ELECTRICAL PRINCIPLES AND TECHNOLOGIES

When you are finished this unit, you should be able to …
- identify and evaluate the energy sources for producing electricity
- distinguish between static electricity and current electricity
- perform electrical calculations
- identify and describe energy types and devices for transferring energy
- distinguish and give examples of conducting, insulating, and resisting materials
- build and evaluate simple storage cells
- construct electrical devices and explain how they work
- construct series and parallel circuits and draw schematic diagrams representing each type
- assess safe and unsafe electrical activities
- describe techniques for reducing and conserving energy

PREREQUISITE SKILLS AND KNOWLEDGE

Prior to beginning this unit, you should be able to …
- explain the structure of the atom
- discuss the safety issues associated with electricity
- perform calculations
- use tools and apparatus safely
- collect and analyze data

Lesson 1 GENERATING ELECTRICITY

Flipping an electrical switch is so common in this day and age that we often take for granted the source and production of electrical power. In Alberta, we are fortunate to have several energy resources available for making electricity. Fossil fuels and water are in abundance and most frequently used. Wind, too, is presently being harnessed to generate power on the smaller scale.

FOSSIL FUEL GENERATED POWER

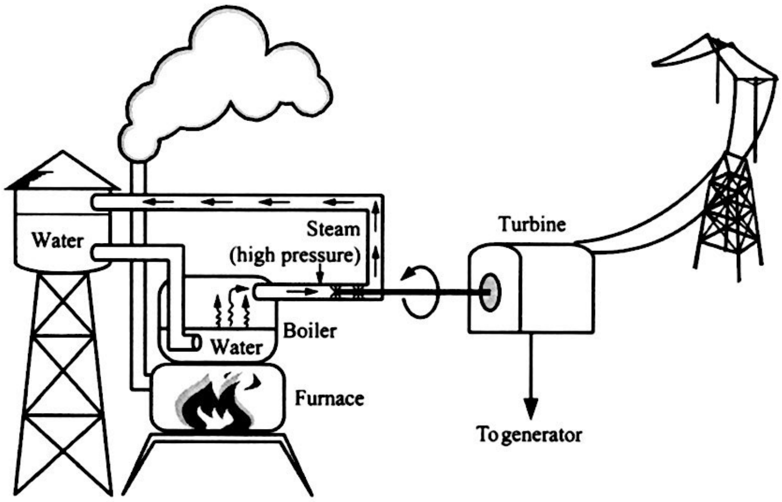
Coal and gas are burned in large furnaces. They provide the heat energy necessary to change water into steam. The superheated steam is piped to giant turbines that spin the generators to produce electrical power.

Fossil Fuels include coal, oil, and gas

"hydro" means water

potential energy: stored energy

Power Generator



Coal- and natural gas-generated power contributes to air pollution. The burning of fossil fuels produces carbon dioxide and sulfur dioxide gases. High carbon dioxide emissions contribute to global warming while sulfur dioxide emissions produce acid rain.

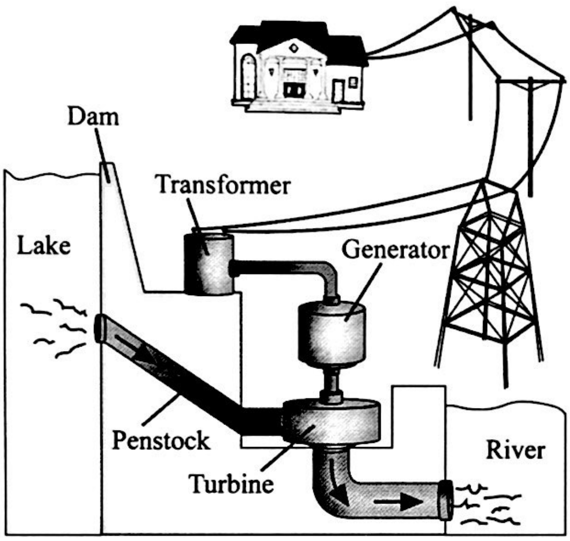
HYDROELECTRICITY

Water power or hydroelectricity is generated in areas where large volumes of water are collected behind dams. The collected water has a high potential energy. When it is sent rushing down the *penstock* of a dam, the fast-moving water spins the turbine and generator to produce electricity.

penstock: channel inside a dam through which water flows

emissions: particles released

Hydroelectric Power Plant



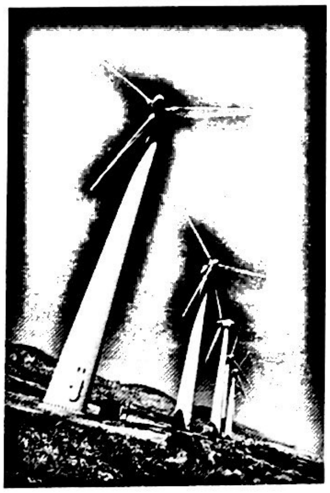
The initial cost of constructing a hydroelectric power plant is high, but once in operation, the cost of producing electricity is lower than that of a coal- generated power. Water is a *renewable resource* and should provide endless energy for making power.

renewable resource: a resource that can be replaced (example: water)

non-renewable resource: a resource that cannot be replaced (example: oil)

WIND GENERATORS

The Pincher Creek area in southern Alberta has strong winds that blow off the mountain slopes. Windmills or wind turbines are common in this area. Each windmill is capable of generating enough power to meet the needs of approximately 20 homes. Although the initial cost of construction is high, wind energy is a renewable resource.



Lesson 2 ALTERNATE ELECTRICAL SOURCES

As non-renewable resources become depleted, alternate energy sources for generating electricity must be considered; these include nuclear, geothermal, biomass, tides, solar, and fuel cells.

NUCLEAR POWER

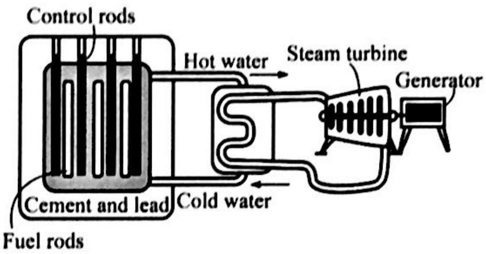
Uranium: radioactive material used in nuclear reactors

Chernobyl: site of a nuclear power plant disaster

Nuclear reactors use uranium to produce heat energy. It is possible to split the nucleus of the uranium atom. When the nucleus is hit, a chain reaction occurs and a tremendous amount of heat energy is released. The heat is used to produce steam for generating power.

A nuclear reactor is designed to make a *controlled* chain reaction and to remove the excess heat safely. Cadmium rods are used for the control. Adding or removing cadmium rods speeds up or slows down the reaction. A nuclear reactor is a source of clean electrical power.

Nuclear Reactor



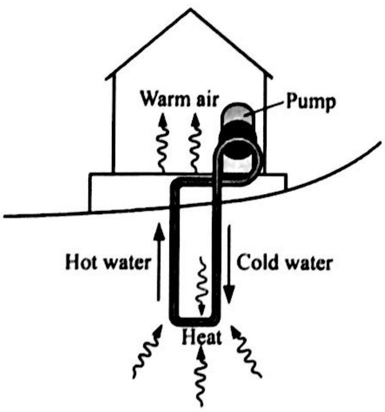
With the discovery of nuclear energy comes the challenge of safely disposing of radiation contaminants. Used radioactive fuel cells are stored in lead and concrete containers. They are buried in abandoned mine shafts far below the surface of Earth.

GEOTHERMAL POWER

Geothermal:
geo—means earth
thermal— means heat

Sulfur: odorous chemical element found in most natural hot springs

Geothermal power is made from energy contained in hot rocks. Molten rock beneath Earth's surface heats the ground water. A system of underground pipes transports the hot water and steam to a power station. Iceland has been using *geothermal* energy for years. Except for the sulfur smell common to underground springs, geothermal energy does not pollute the environment.



BIOMASS

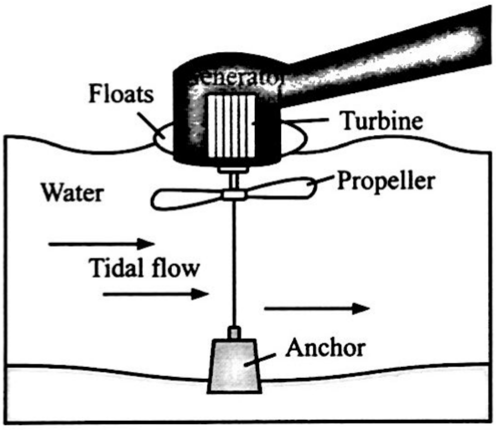
Biomass refers to organic material present in garbage. Organic material decomposes to produce methane gas. The gas is collected and used as fuel for generating electricity. The methane gas produced by the decomposing garbage at the Edmonton Sanitary Landfill is used to provide fuel for the nearby Edmonton Power Plant.

Biomass: organic material present in garbage

Biomass can also be incinerated. Burning garbage provides energy for power plants in certain areas of Germany.

TIDAL GENERATORS

Tidal generators use water currents to produce electricity. Huge tidal waves in the Bay of Fundy area spin specially designed turbine generators to produce a portion of Nova Scotia's electricity. Tidal power is a relatively new concept and in the experimental stages of development. Waves are a good source of energy. They are readily available but somewhat inconsistent in force because they are affected by the changing gravitational pull of the moon.



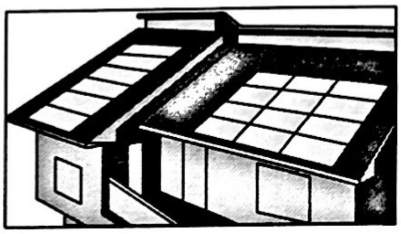
Solar: pertaining to the sun

SOLAR POWER

Solar electricity is generated using sunlight. Becquerel, in the early 1800s, exposed two metallic plates soaked in a conducting solution to sunlight. He detected a small current. This was the beginning of solar power.

Ionic plates are made from the element silicon.

Ionic plates are made from glass, metal, and silicon. Sunlight causes the silicon to release electrons to the metallic plates producing an electric current. It is now common to find solar power used in calculators, lights, and spacecraft. The initial cost of building solar cells is high, but the energy produced in inexpensive and pollution free. However, direct sunlight is not always available.



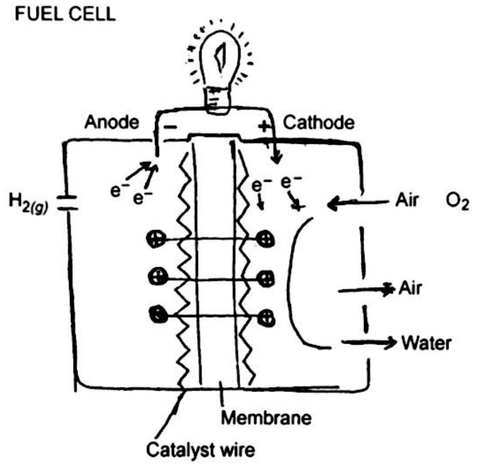
Fuel cells:

—produce clean fuel

—chemical reaction that produces water

FUEL CELLS

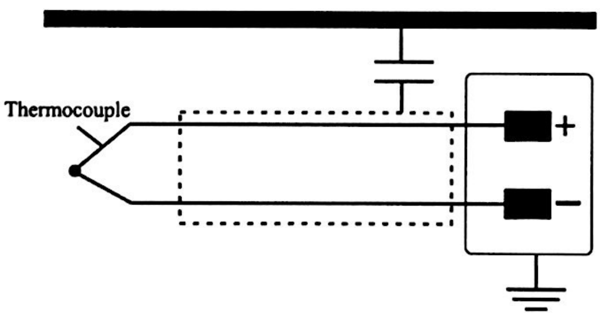
One of the fastest growing areas of energy research involves fuel cells. Fuel cells convert hydrogen gas and oxygen gas into water without combustion. Water, heat, and electricity are the only by-products. Fuel cells are efficient and provide no emissions. Automobile manufacturers are experimenting to develop vehicles powered by fuel cells. Perhaps, this will become the main energy source of the future.



Thermocouple: device that changes heat energy to electrical energy

THERMO-ELECTRIC GENERATORS

A thermo-electric generator converts heat energy into electricity. Heat is passed through two different metals called *thermocouples* to create an electrical potential difference. As the difference increases, the amount of current increases. Thermo-electric generators are often used in isolated areas where small amounts of electricity are required.



WHERE DO WE STAND?

The energy sources for producing electricity are either *renewable* or *non-renewable.*

Renewable sources are replaced as they get used up. Examples include wind, water, geothermal, and light. Non-renewable resources are irreplaceable. Once used up, they are gone. Examples include coal, natural gas, and oil.

Scientists estimate that the supply of fossil fuels will run out in the next 100 years. Therefore, alternate energy sources must be considered.

Lesson 3 STATIC ELECTRICITY

Electricity is the movement of tiny particles called electrons. If the electrons move from one place to another to produce a positive or negative charge, they create *static electricity*. If the electrons move along a conducting wire, they create *current electricity*.

Electrons: tiny moving particles in an atom

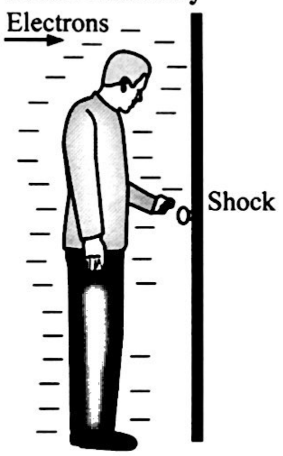
A student walks across a carpeted floor and touches a metal door knob. Zap! The student gets a shock. This is an example of static electricity made by rubbing together two different materials. As electrons are transferred from the carpet to the door knob, electrical charges are produced. The behaviour of these charges is explained by the Law of Electrical Charges.

Static: means "charged"

Law of Electrical Charges:

+ + or – –	repel
+ –	attract
+ neutral, – neutral	attract

Static Electricity



It states that:

- unlike charges attract
- like charges repel
- charged objects attract neutral objects

As shown in the diagram above, walking on a carpet transfers electrons from the carpet to the student's body. The body becomes negatively charged. Touching a neutral or positively charged door knob results in an *electrical discharge* in the form of a spark and a shock. Lightning is a natural example of static electrical discharge.

Van de Graaff generator: static electricity generating machine

Want a hair raising experience? Try placing your hand on the dome of a Van de Graaff generator. A buildup of electrons (negative charge) on the dome is transferred through the hand and body into the hair. The hair becomes negatively charged. Two negatively charged objects repel. This causes the hair to stand on end. A buildup of electrons on the dome can produce 30 000 volts of static electricity. Touching a Van de Graaff generator is not considered dangerous because the amperage produced is very low, less than one-quarter amp.

LIGHTNING

An electrical charge in a certain area is referred to as a *field.* Movement of air in a thundercloud creates an electrical field. Electrons are drawn from the ground by the rising air currents. This makes the ground *positively* charged. The accumulation of extra electrons makes the cloud *negatively charged.* A positive and negative charge coming together makes a *lightning bolt* that produces up to 1 000 000 volts of electrical force and 30 000 amps of current. This is an extremely dangerous discharge of electricity.

The Formation of Lightning

Grounding: method of safely disposing excess electrical charge

Tall buildings are protected from lightning damage by lightning rods. Lightning rods are made from a metal that attracts extra electrons. The electrons are carried through a wire cable to another rod located beneath the ground. It is here that the extra electrons are safely dispersed. This method of protection is called *grounding.*

Lesson 4 CURRENT ELECTRICITY

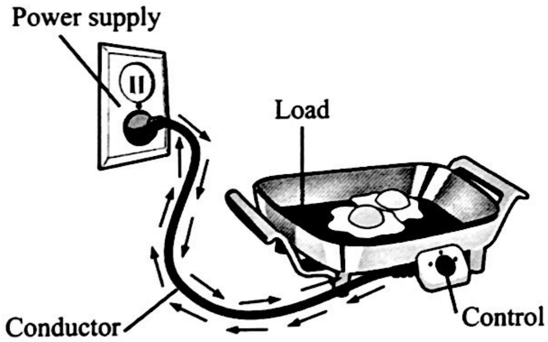
Current electricity is a continuous flow of electrons from an energy source. For example, electrons leave the negative pole of a battery, travel through a conducting wire, pass through a light and a closed switch, and then come back to the positive pole of the battery. This is an uninterrupted flow. Such a flow represents a complete path or *circuit*. Circuits generally consist of four main components:

- power supply
- conductor
- load
- switch

Current electricity: continuous flow of electrons from an energy source that requires a conducting path

Circuit: uninterrupted flow of electrons in a complete path

An electric frying pan is plugged into an electrical outlet (*power supply*). The current travels through one of the wires (*conductor*) in the cord to a switch (*control)* on the handle, through the heating element (*load*) in the pan, out through the second wire in the cord (conductor), and back to the outlet (power supply). This represents a complete path or circuit.



Lesson 5 ELECTROCHEMISTRY

Electrochemistry: electricity produced by chemicals

Major parts of a cell:
—electrodes
—electrolyte

Ions: charged particles

"wet" cell: has a solution electrolyte

"dry" cell: has a paste electrolyte

Cell: device that converts chemical energy into electrical energy

Battery: composed from two or more cells

"Electro" pertains to *electricity* while "chemistry" refers to *chemicals*. Certain reactions use chemicals to produce electricity. A cell or battery is a good example of this. Other reactions use electricity to produce a chemical change. Examples of these are: electrolysis, electroplating, and electro-refining.

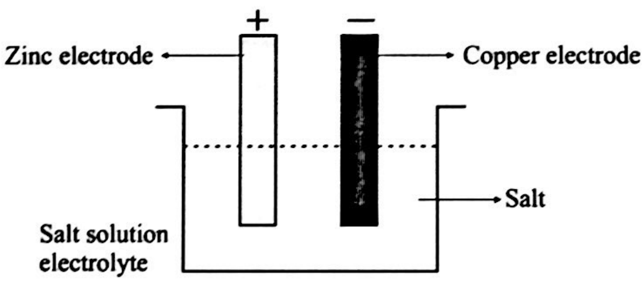
CELLS AND BATTERIES

Cells and batteries serve as an important source of power in many gadgets today. They supply the electrical energy for games, clocks, radios, and lighting devices.

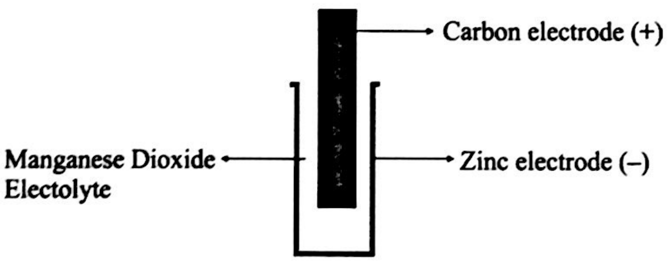
A cell or battery is a device that converts *chemical energy* into *electrical energy*.

Every cell consists of two major components: *electrodes and an electrolyte.* The electrodes, usually made of two *different* metals, produce the electron flow. The electrolyte is a conducting solution or paste that allows the flow to continue. A good electrolyte will carry an *ionic* charge. If the electrolyte is a paste, the cell is called a "dry" cell. It the electrolyte is a solution, the cell is called a "wet" cell.

Simplified Cell



A typical dry cell such as an AA or D cell consists of an outer zinc case (electrode), a centre carbon rod (electrode), and a manganese dioxide paste (electrolyte) all protected in an outer container. A chemical reaction causes the zinc electrode to release electrons through the electrolyte paste to the carbon electrode. The zinc case becomes the negative pole and the carbon rod becomes the positive pole.



Most cells can not be recharged when they become "dead." They are given the name *primary cells.* However, nickel-cadmium cells can be recharged. The ones that can be recharged are called *secondary cells.* Charging reverses the chemical reaction and replenishes the original supply of electrons.

Nickel–cadmium batteries can be recharged.

Point of Interest: A wall clock uses an AA cell—NOT an AA battery. Frequently, for the sake of convenience, cells are mistakenly called batteries.

WHAT IS A BATTERY?

A battery is a device that is made from individual cells connected together. A 9 V battery, often found in smoke detectors, may consist of six 1.5-volt cells connected together. A 12-volt car battery also has a series of cells joined together.

Battery types:

9 V (found in smoke detectors)

12 V (found in cars)

ELECTROCHEMICAL PROCESSES

Certain processes use electricity to produce a chemical change.

Electrochemical Process:

–electrolysis

–electroplating

–electro-refining

Electrolysis

Electricity can split the water molecule into hydrogen gas and oxygen gas, providing a source of fuel.

Electroplating

An electric current that flow through an electrolyte deposits atoms of one metal on to another. Zinc can be electroplated on steel to prevent rusting

Electro-refining

Electricity is used to remove impurities from metal. Impure gold, in an acid electrolyte, can be deposited on a second electrode to form pure gold.

Lesson 6 ELECTRICAL MEASUREMENT AND SAFETY

The **force** of electricity in a circuit is measured in volts. The **quantity** of electricity is measured in amperes. The factor that limits the flow of electricity is measured as **resistance**. All three are important electrical measurements.

VOLTAGE

Voltage: measure of potential difference or force

–term coined by the scientist Volta

Voltage in a circuit is the measurement of pressure or **force**. It is sometimes referred to as the "potential drop" between two ends of a conductor through which the current is flowing. The potential drop is the difference in energy between the positive pole in a cell and the negative pole in a cell. Voltage can be compared with the force of water passing through a pipe. Fast-moving water exerts more force on the walls of a pipe than does slow-moving water. Similarly, fast-moving electrons (big force) have a higher voltage than do slow-moving electrons (small force). Power sources have different voltage outputs.

Example

AA cell	1.5 volts
Car Battery	12 volts
Electrical Outlet	110 volts

Voltage is measured in **volt** (V) units with a **voltmeter.**

AMPERAGE

Ampere:

–measure of the quantity of electrical flow

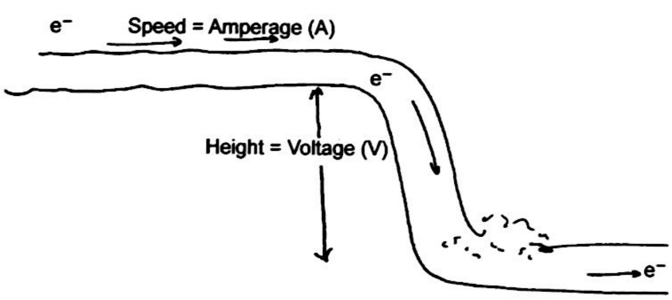
–term coined by the scientist Ampere

Amperage or current is the **quantity** of electrons passing a given point. A higher current has more electrons passing a certain point than a low current does, just as fast-moving water has a greater volume passing a certain point than does slow-moving water.

A strong electrical current is measured in **amperes** (A) with an **ammeter.** A weak electrical current is measured **in milliamps (mA)** with a **galvanometer.**

The connection between voltage and amperage can be illustrated using moving water as an example.

VOLTAGE vs. AMPERAGE



NOTES

Did You Know?

A current with an amperage as little as 0.1 A is felt as a shock but a current of 1.0 A is deadly. Voltage jolts, but amperage "kills".

Voltage jolts, but amperage kills.

RESISTANCE

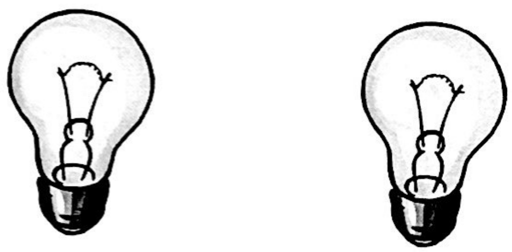
Resistance is defined as a property that restricts the flow of electrons. Because tungsten wire in a light bulb has resistance, the electrons must work harder to get through. The higher the resistance, the greater the amount of light and heat produced. A 100 W light bulb burns brighter and gives off more heat than a 60 W bulb.

Resistance:

–that which limits the flow of electricity

–expressed in ohms

–term coined by the scientist Ohm



Resistance is affected by voltage and amperage. High voltage means high resistance; high amperage means low resistance. Resistance is affected by temperature. A high temperature means more resistance.

V	↑	R	↑
A	↑	R	↓
T	↑	R	↑

Resistance is measured in **ohms** (Ω) with an **ohmmeter.**

Electrical safeguards:

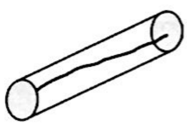
–fuse

–breaker

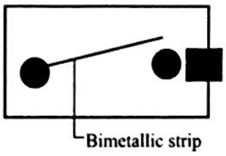
ELECTRICAL SAFETY

An electrical circuit must have a safeguard to prevent overheating and the possibility of a fire. Fuses and breakers inserted into a circuit prevent this.

A fuse is a device as seen in the diagram below with a metal strip having a lower melting point than the wire it is connected to. The metal strip melts before the wire overheats. This causes a break in the flow of electricity. A fuse cannot be reused.



A circuit breaker as seen in the diagram below has a bimetallic strip contact. A surge of electricity produces heat that causes the strip to bend away from its contact point. A break in the circuit occurs and no electricity continues to flow.



Some electrical appliances have two–pronged plugs, others have three prongs. A three–pronged plug has a "ground" connection that serves to carry an overload of current away from the circuit. It is very important not to remove the third prong to make the plug fit into a two-pronged outlet.

A car is tangled up in live electrical wires. What is the best decision that can be made by the person inside the car? **Stay inside!** Do not attempt to get out unless in danger of fire or explosion. The rubber tires act to insulate against the live electrical current. Once outside the car, the person's body would be in contact with "live" wire and would become a conductor of electricity. This situation could turn deadly.

Lesson 7 CONTROLLING ELECTRICAL CURRENT

The current in a circuit can be controlled by using different materials and devices. These include insulators, conductors, resistors, and switches.

NOTES

CONDUCTORS

Conductors are materials that allow the flow of electrons. Electrons in a conducting material are slightly attracted to the nucleus of the atom and have the freedom to move around.

Insulating materials:
–rubber
–plastic

Metals, such as copper, aluminum, silver, and mercury, are excellent conductors.

Best conducting wire: silver

Research is continually being done to improve the conductivity of materials. By lowering the temperature to near Absolute Zero (–273°C), certain materials can be made to be nearly "perfect" conductors. That is, they do not have any resistance to the electron flow. Such materials are called *superconductors*.

Commonly used conducting wire: copper

Absolute zero: lowest possible temperature; –273.15°C

The lower the temperature, the better the conductor.

INSULATORS

Insulators are non-conductive materials that prevent the flow of electrons. Electrons in insulating material are attracted to the nucleus of the atom with strong forces. As a result, their movement is prevented.

Wire is usually protected with a rubber or plastic insulating material. Generally, non-metallic materials such as wood, glass, rubber, and certain plastics, make good insulators.

RESISTORS

Resistors are partial conductors. They limit the flow of electrons by allowing only some electrons to pass through. Electrons in a resistor are slowed down and restricted in movement. Because electrons must work harder to get through, friction between the electrons and material may produce energy in the form of heat and light.

Resistors are beneficial to us today. A light bulb and stove element are examples of resistors that produce light and heat. Circuit boards found in computers, radios, and televisions use commercial resistors to control power and sound. A polygraph or "lie detector test" uses the principle of skin resistance to determine whether a person is telling the truth. Nichrome wire (made from nickel and chromium) is often demonstrated as a resistance wire in schools.

Nicrome wire is an alloy of nickel and chromium.

Tungsten: is what the resistance wire in an incandescent light bulb is made from

Resistor rating: is determined by color bands

Switch: is a control mechanism that breaks or opens a circuit

Rheostat

–variable resistor

–found in a dimmer or volume switch

Interesting Facts:

Commercial resistors are made from a carbon composition mixed with a glue binding material.

A *variable resistor* or *rheostat* is a device that controls the amount of current passing through a circuit. A light dimmer switch or a radio volume control are examples of a rheostat.

SWITCHES

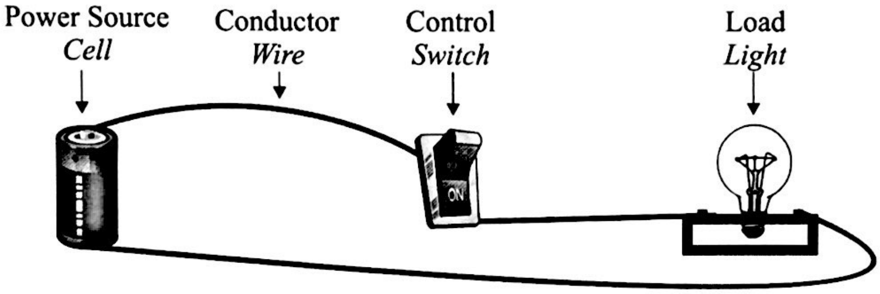
Switches are used to "turn on" and "turn off" electrical devices. A switch is a control mechanism that breaks or opens a circuit. It prevents or allows for electrons to flow continuously.

A switch flipped "on" completes the circuit and causes a door bell to ring, a light to "turn on", and a motor to "run." A switch flipped "off" opens the circuit and prevents devices from working.

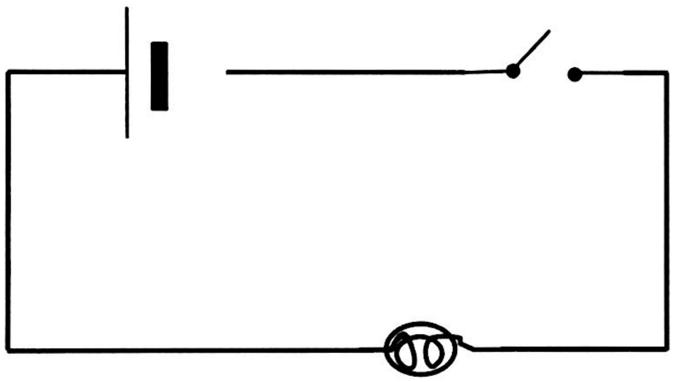
Lesson 8 ELECTRICAL CIRCUITS

Electrical circuits can be simple or complex. They range in size from major wiring patterns in houses to tiny microchip boards found in televisions.

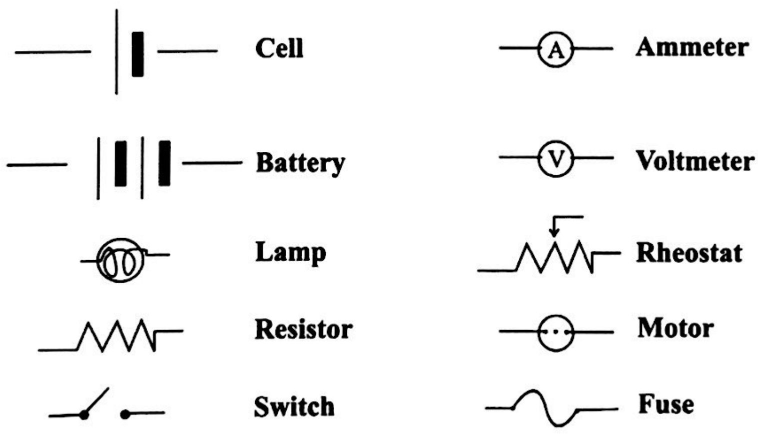
Quick Review: Electrical circuits have four basic parts:



Electrical circuits are drawn as *schematic* diagrams. The diagram below makes it easier to understand how the current flows. The above circuit can be represented in the following schematic.



Constructing a schematic diagram requires knowledge of electrical symbols. The following list shows some of the basic electrical components and their symbols.



There are two methods of connecting electrical components: in series or in parallel.

Circuits can be
–in series
–parallel

Four components in a circuit:
- load
- conductor
- control
- power source

Schematic diagram: electrical diagram using symbols

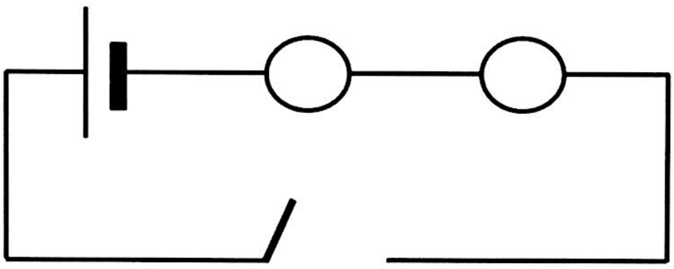
Series circuit: one pathway

IN SERIES

A series circuit has ONE current path. Each component receives the same current. Two lamps connected in series means that each lamp receives half the voltage. Each lamp receives 0.75 V from a 1.5 V D cell.

Disadvantage: If one lamp burns out, the other will not light.

Schematic diagram of lamps connected in series:



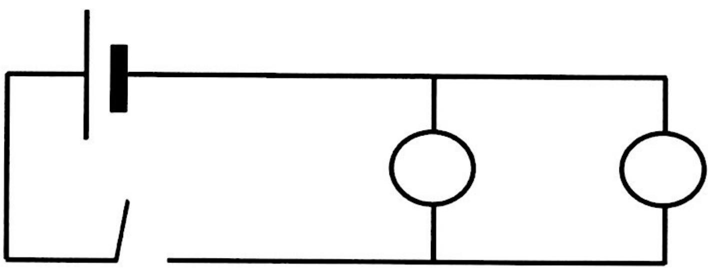
Parallel circuit: multiple pathways

IN PARALLEL

A parallel circuit has multiple current paths. Each lamp has its own path. Both lamps have the same cell voltage across them and will burn just as brightly. A 1.5 V D cell provides 1.5 V of electricity to each lamp.

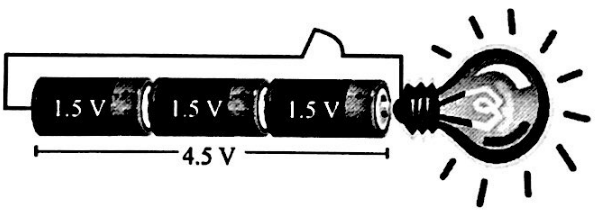
Advantage: If one lamp burns out, the other has its own path and continues to light. The circuits in a house are wired in parallel.

Schematic diagram of lamps in parallel

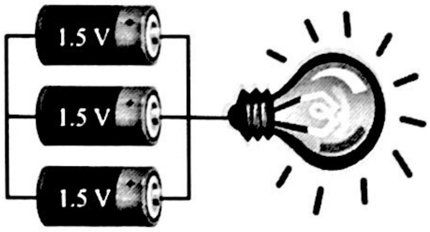


Cells can be wired in series and parallel.

Three 1.5 volt cells wired in *series* produce 4.5 volts of current. This setup uses considerable electricity and will not last a long time.



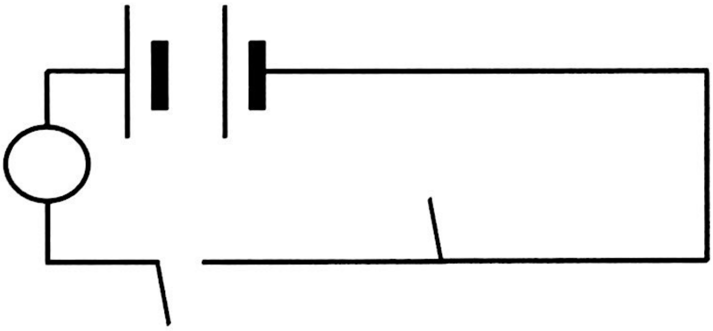
Three 1.5 volt cells connected in *parallel* produce 1.5 volts of current. This setup uses less electricity and will last much longer.



Think About It!

A hallway light needs to be controlled from both ends of the hallway. How is this made possible? By placing a three-way switch at each end of the hall.

Schematic diagram of a three-way switch:



Flipping both switches up completes the circuit from one end of the hall. Flipping the switches down completes the circuit from the other end of the hall.

Lesson 9 ELECTRICAL CALCULATIONS

Ohm's Law: current flowing varies directly to the voltage applied

Ohm's Law: R = V / I

V = I × R

I = V / R

R = V / I

The symbol used for ohm is Ω.

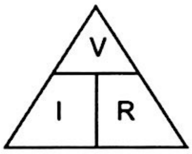
OHM'S LAW

A German scientist, Georg Ohm, linked voltage, current, and resistance together.

Ohm's Law states that: *current flowing through a wire varies directly to the voltage applied.* This means: more voltage, more current.

Ohm's Law also relates to resistance. If the resistance increases, the current decreases.

Volts (V) = Current (I) × Resistance (R)



V = I × R

Hint for remembering the formula: Cover the letter you are trying to sove for and that will reveal the formula.

Knowing any two of the values makes it possible to calculate the third.

CURRENT can be determined using the formula: I = V / R
RESISTANCE can be determined using the formula: R = V / I

Example

What is the voltage of a power source that has a 1.5 A current flowing through a 30 Ω lamp resistance?

Solution
V = I × R
V = 1.5 A × 30 Ω
V = 45 V
The power source has a voltage of 45 V.

Example

A hair dryer produces a resistance of 12 Ω when plugged into a 110 V electrical outlet. What is the amount of current passing through the dryer?

Solution
I = V / R
I = 110 V / 12 Ω
I = 9.2 A
The hair dryer has a current of 9.2 A.

Example

A radio uses a current of 0.2 A when operated by a 9 V battery. What is the resistance in the radio circuit?

Solution
R = V / I
R = 9V / 0.2 A
R = 45 ohms
The resistance in the circuit is 45 ohms.

IN SUMMARY:

- if current remains constant and resistance ↓, voltage ↓
- if resistance remains constant and current ↓, voltage ↓
- if voltage is constant and resistance ↓, current ↑

POWER

The amount of electrical *resistance* in a circuit is dependent on the voltage of the power source and the current passing through it. Voltage is divided by current to find resistance.

R = V / I

The amount of electrical *power* used by the load in the circuit is also dependent on voltage and current. Voltage is multiplied by current to find power.

Power is expressed in watt (W) units, named in honour of James Watt, a Scottish inventor and engineer.

Power = Voltage × Current
P = V × I

Power:
–measured in watts
–coined by James Watt

P = V × I
V = P / I
I = P / V

Example

A curling iron is plugged into a 110 V outlet. It uses 8.33 A of current. What is the power rating of the iron?

Solution
P = V × I
P = 110 V × 8.33 A
P = 1 000W (watts)

The connection of POWER to electrical consumption will be explained in another section.

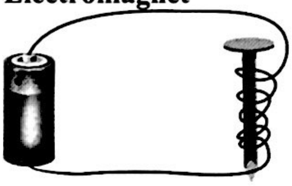
Lesson 10 ELECTRICITY AND MAGNETISM

Electromagnet: device that converts electricity to magnetism

Hans Christian Oersted, a Danish physicist, noticed a relationship between electricity and magnetism. He noted that a compass needle deflected when placed near an electric current. When the current was interrupted, the magnetic field was no longer there. Oersted concluded that *current flowing through a wire creates a magnetic field around the wire.*

Michael Faraday, 11 years later, was credited with discovering the basic principle of *electromagnetism.* He created a magnet using electricity. By wrapping wire around an iron nail, and attaching it to a battery, Faraday made a special magnet. Because this device changes electricity into magnetism it is called an *electromagnet.*

Electromagnet



Today, the principle of electromagnetism is used in electric motors and generators.

ELECTRIC MOTOR

An electric motor is a device that converts *electrical energy* into *mechanical energy* (energy of motion). How does it do this?

A strong electromagnet called an *armature* is made by winding a coil of wire around an iron core. The armature is positioned between two permanent magnets and turns to line up with the magnetic field produced by the permanent magnets. The N pole of the armature (electromagnet) spins towards the S pole of the permanent magnet.

Electric motor: device that converts electrical energy to mechanical energy

Electric generator: device that converts mechanical energy to electrical energy

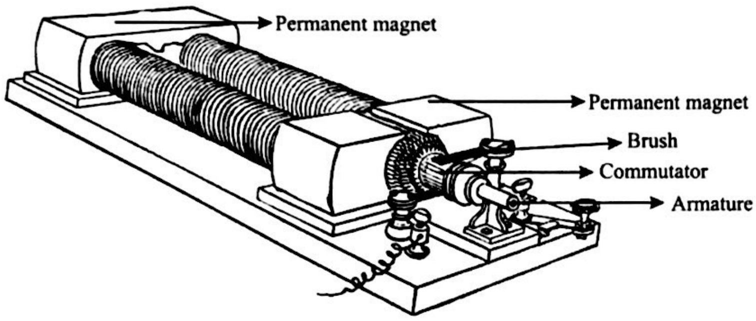
Armature: a strong electromagnet

What keeps the armature spinning?

The trick is to change the polarity of the armature.

The N pole needs to become an S pole and then an N pole again, and so on. This is made possible by a *split ring commutator.* The commutator is a metal ring connector that has a split in it to reverse the current flow.
As the N pole of the armature is attracted to the S pole of the permanent magnet, the commutator reverses the polarity of the armature and changes the N pole to an S pole. Because two like poles repel, the armature continues to spin.

By attracting and repelling at the right moment, the armature can be made to spin continuously.

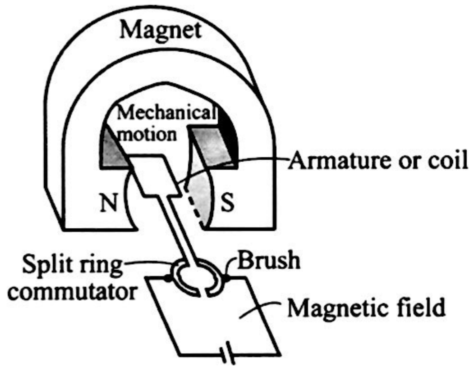


Direct Current (DC): flows in one direction

Alternating Current (AC): flows back and forth

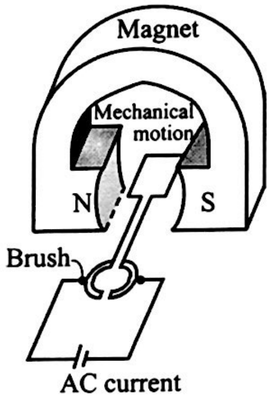
Smaller appliances such as MP3 players and computers, have electric motors that are operated by a *direct current,* or current that flows only in one direction. These are DC motors.

DC Motor



Larger appliances have electric motors that run on an *alternating current.* These are AC motors and are commonly found in dishwashers and refridgerators. A 110 V electrical outlet has an alternating current (AC) that cycles back and forth, 60 times per second.

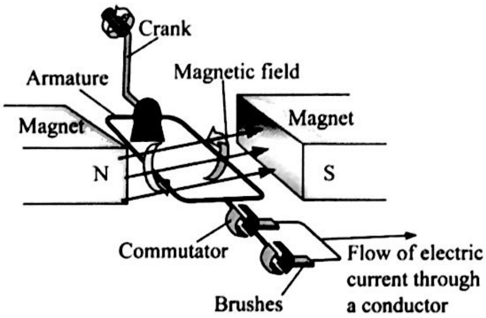
AC Motor



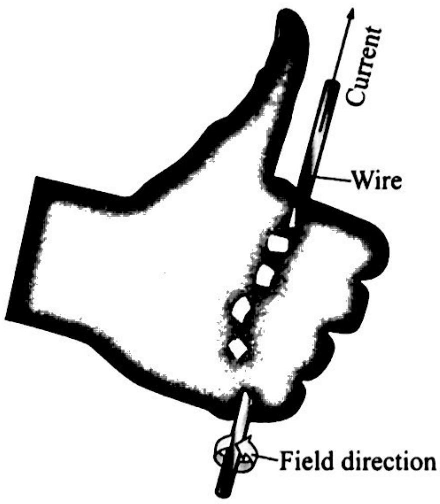
By connecting a pulley or gear to the shaft of the armature, work can be done by the motor. Electric motors are used to operate pumps, power tools, electrical lawn mowers and fans. We say that electric motors convert *electrical energy* into *mechanical energy.*

GENERATOR

Faraday noticed that if a magnet was moved back and forth in a coil of wire, it made a compass needle deflect. Moving a magnet in a coil of wire *induces* an electric current. Similarly, when a generator is made to spin, it produces electricity when the wires cut through a magnetic field.



The direction of current flow and magnetic field can be predicted using the LEFT-HAND RULE: Curl your fingers of the left hand around the wire coming from your generator. The *curled fingers* indicate the direction of the *magnetic field.* The *thumb* points in the direction of current flow.



Generators can produce a direct current (DC) or an alternating current (AC). Generators that produce a current in one direction (DC) are called dynamos. Those that produce a current that switches back and forth (AC) are called alternators. Cars have alternators to generate electricity for making the lights and horn work.

QUICK REVIEW:

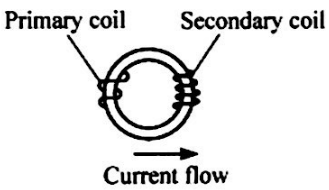
A motor converts electrical energy into mechanical energy.
A generator converts mechanical energy into electrical energy.

TRANSFORMERS

The power produced at an electrical generating plant has a voltage much too high for use in an ordinary house. Some transmission lines from the generating plant can carry as much as 500 000 volts. Special devices called *transformers* must "step down" the voltage to 240 or 120 volts. This is the amount needed to run all appliances in a house. How is this done?

Transformer: "steps up" or "steps down" an electrical current

A conducting wire is wrapped around one side of a circular or rectangular iron core. This represents the primary coil. A second or secondary coil is wrapped around the opposite side of the iron core. If the secondary coil has fewer wraps of wire than the primary coil, the transformer steps-down the voltage. If the secondary coil has more wraps of wire than the primary coil, the transformer steps-up the voltage.



Lesson 11 POWER, ENERGY, AND EFFICIENCY

NOTES

After electricity is generated by a power plant, carried by transmission lines, and reduced to a usable voltage by tranformers, it can be safely used in a home to run appliances. Its consumption is monitored by a meter, and paid for by the kilowatt hour of use.

POWER

Power or the *rate* at which a device converts energy, is measured in *watt* (W) units. Power is dependent on voltage and current (as previously discussed in Electrical Measurement lesson).

Power = Voltage × Current
(watts) (volts) (amps)

Hint: Any value (P, V, or I) can be calculated if the other TWO are known

Formula: $P = V \times I$

Example

What is the power of a toaster that is plugged into a 110 V outlet and uses 12 A of current?

Solution

$P = 110\ V \times 12\ A$
$P = 1\ 320\ W$

Power is also defined as the *energy per unit time.* Power describes the amount of electrical energy converted to light, heat, sound, and other forms.

Power = energy/time
1 Watt = 1 Joule/1 second
watts = joules/seconds

Formula: $P = E/t$

Example

What is the wattage of a frying pan that uses 300 000 joules of energy to cook potatoes for 10 minutes? Hint: Any value (P, E, or t) can be calculated if the other TWO are known.

Solution

$P = E / t$
$P = 300\ 000\ J/(10 \times 60)$ seconds
$P = 500\ W$

The frying pan has a rating of 500 W.

ENERGY

A monthly electrical bill indicates the cost of electrical energy used in a home during that period.

Example

The amount of energy used by the fridge, stove, TV, and four lights in a home can be calculated for the month of April and the cost determined.

- 700 W fridge is used for 32 hours
- 1 500 W stove element used for 16.5 hours
- 250 W TV used for 100 hours
- Four 100 W bulbs used for 55 hours and 45 minutes

The cost of electrical power charged by the company is $ 0.07 / kilowatt hour (7 cents/ kWh). Determine the cost of electrical energy consumed during the month of April by the appliances listed above.

Solution

Change the power wattage of each appliance to KILOWATTS (divide by 1 000 because 1 000 W = 1 kW)
Multiply by the number of such appliances (4 light bulbs)
Multiply by the number of hours (change minutes to hours by dividing by 60 because 60 minutes = 1 hour)
Multiply by the cost per kWh (7 cents)

Fridge: 700 W / 1 000 = 0.7 kW × 32 hr = 22.4 kWh
Stove: 1500 W/ 1 000 = 1.5 kW × 16.5 hr = 24.75 kWh
TV: 250 W / 1 000 = 0.25 kW × 100 hr = 25.00 kWh
Lights: 4 × 100 / 1 000 = 0.4 kW × 55.75 hr (45 / 60 is 0.75)
= 22.30 kWh

Total = 94.45 kWh

Because the cost per kWh is 7 cents, the total monthly cost of using the listed appliances is 94.45 kWh × $0.07 / kWh or $ 6.61

Converting watts to kilowatts: divide by 1 000

Converting kilowatts to watts: multiply by 1 000

kWh: kilowatt hour

EFFICIENCY

Many of the appliances used today are much more energy-efficient than they were in the past. Fridges today use much less power and are more efficient.

Efficiency refers to the *ratio* of the *useful energy output* to *the total energy input.* The efficiency of an incandescent light bulb is much less than that of an equivalent fluorescent light bulb because an incandescent bulb loses energy to producing heat. The useful energy output of an incandescent bulb is much less compared to the total input energy.

Formula: Efficiency = Output energy / Input energy × 100

Efficiency:

–refers to the productive work

–measured as a percentage

–determined by dividing output energy by input energy

Efficiency decreases when a device changes energy to heat.

Example

An incandescent light bulb uses 780 J of energy to produce 31 J of light. What is the efficiency of the light bulb?

Solution

Efficiency = Output Energy / Input Energy × 100
Efficiency = 31 J / 780 J × 100 or 4 %

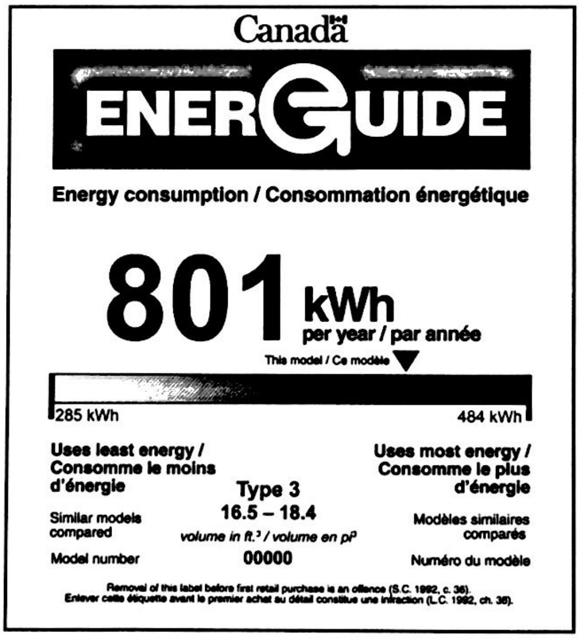
An incandescent light bulb is 4% efficient in producing light. The remaining 96% is changed to heat. A fluorescent light bulb is about 22% efficient. Approximately 78% of its energy is lost to heat.

To reduce the cost of operating electrical devices, companies are making products that use less power. A 21 W compact fluorescent light bulb produces the same intensity of light at a 100 W incandescent bulb. The cost of using the compact bulb is about 5 times less.

Electric motors are more efficient than gas-fueled combustion engines. Electric motors have fewer moving parts. Less energy is wasted.

All appliances sold in Canada must carry an "EnerGuide" label that indicates electrical consumption. Usually, a number on the label such as 857 kWh indicates the average per year consumption of power by that appliance.

EnerGuide: energy consumption sticker that is mandatory on all larger appliances



REVIEW SUMMARY

- Electricity is a form of energy produced by moving electrons. When electrons move from one area to another, they build up a difference in charge.
- *Static electricity* is produced when positive protons are attracted to negative electrons. Lightning is a good example.
- Current *electricity* is the flow of electrons along a conducting path. Current electricity is produced at a power source and flows along a conducting path. Current electricity is produced at a power source and flows along a conductor to a load and back to its power source.
- A circuit is the flow of current electricity in a complete path. A circuit must have a *power source*, *conductor*, *control,* and *load.* A circuit is represented in a schematic diagram using electrical symbols.
- Measurement of voltage, amperage, and resistance can be taken within a circuit.
- Voltage measures the potential differences in electrical charges and is expressed in volts. Amperage measures the force of moving electrons and is expressed in amperes or milliamps. Resistance is that which opposes electron flow; it is measured in ohms.
- Electrical circuits are connected in *series* or in *parallel.*
- A series circuit has one path of electrical flow. If one part of the circuit is interrupted, the other parts will not work.
- A parallel circuit has multiple paths of electrical flow. If one part is interrupted, the others will continue to work.
- A circuit is said to be *closed* when the switch is on. If the switch is turned off, a circuit is said to *open.*
- A cell is a device that converts chemical energy into electrical energy. A cell consists of two *electrodes* made from different metallic material (copper, zinc) and an *electrolyte* (usually a chemical paste.) A chemical reaction causes electrons to travel from the zinc electrode through the electrolyte to the copper electrode producing an electrical current.
- Cells joined together make a battery. Batteries made from primary cells are not rechargeable while batteries made from secondary cells are rechargeable.
- Electricity is often used to produce a chemical reaction. Such is the case in electrolysis, whereby water is split into hydrogen and oxygen gas.
- A conductor (e.g. copper wire) allows electrons to flow freely. An insulator (e.g. rubber) prevents the flow of electrons. A resistor (e.g. tungsten) is between a conductor and a resistor. It allows some electrons to flow through, but with force. Resistors often produce heat and light. Variable resistors (e.g. rheostats) act as dimmer switches by controlling the amount of electricity passing through.
- George Ohm, a German scientist, stated that an electrical current is directly proportional to the voltage if the temperature and resistance remain constant. Ohm's Law can be expressed using the formula:
  $R = V / I$ (Resistance = Voltage / Amperage)

- Given any two values, the third can be calculated.
  V = I × R   I = V/R
- Voltage is measured with a voltmeter. Amperage is measured with an ammeter (large quantities) or a galvanometer (small quantities.) Resistance is measured with an ohmmeter. A multimeter is often used for readings. A multimeter is a single instrument that measures all three.
- One form of energy can be converted into another form.
  - A cell converts chemical energy into electrical energy
  - A motor converts electrical energy into mechanical energy
  - A generator converts mechanical energy into electrical energy
  - A thermocouple converts heat energy into electrical energy
  - A solar cell converts light energy into electrical energy
- An electrical motor uses electricity to produce motion. Basic parts of a motor are: commutator, armature, permanent magnets, and brushes.
- The permanent magnets in a motor have a fixed north and south-pole polarity. The armature changes its polarity from north to south and vice versa. This is made possible by the split ring commutator. When magnetic poles become like, they repel. When the poles become unlike, they attract. The alternating of polarity causes rapid spinning of the armature.
- Electric motors can run on
  - direct current (DC): current that flows in one direction
  - alternating current (AC): current that flows back and forth
  - Generally, large appliances such as a freezer or a washing machine run on AC.
- Generators produce electrical current. The amount of power produced is expressed in watts and is determined using the formula:
  P = I × V   (Power = Current × Voltage)
- Electrical power is bought by the kilowatt hour of use.
- The energy consumption of an electrical device can be determined by using the formula:
  E = P × t   (Energy (j/s) = Power (w) × time (s))
- The efficiency of an electrical appliance is determined by comparing the electrical output to the electrical input.
  Efficiency = Output Energy / Input Energy × 100
- The incandescent light bulb is inefficient because most of the energy is converted into heat.
- Government guidelines make it mandatory for larger appliances to have an EnerGuide sticker to indicate the average monthly or yearly electrical consumption.
- With the depletion of fossil fuels, other energy alternatives have to be considered. Wind, solar power, tides, and fuel cells are being considered as options.