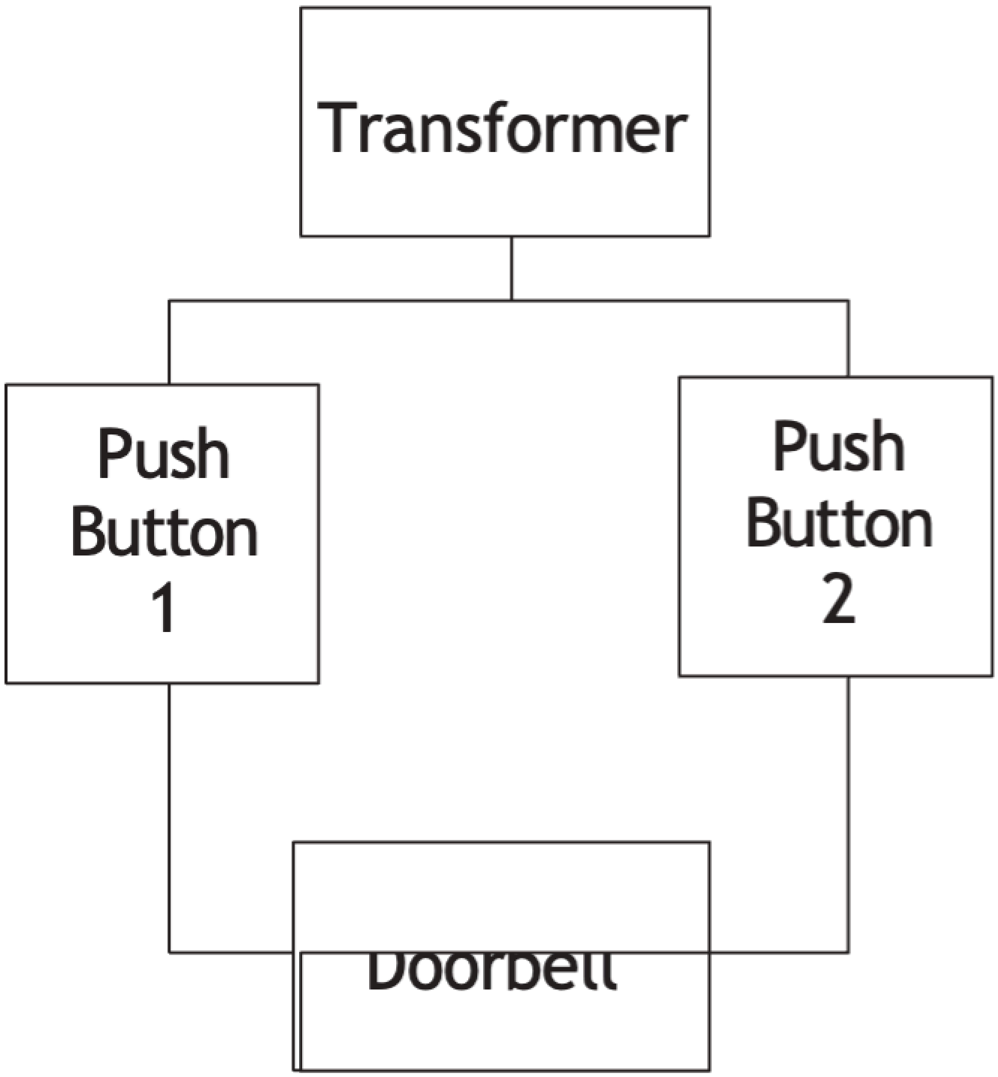


Figure 2 *Block and line diagram (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Wiring Diagrams

A ***wiring diagram*** shows the relative layout of the circuit components using the appropriate symbols and the wire connections (Figure 3). Although a wiring diagram is easy to use for wiring an installation, it is sometimes difficult to understand circuit operation because the components are shown as symbols. It is not as applicable for troubleshooting.

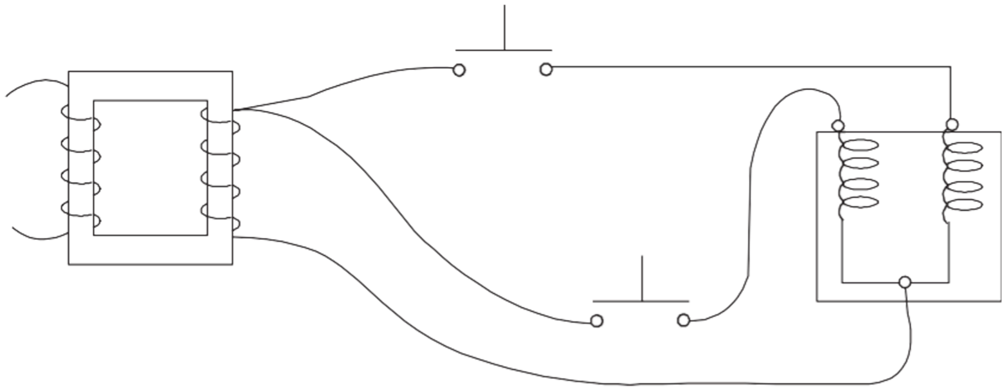


Figure 3 *Wiring diagram (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Schematic Diagrams

A ***schematic diagram***, often called a ***ladder diagram***, is intended to be the simplest, most orderly form of an electrical circuit. This diagram shows the circuit components as symbols on horizontal lines that resemble the rungs of a ladder, without regard to their physical location (Figure 4).

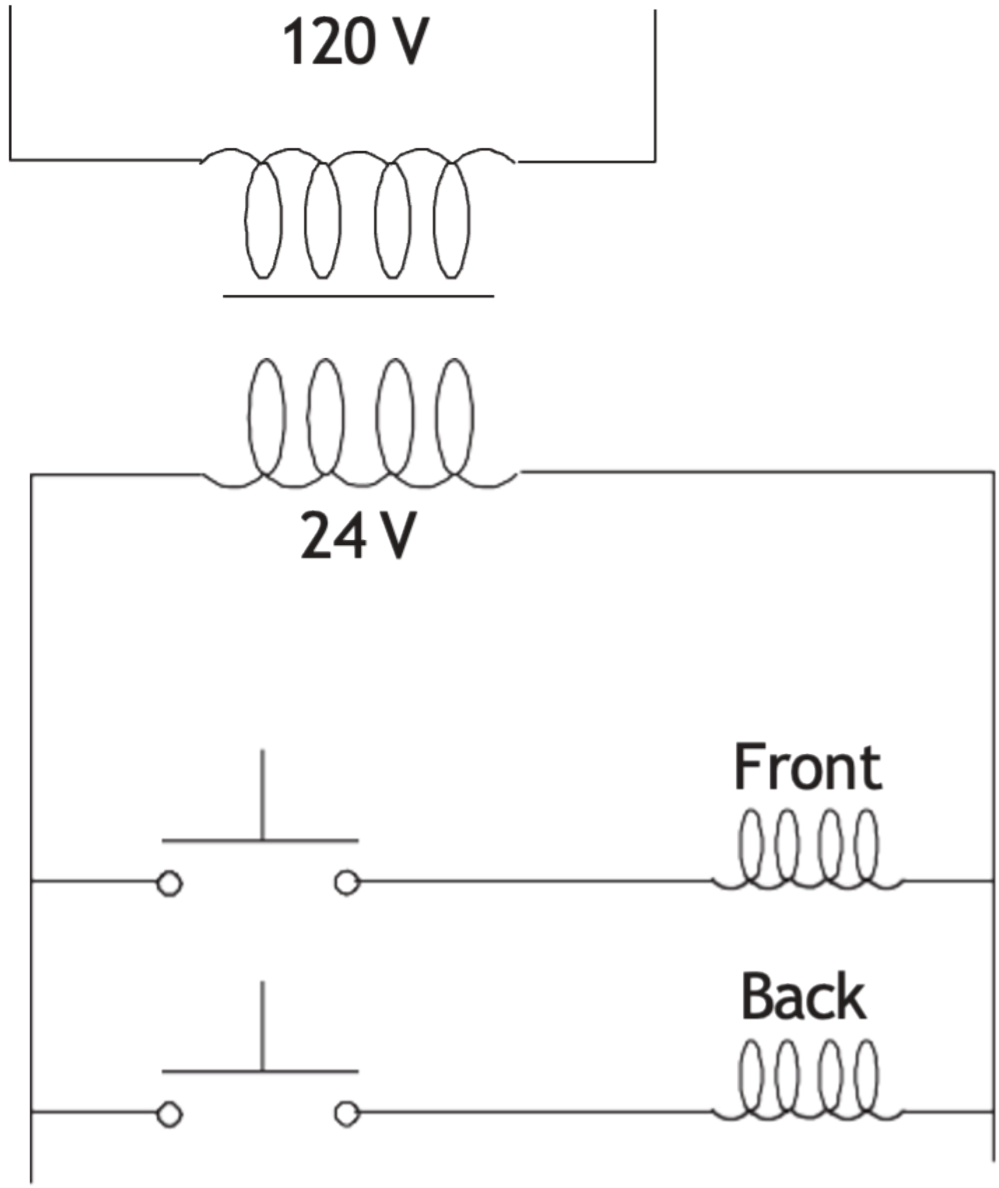


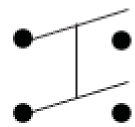
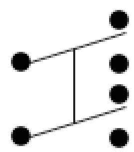
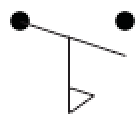
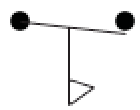
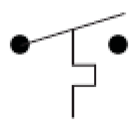
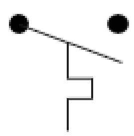
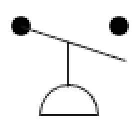
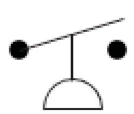
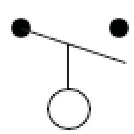
***Figure 4** Schematic wiring diagram (ladder diagram) (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

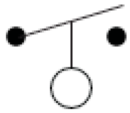
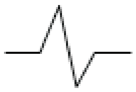
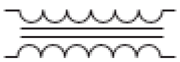
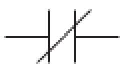
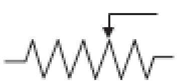
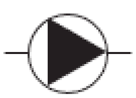
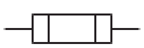
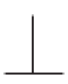
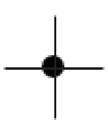
The power source lines of the circuit are parallel and form the rails or sides of the ladder. The loads and switches are drawn between the power source lines, forming the rungs of the ladder.

Ladder diagrams make it easier to tell which loads are wired in series and which are in parallel. As well, no two lines in a ladder diagram ever cross, so it is less likely to get wiring paths mixed up. However, using a ladder diagram requires more knowledge of electricity and ***electrical symbols*** and components than a ***pictorial diagram or schematic***. This is because they do not look like the real components. A service technician must be able to look at the diagram and relate it to the actual unit. They must know the unit components and their corresponding electrical symbols. On most diagrams, these symbols are keyed to a table that names the components.

Symbols

Electrical symbols are used as a shorthand method to represent the various electrical components of a circuit. The following are international schematic symbols for the most commonly used electrical devices.

Symbol	Name	Description
	Single pole, single throw switch (SPST)	Opens and closes one circuit
	Single pole, double throw switch (SPDT)	Opens and closes alternate circuits
	Double pole, single throw switch (DPST)	Opens and closes two separate circuits simultaneously
	Double pole, double throw switch (DPDT)	Opens and closes two alternate circuits simultaneously
	Flow switch	Closes on flow (normally open [NO])
	Flow switch	Opens on flow (normally closed [NC])
	Temperature switch	Opens a circuit when temperature rises
	Temperature switch	Closes a circuit when temperature rises
	Pressure switch	Closes a circuit when pressure rises
	Pressure switch	Opens a circuit when pressure rises
	Float switch	Closes a circuit when liquid level rises

	Float switch	Opens a circuit when liquid level rises
	Load	Typically represents a wire winding or coil (e.g., gas valve, light, motor)
	Relay	Typically represents a coil in a relay
	Wire winding/coil	Similar to “load” above
	Transformer	Transformers increase or decrease voltage between primary and secondary circuits
	Normally open (NO) relay contact	Disallows current flow unless relay coil is energized
	Normally closed (NC) relay contact	Allows current flow while coil is not energized
	Voltage source for direct current	Indicates a battery or other source of DC
	Resistor	Indicates a constant resistance in a circuit
	Variable resistor	Indicates a resistance that can be changed in a circuit
	Pump	The point of the shaded triangle indicates the direction of flow
	Fuse	Opens a circuit when too much current flows
	Fuse	Opens a circuit when too much current flows
	Ground (Earth)	A connection to the earth that has no voltage potential
	Wire connection	The dot indicates a connection between wires

Self-Test C-2.3: Wiring Diagrams and Symbols

Complete Self-Test C-2.3 and check your answers.

If you are using a printed copy, please find Self-Test C-2.3 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2459#h5p-31

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- Steamfitter: Level 2 Competency K-1 Use the Principles of Electricity
- Sprinkler Fitter: Competency C-1 Use Mathematics and Science

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C-2.4 Measuring Electricity

Test Equipment

When you see lightning, you are not seeing electricity itself, but the release of electrical energy in the form of light. Electricity cannot be seen directly, so when an ***electrical circuit*** is not operating correctly, and unless you can see loose or damaged wire connections, you will need instruments that check for the absence or presence of electricity to discover what is wrong.

To measure the effect of electricity, you must use an ***electrical meter***. As electrical quantities vary, so do their effects on the meter. Meters come in a variety of designs, and you must be familiar with some of the most common types used during installation and servicing of hydronic equipment.

Because some electrical effects are very small, most meters are built with delicate operating mechanisms. Meters can be damaged easily, so they must be stored, handled, and used with great care.

Types of Electrical Meters

The most common types of electrical meters are:

- ***Ammeters***
- Voltmeters
- Ohmmeters

For economic reasons, you will most likely not have three separate meters but one unit that combines the functions of all three. This device is referred to as a ***multimeter***. A multimeter is able to measure volts, ohms, and low values of ***current (amps)***. Regardless of the type of meter used, it must be connected correctly to the circuit being tested to obtain accurate readings.

The two major types of meters, *analogue* and *digital* (Figure 1), perform the same functions but look different. The main difference is in the display unit. The key features are very similar and will be explained below.

Figure 1 *Digital multimeter and analogue multimeters (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

Analogue Multimeters (VOMs)

Analogue multimeters, also called *volt-ohm-milliammeters* (VOMs) (Figure 2), are older-style meters that use a moving needle to display readings. While they are not commonly used in the piping trades today, it is important to be aware of them, as you may still encounter them in older equipment or training materials.

VOMs measure ***voltage***, ***current***, and ***resistance***, similar to modern digital multimeters. However, they require careful handling because the needle mechanism is delicate, and incorrect connections—especially when measuring ***direct current (DC)***—can damage the meter. They must also be properly zeroed before use and read from directly in front to avoid ***parallax error***.

In most modern applications, digital multimeters are preferred because they are easier to use, more accurate, and less prone to damage.

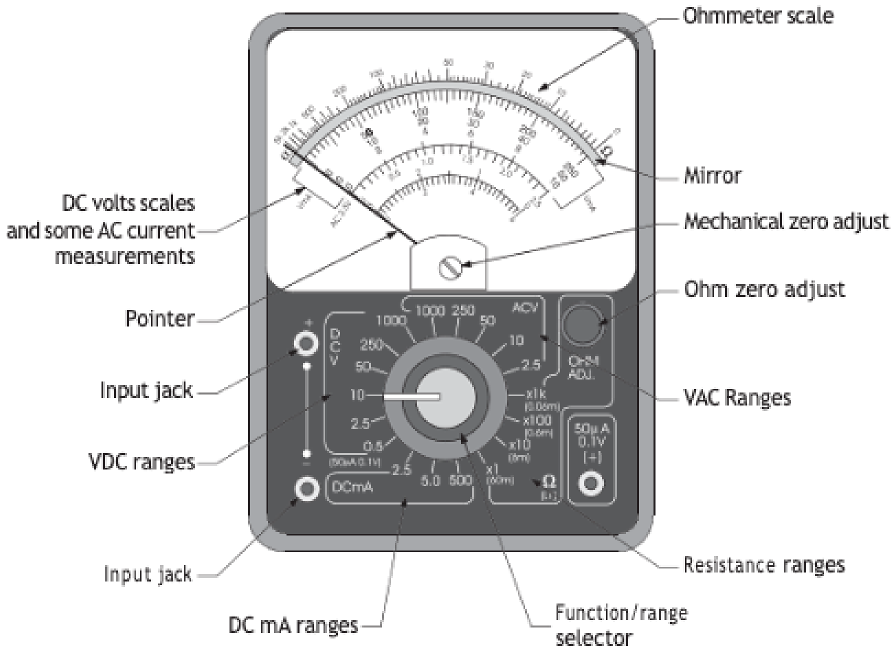

Figure 2 *Analogue VOM (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Measuring Voltage Using a VOM

When performing any tests, it is important to first confirm that the meter is adjusted and working properly. Before using a meter on AC or DC voltage, zero the meter, as shown in Figure 3. Use a blade screwdriver to position the needle directly over the "0" on the left of the scale.

Figure 3 *Mechanical adjustment of the zero reading (BC Industry Training Authority, 2019). CC BY-NC-SA 4.0*

Next, check the meter's operation by exposing it to a known source of voltage. Remember to correctly polarize the leads if using a DC voltage such as a battery. This is done by performing a ***"tap" or "flash" test***: connect one meter lead to a test point and, with the function switch set to a higher DC voltage scale than the source being tested, tap the other lead to the second test point. This will cause the needle to deflect. If the deflection is in the wrong direction, simply reverse the position of the test leads. Then take a reading and confirm that it matches the expected value.

If you are checking the meter using an AC source, such as a wall receptacle, set the function switch to the highest AC setting and insert the two leads into the receptacle's jacks, in no specific position. ***Polarity*** does not matter for AC. Remember that the meter will automatically polarize the signal so the needle will deflect in the correct direction. If the reading matches the expected value, the meter is ready for use.

When measuring voltage, the meter is connected *in* ***parallel*** with the circuit being tested. This means no wires need to be removed from the circuit. The ***voltmeter*** reads the difference between the two test points.

Think of a voltmeter as operating in "subtraction mode"—it measures the difference in voltage between its two leads. This can create a safety hazard if misunderstood. For example, measuring across a closed switch in a live 120 V circuit may show 0 V, even though the circuit is energized.

Always verify circuit conditions before touching components.

Summary of using a VOM to test voltage:

- Zero the needle.
- Check the meter for operation first on a known voltage source.
- Start with the highest voltage scale first.
- Polarize the test leads if testing a DC circuit ("flash test").
- Connect the meter in parallel with the live circuit being tested.
- Interpret the reading and select a lower scale, if possible, for more accuracy.

Measuring Current Using a VOM

Using a VOM to measure *current (amperage)* requires connecting the meter ***in series*** with the circuit being tested. This means disconnecting a conductor and inserting the meter between the wire and the terminal. **This makes the meter part of the circuit**, so all current flowing through the circuit also flows through the meter, which creates a limitation in that the meter leads must be heavy enough to allow current flow, which causes heat, without burning up. Because of this, meter leads must carry current safely. Most multimeters are limited to measuring low current (***milliamps***) when using test leads.

Summary of using a VOM to test DC milliamperage:

- De-energize the circuit to be tested.

- Disconnect a wire and insert the meter in series with the circuit, observing the correct polarity of the test leads.
- Set the meter to the highest DC milliamp range.
- Energize the circuit and interpret the reading.
- Switch to a lower scale, if possible, for more accuracy.
- De-energize the circuit before removing the meter.
- Re-connect the circuit wiring and re-energize the circuit.

Digital Multimeters

All ***digital multimeters (DMMs)*** Figure 4) have similar features and are used in the same way as VOMs, except that the display is a numbered readout of digits rather than a pointer moving over numbered scales. Some digital meters have a function switch that must be set on the appropriate range just like with a VOM, whereas others are *self-ranging* or ***auto-ranging*** and are intuitive to the type of current or voltage that they are being exposed to. They do not differ from the VOMs in their inability to measure units of amperage and are likewise restricted to milliamps of current, but they are easier to read and generally more accurate than ***analogue meter***s.

Figure 4 *Digital multimeter (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

Watch the following video by Afrotechmods (2010) on YouTube titled “THE BEST Multimeter tutorial (HD)” [4:35].

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://c-tradeactivities-electrical-bcplumbingapprl1.pressbooks.tru.ca/?p=2461#oembed-1

If you are using a printed copy, you can scan the QR code with your digital device to go directly to the video: THE BEST Multimeter tutorial (HD).

As mentioned, using a digital meter involves little or no interpretation as to the reading being registered and, for this reason, most technicians favour them over the VOM. One drawback of the DMMs is that they require a battery in good condition for all readings, whereas the analogue variety requires only a battery for resistance/continuity readings. One advantage of the DMMs is that they often have the ability to read current in the range of microamps. An analogue meter would have to be specifically designed for this range only.

Measuring Current Readings Above the Milliamp Range

Current readings above the milliamp range are taken with a ***clamp-on ammeter*** (Figure 5). These devices are usually digital and can be a stand-alone ammeter or can perform all the functions of a multimeter with the added capability of reading full amps. When measuring amperage, the spring-loaded jaws are opened and clamped around a single conductor in the circuit. Current running through a conductor creates an ***electromagnetic field*** around it, and the strength of the field is measured by the device and translated into a current reading. It is important to realize that the current flow through two conductors in a circuit can't be read together. In a two-wire circuit, the direction of the two electromagnetic fields is opposite to each other and will cancel each other out if the meter is clamped around both wires at once.

Figure 5 *Clamp-on ammeter (BC Industry Training Authority, 2019).* CC BY-NC-SA 4.0

Measuring Resistance Using a VOM

A VOM can be used to measure *resistance* or ***continuity*** in a circuit. In the same fashion as in testing for current flow, the meter must be installed in series with the circuit or individual component being tested, with one exception: **the circuit must not be live!**

A battery inside the meter will try to push a small amount of current out through one of the leads and expects to get it back through the other lead. The amount of resistance to this flow of current, measured in ***ohms***, will be read on the topmost scale of the meter. If there is no resistance at all, the needle should move to the far right side of the scale over the "0" mark, indicating no resistance in ohms. If the circuit is completely broken, or open, the needle will not move off the left side of the scale, where the symbol for *infinity* (∞) exists, meaning there is an infinite amount of resistance.

The ohms scale is therefore said to be non-linear in that halfway along the scale is not half of an infinite amount of resistance, because this number cannot be estimated. Because there is only one scale to interpret, it is important to note the reading on the scale and adjust it according to the function switch position. For example, with the function switch set to "×10" a reading of 15 on the scale would indicate a reading of $15 \times 10 = 150 \text{ ohms } (150\ \Omega)$. The same reading with the switch set to the 1K scale would indicate a reading of $15 \times 1,000 = 15,000 \text{ ohms } (15,000\ \Omega)$ (Figure 6).

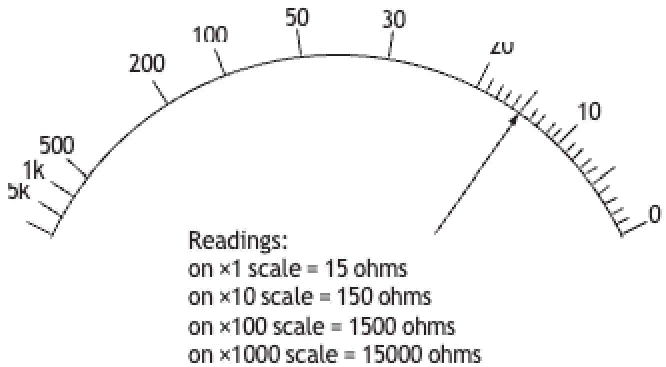

Figure 6 *Reading the ohms scale*

The ***ohmmeter*** must be zeroed before it can be used accurately (Figure 7). To do this, set the function switch to any of the ohms range settings and touch both leads together. The pointer should move to the far right side of the ohms scale and hover directly over the "0" mark. If it is off the mark to either side, use the Ohms Zero dial to correct the reading. The ohmmeter is now ready for use.

Figure 7 *Zeroing the ohms scale*

Measuring continuity is similar to measuring ohms in that the power to the circuit must be turned off. The multimeter sends out a small electrical current, and if it makes it through the circuit back to the meter, the circuit has *continuity*. Some meters emit an audible "beep" to indicate a continuous circuit.

It is important to also return the function switch to the "Off" position (if available) or to the highest AC volts range to ensure the battery doesn't drain during storage.

Summary of using a VOM to measure resistance:

- De-energize the circuit or component to be tested.
- Make sure that current from the meter can only flow through one circuit if there are two parallel circuits connected.
- Set the function switch to the highest range and ***"zero" the meter***.
- Touch the meter leads across the circuit or component and interpret the reading.
- Move to a lower range for more accuracy.
- When finished, turn the meter to "Off" or to the highest AC volts range.

Proper Handling and Storage

The proper care of test equipment and instruments is of utmost importance, whether they are analogue or digital. The length of time an instrument retains its original usefulness and accuracy depends largely upon the care it receives in the hands of the user. These precautions apply equally to digital and analogue 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 you connect 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.

Safety

Although electricity is vitally important in carrying out our daily functions, it can also be deadly if handled carelessly. One-tenth of an ampere of alternating current flowing through a vital organ can be fatal. Take safety precautions whenever working with electricity. Keep in mind the following precautions:

- Never cut off the third prong of a grounded plug. A grounded plug makes power tools and appliances safer to operate.
- Never touch any wire without making sure that it is not a live wire.
- Never turn an electrical appliance on or off while your skin is wet. Dry skin has a resistance of more than 100 000 ohms; wet skin's resistance drops to 1000 ohms.
- A current flow of 0.02 amperes is the maximum that a muscle can carry and still pull away from a conductor.
- Always disconnect the master switch or main disconnect before working on an electrical line or circuit.
- Always unplug an electrical appliance before working on it. Simply turning it off does not necessarily make it safe.
- Replace worn appliance cords.
- Unplug cords by pulling on the plug—not on the cord.
- Never turn an appliance on or off while standing in or touching a wet area.
- Notify the proper authorities whenever you find broken electrical wiring touching the ground. Do not attempt to touch the wire with another object.
- When working on electrical equipment that is live, try to use one hand only. If a person is shocked using one hand, current will probably flow through the hand and down through the feet. If a shock hits both hands, the electrical path would be through the heart, which could be fatal.

Self-Test C-2.4: Measuring Electricity

Complete Self-Test C-2.4 and check your answers.

If you are using a printed copy, please find Self-Test C-2.4 and Answer Key at the end of this section. If you prefer, you can scan the QR code with your digital device to go directly to the interactive Self-Test.

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- Steamfitter: Level 2 Competency K-1 Use the Principles of Electricity
- Sprinkler Fitter: Competency C-1 Use Mathematics and Science

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Self-Test C-2.1: Electron Theory and Causes of Electricity

Complete Self-Test C-2.1 and check your answers.

1. What is an atom that contains only one valence electron known as?
    a. A conductor
    b. An insulator
    c. A semiconductor
    d. A positive ion
2. Which is the only source of electricity that produces alternating current?
    a. Heat
    b. Light
    c. Magnetism
    d. Chemicals
3. A thermocouple uses what form of energy to create electricity?
    a. Heat
    b. Light
    c. Magnetism
    d. Pressure
4. Where would piezoelectricity most commonly be used?
    a. To light a thermocouple
    b. To create electron flow through a light switch
    c. To light a main burner flame
    d. To create the spark in a BBQ lighter
5. Complete the flowing statement: "Electricity occurs when there is a flow of ."
    a. Ions
    b. Neutrons
    c. Electrons
    d. Protons
6. What is an atom that has an electrical charge known as?
    a. An ion
    b. A conductor
    c. An insulator
    d. An element
7. What is electricity that is created by friction known as?
    a. Thermoelectricity
    b. Triboelectricity
    c. Photoelectricity
    d. Piezoelectricity
8. What is the term given to 6.28 quintillion electrons?
    a. A coulomb of charge
    b. A neutron of potential

c. A volt of resistance
d. An ampere of ohms

9. Which term describes the force of the south poles of two magnets brought together?
   a. Repel
   b. Relate
   c. Attract
   d. Conduct
10. Which term best describes a materials readiness to be magnetized?
   a. Saturation
   b. Lines of flux
   c. Permeability
   d. Electromagnetism
11. Which term best describes the phenomenon associated with AC generated from hydroelectricity?
   a. Saturation
   b. Line of flux
   c. Permeability
   d. Electromagnetism
12. What are the four basic components of an electrical circuit?
   a. Source, conductor, switch, load
   b. Capacitor, cable, conductor, resistor
   c. Battery, generator, motor, transformer
   d. Voltage, amperage, resistance, magnetism

Answer Key: Self-Test C-2.1 is on the other page.

Answer Key: Self-Test C-2.1

1. What is an atom that contains only one valence electron known as?
    a. A conductor
2. Which is the only source of electricity that produces alternating current?
    a. Magnetism
3. A thermocouple uses what form of energy to create electricity?
    a. Heat
4. Where would piezoelectricity most commonly be used?
    a. To create the spark in a BBQ lighter
5. Complete the flowing statement: “Electricity occurs when there is a flow of .”
    a. Electrons
6. What is an atom that has an electrical charge known as?
    a. An ion
7. What is electricity that is created by friction known as?
    a. Triboelectricity
8. What is the term given to 6.28 quintillion electrons?
    a. A coulomb of charge
9. Which term describes the force of the south poles of two magnets brought together?
    a. Repel
10. Which term best describes a materials readiness to be magnetized?
    a. Permeability
11. Which term best describes the phenomenon associated with AC generated from hydroelectricity?
    a. Electromagnetism
12. What are the four basic components of an electrical circuit?
    a. Source, conductor, switch, load

Self-Test C-2.2: Electrical Circuits

Complete Self-Test C-2.2 and check your answers.

1. What are the four basic components of any circuit?

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

2. What is the function of a circuit breaker or fuse?
   a. To help maintain constant current flow within a circuit
   b. To create the polarity needed within a circuit
   c. To provide a path to ground for electricity
   d. To act as a switch that opens in the event of too much current flow
3. What is alternating current?
   a. Current that alternates between amps and ohms
   b. Current that alternates its direction
   c. Current that alternates amperage from high to low
   d. Current that creates alternate paths for current to flow
4. How is the formula for Ohm's law expressed?
   a. E = I × R
   b. I = E ÷ R
   c. R = E ÷ I
   d. All of the above
5. If a circuit is powered by 120 volts and has a total resistance of 600 ohms, how much current is running through the circuit?
   a. 5 amps
   b. 120 amps
   c. 0.2 amps
   d. 0.5 amps
6. What is the voltage in a circuit that carries 0.5 amps with a resistance of 200 ohms?
   1. 1 volt
   2. 10 volts
   3. 100 volts
   4. 1000 volts
7. Which definition best describes a series circuit?
   a. There is only one path for electricity to flow through.
   b. There is a series of paths for electricity to flow through.
   c. There are between one and three paths for electricity to flow through.
   d. It is electricity flow created through the use of a series of resistors.
8. What is one advantage of using parallel circuits rather than a series circuit?

a. The ability to use an unlimited number of loads within the circuit
b. The ability to de-energize one leg of the circuit without affecting the others
c. The ability to alternate current through the different legs of the circuit
d. The ability to create different source voltages throughout the circuit

9. What would a three-way switch controlling a hallway light be an example of?
    a. An SPST switch
    b. An SPDT switch
    c. A DPST switch
    d. A DPDT switch
10. What is the term given to a coil of wire into which an iron armature is drawn?
    a. A coil
    b. A fuse
    c. A circuit breaker
    d. A solenoid
11. Which of the following best describes power?
    a. Current flow
    b. Inductive charge
    c. Work performed
    d. Voltage potential
12. Which two factors affect power?
    a. Voltage and amperage
    b. Resistance and capacitance
    c. Magnetism and conduction
    d. Induction and permeability
13. What kind of AC power supply would you expect to find in an industrial setting?
    a. Inductive power
    b. Single-phase power
    c. Three-phase power
    d. Direct current power
14. What voltage potential would you expect to find in a small shop with three-phase power supply?
    a. 120 VAC
    b. 208 VAC
    c. 240 VAC
    d. 775 VAC
15. Which of the following best describes why cities commonly use AC in public infrastructure?
    a. AC provides ideal voltages for battery charging
    b. AC is not commonly used in public infrastructure
    c. AC is ideal for high-intensity carbon arced light sources
    d. AC can be easily stepped up and transmitted over long distances
16. Which of the following statement best describes Kirchhoff's law when applied to voltage in a series circuit?
    a. The voltage drop depends upon the available current.
    b. Voltage available is equal to voltage drop over entire circuit.
    c. All resistors in a Kirchhoff's circuit must have the same voltage ratings.
    d. After the last resistor in a circuit, there must be voltage remaining to return to neutral.
17. Which of the following is both a load and a switch?

a. Relay
b. Resistor
c. Capacitor
d. Transformer

18. Which of the following best describes a transformer that reduces 120 VAC to 24 VACf?
    a. Step-up
    b. Isolation
    c. Capacitive
    d. Step-down
19. Which term best describes two metal plates separated by an insulative material for storage of a charge?
    a. Farad
    b. Ampacity
    c. Capacitor
    d. Transformer

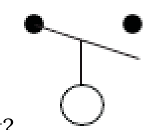
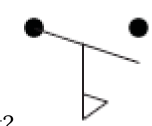
Answer Key: Self-Test C-2.2 is on the other page.

Answer Key: Self-Test C-2.2

1. What are the four basic components of any circuit?
    a. Source, switch, load, conductors
2. What is the function of a circuit breaker or fuse?
    a. To act as a switch that opens in the event of too much current flow
3. What is alternating current?
    a. Current that alternates its direction
4. How is the formula for Ohm's law expressed?
    a. All of the above
5. If a circuit is powered by 120 volts and has a total resistance of 600 ohms, how much current is running through the circuit?
    a. 0.2 amps
6. What is the voltage in a circuit that carries 0.5 amps with a resistance of 200 ohms?
    1. 100 volts
7. Which definition best describes a series circuit?
    a. There is only one path for electricity to flow through.
8. What is one advantage of using parallel circuits rather than a series circuit?
    a. The ability to de-energize one leg of the circuit without affecting the others
9. What would a three-way switch controlling a hallway light be an example of?
    a. An SPDT switch
10. What is the term given to a coil of wire into which an iron armature is drawn?
    a. A solenoid
11. Which of the following best describes power?
    a. Work performed
12. Which two factors affect power?
    a. Voltage and amperage
13. What kind of AC power supply would you expect to find in an industrial setting?
    a. Three-phase power
14. What voltage potential would you expect to find in a small shop with three-phase power supply?
    a. 208 VAC
15. Which of the following best describes why cities commonly use AC in public infrastructure?
    a. AC can be easily stepped up and transmitted over long distances
16. Which of the following statement best describes Kirchhoff's law when applied to voltage in a series circuit?
    a. Voltage available is equal to voltage drop over entire circuit.
17. Which of the following is both a load and a switch?
    a. Relay
18. Which of the following best describes a transformer that reduces 120 VAC to 24 VACf?
    a. Step-down
19. Which term best describes two metal plates separated by an insulative material for storage of a charge?
    a. Capacitor

Self-Test C-2.3: Wiring Diagrams and Symbols

Complete Self-Test C-2.3 and check your answers.

1. What is another term for a schematic diagram?
    a. Pictorial
    b. Wiring
    c. Ladder
    d. Block and line
2. Which diagram shows the relationship of the components with each other?
    a. Pictorial
    b. Wiring
    c. Ladder
    d. Block and line
3. Which diagram doesn't have any lines crossing each other?
    a. Pictorial
    b. Wiring
    c. Ladder
    d. Block and line
4. What does the following symbol represent? 
    a. A pressure switch
    b. A float switch
    c. A transformer
    d. A resistor
5. What does the following symbol represent? 
    a. A flow switch
    b. A low water cut-off
    c. A solenoid
    d. A relay

Answer Key: Self-Test C-2.3 is on the other page.

Answer Key: Self-Test C-2.3

1. What is another term for a schematic diagram?
    a. Ladder
2. Which diagram shows the relationship of the components with each other?
    a. Block and line
3. Which diagram doesn't have any lines crossing each other?
    a. Ladder
4. What does the following symbol represent?
    a. A float switch
5. What does the following symbol represent?
    a. A flow switch

Self-Test C-2.4: Measuring Electricity

Complete Self-Test C-2.4 and check your answers.

1. When measuring current in a circuit, what must you ensure when connecting the multimeter?
    a. That the power is off in the circuit
    b. That the multimeter is connected near the source
    c. That the multimeter is connected in series with the circuit
    d. That the multimeter is connected to source voltage
2. When testing for ohms, the power must be left on in the circuit.
    a. True
    b. False
3. When testing a circuit for voltage, how must the meter be connected?
    a. In parallel with the circuit
    b. In series with the circuit
    c. To a de-energized circuit
    d. With both leads grounded
4. When testing for continuity in a circuit, what must be ensured?
    a. That the circuit is powered
    b. That the meter is grounded
    c. That the source has a short circuit
    d. That the circuit is de-energized

Answer Key: Self-Test C-2.4 is on the other page.

Answer Key: Self-Test C-2.4

1. When measuring current in a circuit, what must you ensure when connecting the multimeter?
   a. That the multimeter is connected in series with the circuit
2. When testing for ohms, the power must be left on in the circuit.
   a. False
3. When testing a circuit for voltage, how must the meter be connected?
   a. In parallel with the circuit
4. When testing for continuity in a circuit, what must be ensured?
   a. That the circuit is de-energized

Plumbing Apprenticeship & Trade Resources in BC

A successful career in plumbing requires a strong foundation of skills, knowledge, and workplace safety awareness. Below are key resources to support plumbing apprentices in BC, including educational pathways, trade certifications, workplace safety guidelines, and mental health and wellness support.

Plumbing Apprenticeship & Certification Resources

- **SkilledTradesBC – Plumbing Apprenticeship** — Overview of plumbing training, certification requirements, and apprenticeship pathways in British Columbia.
- **Red Seal Program – Plumber** — National certification program with exam prep guides and trade mobility information.
- **BC Building Codes & Standards** — Official building and plumbing codes for British Columbia.

Workplace Safety & Regulations

- **WorkSafeBC** — Essential safety resources for plumbers, including:
  - Health & Safety – WorkSafeBC
  - Report Unsafe Working Conditions
  - Report a Workplace Injury or Disease
  - Submit a Notice of Project Form
  - Get Health and Safety Resources (Videos, Posters, Publications, and More)
  - Search the OHS Regulations (and Related Materials)
  - Conduct an Incident Investigation
- **CCOHS: OHS Answers Fact Sheets – Plumber** — Safety guidelines and best practices for plumbers in various work environments.

Financial Supports

- **Financial Support (SkilledTradesBC)** — Information about grants, tax credits, Canada apprentice loans, employment insurance, and the Indigenous Skills and Employment Training (ISET) program.
- **StudentAidBC** — Complete post-secondary education through student loans, grants, and scholarships. There is also programs that help with loan repayment.
- **WorkBC (Government of BC)** — Services for apprentices and employers.

Mental Health & Wellness Support

- **HealthLink BC – Mental Health and Substance Use** — HealthLink BC resources for mental health and wellness support.
- **Here2Talk** — Free and confidential counseling services available to all post-secondary students registered at a BC school.
- **Help Starts Here** — A database with over 2,500 listings of services related to mental health and substance use supports.
- **Hope for Wellness Helpline** — 24/7 online chat and phone line with experienced and culturally competent counselors available to all Indigenous people in Canada.
    - First Nations Health Authority Mental Health Supports Info Sheet [PDF] by First Nations health Authority — List of culturally safe services for Indigenous people.
- **HeretoHelp – BC** — Mental health resources, including videos, articles, and support services in BC.
- **BC Construction Industry Rehabilitation Plan** — Mental health and substance use services for CLRA and BCBT members and their families.
- **Virtual Mental Health Supports (Government of BC)** — Virtual services are available for British Columbians who are experiencing anxiety, depression, or other mental health challenges.

Crisis Support

- **Interior Crisis Line Network** — Call 1-888-353-2273 for 24/7 emotional support, crisis intervention, and community resource information.
- **Talk Suicide Chat Service** — An alternative if calling is difficult; available for crisis intervention.
- **310Mental Health Support** — Call 250-310-6789 for emotional support, information, and resources specific to mental health.
- **1-800-SUICIDE** — Call 1-800-784-2433 if you are experiencing feelings of distress or despair, including thoughts of suicide.
- **Opioid Treatment Access Line** — Call 1-833-804-8111 between 9 am and 4 pm to connect with a doctor, nurse, or healthcare worker who can prescribe opioid treatment medication that same day.
- **KUU-US Crisis Response Service** — Call 1-800-588-8717 for culturally-aware crisis support for Indigenous peoples in BC.
- **Alcohol and Drug Information and Referral Service** — Call 1-800-663-1441 to find resources and support.

Emergency Services — For life-threatening situations, call 911 or visit your nearest emergency department.

Version History

This page provides a record of changes made to this learning resource, Plumbing Apprenticeship Level 1, Block C. Each update increases the version number by 0.1. The most recent version is reflected in the exported files for this resource.

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Version	Date	Change	Details