let's talk science

CHALLENGE

2015 STUDY HANDBOOK

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Message from Bonnie Schmidt, Ph.D.,
President and Founder, Let's Talk Science

Imagine, for a moment, you're an astronaut. You catapult through a wormhole into the future. What would you find? One thing I know might influence decisions you make here on Earth. Over 70% of jobs that will exist in Canada when you graduate will need science technology, engineering and math.

So, congratulate yourself for taking a big step toward your future by being part of the Let's Talk Science Challenge. I hope what you learn through this competition will inspire you to think about the courses you'll take in high school, the exciting jobs you'll have to choose from when you're ready, and even what discoveries you'll make in your life.

You won't have all the answers yet. Actually no scientist really does in the beginning of their explorations. I can tell you the best discoveries ever made have come from asking lots of great questions and being determined!
Everything you learn in this Challenge – including teamwork, creative thinking and problem solving – will help prepare you for your own encounters in the scientific 21st Century! So, have fun, meet new friends, and good luck to all!

Minister's Message

Over the last year, I've had the privilege to re-acquaint myself with the world of Canadian science - and there are so many exciting things going on! From developing the next generation of the world's fastest quantum super computers to watching astronaut Chris Hadfield conduct experiments on the International Space Station, every day I am in awe of our scientists and the research taking place right here in Canada.

Let's Talk Science reminds us all that there are millions of young Canadians who are taking up the challenge to learn about our world and how it works...and who will one day make discoveries that will change our lives forever. As an aspiring scientist, you need to look at the different areas of science, see what interests YOU and ask lots of questions. For example, do you wonder:

- *whether there is anything faster than the speed of light?*
- *whether we really are alone in the universe? or*
- *how might we make improvements in our world if we had answers to these questions?*

This handbook gives you the basics on the big divisions of science – Biology, Chemistry, Earth Sciences, Engineering & Technology, Environmental Sciences, Math, Physics, and Space Science. So what is your passion?

When I visited my first Let's Talk Science Challenge as Minister last year, I asked the students to make a promise to themselves. I will now ask the same of you.

Please promise that you will keep pursuing your passion for science into high school, college or university. Canada is the best place in the world to study and work as a scientist.

So to all of you participating in this year's Let's Talk Science Challenge, have a blast exploring the world of science. As the Minister of State for Science, I know you will be brilliant as you become the leaders, the researchers, and the entrepreneurs of tomorrow.

We're in your hands.

The Honourable Ed Holder
Minister of State (Science and Technology)

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FOREWORD

Welcome to the LET'S TALK SCIENCE CHALLENGE - a competition all about science, technology, engineering and math - STEM! We are happy that you and your teammates are up for an exciting competition in which you will test your smarts and teamwork skills against other students from your community. There are two main parts to the LET'S TALK SCIENCE CHALLENGE – a super-fun ***Test your Knowledge Competition*** and a hands-on problem-solving ***Design Challenge***. Each part requires a different set of skills, so in order to win, you need to prepare. Here are some tips that our volunteers have put together to help you do your best on the competition day.

Test your Knowledge Competition

The Test Your Knowledge Competition is a question and answer session in which you respond to questions based on the information in this handbook. The answers to most questions will be a single word or a few words – no lengthy explanations needed here! But be on the lookout for bonus questions which will be in other formats such as multiple choice. It is important to keep in mind that **ALL** of the answers will come straight out of this handbook. The handbook has eight chapters: Biology, Chemistry, Earth Sciences, Environmental Sciences, Engineering & Technology, Mathematics, Physics and Space Sciences, which have been written by Let's Talk Science volunteers from across Canada (see the **Acknowledgements** section to find out who these great writers are!). Each chapter also has a **Spotlight on...** section that features an innovative person or product from the past or present. This probably sounds like a lot of stuff to read, but there are some ways to make getting ready for the quiz easier.

- Divide the chapters up and have different team members become 'chapter champions.' These can be your go-to people for the given chapters.
- Make up your own questions and test each other.
- Visit the **Student Preparation Centre** on the LET'S TALK SCIENCE CHALLENGE website www.letstalkscience.ca/challenge. Each week, for 10 weeks, a new set of multiple choice practice questions will be posted there. These will give you a good idea about how well you know your stuff (and you never know if you might see these questions again…).

Design Challenge

The Design Challenge is a hands-on problem-solving task that you will do together as a team. You will be given a task to accomplish and a limited amount of materials and time to accomplish that task. What your team creates will be judged on how successfully it accomplished the task, how effectively you used the given materials, and how well you worked as a team.

Ways that you can get ready for this challenge include:

- Trying the Design Challenges in this handbook. Each chapter (except for the Mathematics chapter) has a Design Challenge. The challenges use everyday materials and can typically be done in 30 minutes or less.
- Assign each person a role such as Materials Manager, Timekeeper, Leader, Tester, Presenter, etc. Try out the various roles while doing the practice design challenges in this handbook.
- Try a practice challenge under a time crunch – this will help you to work better under pressure.

Challenge Day

On Challenge Day, you and your team will travel to a university/college campus to face off against other teams who have also studied this handbook to compete for the title of the LET'S TALK SCIENCE CHALLENGE CHAMPIONS! There will be awesome giveaways for all contestants, including recognition for the Let's Talk Science Challenge Champs! You can show your team spirit and creativity by creating matching team shirts or hats, wearing face paint, bringing a flag, writing a team cheer, etc. The team with the best sportsmanship and team spirit can win the coveted SPIRIT AWARD.

Also, on Challenge Day, please say a big thank you to all of the Let's Talk Science **volunteers** who have put this fun day together for you, as well as the **sponsors** who have made the day happen at no charge for you or your school.

Most of all…HAVE FUN!! The LET'S TALK SCIENCE CHALLENGE is a great chance to stretch your brain, learn cool new stuff, travel to a university or college campus, work as a team, and meet other kids.

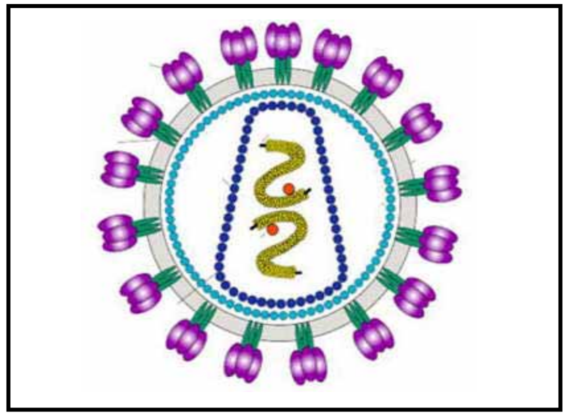
If you have any questions about this handbook or Challenge Day, please contact Lorna Collins at LCollins@letstalkscience.ca.

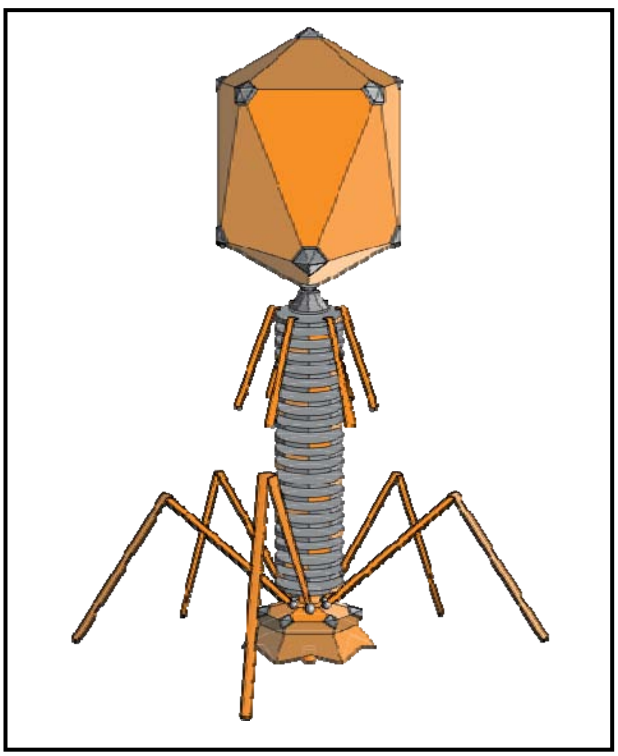
We look forward to meeting you on the day of the competition!

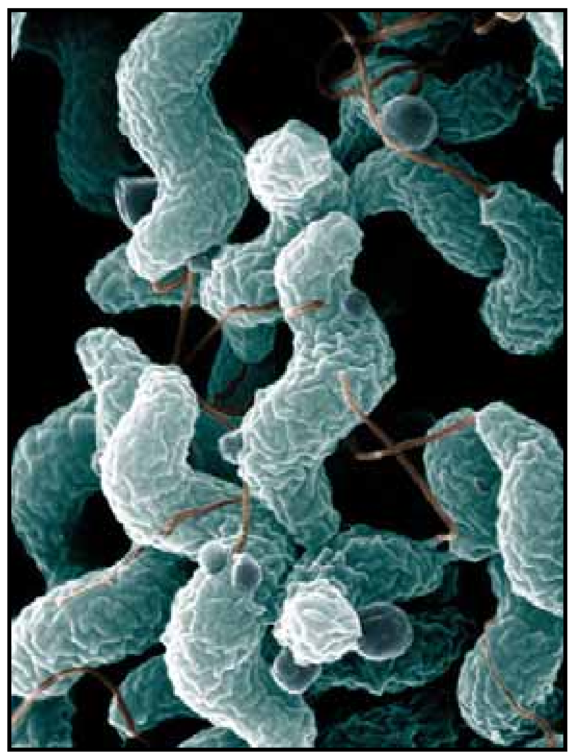
The LET'S TALK SCIENCE CHALLENGE team

Chapter 1

Biology







INTRODUCTION

Biology is the study of living things, from simple viruses and single-celled **organisms** (an organism is any form of life, such as an animal, plant or fungus) to the most complex ecosystems. The diversity of nature cannot be summed up in one short chapter, and so this chapter will explore just one of the many interesting topics in biology. We will take a short look at **microbiology**, which is the study of very small organisms.

Microbiology is the study of organisms that are so small that you can't see them with your eyes alone; you can only see them with a **microscope**. Microscopes are specialized magnifying devices that are used to see **bacteria** and **viruses**, which are the two major groups of microorganisms that you will learn about in this chapter.

BACTERIA

Did you know that the number of bacteria living in your mouth is larger than the number of people who have ever lived on earth? Bacteria have been around for a long, long time; in fact, the earliest fossils of **prokaryotes** (of which bacteria are a major sub-section) are over 3.5 billion years old! Having been around for so long, bacteria have **evolved** (developed gradually) into a wide variety of different types and have **adapted** to a variety of different environments. This includes the inside of your mouth and your intestines.

Bacteria Structure

Bacteria are **single-celled organisms**. This means that each organism is made up of only one cell. This is very different from humans and other animals that are made up of trillions of cells. Bacterial cells are much smaller than human cells. They usually measure around 3 000 nm in diameter (nm is the short form for **nanometre** which is 1/1 000 000th of a millimetre). A human blood cell is around 10 000 nm.

Even though they are small, bacteria have many different parts to their cells.

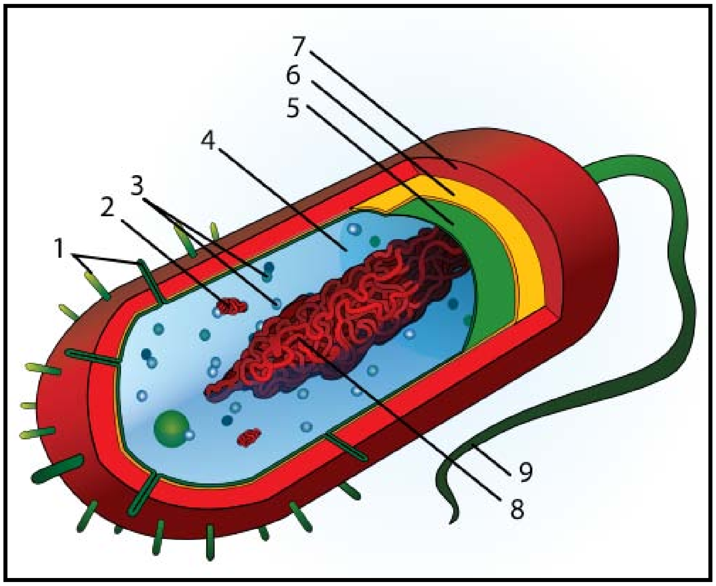


Figure 1: Structure of a typical bacterium.

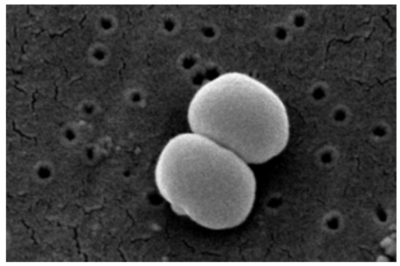
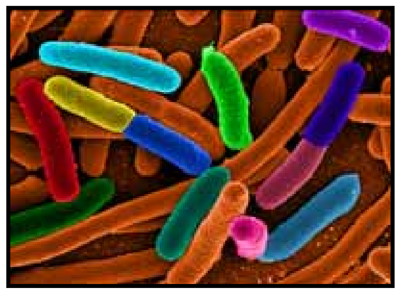
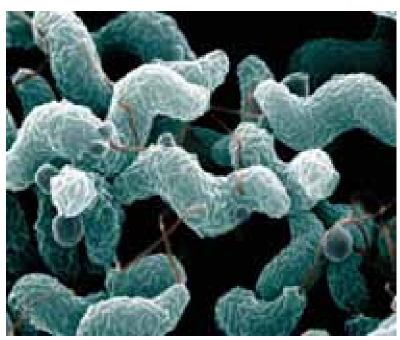
Figure 1 shows the structure of a typical bacterium (bacterium is the singular form of bacteria). Bacteria have structures to help them attach to other bacteria and surfaces (**pili**) **(1)**; genetic material (**DNA**) in the form of the **nucleoid (8)** and **plasmids (2)**; structures to make proteins (**ribosomes**) **(3)**, a gel-like **cytoplasm** in which the ribosomes and genetic material are located **(4)**; outer layers (**plasma membrane (5)**, **cell wall (6)**, **capsule (7)**) that help control the movement of nutrients and wastes into and out of the cell; and structures to help bacteria move and sense their environment (**flagellum**) **(9)**.

One of the most important structures of a bacterial cell is the cell wall. Bacterial cell walls protect bacteria from bursting and help to give bacteria their shape. The cell wall also helps to control entry of molecules into and out of the cell. Most bacteria either have a thin cell wall or a thick cell wall. The thickness of cell walls helps scientists to identify different types of bacteria and put them into categories.

#

Classification of Bacteria

There are millions of different types of bacteria in the world, living in many different environments. Because there are so many different types, it is important to have a system to identify bacteria. Bacteria are usually **classified** (put into categories) based on two characteristics, their shape (see Table 1) and the thickness of their cell walls, which scientists can figure out using a special kind of technique called **Gram staining**. With Gram staining, scientists use different dyes to tell if bacteria have thick cell walls or thin cell walls. Bacteria with thick cell walls appear blue or dark purple when they are dyed. These are known as **Gram Positive** bacteria. On the other hand, bacteria with thin cell walls appear pink or light purple when they are dyed. These are known as **Gram Negative** bacteria.

Table 1: Types of Bacteria		
Bacteria Shape	**Description**	**Example**
Cocci	Sphere-shaped (round)	 **Figure 2:** *Staphylococcus epidermis.* ***Staphylococcus epidermidis*** This type of bacteria lives in human and other animal skin and does not commonly cause disease.
Bacilli	Rod-shaped	 **Figure 3:** *Escherichia coli.* ***Escherichia coli* (*E. coli*)** This type of bacteria lives in the lower intestines of birds and mammals. Some strains of *E. coli* can cause serious disease and even death.
Spirilla	Helix-shaped (shaped like a spiral)	 **Figure 4:** *Campylobacter jejuni.* ***Campylobacter jejuni*** This type of bacteria is commonly associated with poultry (e.g., chickens and turkeys) and lives in the digestive track of many types of birds. It is one of the most common causes of food poisoning.
Vibrios	Comma-shaped	 **Figure 5:** *Vibrio vulnificus.* ***Vibrio vulnificus*** This type of bacteria lives in marine environments such as estuaries and coastal areas. *Vibrio vulnificus* can cause infection after eating seafood, especially raw or undercooked oysters.

Bacteria Replication

Bacteria use a type of cell division called **binary fission** (binary meaning two and fission meaning splitting) to **reproduce** (make copies of themselves). A bacteria cell first makes a copy of its genetic material, typically stored in one circular DNA molecule, and distributes one copy to each side of the cell. Next, the cell stretches sideways and creates a structure called the **Z ring** that squeezes the middle of the cell. A wall, called the **septum**, then forms where the Z ring was, which begins to keep the two sides apart. Finally, the cell membrane pinches off to complete cell division. One cell has become two cells. Because each new cell receives an identical copy of DNA, the cells are called **clones**.

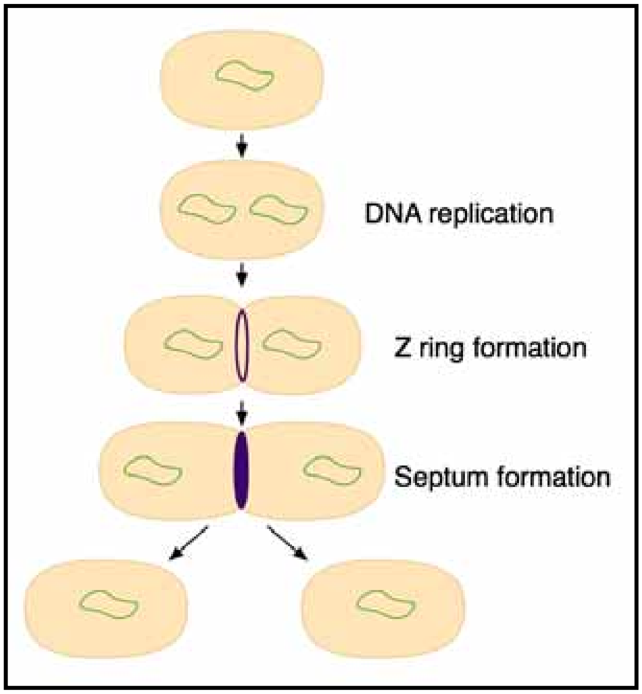


Figure 6: Steps in bacterial replication.

Bacteria Growth

Bacteria used in laboratories are grown in flat plastic containers called **culture flasks**. The flasks contain a **growth medium**, which is a water-based liquid that includes sugars, protein, salts, and other essential nutrients that bacteria need to grow. The growth medium solutions in laboratories are designed to maximize the growth of bacteria. Bacterial growth in the laboratory follows a typical pattern (see Figure 7).

1. The cells first take up nutrients and make proteins and DNA before dividing. This stage of growth is called the **lag phase**.
2. Now the cells are ready to enter the **exponential phase**, when the number of cells doubles with each cell division; from 1, to 2, to 4, to 8 and so on.
3. As the cells continue to divide, they use up all the nutrients in the growth medium. At this point they enter the **stationary phase**, when cell division stops.
4. Without a further source of nutrients, the cells then enter the **death phase** and the number of living cells decreases.

The time it takes for one cell to divide into two during the exponential phase is called the **generation time**. The generation time depends on the nutrients available to the cell, as cell division requires a lot of energy! For example, *E. coli* grown in a lab double about every 20 minutes. In contrast, the *E. coli* that live in our intestines double every few hours.

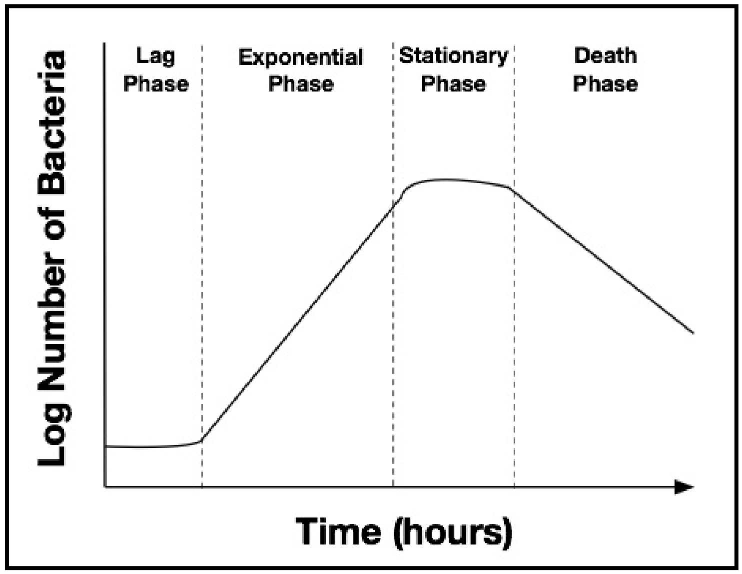


Figure 7: Bacterial growth curve.

Bacteria in our everyday lives

We often think of bacteria as being 'bad' because they can make us sick. These bacteria – known as **pathogenic** bacteria - cause a range of infections including tetanus, typhoid fever, tuberculosis, strep throat, anthrax, and food poisoning. Yet even though we most often hear about pathogenic bacteria, only a very small fraction of the bacteria in the world cause us harm. Actually, many bacteria are very helpful in food production, drug discovery and production, and maintaining human health.

Figure 8: Two examples of food made using bacteria – salami and cheese.

Bacteria are useful for food production because of their ability to perform **fermentation**. Fermentation is the conversion of sugars to acids, alcohols, or gases and is what enriches food with specific flavours, aromas, or textures. **Lactic acid bacteria (LAB)** are one of the most common types of bacteria used in food production, especially fermented dairy products like yogurt, butter and cheese, because they can convert **lactose**, a sugar found in dairy products, into lactic acid. Not only do LAB give these products their flavours and aromas; the lactic acid they produce is also an effective **food preservative** because it lowers the pH of the food and prevents the growth of other microorganisms that cause spoilage. Some other foods that benefit from LAB include wine, chocolate, pickled vegetables, and cured meats.

Bacteria are also useful in the field of medicine because they produce compounds that we can use to treat diseases like cancer and infections. Common soil bacteria of the species ***Streptomyces*** (*strep-toe-my-seas)* naturally produce many **antibiotics** (compounds that destroy other bacteria), which we currently use to treat infections. We can also design bacteria to produce a desired drug. In this process, called **genetic engineering**, bacteria, such as *E. coli*, are given specific sets of genes that allow them to make a compound they were not able to make before. For example, bacteria were recently genetically engineered to produce **insulin**, a drug used to treat diabetes.

We should also appreciate the importance of bacteria in maintaining our everyday health. Our **microbiome**, the bacteria that live in and on the human body without causing harm, helps us digest food, fend off the bad bacteria, and develop a proper functioning immune system. There are over 1,000 different types of bacteria that are living in you right now, but a few that we know are important to our health include ***Lactobacillus*** *(lac-toe-bass-ill-us)* and ***Bifidobacterium*** (*biff-idd-owe-back-tee-ree-um*). Both types of bacteria are typically found in the gut (stomach and intestines), and can also be consumed as **probiotics**. Probiotics are good bacteria that when consumed in high enough amounts provide health benefits. An example is *Lactobacillus* GG, a probiotic with promising results for treating infant diarrhea. Loss or changes in the amount of good gut bacteria might be linked to diseases such as obesity, diabetes, allergies, and inflammatory bowel disease.

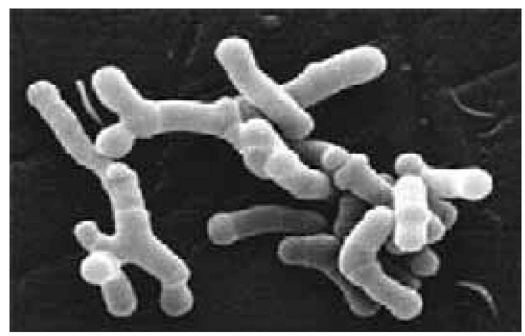


Figure 9: *Bifidobacterium* as seen viewed through an electron microscope.

Bioremediation: Using Bacteria to Clean up the Environment

Toxic pollutants are released into the environment every day and some will remain there for thousands of years. If these sites are not cleaned up they will cause great harm to the environment and the plants, animals and people living nearby. The problem with cleaning up some of these toxic chemicals is that the cleaning process can create even more pollution. Wouldn't it be better if toxic pollutants could be removed in a cleaner way? In the 1960s scientists discovered that soil bacteria were capable of **degrading** (breaking down) **xenobiotic** (*zee-no-bye-awe-tick*) (meaning 'unnatural' or 'synthetic' from the Greek *xenos* meaning 'foreign') chemicals into harmless products that they could use for energy. The process of using microorganisms to clean up toxic sites, such as oil spills, is called **bioremediation**.

Certain bacteria are very good at breaking down xenobiotic compounds; for instance the **genus** (group of organisms) **Pseudomonas** (*sue-doh-moh-nas*) is able to break down more than 100 different compounds. Unfortunately, this is not a perfect process. The breakdown of toxic compounds may be very slow, the bacteria may not be able to break down all of the chemicals and the chemicals may actually kill the bacteria themselves at high concentrations.

VIRUSES

Viruses have a significant impact on humans. The common cold, **influenza** (the flu), **Severe Acute Respiratory Syndrome (SARS)** and diseases such as **Acquired Immunodeficiency Syndrome (AIDS)** are all products of viral infections. Scientists have worked tirelessly for centuries to understand how viruses work and to find better ways of fighting them. The study of viruses is known as **virology**, and those who study viruses are known as virologists.

Virus Structure

Viruses are very small - generally from 17 to 400 nanometres in diameter. This is approximately 1000 times smaller than the diameter of a human hair - or 100 times smaller than the average bacteria! Viruses have a much simpler cell structure than either animal or bacterial cells. Viruses are made up of three basic parts (see Figure 10):

1. **Nucleic acid**: a set of genetic material, either **DNA** or **Ribonucleic acid (RNA)**;
2. **Capsid**: a **protein** coat that surrounds the DNA or RNA to protect it; and
3. **Envelope**: a covering for the capsid that is made up of a mix of proteins, fats and **carbohydrates** (complex sugars). Not all viruses have envelopes – the ones that do not have envelopes are called **naked** or **non-enveloped** viruses.

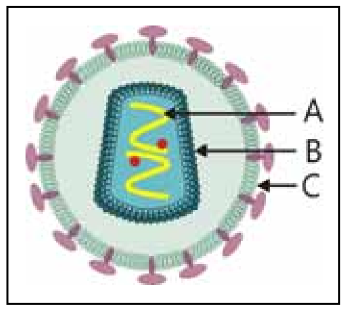


Figure 10: Structure of a virus (HIV). **A:** Nucleic Acid, **B:** Capsid, **C:** Envelope

Classification of Viruses

Viruses are diverse in shape and complexity and, like bacteria, can be classified based on their shape. Pictures of viruses resemble something out of science fiction. Some have heads shaped like **polyhedrals** (many-sided three-dimensional figures) connected to little jointed ‘legs,’ while others look more like popcorn (see Figure 11).

Viruses can be placed in four general categories (see Figure 11):

1. **Helical viruses** look like long rods that can be stiff or flexible. An example of a helical virus is the influenza virus.
2. **Polyhedral viruses** are many-sided viruses, meaning that their capsids can have different numbers of sides. Most polyhedral viruses have 20 triangular sides and 12 vertices (corners). An example of a polyhedral virus is the **adenovirus** which causes respiratory illnesses.
3. **Enveloped viruses** are basically spherical in shape because they have a protein, fat or carbohydrate coat over their capsid. An example of an enveloped virus is the **human immunodeficiency virus (HIV)** which causes AIDS in humans.
4. **Complex viruses** have complicated structures such as capsids attached to leg-like structures. An example of a complex virus is the **bacteriophage** which is a virus that infects bacteria.

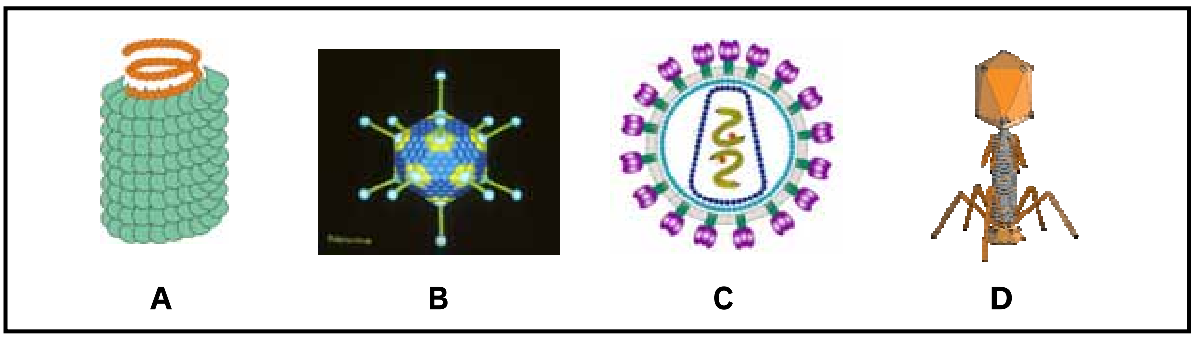


Figure 11: Types of viruses.
A: Helical virus (influenza), **B:** Polyhedral virus (adenovirus), **C:** Enveloped virus (HIV), **D:** Complex virus (bacteriophage)

Virus Reproduction

Despite their appearance, viruses are not actually 'alive.' Viruses do not have a **metabolism** - the chemical reactions that happen in living cells or organisms - that are needed for them to live, which is why we do not consider them to be alive. Viruses also lack the ability to **reproduce** (make more copies of themselves) on their own. A virus must have a **host cell** (i.e., a bacteria, plant or animal cell) in which to live and make more viruses. The steps a virus follows to reproduce are (see Figure 12):

1. **Attachment** (sometimes called **absorption**)
   The virus attaches to the host cell wall.
2. **Penetration**
   The nucleic acid (genetic information) of the virus moves through the cell membrane into the host cell.
3. **Replication (Biosynthesis)**
   Once inside the host cell, the virus forces the host cell to produce the necessary components for its reproduction.

4. **Assembly (Maturation)**
   The newly produced virus parts are assembled into new viruses.
5. **Release**
   The completed viruses are released from the cell and can now infect other cells and repeat the process.

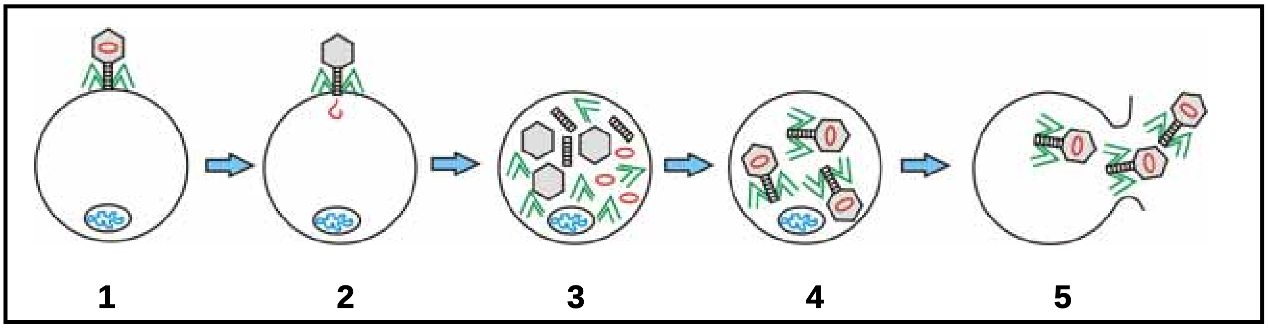


Figure 12: Viral life cycle.
1: Attachment, **2:** Penetration, **3:** Biosynthesis, **4:** Maturation, **5:** Release.

Viruses in the News: Ebola

Ebola is a dangerous virus that causes serious, often fatal, infections. It is found in several parts of Africa where it infects nonhuman **primates** (monkeys, chimpanzees, gorillas), and in rare circumstances, humans.

The Ebola virus is a member of the **Filoviridae** (fill-oh-vair-i-dee) viral family. It contains a single-stranded piece of RNA that is protected within a helical capsid and then surrounded by a lipid membrane. The virus can take on unique shapes, for example a "6", a "U" or a circle. Ebola infects many types of cells in the body, primarily **fibroblasts** (cells that make fibers which connect cells and hold them in place).

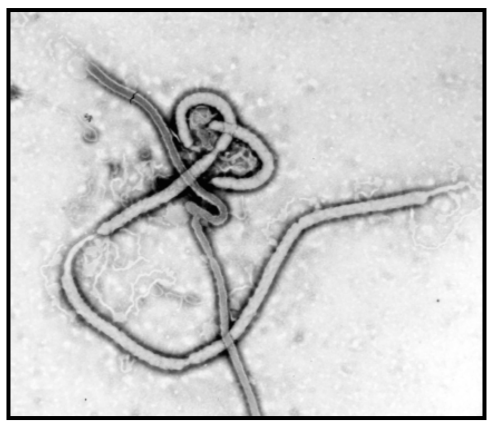


Figure 13: Electron microscope picture of an Ebola virus.

The virus was discovered in 1976 during two **outbreaks** (sudden waves of infection) in Africa, one in Sudan and the other in the Democratic Republic of Congo. There have been many smaller outbreaks across Africa since then, with the number of individuals affected ranging from few to 500 and the **case fatality** (the reported percentage of deaths among infected individuals), ranging from 20-80%. From 1976 to 2012, Ebola is estimated to have claimed 1 590 lives.

2014 Ebola Outbreak in West Africa

The outbreak in Guinea, Liberia, and Sierra Leone that began in March 2014 is the largest and most serious outbreak to date, claiming over 5 000 lives. The **index case** (the first person to become infected), is believed to have been a 2 year old boy. The child is thought to have come in contact with an infected fruit bat. The fruit bat is an Ebola virus **reservoir** (an organism that is infected with the virus but does not show symptoms). Why the outbreak in West Africa is more serious than previous outbreaks is unclear. It is at least, in part, due to the dense population in the region, poor healthcare, and the fact that some of the countries are recovering from wars.

Signs and Symptoms of Ebola

The symptoms of Ebola do not appear until one to three weeks after exposure to the virus. This time is called the **incubation period**. The first symptoms are similar to those caused by the flu, including fever, headaches, fatigue, and muscle pain. Eventually, more serious symptoms develop, including diarrhea, stomach pain, and unexplained bleeding. When symptoms are seen, a person is considered **contagious** (able to transmit the infection to another individual). Currently, there is no cure for Ebola. Recovery requires good health care and a good **immune** response. People that recover from an Ebola infection can develop **antibodies** which can prevent against a future Ebola infection.

Transmission of Ebola

A person can contract Ebola if they come into contact with body fluids from a person infected with Ebola or contaminated objects from an infected person. Ebola is not an **airborne** virus, like a common cold or the flu, meaning that it is not spread when a person coughs or sneezes close to you. The people most at risk during an outbreak are healthcare providers caring for Ebola patients because they frequently come in contact with infected blood or body fluids. It is important that healthcare workers near Ebola patients wear **protective equipment**, such as gowns, gloves, and face shields.

Viruses and the Immune Response

Viruses are very good at what they do. They forcibly take over the processes in a cell to ensure that they multiply while the host cell dies. It is incredible how such a simple organism can be such a lethal killer of cells. But not all is lost; many organisms have developed defense systems against these killers. The human **immune system**, for example, is always on the look-out for intruders such as viruses.

Our immune system springs into action when it detects an **antigen** (a molecule that stimulates an **immune response** – from the words **anti**body and **gen**eration). In the case of viruses, antigens are proteins found on the surface of the viral envelope. The antigens are detected by **antibodies** (proteins produced by the immune system to identify and destroy foreign objects) which lead to the recruitment of specialized cells responsible for getting rid of the intruder.

Vaccination: Using Viruses for a Good Cause

Many of the diseases that killed millions of people generations ago are no longer a major threat because of **vaccination**. Vaccination protects an individual from a viral infection by stimulating the immune system to produce antibodies. Vaccines contain **inactivated** (dead) or **attenuated** (alive but not infectious) viruses; therefore, the virus is not able to hijack the host cell system and use it for its own uncontrolled growth.

Dr. Edward Jenner, considered a pioneer in **immunology** (study of the immune system), was not the first to use **inoculation** (the technique of deliberately infecting people to build up immunity to a disease and lessen its severity). Inoculation was a technique used by the Chinese as far back as the 16th century. Dr. Jenner was interested in finding a cure for **smallpox**, a highly contagious disease that affected rich and poor alike. In the 18th century, the death rate from this disease ranged from 20% to 60% for adults and 80% for infants. During his apprenticeship, Dr. Jenner found that milkmaids (women who milked cows) who had cowpox, a similar but less severe disease, did not get smallpox. Following several years of experimentation and research, Dr. Jenner tested his **vaccination** (from *vacca* the Latin word for 'cow') on his gardener's son. The boy contracted cowpox and recovered as expected. A few months later, when his body had built up immunity, Dr. Jenner exposed the boy to smallpox but he remained clear of the disease. Vaccination was a success. The last case of smallpox happened in 1979 and has not been seen since that time.

Figure 14: Dr. Jenner performing his first vaccination on James Phipps, a boy of age 8, May 14th, 1796 (painted by Ernest Board (1877–1934).

The Flu Shot

Dr. Jenner's experimentation opened the door to the creation of many vaccines that are now common. Usually we receive vaccinations once or twice during childhood to give us protection for life, but we need a 'flu shot' every year because the **strain** (type of virus) of influenza circulating changes. When you receive a flu vaccination, your body recognizes the attenuated virus as an invader and produces antibodies to fight it. When you encounter the actual flu virus, your body remembers that this virus does not belong and your immune system launches an attack to kill it before it can take hold and make you ill. Flu vaccinations are repeated each year because the specific flu viruses differ each year. The flu shot usually consists of three different viruses based on scientist's predictions of the most common strains for the coming flu season. The viruses used in the flu shot are inactive or dead - they cannot actually give you the flu.

Spotlight on Innovation in Biology

Canadians Help Fight Ebola

There is currently no vaccine or treatment for Ebola. The best way to care for a patient is to treat the symptoms. This includes rehydrating patients with **intravenous fluids** (fluids injected into the blood stream), balancing **electrolytes** (body salts), and maintaining good oxygen levels good blood pressure. Several experimental treatments and vaccines are under development. Two promising drugs - brincidofovir and favipiravir – work by interfering with virus reproduction. Another drug, **Zmapp**, is a mixture of antibodies against Ebola. Two vaccines are also undergoing testing, one developed by the pharmaceutical company GlaxoSmithKline in collaboration with the US National Institute of Allergy and Infectious Diseases. The other was developed by the Public Health Agency of Canada at the National Laboratory in Winnipeg and is being produced by a company called NewLink Genetics in the US. Both vaccines are currently in **Phase I clinical trials**. The purpose of a Phase I clinical trial is to test the safety of the vaccine in healthy individuals. Other trials will follow to make sure the vaccine is safe to use.

We hope that you have enjoyed this chapter about organisms from the micro-world!

BACTERIOPHAGE DESIGN CHALLENGE

Challenge:

Your challenge is to work as a team to design and build a working bacteriophage model (see page 12 in this chapter) using the materials provided. Your bacteriophage must be able to inject its '**genetic material'** (coloured water) into a '**bacterial cell**' (resealable bag filled with water) without the cell leaking.

Materials:

- 1 small resealable plastic bag filled with water and taped shut with masking tape (the bacterial cell)
- 1 small balloon (the **head** of the bacteriophage)
- 1 roll of masking tape
- 1 small funnel
- Water with food colouring added (the genetic material)
- Plastic container to test in (e.g., plastic tub, bucket, etc.)

Choice of:

- Drinking straws
- Plastic stir sticks (hollow kind)
- Empty plastic ball point pens (ink tube removed)
- Pipe cleaners

Rules:

- The genetic material must travel from the head of the bacteriophage (balloon) into the bacterial cell (bag filled with water).
- The bacteriophage must be attached to the bacterial cell when it inserts its genetic material into the cell.
- The bacteriophage must be able to stand upright on the cell **<u>on its own</u>** (without someone holding on to it); however, you can squeeze the balloon to insert the genetic material.

Success

- Your group will be successful when:
  a) the 'genetic material' is seen in the 'bacterial cell'
  b) the bacterial cell remains intact (does not leak)
  c) the bacteriophage stands atop the cell on its own

Pushing the Envelope

- Can your bacteriophage insert a circular piece of DNA (e.g., a piece of string or elastic band) into your bacterial cell?

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Figure 1: Structure of a typical bacterium.
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Public domain image by Mariana Ruiz Villarreal on Wikimedia Commons.

Figure 2: *Staphlyococcus epipdermidis.*
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Public domain image by Janice Carr working on behalf of the Centers for Disease Control and Prevention's Public Health Image Library (identification number #259) http://phil.cdc.gov/phil/details.asp on Wikimedia Commons.

Figure 3: *Escherichia coli.*
http://commons.wikimedia.org/wiki/File:Diverse_e_Coli.png (Accessed Dec. 1, 2014)
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Figure 4: *Campylobacter jejuni.*
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Figure 5: *Vibrio vulnificus.*
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Figure 6: Steps in bacterial replication.
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Figure 7: Bacterial growth curve.
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Figure 8: Two examples of food made using bacteria – salami and cheese.
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Figure 9: *Bifidobacterium* as seen viewed through an electron microscope.
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Figure 10: Structure of a virus (HIV).
Image ©2011 Let's Talk Science.

Figure 11: Types of viruses.
A: Helical virus (influenza)
Image ©2011 Let's Talk Science.
B: Adenovirus
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Public domain image by Dr. Richard Feldmann of the National Cancer Institute on Wikimedia Commons.
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D: Bacteriophage
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Figure 12: Viral life cycle.
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Figure 13: Electron microscope picture of an Ebola virus.
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Figure 14: Dr. Jenner performing his first vaccination on James Phipps, a boy of age 8, May 14th, 1796 (painted by Ernest Board (1877–1934).
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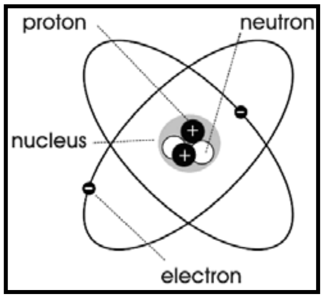
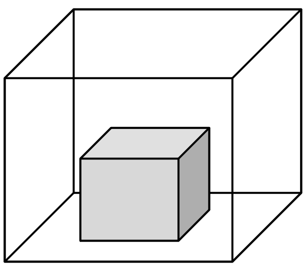
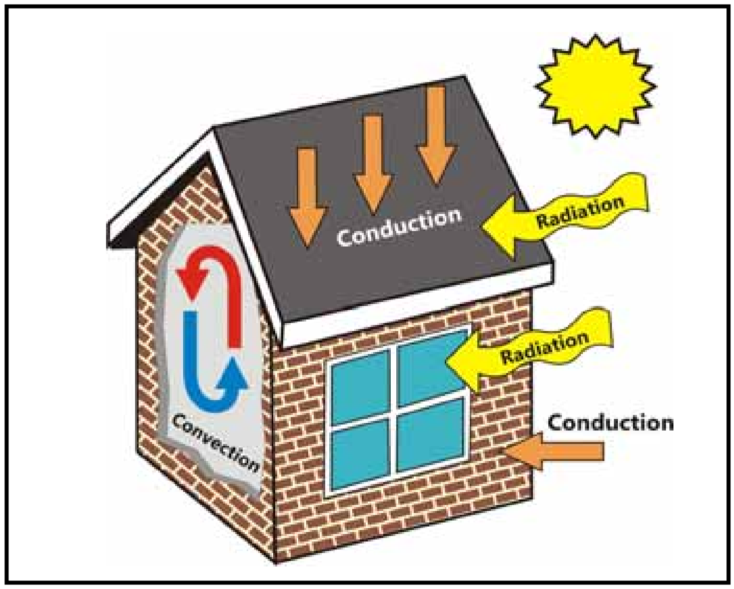
Chapter 2

CHEMISTRY







Group → / ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo

Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

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let's talk science CHALLENGE

INTRODUCTION

Chemistry helps us understand the properties and composition of the world around us. In this chapter you will learn about the characteristics of matter, how matter is classified and how heat is transported or “conducted” through matter.

THEORY OF MATTER

Matter is defined as anything that has mass and takes up space. It is a general term that refers to all the things that are physically around us even if they are so tiny that they are not visible to the human eye.

The **Particle Theory of Matter** is a **model** (a scientific way of thinking) that has been developed to help us understand matter. It helps us to visualize how matter behaves as well as helps us to explain why different matter can display different properties. The main ideas of the Particle Theory of Matter model are:

- All matter is made of tiny particles - either individual **atoms** or groups of atoms called **molecules** (see Figure 1).
- In the center of each atom is the **nucleus**. Within the **nucleus** there are positively charged particles called **protons** and particles with no charges called **neutrons**. This gives the nucleus an overall positive charge; for example, a helium atom that has 2 protons and 2 neutrons would have an electric charge of +2.

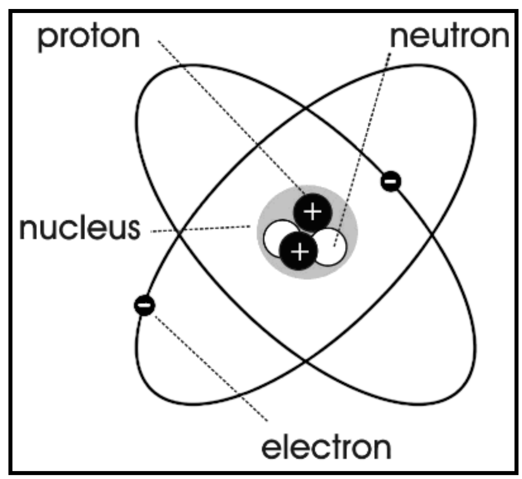

Figure 1: The basic structure of a helium atom.

- The nucleus is held together by the **strong nuclear force**.
- Orbiting around the nucleus are negatively charged particles called **electrons**.
- **Electrostatic forces** (forces that attract negatively charged and positively charged particles to each other) keep the electrons orbiting around the positive charges of the nucleus.
- The number of protons in the nucleus defines the type of atom; for example, all gold atoms have 79 protons and all silver atoms have 47 protons.

- Protons and neutrons are much heavier than electrons (2 000 times heavier), so most of the weight of an atom is due to the nucleus.
- There is nothing in between the nucleus and the electrons. In other words, atoms are mostly empty space; for example, if a nucleus was the size of a button and was placed at the centre of a baseball stadium, than the nearest electron would orbit just outside the stadium. Most of the volume of an atom is empty space.
- Each substance has unique particles that are different from the particles of other substances.
- At temperatures above -273.15 degrees Celsius (also called 0 kelvins (0 K) or **absolute zero**), the particles of matter are constantly moving, even though the human eye cannot see them move.
- Speed affects the temperature of the particles. The higher the average speed of the particles, the higher the temperature.

Subatomic Particles

The particles of matter are very, very small (between 10 000 and 1 000 000 times smaller than the diameter of a strand of your hair); therefore, we cannot actually see them with our eyes, and we can only detect their presence with certain very sensitive instruments. As a general rule any particle smaller than an atom is called a **subatomic particle**. You have just learned about three subatomic particles: protons, neutrons and electrons. But did you know that there are many more? The study of these particles is called **particle physics**, **subatomic physics** or **high energy physics**.

Fundamental Particles

The smallest building block of the universe has to be something that is not made out of smaller parts. For a long time, people thought that atoms were the smallest building block of the universe. They thought that atoms were not made of smaller particles, and therefore that they were the fundamental particle of the universe. Later on, when protons, neutrons and electrons were discovered, people thought that those were the smallest parts of the universe – but now, we know that even those particles are made of smaller parts.

THE STANDARD MODEL

Over the past century, thousands of scientists have explored and furthered our understanding of the fundamental structure of matter. What scientists now agree on is that everything in the universe is found to be made of twelve basic building blocks called **fundamental particles** which interact with+ four **fundamental forces**. The current, best theory of how these particles and forces relate to each other is summarized in the **Standard Model** (of particles and forces). Over time and through many experiments by scientists, the Standard Model has become established as a well-tested theory.

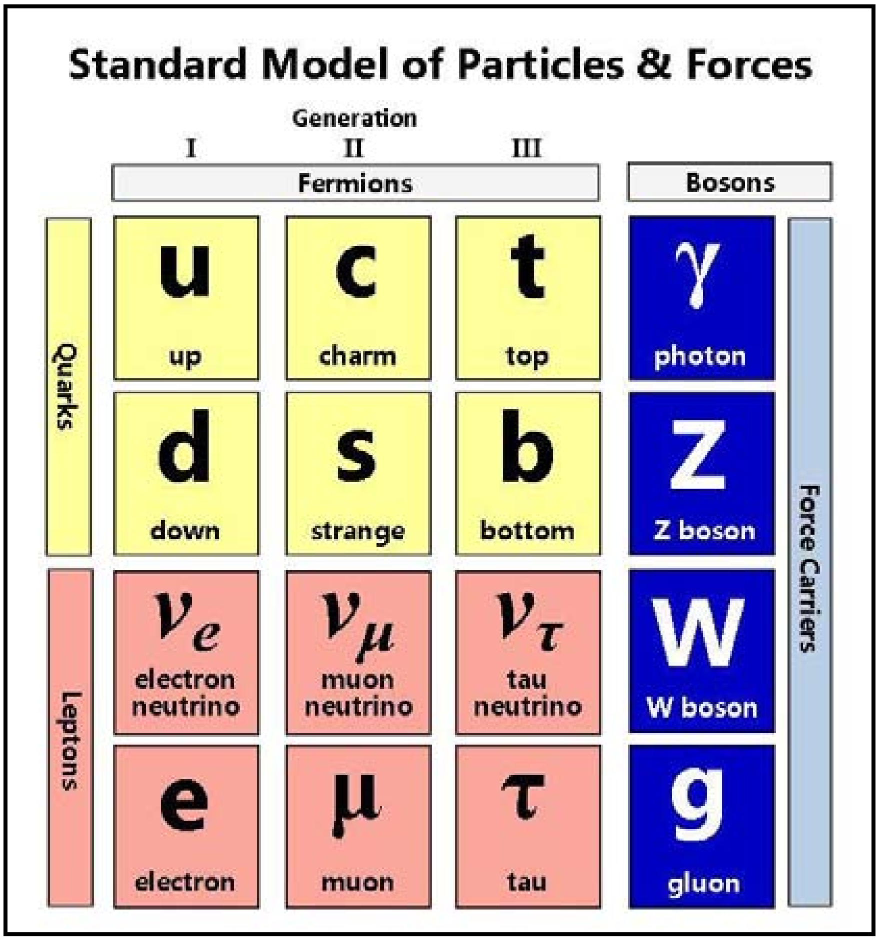

Figure 2: The Standard Model of particles and forces

Matter particles (**Fermions**) are grouped into two basic types called **quarks** and **leptons**. Each of these groups consists of six kinds of particles organized in pairs. The lightest and most stable particles make up the first generation (pairs in **Generation I**), whereas heavier and less stable particles are in **Generation II** and **Generation III** (see Figure 2). The Fermions are affected by four **fundamental forces** (see Figure 2); the **strong force**, the **weak force**, the **electromagnetic force** and the **gravitational force**. These forces are carried by **Force carrier particles** called **Bozons** (see Table 1 on the next page).

Fundamental Force	Strength	Range	Force Carrier Particle
Strong force	Strongest (about 100 x stronger than electromagnetic force)	Short (10^{-15} m)	Gluon
Weak force	Second strongest	Short (10^{-15} m)	W and Z bosons
Electromagnetic force	Stronger than gravity	Infinite	Photon
Gravitational force	Weakest	Infinite	Graviton (hypothetical)

Table 1: Fundamental forces and some of their characteristics

Strong Force

The strong force is the force that holds the protons and neutrons together to form the nucleus of an atom. It is also the force (carried by **gluons**) that holds **quarks** together to form protons and neutrons. When we talk about the force that holds the nucleus together, we sometimes refer to this force as the **nuclear force**.

Weak Force

The weak force acts on all fermions. It is believed that the weak force is caused by the exchange of **W** and **Z bosons**. The weak force is responsible for **radioactive decay** (the spontaneous breakdown of a nucleus resulting in the release of energy and matter from the nucleus) as well as hydrogen **fusion** in stars.

Electromagnetic Force

The electromagnetic force acts on particles that are electrically charged and on metals that can be magnetized. This force is commonly experienced in everyday life in the form of **electric fields** (which cause **electric voltage** and **current**) and **magnetic fields** (magnets). Electromagnetism also plays an extremely important role in chemical reactions when atoms and molecules interact with each other. The force carrier particle of electromagnetism is the **photon**.

Gravitational Force

Also known as **gravity**, gravitational force occurs between physical objects which attract with a force proportional to their masses. We know gravitation as the force which makes things fall to the ground when dropped. Gravitation is responsible for keeping the Earth and other planets in their orbits around the Sun. Although not yet proven, it is believe that there is a force carrier particle for gravitation. This hypothetical carrier is called a **graviton**.

THE STATES OF MATTER

Depending on **temperature**, **pressure** and a substance's properties, a substance can take different physical forms. We call these physical forms **States of Matter**. We will discuss three very well-known states of matter: **Solids**, **Liquids**, and **Gases.** Other states of matter also exist. These include **Plasma** (a state of matter similar to a gas, but that contains free-moving electrons and ions - atoms that have lost electrons) and **Bose-Einstein Condensates (BECs)** (waves of matter that can occur with some types of atoms at super cold temperatures).

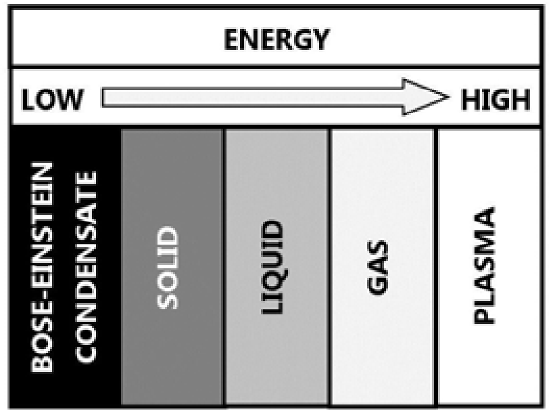

Figure 3: The states of matter.

The attraction forces between particles and the outside pressure on particles are what keep the particles together; however, if we warm up matter (add **energy**), the particles start moving faster and they tend to spread apart. Depending on whether the particles are close together or further apart, matter can be solid, liquid, or gas.

Solids

In solids, the forces keeping the particles together are relatively strong, and the particles stay very close to each other. The particles can vibrate but they are not moving around much. This is why solids are hard and rigid. Left on their own, solids will keep their shape.

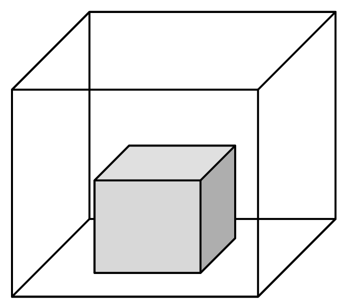

Figure 4: A solid.

Liquids

In liquids, the forces between the particles are weaker than in solids. Particles are still close together, but they can move around freely; therefore, liquids can flow around inside a container, and don't have any particular fixed shape.

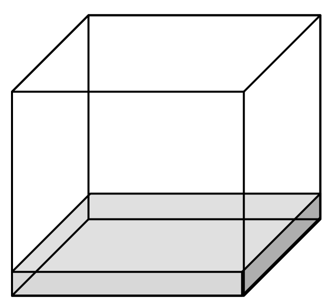

Figure 5: A liquid.

Gases

In gases, the forces between particles are no longer strong enough to keep the particles close together because the particles are moving very fast and have a lot of energy.

Like liquids, gases are also able to flow around and don't have a particular shape because the particles can move around so freely. The difference between liquids and gases is that the particles in gases are spaced much further apart. This means that in general, for the same volume, a gas is lighter than a liquid.

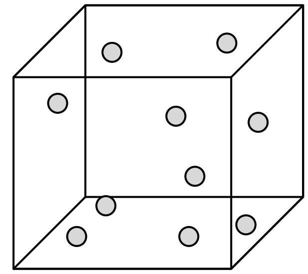

Figure 6: A gas.

Spotlight on Innovation in Chemistry

A Change of State: 3D Printers

Have you heard about 3D printers? A 3D printer can make pretty much anything from ceramic cups to plastic toys, metal machine parts, and even human body parts! The simplest method of 3D printing works by a process called **Additive Manufacturing (AM)**. This involves creating a solid object by putting down thin layers of material such as plastic and metal.

If you wanted to make a keychain with a 3D printer, you need to start with a 3D design of the keychain created by a computer assisted design (CAD) program. The CAD program will slice the keychain into hundreds or thousands of layers, which will be printed one on top of the other until the keychain is complete. During the printing process, a thread of material, either a metal wire or thin piece of plastic, is run through the machine and a nozzle at the printing head heats up the material. The temperatures in these machines can be very hot, from 200 to 1 000°C, depending on the material! The heat from the nozzle melts the plastic or metal from a solid state to a soft, rubber-like state called the **glass transition state**. The printer can then print many layers of the material while it is soft. The layers then cool and harden together.

The technology for 3D printing was invented by Scott Crump in the 1980s and has taken over 30 years of hard work to develop affordable 3D printers. Within the next 5 – 10 years the cost of 3D printers will go down and we will probably all have one in our homes, then wonder how we managed all these years without it.

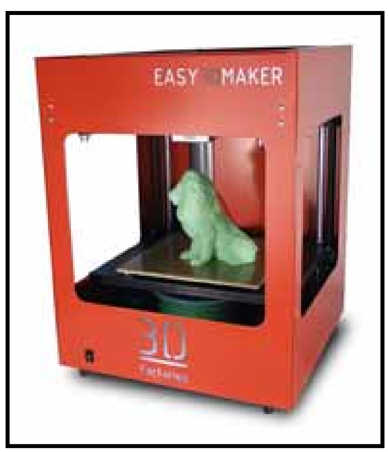

Figure 7: One example of a 3D printer.

DESCRIBING AND CLASSIFYING MATTER

Describing Matter

Each type of matter has its own unique properties. A **property** is something that describes matter. Properties of matter allow us to identify substances.

Physical Properties

A **physical property** is a characteristic of matter that we can measure. Colour, odour, taste, size, shape, boiling point, melting point, hardness, **malleability** (ability to be pounded flat), electrical conductivity, magnetism and density are examples of physical properties.

Chemical Properties

A **chemical property** is a characteristic of a substance which describes its potential to undergo a chemical reaction or change. The following are some chemical properties:

- **Flammability** = ability to burn (e.g., wood, etc.)
- **Reactivity** = ability to react when combined with another substance (e.g., baking soda and vinegar, etc.)
- **Corrosiveness** = ability to 'eat away' another substance (e.g., oxygen causes iron to rust and flake off, etc.)
- **Toxicity** = ability to cause damage to living organisms (e.g., lead, mercury, chlorine gas, etc.)

In addition, physical and chemical properties can be either intensive or extensive. An **intensive property** is a property that does not depend on the amount of matter. Examples of this are colour, odour, density and melting point. An **extensive property** is a property that depends on the amount of matter. Examples of this include mass and volume.

Classifying Matter

Matter can be classified in different ways; for example, all matter can be described as either a pure substance or a mixture.

Pure Substances

Pure substances have a fixed composition and cannot be separated into other pure substances by physical means. The physical properties of a pure substance never change; for example, the melting point of ice is always zero degrees Celsius at a pressure of 101.3 kilopascals. Pure substances include **elements** and **compounds**. **Elements** are substances that are made of only one type of atom. Examples of elements are carbon (C), silver (Ag) and gold (Au). Currently, there are 116 known elements, several of which have been discovered during your lifetime!

Scientists have organized the elements graphically into a table called the **Periodic Table of the Elements** (often shortened in everyday language to the Periodic Table) (see Figure 8 below).

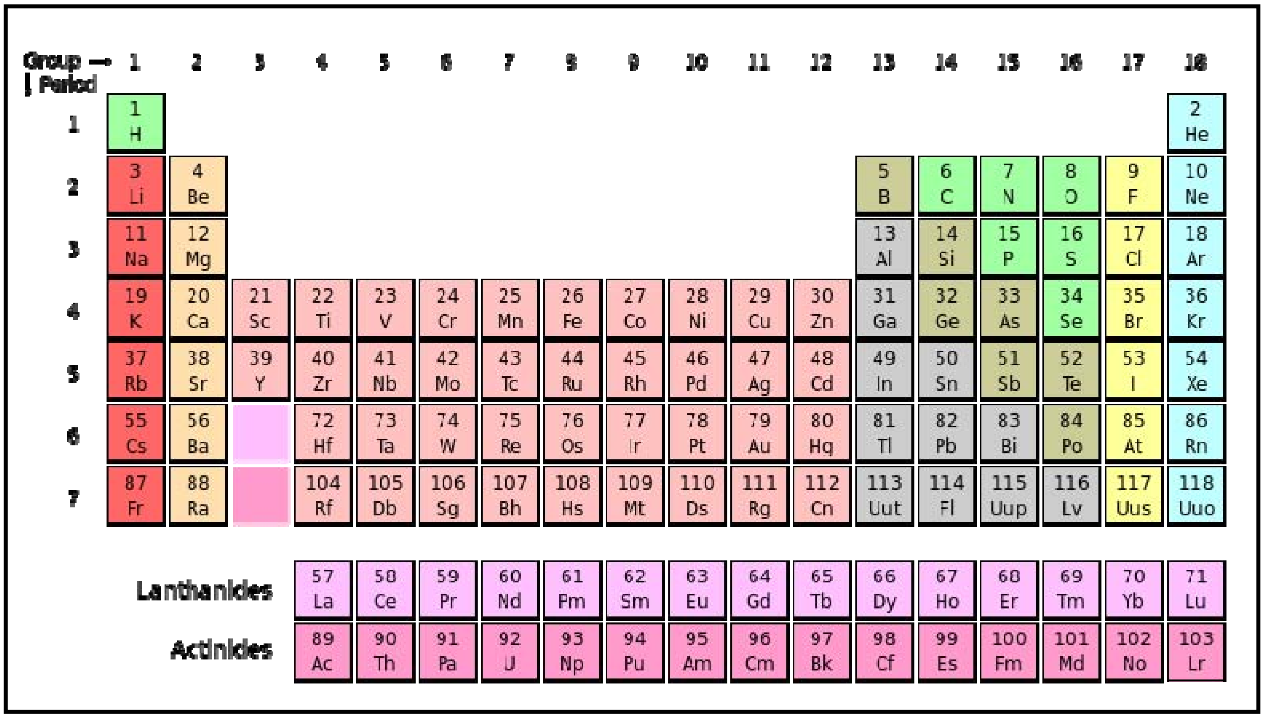

Figure 8: The periodic table of elements (current as of December 2014).

Compounds are substances formed by the union of two or more elements. In a compound, the elements are chemically held together in a fixed ratio and can be broken down to individual elements by chemical means. The properties of a compound are different from the properties of the elements that form it. Water, for example, is a compound made up of of two hydrogen atoms (H) and one oxygen atom (O). Water has very different properties than hydrogen and oxygen.

Mixtures

Mixtures are a combination of two or more pure substances. When mixed together each pure substance retains its own properties. Mixtures can be either **homogeneous** or **heterogeneous**.

- A **homogeneous mixture** is a mixture that is completely uniform in composition. Salt water is a good example of a homogeneous mixture. Another name for a homogeneous mixture is a **solution**. There are also solutions made of gases, such as air, and solutions made of solids. When the solids are metals, such as bronze or brass, they are also known as **alloys**.
- A **heterogeneous mixture** is a mixture that is not uniform in its composition. Furthermore, it is a mixture in which the individual components can be seen. An example of a heterogeneous mixture is oil and vinegar salad dressing.

HEAT AND CONDUCTIVITY

Energy is the capacity to do work. Energy can be classified into two types:

1. **Potential energy** (**E_P**) – stored energy
2. **Kinetic energy** (**E_K**) – the energy of motion

The total energy in a particular system is the sum of the kinetic and the potential energy present:

$$E_{total} = E_K + E_P$$

Potential energy (E_P), for example, is stored in the chemical bonds of propane (barbeque gas). Upon lighting the barbeque, propane combines with oxygen in a combustion reaction and the potential energy of the stored fuel is partly converted to heat – a form of kinetic energy.

Heat is a form of energy that is associated with the motion of atoms, molecules and other particles. As temperature increases, molecular motion become faster and faster.

Heat energy can be transferred from one object to another as the result of a temperature difference between the two objects. When a warmer object is brought into contact with a cooler one, the cooler object will get warmer until eventually the temperatures between the two become equal. The flow of heat energy is always in the direction from a warmer body to the cooler body. In this manner, heat is a way for energy to be exchanged between a system and its surroundings. Heat is measured in **Joules (J)** or sometimes in **calories (cal)** (e.g., the energy in food).

Heat can be transferred in three ways:

1. Conduction
2. Convection
3. Thermal radiation

Conduction

Conduction involves the transfer of heat within and between materials and objects which are in direct contact with each other. How does it happen? Well, when molecules get warmer, they **vibrate** (move back and forth) more rapidly. This means that molecules at the warmer end of a material/object will vibrate more rapidly than those at the colder end of a material/object. The faster molecules will collide with the slower molecules; causing them to vibrate faster themselves. This, together with the motion of the electrons, is how the energy is transferred.

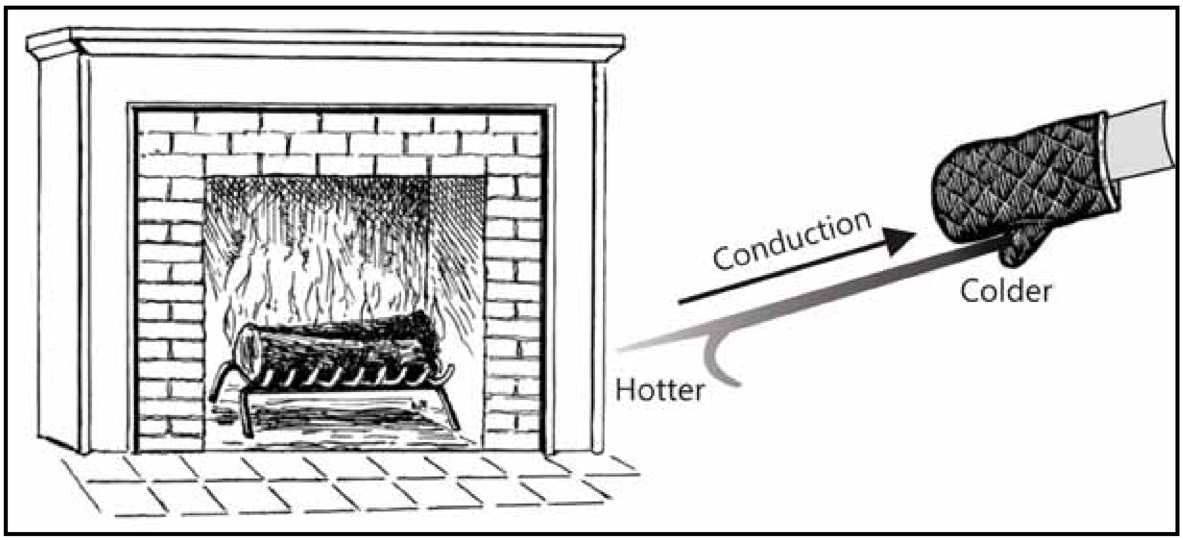

Figure 9: Conduction of heat through a metal rod.

Think of a metal rod that has just been poking around in a fireplace. Energy from the hot end (the end that had been touching the hot embers in the fire) will transfer by way of conduction along the rod to the colder end (the end where your hand is) until the temperature of the entire rod is the same (see Figure 9). This is why it is important to wear a glove when handling a hot metal rod!

Thermal conductivity is a property of a material which measures how well it conducts heat. Metals such as silver, copper and aluminum are good at conducting heat and are known as **conductors**, whereas materials such as Styrofoam, snow and fiberglass are not good at conducting heat and are known as **insulators**. If your home has good insulation, then it does not lose much heat energy to the outside environment through conduction.

Convection

Convection is the movement of molecules within fluids (liquids and gases) caused by the transfer of heat. Heat transfer through convection occurs when the liquid or gas molecules physically move, as opposed to simply vibrate more quickly, as in the case of conduction. When warmer air or water moves away from a source of heat, it carries energy with it; for example, when you heat water in a pot on the stove or in a kettle (see Figure 10), the hot water rises.

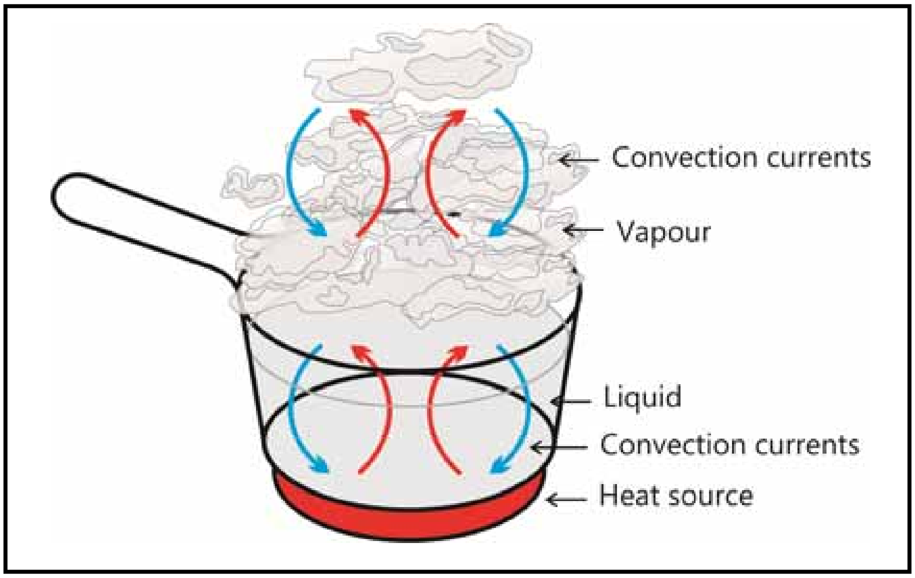

Figure 10: Convection heat transfer in boiling water. Convection currents occur both within the liquid and the vapour.

This is because hot water is less dense than cold water. As the water rises, it carries heat energy upwards with it. When the water is far enough from the heat source, it cools, becomes denser and sinks and the cycle begins again (see Figure 10). Solids do not undergo convection (they mostly undergo conduction).

Thermal Radiation

Heat transfer through **thermal radiation** is the transfer of energy via **electromagnetic (EM) wave**. A hot campfire (see Figure 11), a glowing heating element on the stove and the Sun are all examples of objects that can transfer heat through thermal radiation.

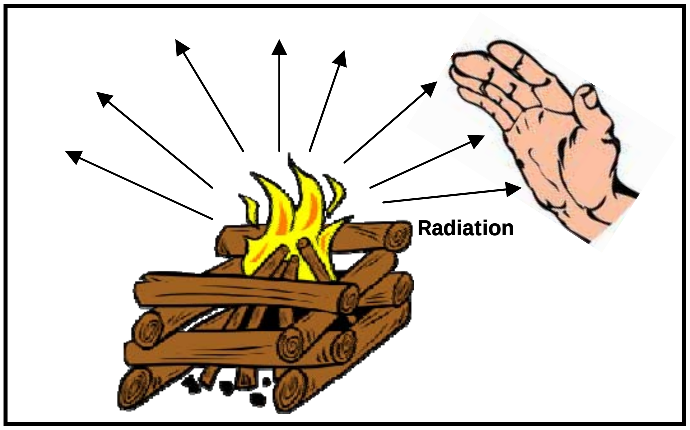

Figure 11: Heat transfer via thermal radiation.

Heat Transfer in a House

An example of all three heat transfer processes occurring at the same time is the heating/cooling of a house (see Figure 12).

1. Conduction can either heat the house (in summer, heat is transferred from the warm air outside into the house through the walls or roof), or cool the house (in winter, heat is transferred from the warm air inside the house out through the wall or roof).
2. Convection occurs inside each room as warmer air rises towards the ceiling and cooler air sinks towards the floor. Convection is also why the second floor of a house feels hotter than the basement.
3. Thermal radiation from the Sun heats the roof of the house and can also transfer heat energy through windows.

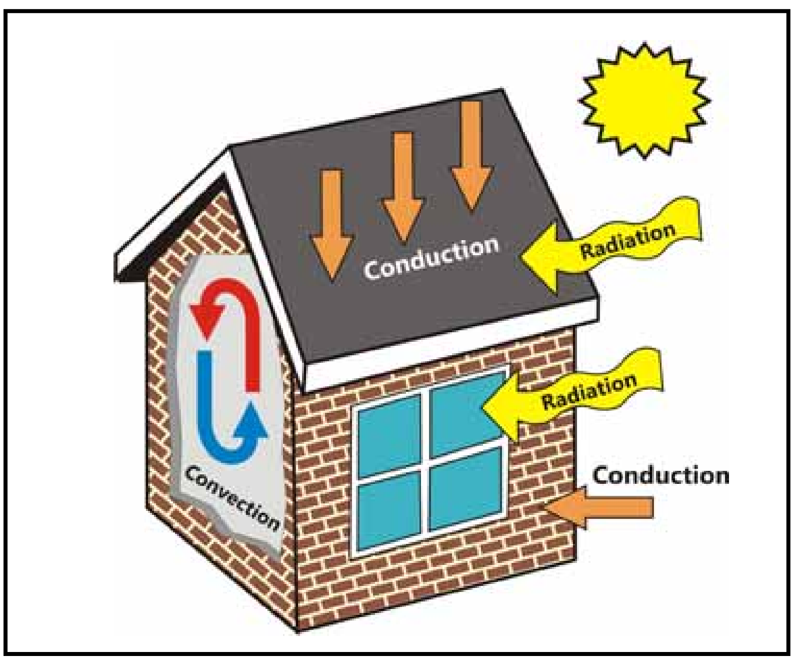

Figure 12: Conduction, convection and thermal radiation heat transfer in a house.

HEAT TRANSFER DESIGN CHALLENGE

Challenge:

Your challenge is to work as a team to design and build an insulating device which will keep a refrigerated juice box as cold as possible for two hours.

Materials:

- 2 identical juice boxes:
  - 1 cold juice box (kept in the refrigerator or a cooler overnight) (test subject)
  - 1 room temperature juice box –to be used to design the **prototype**
- variety of paper (e.g., construction paper, newspapers, cardboard, etc.)
- variety of fabric pieces
- 1 L plastic margarine container with lid
- Styrofoam chips
- peat moss
- white glue
- masking tape
- thermometer

Rules:

- Do NOT remove the juice box from the refrigerator or cooler or puncture the hole for the straw until you are ready to start timing.
- Use the room temperature juice box when building your prototype.
- The juice box must be placed in the 1 L margarine container.
- Insulating materials can only be placed inside the margarine container.

Once you are satisfied with your design and are ready to start timing:

- Measure the temperature in the refrigerator or in the cooler. This will be the **control temperature**. Record this temperature.
- Replace the juice box in the prototype with the juice box from the refrigerator/cooler. Put the lid on the container.
- Place the container away from heat sources. It will need to sit there for two hours.
- After two hours, open the container and measure the temperature of the juice.
- Calculate the difference between the control temperature and temperature of the juice box.

Success

- You have created an insulating device in which keeps the test juice within <u>5°C</u> of the control temperature.

Pushing the Envelope

- Would you change your choice of materials if you want to keep a hot drink hot? Why?

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Figure 1: The basic structure of an atom
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Source: www.wpclipart.com Public domain image.

Figure 2: The Standard Model of particles and forces
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Figure 3: The states of Matter
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Figure 4: A solid.
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Figure 5: A liquid.
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Figure 6: A gas.
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Figure 7: One example of a 3D printer.
http://commons.wikimedia.org/wiki/File:Easy3Dmaker.jpg
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Figure 8: Periodic Table of the Elements
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Figure 9: Conduction of heat through a metal rod.
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Figure 10: Convection heat transfer in boiling water.
Image ©2011 Let's Talk Science.

Figure 11: Heat transfer via thermal radiation.
Image ©2011 Let's Talk Science.

Figure 12: Conduction, convection and thermal radiation heat transfer in a house.
Image ©2011 Let's Talk Science.

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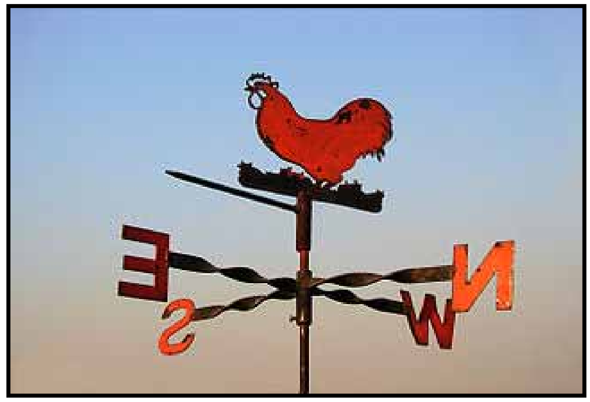
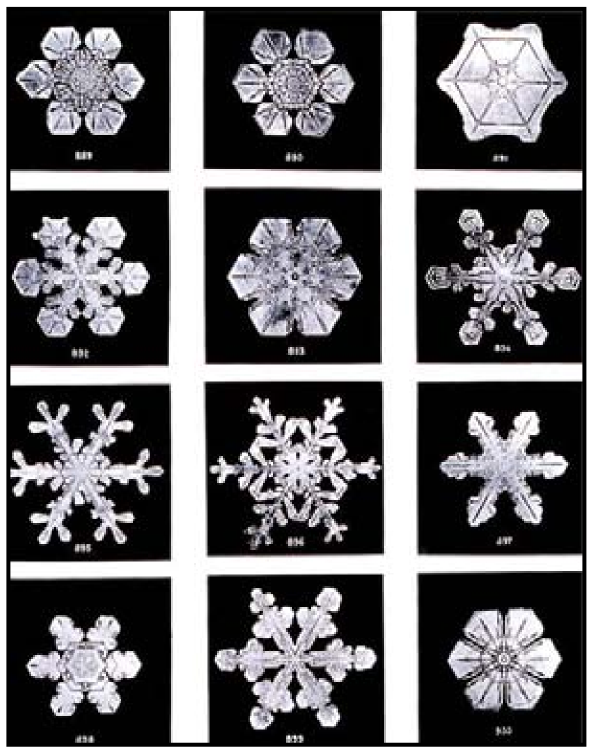
Chapter 3

Earth sciences





METEOROLOGY

Climate and Weather

Weather is the state of the atmosphere that includes six aspects: atmospheric pressure, temperature, clouds, winds, precipitation, and humidity. **Climate** is the long-term weather characteristics of a region.

The Atmosphere

The **atmosphere** is an envelope of **gases** surrounding a planet or other body in space. There are no visible boundaries in the air that surrounds the Earth; however, after studying the atmosphere, scientists have identified five distinct layers (see Figure 1);

1. **Troposphere**: The word comes from the Greek words *tropos* meaning 'to turn or mix' and *sphaira* meaning 'ball.' The highest point of the troposphere is at the equator, where it can be up to 20 km high. Almost 80% of the total atmospheric mass (air) is contained within the troposphere, and most weather variation occurs in the troposphere. Life on Earth (the **biosphere**) is found in the troposphere and the **hydrosphere** (bodies of water).

2. **Stratosphere**: The stratosphere extends out to an altitude of about 50 km. This is a very stable layer of the atmosphere. The **ozone layer** occurs within the stratosphere.

3. **Mesosphere**: From the Greek word *meso* meaning 'middle,' the mesosphere extends from about 50 km up to 80 - 85 km. Meteors burn up in the mesosphere.

4. **Thermosphere**: The thermosphere extends from 80 - 85 km up to 640+ km above the Earth's surface. During **solar flares**, the Northern Lights (**aurora borealis**) and the Southern Lights (**aurora australis**) are sometimes visible in the thermosphere.

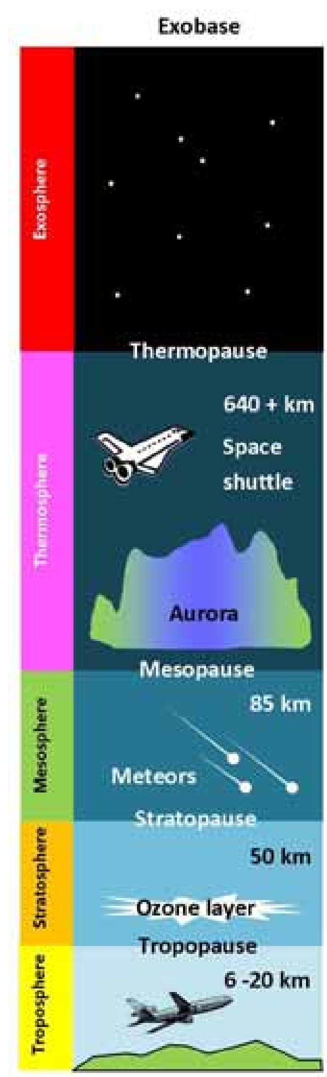


Figure 1: The layers of Earth's atmosphere.

5. **Exosphere**: The Exosphere is the outer layer of the Earth's atmosphere and extends from 500-1 000 km up to 10 000 km.

The boundaries between these regions of the atmosphere are named the **tropopause**, **stratopause**, **mesopause**, **thermopause** and **exobase**.

Atmospheric Pressure

An important aspect of the atmosphere is **pressure**, as it plays a role in determining weather and wind patterns. Although the atmosphere seems invisible and weightless, it actually has mass and weight. **Atmospheric pressure** is caused by air exerting a downward force onto the surface of the Earth. A one square centimetre column of air that reaches from sea level to the top of the atmosphere weighs about one kilogram! The exact weight of an air column depends on the number and types of molecules that it contains.

Air is made of molecules of a variety of gases. Increasing the number of air molecules in a given area increases the density, weight and pressure of the air. Decreasing the number of air molecules decreases the density, weight and pressure of the air. As with all molecules, molecules in the atmosphere are always moving - this is called **Brownian motion**. The higher the temperature, the more the molecules will move. This increased movement means that more molecules will bump into neighbouring molecules; thus, at higher temperatures molecules tend to be farther apart, resulting in fewer molecules per unit volume and therefore lower air pressure. Air pressure is measured with a tool called a **barometer**.

Low Pressure Areas

Low pressure areas have fewer molecules pushing down (lower pressure) than the surrounding areas. This means that a cluster of air columns with less density (and thus higher temperatures) are surrounded by columns with higher density (and thus lower temperatures). This arrangement of air columns causes an inward spiralling mass of air (see Figure 2). Low pressure systems do not hold water down on the Earth's surface as easily as high pressure systems. In general, low pressure systems

Figure 2: Low pressure area over Iceland.

are associated more with warm, humid air masses that have clouds and sometime result in precipitation, especially when they collide with high pressure systems. On a weather map, low pressure areas are marked with a capital **L**.

High Pressure Areas

High pressure areas have more molecules pushing down (higher pressure) than the surrounding areas. This means that a cluster of air columns with greater density (and thus lower temperatures) is surrounded by columns with lower density (and thus higher temperatures). This means that in a high pressure area there is a cold, dense centre surrounded by warmer, less dense air. As a result, the high pressure centre spirals outward. Air with high atmospheric pressure tends to hold water molecules close to the Earth's surface; therefore, high pressure areas generally have fair weather with cool temperatures, dry air and few clouds. On a weather map, high pressure areas are marked with a capital **H**.

Weather Fronts

Weather fronts are the boundaries that separate air masses of different densities (and thus different temperatures). **Cold fronts** (see Figure 3) occur when a mass of colder air is moving towards a mass of warmer air. The colder, denser air rapidly pushes the warmer, less dense air up into the atmosphere where it cools and condenses, often causing short-lived showers and thunderstorms.

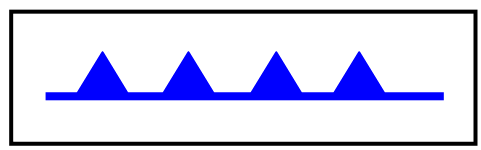


Figure 3: The symbol on weather maps for a cold front. The triangles point in the direction the front is travelling.

Warm fronts (see Figure 4) occur when a mass of warmer air is moving towards a mass of colder air. The warm air gradually moves over the cold air and up into the atmosphere where it condenses and causes precipitation that lasts much longer than the precipitation caused by cold fronts. The reason that warm fronts cause longer periods of precipitation is because an approaching mass of cold air pushes warm air up very quickly but an approaching mass of warm air moves slowly over a mass of cold air causing a longer period of condensation and thus precipitation.

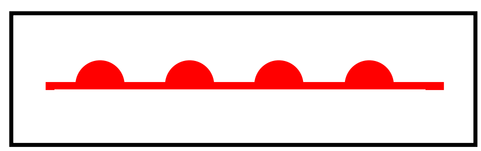


Figure 4: The symbol on weather maps for a warm front. The semicircles point in the direction the front is travelling.

Wind

Wind is the movement of air relative to the surface of the Earth. Winds are named for the direction from which they blow; for example, **Northeasterly winds** blow from the northeast and a **land breeze** blows from the land towards the sea.

Air moves because the Sun does not warm the surface of the Earth evenly. If the Earth did not rotate, hot air at the Equator would rise up into the atmosphere and then push cold air from the poles towards the equator along the surface of the Earth. However, the Earth's spin generates a force called the **Coriolis force** which deflects the winds (see Figure 4). From the latitudes 30° south to 30° north (near the equator), the winds are deflected from the east producing the **Prevailing Easterlies** which are also known as the **Trade Winds**. In the middle latitudes (30° to 60°N and 30° to 60°S) the air is deflected to the east from the west to produce the **Prevailing Westerlies**. At the poles the Coriolis force produces the **Polar Easterlies**.

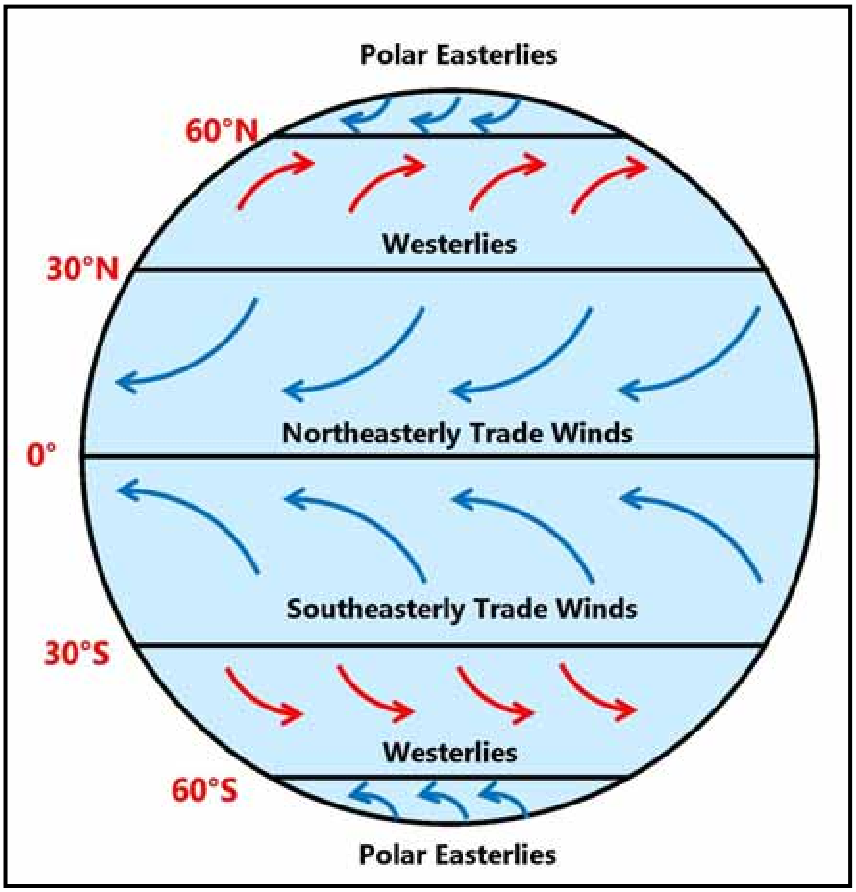


Figure 5: The surface winds on Earth.

Measuring Wind

Winds are described according to their **strength** (the speed at which they blow) and direction (see above). We have all experienced short bursts of high speed wind. These are called **gusts**. Winds that blow non-stop for around a minute are called **squalls**. Winds that last longer than a minute have various names associated with their average strength, such as **breeze**, **gale**, **storm**, **hurricane** and **typhoon**.

Over time people have created a number of tools to measure the wind. If you see a rooster and the symbols for north, south, east and west on the top of a barn, you are looking at a wind measuring tool called a **weather vane** (see Figure 6). The vane pivots in the wind showing which way the wind is coming from.

Figure 6: Weather vane.

At airports, **windsocks** (see Figure 7) are used to indicate wind direction, and they can also be used to estimate wind speed according to how they hang. Wind socks are made of tubes of thin material which blow very easily in the wind. When the wind is not blowing, the sock hangs straight down and when there is a strong wind, the sock is parallel to the ground.

Figure 7: Wind sock.

For a more precise measurement of wind, people use a tool called an **anemometer**. The word comes from the Greek word *anemos* meaning 'wind.' Like weather vanes, the most basic anemometers are made of cups mounted on arms that pivot in the wind. The faster the wind blows, the faster the cups spin. Other anemometers are more like propellers (see Figure 8). The speed of the propeller indicates wind speed, and the tail (which makes the device pivot) indicates wind direction.

Figure 8: Windmill style anemometer.

The **Beaufort Wind Force Scale** is an **empirical** (based on observations) measure of wind speed. The scale was created by Sir Francis Beaufort in 1805 and originally only had 13 levels. In the 1940s, the scale was expanded to 17 levels (see Table 1). The levels originally coincided with the number of turns of an anemometer.

Beaufort Scale	Term	Beaufort Scale	Term
1	Calm	10	Strong gale
2	Light air	11	Whole gale
3	Light breeze	12	Hurricane
4	Gentle breeze	13	
5	Moderate breeze	14	
6	Fresh breeze	15	
7	Strong breeze	16	
8	Moderate gale	17	
9	Fresh gale		

Table 1: The Beaufort Wind Force Scale (often shortened to the Beaufort Scale).

In Canada, maritime winds forecast to be in the range of 6 to 7 are designated as **strong**, 8 to 9 as **gale force**, 10 to 11 as **storm force**, and 12 as **hurricane force**. Appropriate wind warnings are issued by Environment Canada's Meteorological Service.

Clouds

Clouds are made up of tiny water droplets called **cloud droplets**, which are 100 times smaller than rain drops. These tiny droplets are formed when **water vapour** condenses around tiny particles of dust in the sky. When billions of these condensed water droplets come together, a visible cloud is formed. Clouds usually build up in the troposphere where cold, dry air meets warm, moist air. The heavier cold air pushes up the warm air, which cools in the higher atmosphere and forms clouds.

One of the interesting things about clouds is that they come in many different shapes, sizes, and even colours. Clouds were first classified based on their appearance and **altitude** (height above the Earth) by an Englishman named Luke Howard in the winter of 1802-1803. To describe certain altitudes, he used Latin prefixes. The prefix '**cirro**' refers to high clouds which are at least 6 250 metres above the Earth. The prefix '**alto**' refers to mid-level clouds between 1 875 and 6 250 meters above the Earth. Low-level clouds (less than 1 875 metres) were not given a prefix. He also identified three cloud shapes using Latin names:

1. **Cumulus** clouds are fairly vertical fluffy clouds that appear alone, in lines or in clusters.
2. **Stratus** clouds are flat, horizontally layered clouds that usually cover most of the sky.
3. **Cirrus** clouds are wispy and feathery like a stretched out cotton ball.

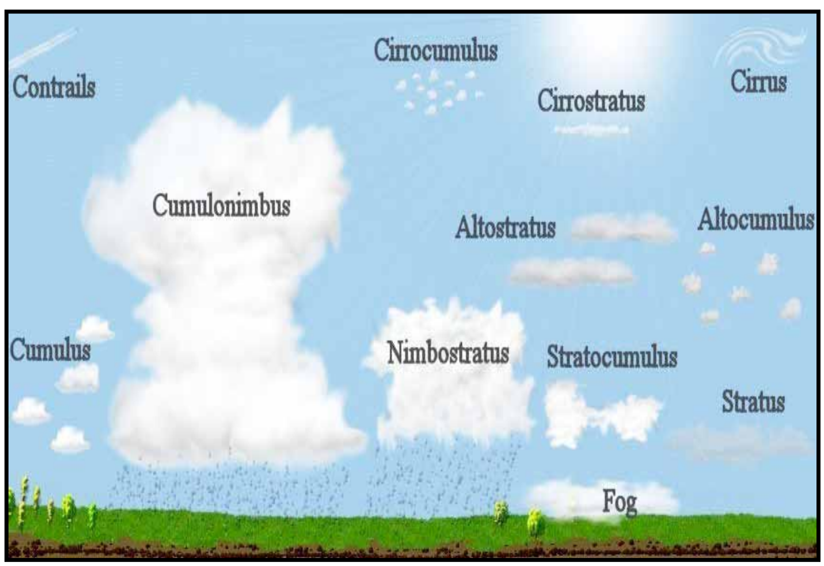


Figure 9: Cloud types.

Finally, he used the prefix '***nimbo***' or suffix '***nimbus***' to identify clouds that produce precipitation. While this might sound quite confusing, it is a method of cloud identification still used to this day. Look at Figure 9 to see how the different cloud shape names and cloud altitude prefixes are combined.

Sometimes the sky can look incredible with streaks of purple, pink and even orange clouds. Other times, you will see white fluffy clouds and on dreary days you'll see a mass of grey, gloomy clouds. How can clouds be different colours? Clouds can be different colours because the water droplets that make up the clouds can reflect and scatter light from the Sun. When you see white clouds, the water droplets are reflecting all of colours of light to your eyes. In contrast, the candy-coloured clouds scatter sunlight, making beautiful sunsets and sunrises. When clouds are very thick the light cannot pass through them, so all you will see is a dull grey colour.

Humidity

Humidity is the amount of water vapour in the air. **Dew**, **frost** and that 'muggy feeling' on hot days are signs of moisture in the air. Humidity is an important factor of any habitat and determines which plants and animals can thrive in a given environment. People too are affected by humidity. When humidity increases, evaporation of **sweat** (what keeps us cool on a hot day) decreases. If severe enough, this can result in **heat stroke**. To keep humidity bearable, people invented devices called **dehumidifiers** which can take moisture out of the air.

Precipitation

Precipitation is one of the key components of the Earth's **water cycle** (together with condensation and evaporation). **Drizzle**, **rain**, **snow**, **sleet** and **hail** are all different kinds of **precipitation**. All forms of precipitation start out as water vapour which condenses into droplets and falls from the sky. Some droplets stay as liquid while other droplets freeze.

Rain

In the clouds, small water droplets bump into each other to form larger droplets which eventually become so heavy that they fall to Earth. When the air is unstable, more and more droplets collide, resulting in bigger raindrops. Raindrops range in size from 0.1 mm to 9 mm (that's a pretty big raindrop!).

Figure 10: Late summer rainstorm.

Snow

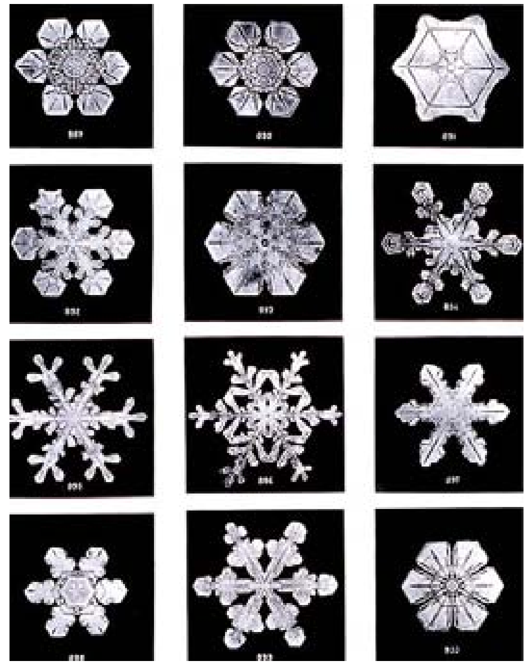


Figure 11: Selection of Wilson Bentley photographs taken in 1902.

Sometimes, water droplets in clouds freeze to form **ice crystals**. One type of ice crystal very familiar to us is the **snow crystal**. Snow crystals form when cloud droplets become supercooled and form a six-sided **crystal lattice** (crystal structure). As the snow crystals bump into water droplets in the clouds, the crystals grow bigger and bigger. When they get heavy enough, like raindrops, they fall to Earth. On the way down, they may collide and stick together with other snowflakes. Sometimes, around −2 °C, snowflakes can become 3-dimensional! It is said that "no two snowflakes are exactly alike," but the question is – how could you prove this? Attempts were made by photographer **Wilson Alwyn Bentley** (1865 – 1931), who photographed thousands of snowflakes using a microscope (see Figure 11). Although he didn't find two identical snowflakes, Bentley's photographs played an important role in our understanding of snowflake types.

Hail and Sleet


Figure 12: Hailstone.

Hailstones, better known as **hail**, are formed when ice crystals fall to the Earth on warm days. Rising, warm air masses within the clouds push water droplets back up into the atmosphere numerous times, forcing the ice crystals to fall and rise into and out of the colder temperatures at the higher altitudes. While going up and down in the clouds, the ice crystals have time to gather together and grow, forming hailstones. The ice chunks drop to Earth once they get heavy enough to overcome the forces of the rising air pushing them up. Hail has a diameter of 5 mm or more and hailstones about the size of golf balls are one of the most frequently reported hail size!

Ice pellets, also known as **sleet**, are small translucent balls of ice, typically smaller than hail. You can often see ice pellets bounce when they hit the ground and do not tend to freeze into a solid mass when on the ground. Ice pellets form when there is a layer of warmer air between two layers of colder air. Snowflakes formed in the upper layer of air, partially melt as they fall through the warmer layer of air and then freeze again when they pass through the lower layer of cold air.

Temperature

Altitude

Rising air that has been heated by the **radiation** of the Sun on the Earth's surface expands and cools as it rises. This expansion and cooling is known as **adiabatic cooling**. Adiabatic cooling is caused by decreases in pressure, not loss of heat. This is why the temperature is cooler on the top of mountains compared to at sea level at the same latitudes.

Latitude

Locations on Earth vary greatly in their average temperatures and weather patterns; for example, have you ever wondered why the Arctic is always cold while the Tropics are always hot? It all comes down to the Sun. The more sunlight that shines on an area, the hotter the temperatures in that area will be. Since the Earth is a sphere, the parts where the sunlight hits the Earth at a right angle (**equatorial region**), receive a lot of sunlight in a small, concentrated area, whereas the parts where the sunlight hits the Earth at a shallow angle (**polar regions**) receive the same amount of sunlight, but spread over a much larger area, making it much less concentrated. In Figure 13, you can see that the same amount of sunlight will cover an area of **a** at a polar region and an area of **b** at the equatorial region. Because area **b** is smaller than area **a**, the sunlight is more concentrated at **b**, resulting in warmer temperatures at **b** than at **a**.

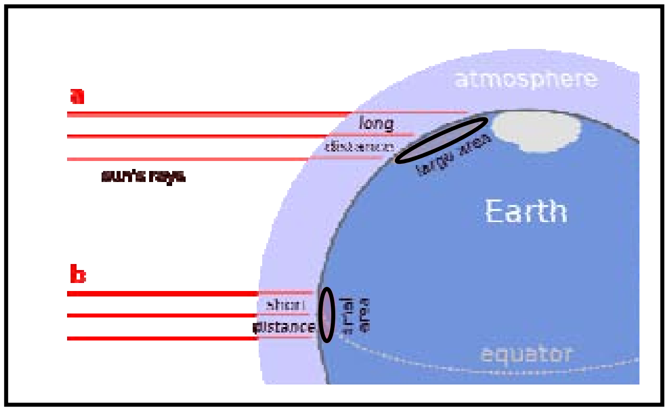


Figure 13: How the Sun's rays strike the Earth.

Seasonal Temperatures

If the Earth stood upright, meaning that the axis it spins on was perpendicular (at right angles) to its orbit, the equator would always face the Sun. This would mean that the northern hemisphere would stay equally cold all year round, but we know that is not true. In North America, have a colder season (winter) and a warmer season (summer) with intermediate seasons between (spring and autumn). The Earth has seasons because the Earth's axis is tilted at a fixed angle of **23.5°**. The northern end of the Earth's axis always points to the same place in space, which explains why the North Star can always be used to find north in the Northern Hemisphere. As the Earth moves around the Sun, the Earth is tilted either towards or away from the Sun. Let's see how this works in different seasons.

In our summer, the **Northern Hemisphere** (area north of the Equator) is tilted towards the Sun. Our calendars are set so that on June 21 (the **Summer Solstice** – see Figure 14) the Sun is directly overhead at its furthest north position. You can also see from Figure 14 which part of the Earth is lit (day) and which part is in shadow (night). You will notice that for the Northern Hemisphere, there is more in the light half than in the dark half. This is why the days are longer in the summer. In fact, above the Arctic Circle, there are 24 hours of daylight at the Summer Solstice!

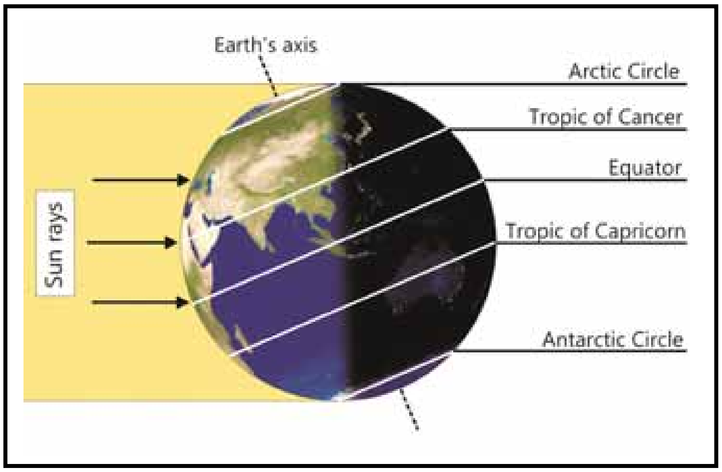


Figure 14: Summer Solstice.

The opposite occurs in our winter. In this part of the Earth's orbit, the Northern Hemisphere is tilted away from the Sun. Now you can see (see Figure 15) that the northern hemisphere is more in the dark half than the light half. This is why winter days are shorter (and nights are longer). As you may have guessed, there are 24 hours of darkness at the **Winter Solstice** (December 21).

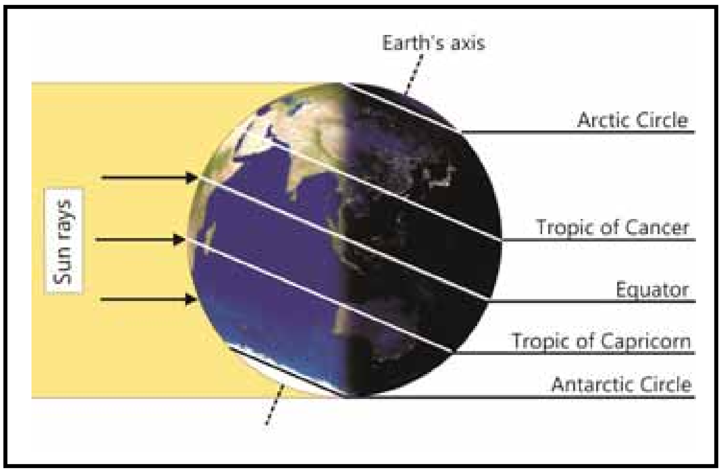


Figure 15: Winter Solstice.

At the **Spring Equinox** (also called the **Vernal Equinox**) and **Autumnal Equinox** (see Figure

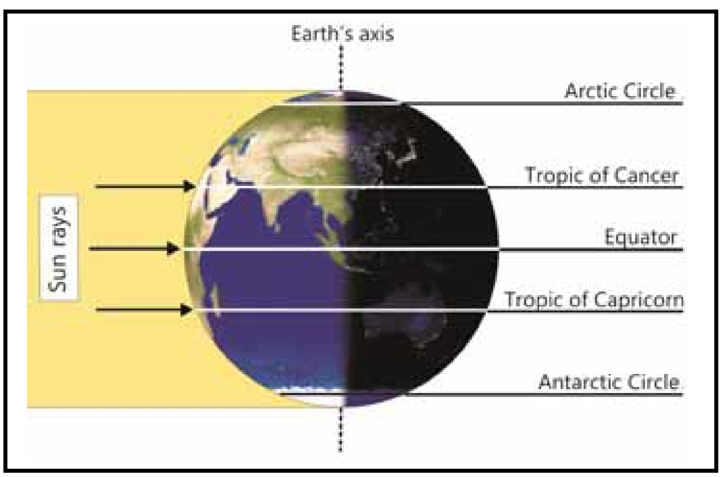


Figure 16: Spring and Autumnal Equinoxes.

16), the Northern Hemisphere is neither tilted towards nor away from the Sun. Day and night are exactly the same length. Equinoxes and solstices are points in time, rather than entire days.

Polar Climates

Polar Regions have very unique climates. The air in Polar Regions is very dry (contains little moisture). This is due to the extremely cold temperatures. Since there is little moisture in the air, clouds are rarely seen – let alone rain or snow! Some polar regions receive less than 25 cm of precipitation each year, and so are technically deserts! Near the North and South Poles, the temperatures can be so low that when snow does fall, it does not melt. Instead, the snow gradually accumulates over millions of years to form thick sheets of ice. In the **Southern Hemisphere** (area south of the Equator), these **ice sheets** cover the entire continent of Antarctica. In the Northern Hemisphere, the ice sheets are much smaller and are restricted mainly to Greenland. In the Arctic, above the Arctic Circle, the Arctic Ocean itself freezes to form sea ice, but this ice is rarely more than a few tens of meters thick. This is known as the **Polar Ice Cap**.

Global Warming

The Earth's climate is strongly affected by a phenomenon called the **greenhouse effect**. The greenhouse effect is a natural phenomenon that causes the temperature of the Earth to be warmer than it otherwise would be. The temperature of the Earth is determined by the amount of incoming **solar radiation** (energy from the Sun) and the amount of outgoing **longwave infrared radiation** (energy on the red end of the electromagnetic spectrum) from the Earth to space. Shortwave radiation from the Sun that isn't absorbed by the ozone layer or the outer atmosphere is absorbed by the surface of the Earth. This energy is then sent out from the Earth as infrared radiation. As the infrared radiation leaves the Earth, it can be trapped by greenhouse gases such as **carbon dioxide** in the atmosphere, causing a warming of the lower atmosphere and the Earth's surface (see Figure 18).

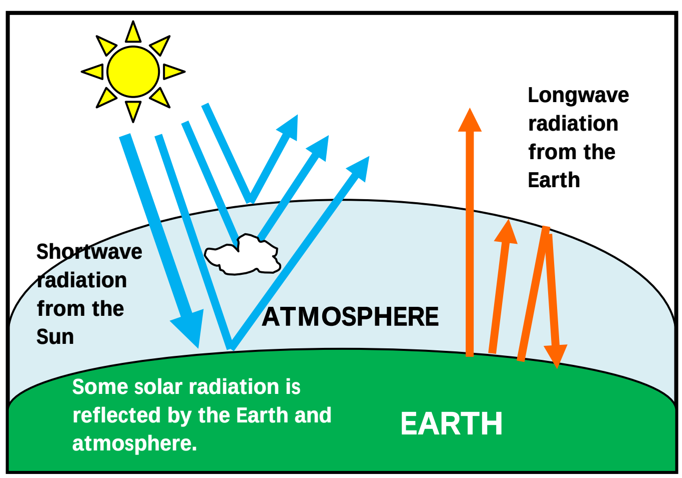


Figure 17: The Greenhouse Effect.

Common greenhouse gases are carbon dioxide, **water vapour**, **methane** and **nitrous oxide**. The more of these gases that there are in the atmosphere, the more infrared radiation is trapped and the warmer the Earth becomes. This process is called the **natural greenhouse effect**. Although atmospheric greenhouse gases make up less than 0.1% of air, they play a very important role in maintaining Earth's climate. Without the natural greenhouse effect, the average temperature of the planet would be 18 °C cooler than the Earth's temperature today. The balance between the amount of incoming solar radiation absorbed by the Earth and outgoing infrared radiation radiated from the Earth to space keeps the average temperature of the Earth in a steady state, and at a temperature suitable for life. If the average temperature of Earth increases or decreases too much, it may no longer be suitable for humans to live on.

Unfortunately, recent human activities appear to be affecting the natural greenhouse effect. Large amounts of greenhouse gases such as carbon dioxide are being released from the Earth into the atmosphere due to the burning of fossil fuels, **deforestation** (cutting down trees), agriculture and industry. These heat-absorbing greenhouse gases are **accumulating** (building up) in the atmosphere. The increase of greenhouse gases in the atmosphere causes more infrared radiation to be absorbed, and the temperature of the Earth to increase. This process is known as the **enhanced greenhouse effect**. The enhanced greenhouse effect, which causes the temperature of the Earth to increase, leads to the warming of the entire planet, known as **global warming**.

Over the last 300 years, concentrations of carbon dioxide in the atmosphere have increased by 30%, mostly due to human activities. The average temperature on Earth has increased by 1 °C over the past 100 years. Some ways that scientists can determine that global warming is occurring are to keep a record of the Earth's temperature, and to examine how the planet's surface is changing. Scientists, for example, can study the melting of glaciers, the melting of ice and **permafrost** (permanently frozen ground) at the Earth's poles and the rising sea levels. Although it is hard to predict the exact effect of releasing so many greenhouse gases to the atmosphere, using their observations on Earth and computer modeling programs, scientists can predict that as long as humans continue to release so many greenhouse gases to the environment, the temperature of the Earth will continue to increase.

Spotlight on Innovation in Earth Sciences

It’s a bird, it’s a plane, no – it’s a Radiosonde!

Commonly called weather balloons, **radiosondes** are instruments meteorologists use to study Earth’s atmosphere. ‘Sonde’ is the French word for probe, and that is precisely what a radiosonde does! Radiosondes are small boxes of scientific instruments that probe the atmosphere, taking measurements of wind speed and direction, temperature and humidity. This information is communicated back to the weather station on the ground using radio signals (hence ‘radio’sonde). To reach the upper atmosphere, radiosondes are lifted by balloons filled with hydrogen or helium up to elevations as high as 32 km (that’s four times the height of Mount Everest). The balloon becomes larger and larger as it rises due to the decrease in atmospheric pressure, and it can eventually reach the size of a small house! When the balloon finally bursts, the radiosonde falls back to Earth’s surface on a free-fall journey that takes about 30 minutes. Depending on the atmospheric winds, it can land more than 100 km from the location where it was launched. Twice every day, at 00h00 and 12h00 GMT, more than 800 radiosondes are simultaneously released from weather stations all around the world. In Canada, there are approximately 50 weather stations where radiosondes are released and, when combined, the data from these radiosondes can be used to create the weather forecasts that we use to coordinate our everyday lives.

Figure 18: Laura Thomson, from the University of Ottawa, releasing a radiosonde in Eureka, Nunavut.

WINDPROOF STRUCTURE
DESIGN CHALLENGE

Challenge:

Your challenge is to work as a team to design and build a structure using the provided materials that can shelter two toy people (castaways on a tropical island) and withstand wind forces from an electric fan (a hurricane).

Materials:

- 2 small toy people, approx. 5 cm (2") tall (e.g., LEGO® people)
- 6 craft sticks
- 50 cm (~18") of string
- 1 piece of paper, 5.5" x 8.5" size (half of a letter-sized piece of paper)
- 1 small piece of stick tack (about the size of your fingernail)
- 1 piece of cardstock
- Scissors
- 1 electric fan

Rules:

- You may use only the provided tools and materials to build your structure.
- The structure must be attached to the piece of cardstock using the stick tack. You cannot use the stick tack for anything other than attaching your structure to the cardstock.
- Your completed structure must be set up 60 cm (~2') away from the electric fan, with the electric fan pointing directly at your structure.
- Turn the fan on its lowest setting for 30 seconds. If your structure withstands that force, turn the fan up to the next setting for 30 seconds. Continue until the fan is at the maximum setting.

Success

- You have created a structure that your toy people can safely sit under and will not fall apart when blown upon by the electric fan at maximum power for at least 30 seconds.

Pushing the Envelope

- Can your structure withstand the wind from all directions? Rotate your structure so that each side is exposed to the wind.
- Can you make a structure that will protect your toy people from water as well?

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Figure 1: The layers of Earth's atmosphere.
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Figure 2: Low pressure area over Iceland.
http://commons.wikimedia.org/wiki/File:Low_pressure_system_over_Iceland.jpg (Accessed Dec. 15, 2014)
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Figure 3: Map symbols for a cold front.
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Figure 4: Map symbols for a warm front.
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Figure 8: Windmill style anemometer.
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Figure 9: Cloud types.
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Figure 10: Late summer rainstorm.
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Figure 11: Selection of Wilson Bentley photographs.
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Figure 12: Hailstone.
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Figure 15: Winter Solstice.
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Figure 16: Spring and Autumnal Equinoxes.
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Figure 17: The Greenhouse Effect.
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Figure 18: Laura Thomson releasing a radiosonde in Eureka, Nunavut.
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Chapter 4

Engineering & technology

Thank you to our Engineering & Technology chapter sponsor 3M

Let's talk science CHALLENGE

INTRODUCTION

Human beings are driven to modify the natural environment in order to satisfy needs and wants, solve problems and extend human capacities. **Technological problem-solving** is the process of using knowledge of mathematics and sciences, such as physics and chemistry, to find solutions to technological problems. **Engineering** is a form of technological problem-solving which tends to involve designing and building structures, machines and systems. A person who does engineering is called an **engineer**.

Branches of Engineering

There are many types of engineering. Each type specializes in using certain types of materials (e.g., chemical engineering, materials engineering), exploring certain types of phenomena (e.g., electrical engineering, nuclear engineering), developing certain types of processes (e.g., mechanical engineering, civil engineering) or technologies (e.g., computer engineering, aerospace engineering). Let's look at some of these branches of engineering in more depth.

Chemical Engineering

Chemical engineers use knowledge of chemistry, and in some cases biology, to create new types of chemical products such as fuels, adhesives and gels as well as medicines such as antibiotics.

Materials Engineering

Materials engineering involves applying knowledge about the properties and structure of matter at the atomic level. Materials engineers create new types of **biomaterials** (materials which interact with biological systems), **ceramics**, **composite** materials (materials made of two or more materials such as fibreglass), metals, **polymers** (large molecules with repeating units such as plastic) and **semiconductors** (see the Physics chapter for more information).

Electrical Engineering

Electrical engineering deals with the study and applications of electricity, **electronics** (electrical circuits and electrical components such as circuit boards) and **electromagnetism** (see the Physics chapter for more information about this). Electrical engineers deal with large-scale electricity generation systems (see the Physics chapter for more information) as well as small-scale electronic systems such as Smartphones.

Mechanical Engineering

Mechanical engineering is a broad field that uses physics to design, manufacture and maintain mechanical systems. Mechanical engineers mainly study how **forces** affect objects (**mechanics**). This includes the study of **statics** (how non-moving objects behave when supporting a load), **dynamics** (how forces affect moving objects), **fluid mechanics** (how fluids such as water and air react to forces), **kinematics** (the motion of objects and groups of objects) and **thermodynamics** (the transfer of heat and the effects of heat on objects – see the Chemistry chapter for more).

Civil Engineering

Civil engineering deals with the design, construction and maintenance of **structures** such as roads, bridges and buildings. These engineers make sure that the roads we drive on and the buildings we live in are safe. They are concerned with the strength and stability of structures.

These are just a few of the many types of engineering. The technologies created by these engineers are all around us and impact us every day in many ways – from the home that we live in and the devices that connect us to the clothing we wear and the dishes we eat off of. Did you know that engineers even play an important role in sports? In this chapter you will see how many different types of engineering as well as technology are involved with one of Canada's favourite sports – hockey!

GOOD OLD HOCKEY GAME

"He shoots... He scores!" We have all heard this statement, blaring over the radio or television as a hockey player sends the puck into the back of the net. Apart from his or her teammates, would you believe that hundreds of engineers assisted that goal? The rest of this chapter will explore the engineering and technology behind hockey rinks, hockey equipment and ways that people protect themselves when playing hockey.

Artificial Ice

Early forms of stick and ball games on ice which resembled hockey were played on naturally-occurring frozen ponds and lakes and eventually on outdoor ice rinks. One famous early Canadian indoor ice rink was the Victoria Skating

Figure 1: Victoria Skating Rink, 1893.

Rink located in Montreal, Quebec, which opened in 1862 (see Figure 1). This early indoor rink holds a special place in hockey history as it hosted the first recorded organized indoor ice hockey game on March 3, 1875. The game included two teams (nine players per side), goaltenders, a referee, a puck, pre-determined rules and a pre-determined length of time (60 minutes). Unlike modern indoor ice rinks, the ice at the Victoria Ice Rink was kept frozen by cold, winter temperatures rather than by artificial means. In the summer, the rink was used for other types of events such as flower shows.

It was not until 1911 that an artificial ice rink was built in Canada. The first rinks were built by the Patrick brothers, Lester and Frank, and located in Vancouver and Victoria, British Columbia. In 1912, artificial ice was installed in Toronto, the first in Eastern Canada. By 1920, only four artificial ice rinks were running in all of Canada.

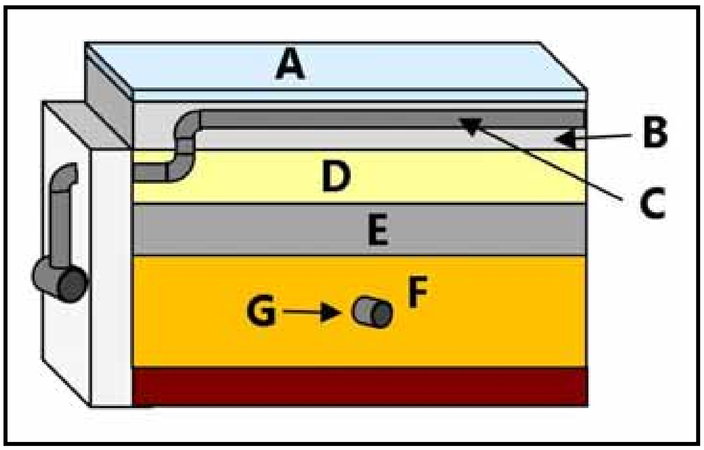

Figure 2: The layers of an ice rink.
A: Skating Surface
B: Chilled concrete
C: Pipes that pump brine
D: Insulation
E: Heated concrete
F: Sand and gravel base
G: Ground water drain

An artificial ice rink is a complex piece of engineering. There is a lot going on under the ice that we cannot see (see Figure 2). Underneath the **skating surface** (**A**) is a large **concrete floor** (**B**) (also known as the 'ice slab') which contains hundreds of meters of **pipes** (**C**). **Brine** (water with a high concentration of salt) flows through the pipes and keeps the ice at -4°C. The concrete floor sits on a layer of **insulation** (**D**) which allows the ice to expand and shrink as necessary. Underneath the layer of insulation is a layer of **heated concrete** (**E**) which prevents the natural contraction and expansion of the ground from cracking the layers above. The entire structure sits on a **sand and gravel base** (**F**) which contains a **groundwater drain** (**G**). If people want to get rid of the ice, they can melt it by pumping hot brine through the same pipes that pumped cold brine.

To make the ice, first the concrete base (the 'ice slab') is cooled by the brine flowing through the pipes. Once the 'ice slab' is cold enough, then layers of water are added. Once this base of ice is completely frozen, the hockey markings (lines, team logo and advertisements) are painted on the ice. Finally, 8-10 thin layers of water are added to protect the paint. To prevent the ice from getting cloudy, mechanical engineers create

filtration systems to remove impurities from the water. The clean water freezes to form transparent ice that allows players and viewers alike to easily see the black puck slide over the goal line.

By calculating how much the water must be cooled, a mechanical engineer can determine how fast the brine must flow through the pipes. The engineer also needs to decide on a lot of other things – such as what type of insulation will be the best for the base, which pipes will allow for the best heat transfer and what size of pump can move the brine as fast as needed. Calculations that have to do with **heat transfer** (see the Chemistry chapter for more information), like these ones, are part of **thermodynamics**.

What We Call a Zamboni

In the 1940s, resurfacing the ice of a hockey rink meant:

1) pulling a scraper behind a tractor to shave the ice surface;
2) scooping away the shavings;
3) spraying water over the surface; and
4) squeegeeing it clean.

The whole operation took between 60 and 90 minutes, depending on the environment near the water, and it's time to freeze. The challenge of automating the whole operation became the obsession of **Frank J. Zamboni**, the owner of an ice rink in southern California. In 1952, Zamboni created the first mechanized **ice resurfacer** using a Jeep with an elevated driver seat at the rear and snow tank on the bottom. The basic design of ice resurfacers – better known as 'Zambonis' – has remained the same ever since.

Figure 3: A Zamboni at work resurfacing ice.

An ice resurfacer is more than just a machine which sweeps snow and pours warm water on the ice. First, a sharp **blade** shaves the ice and then the shavings are collected and propelled upward into the **snow tank**. This movement of shavings is done using precisely designed **augers** (screws), similar to those used in snow blowers. After collecting the shavings, water from another tank is poured into the snow tank to wash the ice. The dirty water is then **vacuumed** out and a final coat of warm water (near 65°C) is applied to the ice with a pad. Why warm water? Warm water is used because it blends more quickly with the ice than cold water. Warm water helps melt the remaining rough surfaces and replaces the original layer of ice that was shaved off. Not only do ice resurfacers have many mechanical parts, they also have a number of electronics which are used to control the hydraulic valves, the drivetrain and the blades.

Hockey Pucks

Hockey wouldn't be hockey without the hockey puck! A hockey puck is a hard disk that players try get into the opposing team's net. In the first hockey game, a puck was used instead of a ball because the Victoria Skating Rink did not have boards and there was concern about the spectators getting hit by the ball.

To begin with, hockey pucks were made of wood, but nowadays pucks are made of vulcanized rubber. **Vulcanization** is a chemical process which changes soft rubber into more durable materials. By changing the chemical make-up of the rubber (such as by adding sulphur), the temperature and the pressure that the rubber is subjected to, a materials engineer can make a hockey puck harder, softer, lighter or heavier. A puck that is too hard will bounce too much and one that is too soft will not bounce enough. By choosing a hockey puck's material properties, a materials engineer influences how a puck will react to the drop on a face-off or a slap shot.

Hockey Sticks

The sharp, short force exerted by a slap shot is known as an **impulse force**. An impulse force is essentially a very fast collision – in this case between the stick and the puck. As a result of **Newton's Third Law of Motion** which states that "for every action, there is an equal and opposite reaction" during a collision, a hockey stick experiences the same force as the puck. This force can be large enough to break a hockey stick. Once again mechanical engineers can help.

Stick Structure

A hockey stick is like a tree branch. The thicker the branch or the harder the wood, the harder it is to break. Mechanical engineers use these principles when designing hockey sticks. By doing a **stress analysis**, mechanical engineers can find out where a hockey stick will experience the greatest forces (stresses) and where it will need to be stronger. A hockey stick should be made out of materials that are very strong, yet flexible and lightweight. The **blade** (see Figure 4) of a hockey stick is usually made up of thin sheets of wood, fibreglass or carbon fibre that are stuck together to give the blade its shape and strength. Reinforcing the **base** (see Figure 4) of the hockey stick gives it extra strength where it is subjected to the most force. Many weights and shapes of hockey sticks are available and each player will choose one that he/she feels most comfortable using.

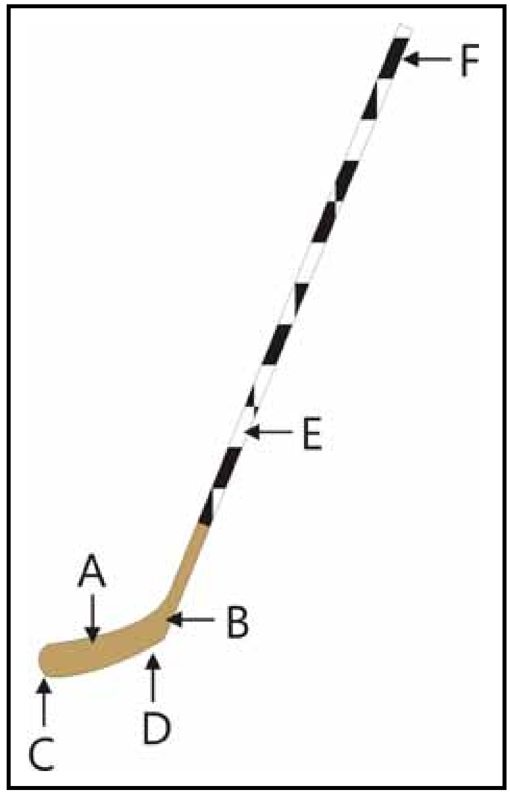

Figure 4: Anatomy of a hockey stick. **A:** Blade; **B:** Base; **C:** Toe; **D:** Heel; **E:** Shaft; **F:** Butt-end

Taping Hockey Sticks

If you've ever wondered why hockey players tape their hockey sticks, you've come to the right section! There are many reasons why players choose to tape their sticks, and while most tape their sticks in a similar fashion, many players will personalize their tape job to suit their own needs.

Almost all hockey players choose to tape the blade of their hockey stick to some degree, so in a way, the players themselves are re-engineering their sticks!

Taping the stick:

- improves control of the puck by providing additional **friction** (resistance between the stick and puck);
- deadens **vibrations** (movement back and forth) in the stick when a hard pass is received (or when taking a shot); and
- creates a protective barrier between the stick and moisture from the ice, prolonging the life of the stick.

Taping the blade from the **toe** (C in Figure 4) to the **heel** (D in Figure 4) allows the player to put more spin on the puck as he/she shoots or passes, which improves control and accuracy. Bobby Orr, one of the greatest defensemen or all time, commonly used only one strip of tape, right across the middle of the blade in the sweet spot of the stick.

Most players use a specific type of tape, called **friction tape**, which is made of cotton fabric mixed with rubber adhesive. When applied, the tape gives the blade a slightly sticky surface that helps to maintain puck contact on the blade. Other players choose to use hockey tape that is not adhesive because shot speed tends to be lower when leaving a sticky stick! Wayne Gretzky, who some say was the greatest player in the National Hockey League (NHL), did something in between. He used friction tape, but sprinkled baby powder on the blade afterwards to reduce the adhesiveness of the tape.

Figure 5: Taped hockey sticks.

Players generally use either white or black tape. White tape allows the player to see the puck better on their stick, and for this reason most goalies will use white tape on their sticks. Other players use black tape for the opposite reason: they believe black tape will camouflage the puck on their stick and therefore prevent the goalie from seeing the release of the shot for an extra split second. When Luc Robitaille played in the NHL, he used black tape in the 1st and 3rd periods, but switched to white tape during the 2nd period of his games.

In addition to taping the blades of their sticks, most players will also apply tape around the **shafts** (E in Figure 4) of the sticks. This is most common at the **butt-end** of the stick (F in Figure 4), where players will wrap several layers of tape over the same area to produce a raised area. This helps players hang onto their sticks when **poke-checking** (using the stick to poke the puck away from an opponent) which is an extremely important technique for **defencemen** (defensive players who play near their team's goal line) and **goalies**. The extra tape on the shaft also makes it easier for players to pick up dropped sticks without having to remove their gloves because it raises the shaft of the stick a little off the surface of the ice. Sometimes players will also tape areas further down the shaft of their sticks; for example, **centremen** (offensive players who primary zone of play is the middle of the ice) may tape a small area of the shaft closer to the blade where they grip the stick during a **faceoff** (opposing centremen attempt to gain control of the puck after it is dropped between their sticks by the referee) while other players may choose to reinforce the area where the shaft meets the blade to prevent stick breakage (see the Stick Structure section above).

Hockey Skates

Since E.W. Bushnell invented the steel blade skate in 1850, nothing much has changed in hockey skate design. Today's skates may be fancier, lighter and perhaps sturdier than before, but hockey players of 150 years ago could still look at a modern skate and see a steel blade attached to a boot. Although, with a closer look, you can see how important engineering is to the design of the skate. Engineering and technology have a lot to do with the shape and groove of the blade as well as with the materials used to make the boot.

Blades

Skate **blades** are typically made of **stainless steel**, and are sometimes coated with a thin layer of **titanium** (which is what makes some skate blades look like they are made of gold) for extra rust protection and to increase their durability. Unlike figure skates, hockey skates have blades which are rounded at both ends (see Figure 6). This curved shape allows hockey players to make sharp turns and to lean forward.

Figure 6: Hockey skates.

In order to move quickly and easily, a hockey player needs blades which are properly **grooved**. The role of the groove is to stabilize the skate on the ice. Players (other than the goalie) want larger grooves in their blades while goalies want their blades with smaller grooves since they frequently need to move sideways.

The sharp edge of a freshly sharpened blade easily cuts into the ice and provides grip so that a player can speed up or stop quickly. Speaking of speed, a high-tech heated-blade skate came on the market in 2007. Why a heated blade? Tests showed that a heated blade can cut down on the **friction** (force resisting motion on solid surfaces) between the blade and the ice by up to 50%. By lowering the friction, a hockey player has to expend less energy to move. At the elite level, less energy wasted on friction means more energy for playing hockey and longer shifts for the best players. As good as this technology sounds; heated blades have not caught on with professional hockey players.

Boots

In the past, the boot part of a hockey skate was made of leather. Today, nylon and other tough **synthetic** (human-made) materials are used (goalie boots are made of even tougher materials!). Engineers in the skating industry are continually looking to improve the design of boots, making them even more durable and, most importantly, comfortable to wear. Recently, gel-like substances were introduced into the inside of the padding of the boot to provide extra cushioning and to mould to the shape of the ankle for a better grip on the foot. Extra protection has been customized for skaters (mostly for shot-blocking defensemen) to protect the top of the foot and the front of the ankle. The challenge with this extra protection has been to make the player not notice it, which is why light and strong **graphite composites** (materials made by combining carbon fibres with resin) are used. Boots for goalie skates have a similar material covering the toe-part of their skates.

Spotlight on Innovation in Engineering & Technology

Sledge Hockey

For people with a physical disability in the lower part of the body, ice hockey may not be possible, but this doesn't mean they can't participate in the good old hockey game. For these people, **sledge hockey** could make their dreams of hockey greatness a reality. Sledge hockey follows the same rules as ice hockey, but instead of wearing skates, players sit strapped to a two-blade **sledge** that is raised high enough to allow the puck to pass under it. Players also use two 75cm long hockey sticks, with spikes on one end and blades on the other. The spikes help the player to push the sledge and the blades are used to help the player handle the puck. Since its introduction at the 1994 Lillehammer Paralympic Winter Games, sledge hockey has continued to grow in popularity around the world.

Figure 7: Paul Rosen, goalie for Canada's 2010 Paralympic team.

Hockey Helmets

Concussions

As hockey players young and old suit up for a game of hockey, they know that one of the most important pieces of equipment is their helmet. Helmets are worn to prevent head injuries, in particular, **concussions**. Concussions are brain injuries that occur when the brain hits the inside of the skull due to a head impact. Hockey, as you can probably imagine, is one of the sports in which players suffer the greatest number of concussions. You may have noticed in the last few years that there have been more stories about sports concussion in the news. It is not because more athletes are getting concussions, but rather because more people are aware of the symptoms of concussion. As more athletes, coaches and parents are on the lookout for concussions, more concussions are being correctly diagnosed. Along with increased awareness, the media hype about concussions has also encouraged the invention of new technologies to help prevent and alert people to these brain injuries.

Recently, helmets have received a technological boost to help detect concussions. An Ottawa, Ontario entrepreneur named Danny Crossman has created a sensor that fits into an athlete's helmet. Called the **Shockbox**, the tiny device is able to calculate the force of a hit received by an athlete's head. When the Shockbox senses a jolt that is stronger than a **g-force** (a measurement of a body's acceleration or deceleration compared to the force of gravity) of 60, it sends a wireless signal to a Smartphone or laptop, letting coaches know that the player needs to be brought off the ice and checked for signs of a concussion.

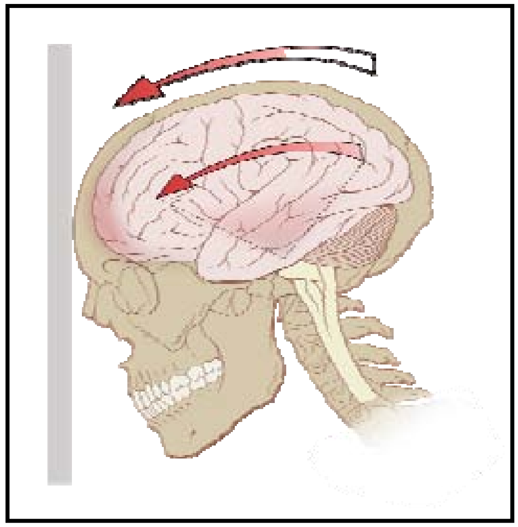

Figure 8: Concussion.

Jeff Archbold, a forensic engineer from Toronto, Ontario, has also been working on what he believes will be a better helmet. His helmet contains tiny air bags that would go off when the helmet is hit hard enough. Not only would the air bags help cushion the skull, they would also show a coach or a parent that the person had received a hard hit.

Even hockey legend Mark Messier has got into act with the Messier Project™. The mission of the project is to promote safe hockey and reduce what they call the "concussion epidemic." One way they are doing this is through the creation of new type of helmet called the M11 (those of you who know hockey will remember that Messier was number 11). The helmet uses what is called Seven Technology™, which is a unique type of liner system that contains little tubes which **compress laterally** (squish and spread sideways) upon impact. As the tubes do this, they absorb energy and then return to their original shape, much like springs.

Goalie Masks

A goaltender mask, also called a **goalie mask**, is a special mask worn by goalies to protect their faces and heads from the impact of pucks, sticks, and other players. In the early days of organized hockey, goalies did not wear masks because pucks were simply slid along the ice. Over time, players began to hit pucks harder, faster and higher, which meant that pucks could be flying straight at a goalie's face. A few people tried wearing face protection such as fencing masks and baseball catcher's masks, but it wasn't until **Jacques Plante** created and used a practical mask in 1959 that goalies wore masks on a regular basis.

Figure 9: Modern goalie helmet.

After the initial face-hugging masks, hockey helmets with cages on the front became popular for goalies in the 1970s (this is what most kids' helmets look like today). The concern with these masks is that they do not provide enough protection for the face and head; however, many non-professional players still wear this style because they are lighter and have better visibility than modern fibreglass or composite masks.

Today many professional hockey players wear highly engineered masks made of fibreglass, polymers reinforced with carbon fibres or **Kevlar**® (very strong synthetic fibre) (see Figure 8). These masks can stand up to high-speed pucks and are believed to better disperse the energy of pucks than helmet and cage masks. Goalie masks are as individual as the players who wear them. To see some examples of masks, check out the References section.

Protective Equipment

Hockey is a punishing sport which includes bodies smashing into ice, boards, and other players (colliding with other players, often on purpose, is known as **checking**). It is no surprise then that players cover most of their bodies with protective gear to lessen their risk of serious injury. We have already looked at how helmets and goalie masks protect players. This section will focus on the other types of equipment worn by hockey players.

Padding

Pads are pieces of equipment made of shock-absorbing foam under a hard plastic covering. Engineers make sure that these pads can withstand the impact forces from different objects. **Shoulder pads**, which also cover the collar bone, chest, back, and upper arms, protect against flying pucks and checks. **Elbow pads** are very important pieces of equipment as they protect elbow joints and arms during falls and checking. Most elbow pads are adjustable and are strapped on using Velcro. **Hockey pants** also have padding built in which protects the thigh, hip, pelvic bones and tailbones, with the padding varying depending on whether the pants are being worn by skaters or goalies. Goalies also wear special **goal pads** to protect their shin and knees. Skating players wear **hockey gloves** which are thin on the palm-side so that they can grip their stick and thick on the back side of the hand to protect the hand from pucks, skates and sticks. The funny part is, when players fight (which is not an uncommon sight during a hockey game), they almost always take off their gloves and fight with bare fists! Unlike skaters, goalies have their own specially-designed gloves which are more for catching and blocking pucks than they are for protecting hands. On the hand, with which the goalie holds his or her stick, the goalie wears a **blocker**. This glove is used to deflect shots. On the other hand, often called the **glove hand**, the goalie wears a glove called a **trapper**. The trapper looks a bit like a baseball glove and is used to catch pucks. Keep in mind that a puck, especially during a **slapshot**, can be going at a speed of up to 160 km/h when it is caught by a goalie!

Figure 10: Protective equipment.

Guards

Some pieces of equipment 'guard' certain parts of the body from injury. A **Neck guard** protects the neck and throat from skates, sticks and pucks. Neck guards have been mandatory for goalies in the NHL ever since 1989 when the skate blade of a fallen skater sliced open a goalie's neck, almost causing his death. **Shin guards**, which include **knee pads**, protect knees and shins and **jockstraps** (protective cups) protect the pelvis and genitals. Finally, there are **mouthguards**. Mouthguards protect teeth and gums from falls, sticks, pucks - and fist fights. In days gone by players did not wear mouthguards, which is why so many veteran hockey players are missing more than their fair share of teeth! Today many amateur hockey players use mouthguards made of a type of **thermo-plastic** (plastic which is sensitive to heat) which can be heated and moulded to fit the shape of their teeth. Professional players tend to have custom-made mouthguards so that they know their mouthguards will fit properly and be comfortable.

SHIN PAD DESIGN CHALLENGE

Challenge:

Your challenge is to work as a team to design and build a shin pad structure, using the materials provided, to protect a plasticine 'leg' from the impact of a hockey puck which is dropped from a height of 1 metre.

Materials:

- 1 cardboard base (letter-sized)
- 1 ball plasticine (~8 cm diameter)
- 1 hockey puck
- 1 roll masking tape
- 1 pair of scissors
- 1 large plastic tote

Choice of:

- Corrugated cardboard, thin sponges, foam meat trays, bubble wrap, cotton balls

Rules:

- Create your 'leg' by rolling the ball of plasticine into a smooth cylinder shape. Press the plasticine onto the cardboard base.
- Using only the building materials provided (the scissors and tote CANNOT be part of your design or be attached to it), design a shin pad that will protect the leg.
- Your design must be secured in place over the leg but must also be easy to remove in order to check for signs of impact.
- To test the shin pad, your completed design must be placed in the bottom of the plastic tote and then a puck will be dropped on it (narrow side down) from a height of 1 m.
- Examine how much damage has occurred to the leg.

Success

- You have created a shin pad that prevents any damage to the plasticine leg from a puck dropped from a height of one metre.

Pushing the Envelope

- Can your shin pad withstand the puck impact from a greater height (e.g., 1.5 m)?
- Can you design a structure using fewer materials?
- Can you think of another way to test the strength of the shin pad? Try it on your design.

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http://commons.wikimedia.org/wiki/File:Victoria_Rink_Montreal.jpg (Accessed Dec. 9, 2014)
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Figure 2: The layers of an ice rink
Image ©2011 Let's Talk Science.

Figure 3: A Zamboni at work resurfacing ice.
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Figure 4: Anatomy of a hockey stick.
Image ©2012 Let's Talk Science.

Figure 5: Taped hockey sticks.
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Figure 6: Hockey skates.
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Figure 7: Paul Rosen, goalie for Canada's 2010 Paralympic team.
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Pucks

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Hockey sticks

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The **Gear** section of the Exploratorium's Science of Hockey website talks about hockey sticks and some of the high-tech materials that are now being used to make sticks.

Skates

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Helmets and Concussions

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Goalie Masks

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The **Gear** section of the Exploratorium's Science of Hockey website talks about goalie gear including equipment such as padding, sticks and masks.

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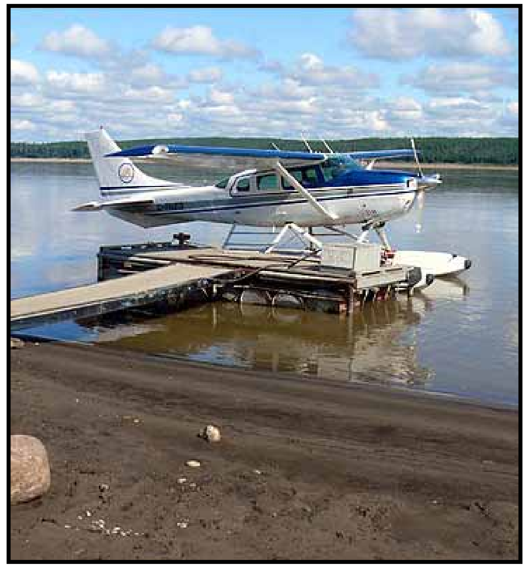
This page, from the Canadian Paralympic Committee, describes in detail the sport of Sledge Hockey. You can also read about some of Canada's Sledge Hockey athletes.

Chapter 5

Environmental sciences



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let's talk science CHALLENGE

INTRODUCTION-FRESHWATER ECOSYSTEMS

The Earth is made up of many diverse **ecosystems**. An ecosystem consists of all of the **biota** (living organisms) as well as the **abiotic** components (e.g., non-living things like air, soil, water, light) in a given area. The ecosystems on Earth can be grouped according to whether they are **terrestrial** (on land) or **aquatic** (in water). This chapter will focus on one of the two types of aquatic ecosystems – **freshwater ecosystems** (the other being **marine ecosystems**).

Freshwater ecosystems include lakes, ponds, rivers, streams and wetlands. The difference between freshwater ecosystems and marine ecosystems (such as oceans and seas) is that the water in freshwater ecosystems has less salt in it. Freshwater ecosystems can be divided into two main types: **lentic ecosystems** (still water) and **lotic ecosystems** (flowing water). The study of freshwater ecosystems is called **Limnology**.

LENTIC ECOSYSTEMS

Figure 1A: Satellite image of the Great Lakes, with Lake Michigan-Huron in the centre.

Figure 1B: Garden pond.

Lentic (meaning ‘slow’ from the Latin word *lentus* which literally means ‘slow’) ecosystems are bodies of freshwater that do not flow. These ecosystems range in size from one square metre in area of the smallest garden **pond** to hundreds of thousands of square kilometres in the Great Lakes. The largest **lake** by area in the world **is Lake Michigan-Huron** (Lake Michigan and Lake Huron are considered geologically to be a single body of water because they are connected by the Straits of Mackinac, have the same surface altitude and their water levels raise and lower at the same rate). A pond is considered to be any water body with an area smaller than two hectares (20 000 m^2), while a lake is considered to be any water body with an area larger than two hectares.

Geography

Lakes can be formed by a number of natural and artificial processes. During **glaciations** (cold periods when huge sheets of ice called **glaciers** covered nearly Canada's entire land surface) the moving glaciers can create valleys and depressions in the ground surface that fill with water when the ice melts. This is how the Great Lakes, including Lake Michigan-Huron, were formed, as well as numerous smaller lakes called **tarns** or **potholes**. Land exposed to glaciers also contain numerous small depressions that hold ponds and wetlands. In places where the land is low, meandering rivers regularly create **oxbow lakes** as patterns of **deposition** (build-up of sediments such as gravel, sand and silt) and **erosion** (breakdown and movement of rocks and soil) cut-off sections of the river from the main channel (see Figure 2).

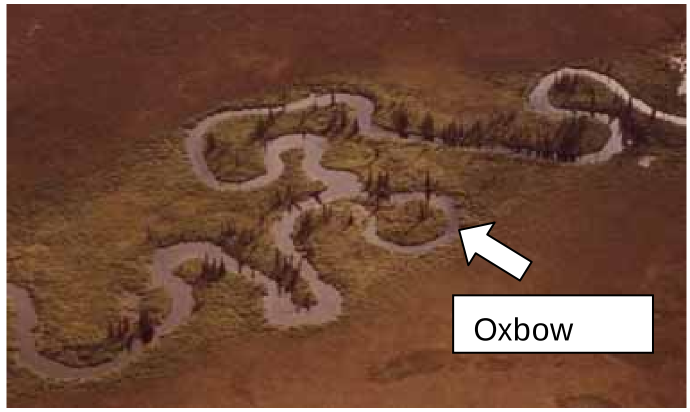

Figure 2: Oxbow lake.

Many smaller ponds and lakes are created by humans. A **reservoir** (from the French word *réservoir* which means 'storehouse') is an artificial lake created to store water. One way to create a reservoir is to **dam** (stop the flow of water using a barrier) a river. Another way is to dig a big hole in the ground and fill it with water (**service reservoir**). Artificial ponds are often created on farmland as sources of water for animals. Smaller ponds can be temporary in nature, drying out when the weather is dry and filling again when it rains.

Chemistry

The chemicals in pond or lake water are determined by two factors - the land over which water passes to enter the pond or lake and the nature of the base of the pond or lake. Lakes that are located in **alpine** (mountain) valleys, for instance, tend to contain very few chemicals created by people, since the land over which the water passes to get to the lakes is has few people living in it. These lakes also tend to be low in organic matter as there are relatively few plants and animals (the source of the organic matter). Lakes close to roads or more populated areas tend to be polluted with chemicals such as paint, oil and road salt. Lakes close to agricultural land tend to be polluted with **fertilizer** (chemicals which help plants to grow) and **pesticides** (chemicals which kill 'pests' such as weeds and insects). Cities can be a major contributor of pollutants due to the release of household and commercial/industrial wastewater from sewage treatment plants. Fertilizers and sewage can upset the ecosystems of ponds and lakes. Fertilizers provide too many nutrients (especially **nitrogen** and **phosphorous**) to the **algae** (tiny aquatic plants) living in ponds and lakes, causing them to rapidly grown and multiply. These algae then dominate the ecosystem, leaving little room for other species. This process is called **eutrophication**.

Ecology

Lakes and ponds differ in their ecological **communities** (groups of plants and animals) depending on their size, location and chemical characteristics. Small ponds are dominated by **phytoplankton** (microscopic, free-floating plants) and **zooplankton** (microscopic, free-floating animals). The zooplankton feed on the phytoplankton and on each other in a tiny microscopic **food web**. Often these small ponds also contain small **invertebrates** such as **insects** (e.g., beetles, flies, etc.), worms, leeches or **crustaceans** (e.g., shrimp, crayfish, etc.) (see Figure 3).

The invertebrates and crustaceans also feed on the phytoplankton and zooplankton, as well as more complex plants that may be present. In larger bodies of water, there might be enough plants and animals to provide food for larger animals such as fish and **amphibians** (e.g., frogs, toads, newts, salamanders, etc.). Only the largest lakes contain the largest species as there needs to be a sufficient food to feed them!

Figure 3: A collection of invertebrates from a pond in Ottawa as seen through a microscope.

While large lakes are necessary for some larger species, ponds actually contain a greater variety of species than lakes when considered as a whole. This is because there are many ponds scattered across the landscape and these create a diverse array of habitats which suit different species. Some ponds are **acidic** (low pH) while others are **alkaline** (high pH), some are deep while others are shallow and some may be rich in nutrients while others contain few nutrients. Lakes, on the other hand, tend to be comparatively similar in their biological makeup. Smaller ponds and lakes also act as ‘stepping stone’ habitats so that species requiring fresh water can move through the landscape. This is especially important as species move in response to climate change.

Finally, since ponds are small and not connected, if there is a problem in one pond, such as pollution, the damage will be limited to the single pond (or possibly surrounding ponds). On the other hand, in a lake where all of the water is connected, such a disturbance would spread out to affect a much larger proportion of the ecosystem.

Figure 4: Temporary pond.

Temporary ponds are home to groups of animals with specific characteristics that allow them to survive the occasional (and sometimes unpredictable) times of low **precipitation** (rain, snow, etc.). Some animals, such as the water flea **Daphnia**, are able to form drought-resistant life stages while others, such as dragonflies, are able to move between water bodies easily and establish themselves in ponds when they become filled with water. Fish tend not to be present in temporary ponds because they cannot survive if the ponds dry out and they cannot transport themselves to new ponds. This means that the food chains in temporary ponds are dominated by insects, such as predatory beetles and dragonflies.

Lentic Ecosystems and Humans

Figure 5: Animals at a pond.

Lakes and ponds provide many benefits to humans. Ponds are very important as they provide drinking water for humans and their livestock. They can also be used to reduce **flooding**, particularly in areas where human development has led to large areas of **impermeable** (water cannot pass through) surfaces such as roads and buildings.

During times of heavy rain, ponds and lakes can hold water temporarily and slow down its movement into rivers which reduces the peak of the flow. While the water sits in these ponds, it also has a chance to deposit some of the material that it carried as it flowed over land. This material can include pollutants and silt that collect in the ponds. In addition to providing these practical benefits, ponds can also introduce wildlife into urban areas that have few parks or other green spaces. It is felt by many that being close to nature improves the well-being of people.

Another important function that ponds can perform is the collection of **carbon** (an atomic element) from the atmosphere. This is called **carbon sequestration** and is carried out by the plants that live in the ponds. When ponds experience eutrophication (described above), pond plants and algae become extremely productive (grow very quickly) and, as they do so, they absorb **carbon dioxide** from the air, which they use as an energy source. When these plants die, they sink to the bottom of the pond and trap the carbon that they absorbed with them. There is great concern that factors, such as the current levels of carbon dioxide in the atmosphere and the **greenhouse effect** (see the Earth Sciences chapter) are linked to climate change. Ponds may provide one potential solution to this problem.

Conservation

It is important to understand that larger lakes are not necessarily the most important lentic ecosystems in the environment. Smaller lakes and ponds play an important role in providing diverse habitats for a wide array of species. Also, the conservation of lakes and ponds should not focus solely on the water that is contained within them. The banks of the body of water, called the **Riparian Zone** (see Figure 6), and the terrestrial areas surrounding lakes are used by animals such as winged insects (e.g., mayflies, dragonflies, etc.) and amphibians and so must be conserved to preserve the animals living by the water.

Figure 6: Riparian zone (river bank) of the Little Rouge River, Ontario.

LOTIC ECOSYSTEMS

A **lotic ecosystem** is an ecosystem associated with flowing water, such as a river, stream or spring. The word 'lotic' comes from the Latin word *lotus*, which is a form of the verb *lavere* which means 'to wash.' Lotic ecosystems vary widely in size, from tiny springs and creeks to large rivers that may be a few kilometres wide. No matter what their size, lotic bodies of water share some common features: they flow in one direction and there is always new water which flows from the **headwaters** (the source of the river or stream) to the **downstream terminus** (where the river or stream ends).

Geography

Rivers are natural **watercourses**, which flow over the surface of land in **channels** and drain given areas of land. The presence, size and flow of a river are influenced by the availability of water, the size of the channel and the slope of the land. In this sense the term 'river' includes all kinds of watercourses, from the tiniest **creeks** to the largest rivers such as Canada's Mackenzie River, which is the 10th longest river in the world!

Figure 7A: Sprout Creek.

Figure 7B: Floatplane on the Mackenzie River.

The volume of water flowing in a river together with how fast it flows and when it flows determines how a river shapes the surrounding landscape. When a river's slope is steep, swiftly flowing water can **erode** (wear away) the underlying **terrain** (rock, soil and organic matter). In some cases, a river can also carve steep **valleys** (deep grooves in the surrounding rock), especially near its headwaters. When a river's slope is less steep, slow moving water can **deposit** (unload) materials (e.g., silt, dead plants, etc.). Deposition of material usually occurs in the lower parts of a river, especially near the **mouth** of the river (downstream terminus) where it joins up with either a lake or an ocean. These deposits may create landforms called **deltas**.

Rain, melted snow and groundwater all contribute to the volume of flow, producing variations from season to season and year to year. In Canada, river levels are highest and **flooding** (rivers or streams overflowing their banks) occurs most often in the spring after the snow melts. Heavy rains can also cause high water levels and flooding in smaller rivers and streams. In Canada, river levels and flows tend to be low in late summer, when **precipitation** (see the Earth Sciences chapter) is low and **evaporation** combined with use of water by plants is high. River levels also tend to be low in winter, when rivers are ice-covered and precipitation is in the form of snow that accumulates on the land until it melts in the spring.

Drainage Patterns

The area of land that supplies water (surface water from rain and melted snow/ice and ground water) to a particular river is called a **watershed** (also called a **drainage basin**) (see Figure 8). A river's watershed is separated from the watersheds of neighbouring rivers by higher lands called **drainage** or **watershed divides**.

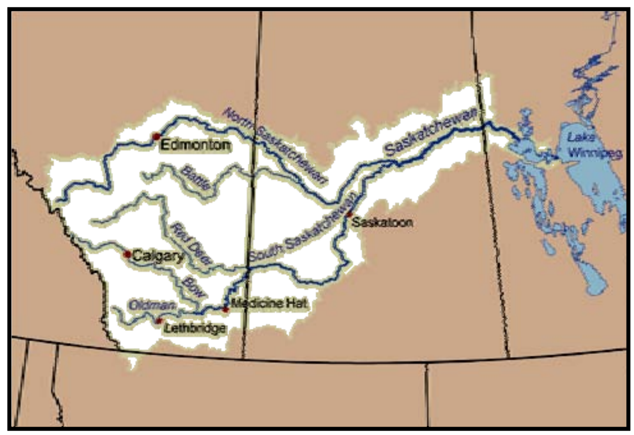

Figure 8: The drainage basin of the Saskatchewan River.

Small drainage basins generally supply water to streams. The drainage basins of several streams often combine to form the drainage basin of a river. The drainage basins of several rivers combine to make up **regional watersheds**, which in turn join other regional watersheds to form **continental watersheds** (also known as **Ocean watersheds**).

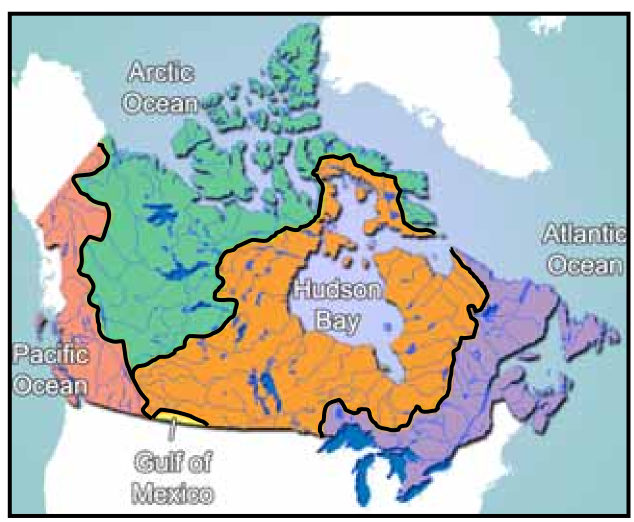

Figure 9: Canada's continental watersheds.

Rivers in Canada are a part of five continental watersheds. The rivers in a given continental watershed flow into the ocean (or equivalent body of saltwater). Rivers in Canada flow into the Pacific Ocean, the Arctic Ocean, the Atlantic Ocean, Hudson Bay or Gulf of Mexico (see Figure 9).

Measuring River Flow

Often in the spring you hear an announcement like "Bear Creek is expected to crest later today at 6.3 meters." The 6.3 metres the announcer is referring to is called the **stream stage**. Stream stage is important in that it can be used to calculate stream flow or **discharge** (the volume of water flowing in the stream at any instant). Stream stage is the height of the water surface above an established mark which is considered to be zero. While the zero level is arbitrary, it is often close to the stream bottom. The stream stage can be read off a tool called a **stream gauge** (see Figure 10) or recorded electronically by sensors placed in the stream that send information about the stream stage to a data centre.


Figure 10: Stream gauge.

Water level and discharge information is important for the management of water resources; for example, the information can be used to:

- minimize the impacts of extreme flows (i.e., flood protection, mapping of **floodplains** – areas near rivers which are prone to flooding and canals to divert excess water);
- design and construct structures near rivers such as bridges, roadways and **culverts** (tunnels that allow water to pass under roads);
- plan and conduct environmental programs related to water quality, fisheries, and wildlife habitat; and
- ensure that Canada's water resources are developed in a manner that conserves and protects the environment.

Chemistry

Water quality is defined as the **chemical content** (e.g., concentration of substances such as dissolved oxygen, heavy metals, etc.), **physical characteristics** (e.g., temperature, etc.) and **biological nature** (e.g., abundance and types of algae, etc.) of water. Water quality is affected in many ways, often caused by nature's own patterns but also by human activity. The water quality of rivers changes both geographically and seasonally.

Figure 11: Water chemistry sampling.

Even in the healthiest rivers the water contains some dissolved minerals. All water contains minerals such as **sodium**, **chloride**, **calcium**, **magnesium** and **potassium**. Many of these minerals come into rivers from rain and snow. Dust, volcanic gases and natural gases such as carbon dioxide, oxygen and nitrogen can combine with water in rain. When other toxic substances such as **sulphur dioxide** and **lead** are in the air, they also become part of rain.

When rain reaches the Earth's surface, it flows over and through the soil and rocks, dissolving and picking up other substances; for example, if soil contains large amounts of **soluble substances** (substances which can dissolve) such as **limestone**, the **surface runoff** (water from rain that flows over the land) will have high concentrations of **calcium carbonate** (which is what limestone is made of). If the water flows over rocks high in metals, such as ore bodies, it will dissolve those metals. In the Canadian Shield, there are large areas with little soil and few soluble minerals. As a result, the rivers and lakes in these areas have very low concentrations of minerals and other substances.

Another factor influencing water quality is the runoff from urban areas. Runoff in cities and towns picks up debris littering the streets and carries it to nearby streams or water bodies. Urban runoff tends to make water quality in rivers and lakes worse by increasing the concentrations of such substances as **nutrients** (e.g., phosphorus, nitrogen, etc. – see eutrophication above), sediments (e.g., sand, silt, etc.), animal wastes (i.e., **fecal coliform** – a type of bacteria, and other pathogens – see microorganisms in the Biology chapter), petroleum products and road salts.

Industrial, farming, mining and forestry activities also significantly affect the quality of Canadian rivers, lakes and groundwater. Farming can increase the concentration of nutrients, **pesticides** and suspended sediments. Industrial activities can increase concentrations of metals and toxic chemicals, add suspended sediments, increase temperature and lower dissolved oxygen in the water (keep in mind that fish get their oxygen from water). Each of these effects can have a negative impact on the aquatic ecosystem and/or make water unsuitable for existing or future uses.

Ecology

Figure 12: Sampling benthic invertebrates.

In addition to the chemical and physical characteristics of water, many types of organisms are recognized as environmental indicators of water quality. Such organisms included invertebrates, **aquatic macrophytes** (large aquatic plants that grow in or near water such as cattails, bulrushes and pondweeds), algae, zooplankton and fish. One group of organisms often used to assess water quality are **benthic invertebrates** (bottom-dwelling aquatic animals without backbones). This group includes the larval stages of many insects such as mayflies, dragonflies and mosquitoes, as well as other animals such as worms and mites. These organisms are ideal indictors of water quality because they are sensitive to a variety of substances.

Lotic Ecosystems and Humans

Lotic ecosystems have played a significant role in the history and culture of Canada and they continue to play an important role in transportation, electricity generation and recreation. In the past, Canadian rivers provided routes for exploration and commerce such as the fur trade and fishing. Today rivers continue to play an important role in transporting goods from inland centres to international markets. They also continue to be an important source of hydroelectricity; providing more than half of Canada's electricity supply. Finally, Canada's rivers and streams attract many visitors from around the world who enjoy their scenic beauty.

Conservation

Many people in Canada take clean water for granted, but if we want a good supply of clean water, we all need to do our part. Here are some things you and your family can do to help improve water quality, and the environment as a whole;

- Don't rinse bits of food down the drain;
- Don't flush garbage down the toilet;
- Use 'environmentally friendly' products such as bathroom cleaner and detergent;
- Do not use pesticides or chemical fertilizers in your garden;
- Do not pour paints or other chemicals down the drain in your home or into your storm drain – storm drains empty directly into nearby streams and rivers; and
- Don't throw garbage overboard when boating!

WETLANDS

Wetlands are habitats which are **submerged** (under water) or **permeated** (soaked with water) either all the time or some of the time. Freshwater wetlands include marshes, swamps, bogs and fens.

Geography

Wetlands cover about 14% of the land area of Canada. There were once many wetlands located all over Canada, but more recently, wetlands have become an increasingly scarce resource in populated areas of the country. In southern Ontario, for example, 68% of the original wetlands have been converted from their natural state to support alternative uses such as agriculture and housing. Similarly, only about 25% of the original wetlands of the 'pothole' region of southwestern Manitoba remain. The good news is that in the northern part of Canada, most of the wetlands are intact.

Ecology

The presence of water is not always a good indicator of a wetland. The amount of water in a wetland can change depending on temperature and the amount of precipitation; therefore, we must look at other factors to determine if an area is a wetland or not. One way is to examine the soil and vegetation. Wetlands have **hydric** soils, which have a unique color and texture. When the soil is saturated with water, bacteria and other organisms that live in the soil consume the oxygen quickly, leaving very little for plants to use. Plants that are found in wetlands, therefore, have special adaptations that allow them to grow in these low-oxygen conditions. These plants (such as cattails and bulrushes) are emergent types of **aquatic macrophytes**, and their presence in an ecosystem indicates the presence of a wetland area.

Wetlands are important to many familiar animals, as well as to less commonly known creatures. Every drop of water contains microscopic zooplankton, which are a vital component of the food chain. The water's surface and the wetland bottom are covered with insect eggs, larvae, and nymphs. Fish, amphibians, and reptiles are also dependent on the habitat provided by wetlands. Numerous bird and mammal species make extensive use of the water and its adjacent shores.

Let's look more closely at the different types of wetlands and some of the plants and animals found there.

Marshes

Figure 13: Cattails (*Typha latifolia*).

Marshes are permanently or periodically covered by standing or slowly moving water. Marshes are rich in **nutrients** and are characterized by **emergent vegetation** (plants that grow up through the water) of **reeds**, **rushes**, **cattails** (see Figure 13) and **sedges**. Water remains within the rooting zone of these plants for most of the growing season. Marshes are the most **productive** (produce the most organic matter) type of wetlands. Some of the species protected in marshes include the Bald Eagle, Sandhill Crane, Fox Snake and Fowler's Toad.

Swamps

Figure 14: Red-shouldered Hawk (*Buteo lineatus*).

Unlike marshes, **swamps** contain many trees and shrubs. Swamps may be flooded seasonally or for long periods of time. Like mashes, swamps are also nutrient-rich and productive. Plants include **coniferous** (cone-bearing) trees and **deciduous** (leaves drop in the fall) trees. Swamps are most common in the southern part of Canada. Some of the species protected in swamps include the Prairie-Fringed Orchid, Loggerhead Shrike, Red-shouldered Hawk (see Figure 14) and Blanding's Turtle.

Bogs

Figure 15: Mer Bleue Bog conservation area (a protected sphagnum bog near Ottawa, ON).

Bogs are peat-covered wetlands. **Peat** is a build-up of partially decayed vegetation. In some parts of the world, peat is harvested as a source of fuel! Due to poor drainage and decaying plant material, the water in bogs is very acidic. The main types of vegetation in bogs are **sphagnum mosses**, which are better known as **peat moss**, and **heath shrubs** (small shrubs which grow in acidic soil). Some of the species protected in bogs include the Swan's Sedge, Toadflax, Opossum, Back Rat Snake and Massasauga Rattlesnake.

Fens

Fens are wetlands which are fed by mineral-rich surface water or groundwater. The water in a fen may be acidic or alkaline. Fens are not as low in nutrients as bogs, and as a result, are more productive than bogs. Although fens tend by be dominated by sedges, they also contain shrubs and trees. Like bogs, fens are more common in the northern part of Canada. Some of the species protected in fens include the Twin-scaped Bladderwort, Cooper's hawk and Spotted Turtle.

Wetlands and Humans

Unfortunately, the importance of wetlands has not always been realized. In the past, people often considered these areas useless land, and many wetlands were filled in with soil so that farms and homes could be built on the land. People should remember that wetlands are useful for many reasons:

- during floods, they can act like giant sponges and absorb extra water;
- they store water (most of the water we use in our homes and businesses comes from water stored beneath wetlands);
- they filter suspended particles, fertilizers and toxic pollutants from the water, thereby improving water quality;
- they supply food and habitat for many species of insects, fish, birds, reptiles, amphibians, and mammals ;
- they are important spawning areas for many species of fish;
- they provide resources to humans such as food (e.g., wild rice, cranberries, fish, etc.), fuel (i.e., peat, wood, charcoal) and building materials (e.g., wood, etc.); and
- they provide recreational areas for hunting, fishing, paddling and bird watching.

Stresses on Wetlands

There are many direct and indirect stresses that humans cause on wetlands. Direct stresses tend to be highly visible and can result in rapid changes to a wetland. Indirect stresses are often less visible and impact a wetland over a longer period of time.
Direct stresses include:

- **dredging** (digging out) wetlands to create harbours for ships;
- filling in or draining of wetlands to create farms and urban areas; and
- **invasive species** (plants and animals were are not native to a given habitat), which can outcompete native species in a wetland. A common wetland invasive species is **Purple Loosestrife** (a flowering plant).

Indirect stresses include:

- building of hydroelectric dams on rivers, runoff from fields and sewage treatment plants.

Conservation

Recently the value of wetlands has been recognized and efforts have been made to restore and preserve these ecosystems. Conservation of wetlands includes **rehabilitating** (restoring to good health), creating and **securing** (purchasing and managing) wetlands in order to protect and conserve these important habitats. Rehabilitation can include re-establishing natural water levels, controlling invasive species and removing contaminated sediments. Many regional, national and international partnerships exist to conserve wetlands such as The Great Lakes Wetlands Conservation Action Plan, the North American Waterfowl Management Plan, and Ducks Unlimited.

Spotlight on Innovation in Environmental Sciences

Bioreactor Solar Panels

Figure 16: Bioreactor solar panels.

Do you know how you can use the sun to clean contaminated water? **Bioreactors** use organic mulch-filled pits with groundwater recirculation systems powered by solar energy. This combination of **bioremediation** (organisms break down the pollutants) and solar-powered pumping reduces the time it takes to clean contaminated water by more than 95 percent. The carbon footprint of a solar-powered bioreactor is less than 10 percent than that of a traditional pump and treatment system that would achieve the same result. Additionally, solar-powered bioreactors work in remote areas because they use an alternative energy supply.

Bioreactors treat water starting with the removal of contaminated water from the ground using a solar-powered pump. The water makes its way through coils of black hose that are heated by the Sun. Then, the water enters the bioreactor where chlorine-containing chemicals harmful to the water are **biodegraded** (broken down by the organisms). The increase in temperature of the water entering the bioreactor increases the rate and success of the biodegradation, which is particularly important in colder climates like Canada.

WATER FILTER DESIGN CHALLENGE

Challenge:

Your challenge is to work as a team to design and build the least 'expensive' water filter using the materials provided. You will use your filter system to filter dirty water until it is clean.

Tools (no charge):

- 1 pair of scissors
- 1 – 500 mL plastic water bottle (for collecting the filtered water)

Dirty Water Solution (no charge):

- 1 – 500 mL plastic water bottle
- 1 – 15 mL measuring spoon
- Approximately 400 mL water
- 15 mL sand
- 15 mL dirt

Materials:

- 1 – 500 mL plastic water bottle **($100)**
- 1 coffee filter **($100)**
- 1 paper towel **($100)**
- 10 cotton balls **($25 each)**
- 50 mL clean gravel **($50)**
- 15 cm x 15 cm nylon stocking **($50)**
- 1 old sock **($50)**

Rules:

- Make the dirty water solution by adding the water, sand and dirt into the 500 mL plastic water bottle. Shake well.
- Design and build the filter. To test, pour the dirty water though the filter and catch the clean water in the empty 500 mL water bottle.
- If you are not successful the first time, try again. Think about the types of materials you used, the order of the materials and the quantity of materials.

Success

- You have created a device which filters water, and that the filtered water contains no visible particles.

Cost of your filter: $ _________

Pushing the Envelope

- What is the best order for the materials in the filter? Does the order matter?
- Can you use other materials to make even cleaner water?
- Can you make a 'cheaper' filter that works as well as a more 'expensive' one?

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Figure 10: Stream gauge.
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Figure 13: Cattails (*Typha latifolia*).
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Figure 16: Bioreactor solar panels.
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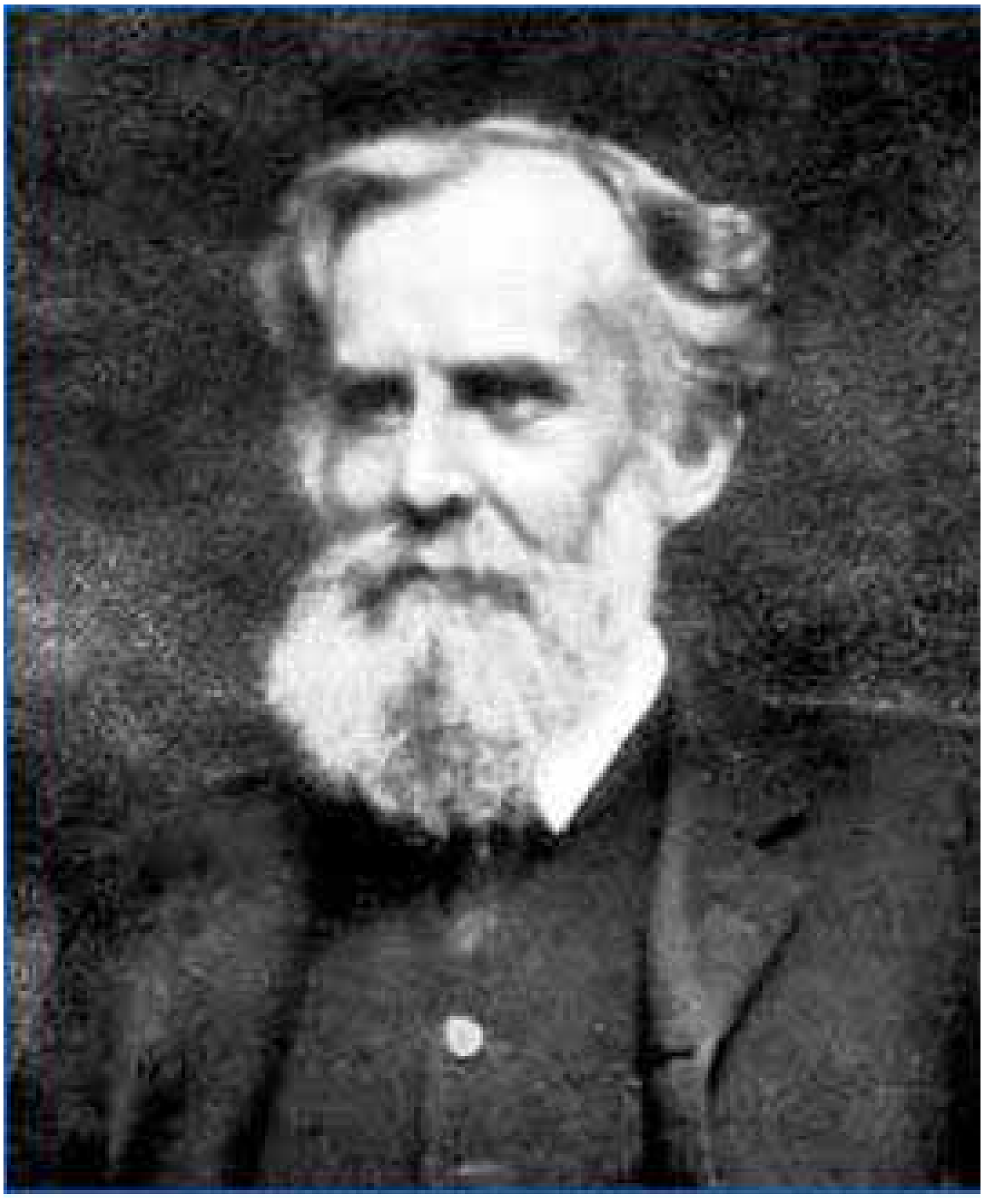
Chapter 6

mathematics



NUMBER THEORY

Number Theory studies properties of the natural numbers 1, 2, 3,...

Prime Factorization

There are certain numbers that are the building blocks of all others, and these special numbers are called **prime numbers**. A prime number (sometime called a **prime**) is any number which can only be divided evenly by the number **1** and itself; that is, it cannot be divided by any number other than **1** and itself without leaving a remainder. The number **5**, for example, is a prime number because the only numbers that divide evenly into it are **1** and **5**. On the other hand, the number **6** is not a prime number because **6 ÷ 2 = 3**. That is, both **2** and **3** are **factors** of **6**. A **factor** is any number than can divide into another number evenly (without leaving a remainder).

Writing the **prime factorization** of a number means writing it as a product of primes. Let's find the prime factorization of the number 12. Since 12 is not a prime number, it has at least one more factor; for example,

3 is a factor of **12** Since **12 ÷ 3 = 4** So, we can write **12 = 4 x 3**

Is this a prime factorization?

Well, **3** is a prime number, but **4** is not a prime number:

Since **4 = 2 x 2** So, we can write **12 = 2 x 2 x 3**

All three numbers on the right side of this equation are now prime number; therefore, we have succeeded in finding the prime factorization of 12!

You can find the prime factorization of any number using this method. Can you find the prime factorization of 8, and of 30? Try them yourself before looking at the answers (the answers are found at the end of this chapter).

Q1: What is the prime factorization of 8? 8 =

Q2: What is the prime factorization of 30? 30 =

There is only one possible answer to a prime factorization question. It's a mathematical fact that there exists only one prime factorization for any number; that is, there is only one way to break up a number as a product of primes.

One tool that can be quite useful when trying to find the prime factorization of numbers is a **division diagram**. If you draw a division diagram like in the example shown below, the numbers making up the prime factorization will appear in a diagonal on the left side.

EXAMPLE 1:

```
    3
3 )9      so 9 = 3 x 3
```

EXAMPLE 2:

```
         5      Note: you should start
      3)15      with the smallest possible
    2) 30       number that divides into the
   2)  60       number without a remainder.
  2)  120
 2)   240    so 240 = 2 x 2 x 2 x 2 x 3 x 5
```

Least Common Multiple

You can apply what you learned about prime factorizations to another mathematical idea called **Least Common Multiple** (**LCM**). Did you ever have to find a **common denominator** when adding **fractions**? Say you wanted to add:

$$\frac{1}{6} + \frac{1}{28}$$

you would have to find the common denominator **84** before concluding that

$$\frac{1}{6} + \frac{1}{28} = \frac{14}{84} + \frac{3}{84} = \frac{17}{84}$$

But where does this mysterious common denominator come from? Is there an easy way to find it? In fact there is, using the LCM.

To find the least common multiple of two numbers, you must first write down the prime factorization of each of the numbers; for example, if you wanted to find the LCM of 6 and 28, you would write the prime factorizations:

6 = 2 x 3 28 = 2 x 2 x 7

Then, you look at how many times each prime number appears as a factor of the first number and as a factor of the second number. First, write down the prime as many times as it appears in the factorization where it occurs the most times. In the example above, the prime number **2** appears one time in the factorization of **6** and two times in the factorization of **28**. The most times it appears in these factorizations is two times, so you would write:

2 x **2**

Next, the prime number **3** appears one time in the factorization of 6 and zero times in the factorization of 28. The most times it appears in a factorization is one time, so next you would the number **3** one time, hence:

2 x 2 x **3**

Finally, the prime number **7** appears zero times in the factorization of 6 and one time in the factorization of 28. The most times it appears in a factorization is one time, so finally you would write the number **7** one time, hence:

2 x 2 x 3 x **7**

Once you are finished copying all of the prime numbers, you can find the LCM by simply multiplying them all together:

2 x 2 x 3 x 7 = **84**

That is, the LCM of **6** and **28** equals 2 x 2 x 3 x 7 = **84**.

Can you find the prime factorization of 18 and 75 and then use the result to find the LCM of 18 and 75?

Q3: Prime factorization of 18 18 =

Q4: Prime factorization of 75 75 =

Q5: LCM of 18 and 75 LCM =

Gauss Summation

There once was a ten year old boy named Carl Gauss. One day while he was sitting in class, his math teacher was really bored. She was so tired of teaching her students things that they weren't interested in. All she really wanted to do was read her romantic novel. So, she figured she would give the students a difficult problem to work on. That way she could get some peace and quiet.

She asked all of the students in the class to add up the numbers from **1** to **100**, that is, she wanted them to calculate:

1 + 2 + 3 + 4 + 5... all the way up to 100!

Just as the teacher began to settle down with her reading, little Gauss walked up to her desk. He handed her a paper with the correct answer of **5050** on it. She could hardly believe that Gauss had completed the calculation so quickly. How do you think he did it?

Well, if you simply tried to add the numbers one by one, it would take a long time, right? So, there must be a faster way.

There is! The trick is to notice that it doesn't matter what order we add the numbers because we get the same result either way.
For example:

2 + 3 has the same answer as **3 + 2**.

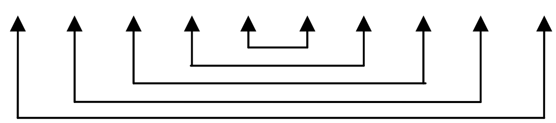
The first thing to do when adding the numbers from **1** to **100** is to group them in a clever way. Here is a simple example which will show you how this grouping strategy works.

Say you wanted to add the numbers from **1** to **10**.

1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10 = ?

You could group the numbers in this addition in pairs. This means adding the first number with the last number, the second number with the second to last number, and so on:

1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10 = ?



(1 + 10) + (2 + 9) + (3 + 8) + (4 + 7) + (5 + 6) = ?

Now, there is something funny going on! Each of these pairs adds up to 11...

(1 + 10) + (2 + 9) + (3 + 8) + (4 + 7) + (5 + 6) = ?
(11) + (11) + (11) + (11) + (11) = ?

Since we have 5 pairs, our answer is

11 + 11 + 11 + 11 + 11 = 11 x 5 = 55

Well, this is getting somewhere!

Can we do the same thing to sum all the numbers from **1** to **100**? Try it yourself. Pair up the numbers (the first number with the last number, the second number with the second to last number, and so on). Figure out how many pairs there are. Calculate what each pair sums up to. The answer should be easy from there! Try it out before you look at the answer.

Q6: 1 + 2 + 3 + 4......99 + 100 = ?

Clock Math

We all learned to tell time when we were very small. It is something that we are familiar with, and we find it quite easy; however, hidden behind this simple notion is a more sophisticated type of math called **modular arithmetic**. The idea goes like this: say you are going on a ski trip, and you want to know what time it will be when you arrive at the slopes if you begin driving at **3:00** p.m. and it is a **2** hour drive. So...

3 + 2 = 5

It will be **5:00** p.m. when you arrive.

What if you were going on a longer road trip, perhaps to visit you grandparents in another province? Let's say that you plan to leave your home at **5:00** a.m. and it is a **9** hour drive. What time do you expect to arrive? You would expect to arrive at **2:00 p.m.**, right?

Right! But wait ... are you telling me that:

9 + 5 = 2?

How can that be when everyone knows that:

$9 + 5 = 14$?

The point is that on a clock, we use a special way of counting. Once we get to **12** o'clock, the next hour is **1** o'clock, not **13** o'clock, and the next after that is **2** o'clock, not **14** o'clock. But this is a just a choice of words. In reality, we could equally well say it was **14** o'clock or **2** o'clock. Either way we would mean **2** hours after **12** o'clock. In that sense, on a clock, **14** means the same thing as **2**.

Does that mean that **14 = 2**? Maybe in a special way it does...

Congruent Modulo

We can think of it as 'clock equals.' Mathematicians have a special way of saying this. They say that two numbers are **congruent modulo 12** if the difference between the two numbers is **12**, **24**, **36** or any other multiple of **12**; for example, **2** and **14** are congruent modulo **12** because their difference, twelve, is divisible by **12**. This means that on a clock, **2** and **14** mean the same thing. We express this mathematically as:

$$2 \equiv 14 (\text{mod} 12)$$

The mathematical symbol for congruency is ≡. Here, 2 and 14 are the numbers, and the number in brackets (12) is the **modulus**. Another example of two numbers being congruent modulo **12** is:

$$3 \equiv 39 (\text{mod} 12)$$

because the difference between **39** and **3** is **36**, and **36** is divisible by 12. Not all numbers, however, are congruent modulo 12; for example:

$$4 \not\equiv 17 (\text{mod} 12)$$

because the difference between **4** and **17** is **13**, and **13** is not divisible by **12**.

Now imagine that we live in a world where the clocks have **7** hours instead of **12**. This may seem weird but it will give you a chance to try counting using modulo **7**. In this way of counting, we say that two numbers are congruent modulo **7** if their <u>difference</u> is divisible by **7**; for example:

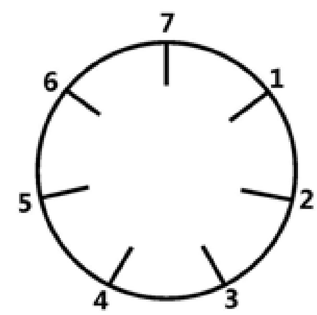
$$2 \equiv 9 (\text{mod} 7)$$

because the difference between them (**9 – 2 = 7**) is divisible by **7**. On the other hand,

$2 \not\equiv 14(\text{mod}7)$

because the difference between them (**14 – 2 = 12**) is <u>not</u> divisible by **7**.

Are the following pairs of numbers congruent modulo **7**? Hint: use the 7-hour clock if you need help.



Q7: Does **3** ≡ **9**(mod7)? Why or why not?

Q8: Does **1** ≡ **7**(mod7)? Why or why not?

Q9: Does **2** ≡ **16**(mod7)? Why or why not?

Modulo Arithmetic

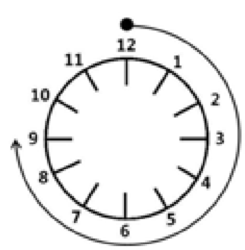
Let's go back to our regular 12 hour clock. In the modulo **12** system, the answer to any calculation we do has to be less than **12**; for example, the first problem in this section was **9+5**. In regular arithmetic, we would say **9+5=14**; but in modulo **12** arithmetic, **14** is too big a number to be the answer (it doesn't appear on a clock). We must, therefore, find its equivalent.

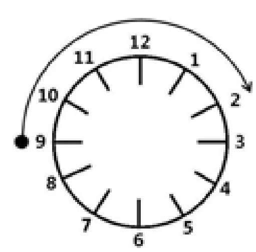
Since we know that the number **14** is congruent with the number **2**:

$9 + 5 \equiv 2(\text{mod}12)$

we give **2(mod12)** as the correct answer for the question **9+5**.

Here is another way that you can think about it using a 12 hour clock again. Starting at 12:00, take the first number and go around the clock 9 positions (for the **9**). Next, go around 5 more positions (for the **5**). Where did you end up? The **2** position. The **2** is the number in front of the modulus (mod12).





Here is one more way to figure out an addition problem using division. Let's use **9+5** again. In normal addition, we say **9+5=14**. Divide the modulus (the number in the brackets) into the total.

$$\begin{array}{r} 1 \\ 12\overline{)14} \\ \underline{12} \\ 2R \end{array}$$

The remainder (**2**) is what goes in front of the modulus 2 (mod12). What about the number on top? The answer (number of times it divides) is irrelevant for modular arithmetic.

If the two numbers add up to exactly a multiple of the modulus, then you can write either a zero or the number before the modulus:

$3 + 4 \equiv 0(\text{mod}7)$
OR
$3 + 4 \equiv 7(\text{mod}7)$

Mathematicians prefer to use zero, but 7 is also correct in the case above.

Try the following using modulo **7** arithmetic. Keep in mind that your answer should be between **0** and **6.**

Q10: 3 + 18 = ___ (mod7)

Q11: 2 + 4 = ___ (mod7)

Q12: 19 + 10 = ___ (mod7)

There is, in fact, nothing special about modulo **12** or modulo **7**. We can choose any number to use as a modulus; for example, we could do math in modulo **5999** or **327** or **16** if we wanted to!

Set Theory

Sets

A **set** is a collection of things, which could be numbers. **Set Theory** is the study of sets and the properties that they have. The things that make up a set are called the **elements** of the set.

Here is an example of a set, called set **A**:

A = {3, 8, 20}

The number of elements of **A** is a property of the set **A**. **A** has three elements: the numbers **3**, **8** and **20**. We can also show that something is an element of **A** using the symbol $\in$. So, for set **A**:

3$\in$**A**, **8**$\in$**A** and **20**$\in$**A**

One important thing about sets is that the order of the elements does not matter. For example:

A = {3, 8, 20} is the same set as **A** = {8, 3, 20}

Here are examples of other sets, from Mrs. Brown's class
B = {all of the people with brown hair} = {Roberta, Jessica, Abdul, Yuto}
C = {all of the people with blue eyes} = {Riley, Josiah, Kobe, Roberta, Jessica}

How many elements are there in these sets?

Q13: How many elements are in set **B**? **B** = ______

Q14: How many elements are in set **C**? **C** = ______

Subsets

A **subset** is a set that is 'contained' within another set. For example:

D = {**3, 8**} is contained in the set **A** = {**3, 8**, 20}

There is also a symbol to show that a set is a subset of another set. It is $\subseteq$. So, for our example above:

D $\subseteq$ **A** and {3, 8} $\subseteq$ {3, 8, 20}

Q15: What are the possible subsets found in the set {**1, 2, 3**}?

Intersection

As you might guess, sometimes sets have some elements in common. The **intersection** of two sets is a set of all the elements that the two sets have in common. The symbol for intersection is $\cap$. Let's look at an example.

Let's take the sets of people from Mrs. Brown's class (remember sets **B** and **C**). The intersection of sets **B** and **C**, written **B** $\cap$ **C**, would be all the people who are in set **B** (all of the people with brown hair) who are also in set **C** (they also have blue eyes). So:

B $\cap$ **C** = {All of the people with brown hair **AND** blue eyes}

Q16: Which students are **B** $\cap$ **C** in Mrs. Brown's class?

Here is another example that uses numbers:
X = {0, 8, 2, 100}
Y = {1, 12, 50, 8}
Z = {8, 12, 1, 42, -1}

Q17: What is **X** $\cap$ **Y?**

Q18: What is **Y** $\cap$ **Z?**

Union

Another interesting concept in Set Theory is **union**. The union of two sets is what you get when you combine two sets together. It's like adding them but, if the sets have an element in common, for example if they both contain a 4, then the union of those sets will only have ONE 4, not two. The symbol for union is ∪. Look at the following example.

{4, 11} ∪ {2, 11} = {2, 4, 11}

Notice how the **11** is written only once.

Let's look at the sets in Mrs. Brown's class again (sets **B** and **C**).
B = {all of the people with brown hair} = {Roberta, Jessica, Abdul, Yuto}
C = {all of the people with blue eyes} = {Riley, Josiah, Kobe, Roberta, Jessica}

The union of sets **B** and **C**, written **B** ∪ **C**, is the set of all the people who are in at least one of these sets; therefore, it is the people with brown hair, blue eyes or both brown hair and blue eyes. For union, each element (in this case person) is counted only once.

B ∪ **C** = {All of the people with brown hair and all of the people with blue eyes and all of the people with both brown hair and blue eyes}
B = {all of the people with brown hair} = {**Roberta**, **Jessica**, **Abdul**, **Yuto**}
C = {all of the people with blue eyes} = {**Riley**, **Josiah**, **Kobe**, Roberta, Jessica}
B ∪ **C** = {**Roberta**, **Jessica**, **Abdul**, **Yuto**, **Riley**, **Josiah**, **Kobe**}

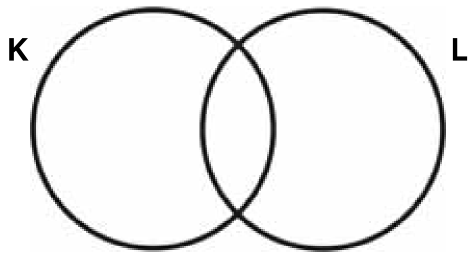
Try these with the sets **X**, **Y** and **Z**.
X = {0, 8, 2, 100}
Y = {1, 12, 50, 8}
Z = {8, 12, 1, 42, -1}

Q19: What is **X** ∪ **Y?**

Q20: What is **Y** ∪ **Z?**

Venn Diagrams

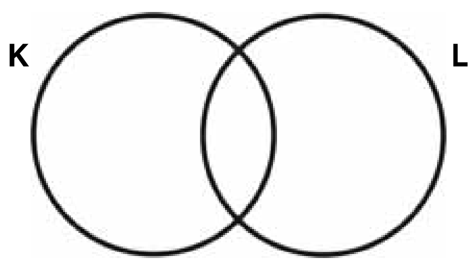
Sometimes we use pictures to draw sets. One type of picture is called a **Venn Diagram**. Venn diagrams help to show visually the relationships between sets. Typically Venn diagrams have two overlapping circles, but you can draw Venn diagrams with three or more overlapping closed curves. To learn more about the history of Venn diagrams, see the spotlight on page 101. Venn Diagrams do not always show what is in the set specifically; for example, the picture below shows the sets K and L:



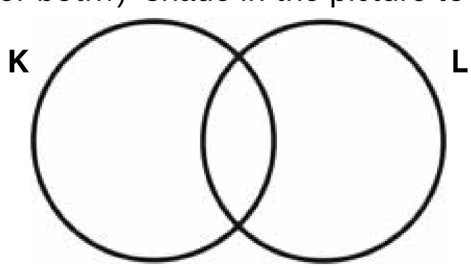
Each circle represents all the elements of the set. With only a picture, you can ask the same kinds of questions as before about subsets, intersection and union.

Is **K** $\subseteq$ **L** (is K inside of L)? NO.
Is **L** $\subseteq$ **K** (is L inside of K)? NO.

Q21: What is **K** $\cap$ **L?** (What area is inside both sets?) Shade in the picture to show your answer.

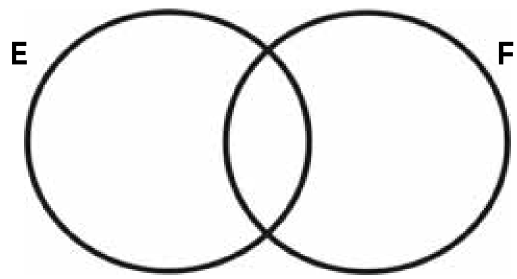


Q22: What is **K** $\cup$ **L?** (What is the total area which is in set K, set L, or both?) Shade in the picture to show your answer.



E = {1, 3, 8, 9, 14, 17}
F = {0, 14, 3, 5, 10, 20}

Q23: Use a Venn diagram to show the sets **E** and **F**.

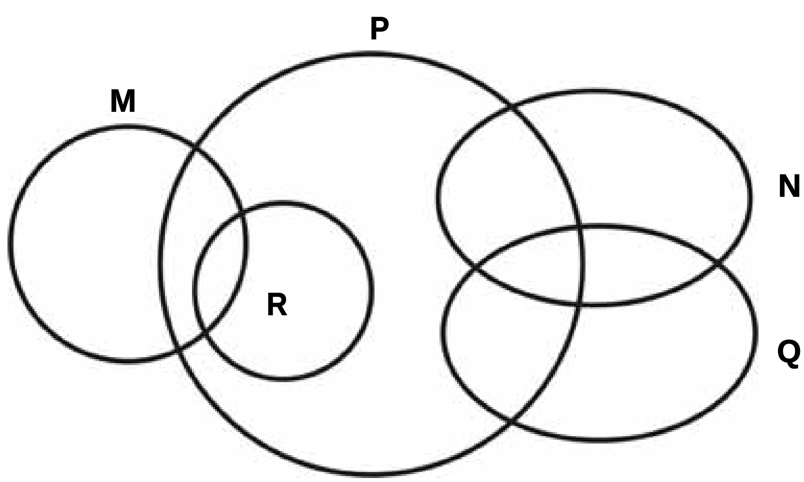


What is **E** ∩ **F?** ___________

What is **E** ∪ **F?** ____________

Euler Diagrams

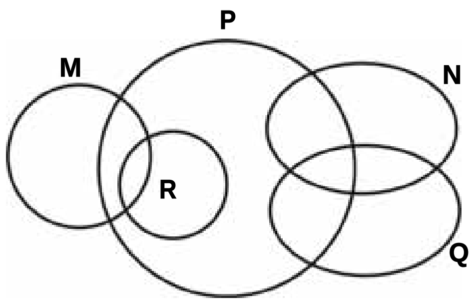
Another way to show sets and their relationships is by using a **Euler Diagram**. These diagrams are similar to Venn diagrams, but tend to be more complicated and often show subsets as well as intersection and union. In a Euler diagram, the size and shape of the circles/ovals is not important; what is important is how they overlap or do not overlap.



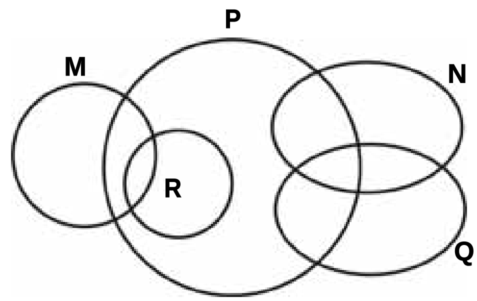
Q24: Is any set a subset (⊆) of another? _______

If yes, which one? ____________________________

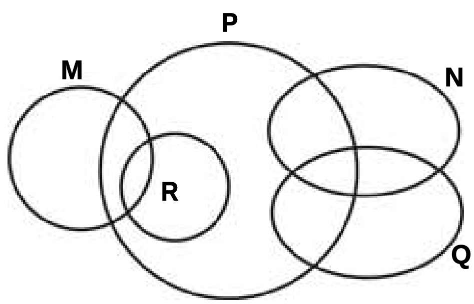
Q25: A) Shade in **N** ∪ **Q**



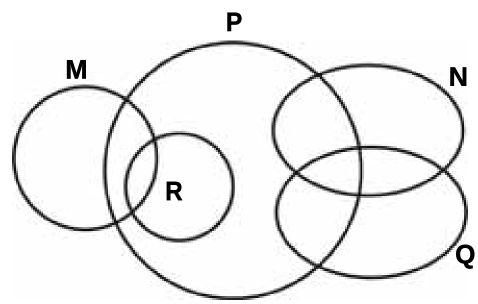
B) Shade in **M** ∩ **R**



C) Shade in **P** ∩ **N** ∩ **Q**



D) Shade in **M** ∪ **P** ∪ **R**



Is **N** ∩ **R** possible? No! **N** and **R** do not overlap. In set theory, we call this the **Null Set** or the **Empty Set** because it contains nothing. The symbol for a null set is ∅. Here is another example of a null set:

B is the number of giraffes in Mrs. Brown's class. B = { } = ∅

Spotlight on Innovation in Mathematics

Who Was Venn?

John Venn (1834-1923) was an English **logician** (studied ways of logical thinking) and philosopher who is remembered for inventing the diagram that bears his name – the Venn diagram.

Venn was brought up by his father who was a Reverend of the Church of England (his mother died when he was very young). He went to Cambridge University where he won a mathematics scholarship in his second year. Even though he excelled at math while at school, after graduating he became a Reverend like his father and grandfather.

Venn never stopped thinking about mathematics, and so after doing religious work for a few years, in 1862 he went back to Cambridge where he taught about logic and probability. In 1867 he married and had one son – John. His son John eventually became the president of Queen's College at Cambridge University where he did important research projects with his father.

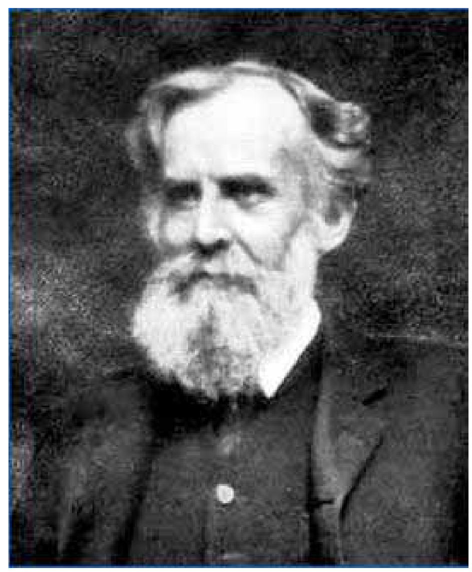


Figure 1: John Venn.

Venn's diagrams were first published in 1880 in an article called article called, "On the Diagrammatic and Mechanical Representation of Propositions and Reasonings." in "Philosophical Magazine and Journal of Science."

For Venn's 180th birthday (August 4, 2014), Google created a doodle illustrating his diagram.

ANSWERS

Q1: **2** is a factor of **8**
Since **8 ÷ 2 = 4**
So, we can write **8 = 4 x 2**
But **4** is not a prime number since **4 = 2 x 2**
So, we can write **8 = 2 x 2 x 2**

Q2: **2** is a factor of **30**
Since **30 ÷ 2 = 15**
So, we can write **30 = 2 x 15**
But **15** is not a prime number since **15 = 3 x 5**
So, we can write **30 = 2 x 3 x 5**

Q3:

```
     3
  3) 9
2) 18     so 18 = 2 x 3 x 3
```

Q4:

```
     5
  5)25
3) 75     so 75 = 3 x 5 x 5
```

Q5: **LCM 18 and 75**
18 = 2 x 3 x 3 and 75 = 3 x 5 x 5
So, from 18 you can take two 3's and a two
2 x 3 x 3
And from 75, since we already have one **3**, you don't need to take another one, but you do need to take the two fives
5 x 5
Put them together and you get 2 x 3 x 3 x 5 x 5 = **450**

Q6: 1 + 2 + 3 + 4……99 + 100 = ?
The pairs will be (**1+100**) + (**2+99**) + (**3+98**) +…..+ (**50+51**).
Each pair sums to **101** and there are **50** pairs, so the answer is **101 x 50 = 5050**.

Q7: Does **3** $\equiv$ **9**(mod7)?
3 $\not\equiv$ 9(mod7)
No, because the difference between them (**9 – 3 = 6**) is <u>not</u> divisible by **7**.

Q8: Does **1** $\equiv$ **7**(mod7)?
1 $\not\equiv$ 7(mod7)
No, because the difference between them (**7 – 1 = 6**) is <u>not</u> divisible by **7**.

Q9: Does **2** ≡ **16**(mod7)?
2 ≡ 16(mod7)
Yes, because the difference between them (**16 – 2 = 14**) is divisible by **7**.

Q10: 3 + 18 = 0(mod7)
3 + 18 = 21
21 ÷ 7 = 3**R0**. Since there is no remainder, we put a 0 in front of (mod7).

Q11: 2 + 4 = 6(mod7)
2 + 4 = 6
6 does not divide evenly by 7. In fact, it does not divide at all; therefore, it has a remainder of itself (**6**) which we put in front of (mod7).

Q12: 19 + 10 = 1(mod7)
19 + 10 = 29
29 ÷ 7 = 4**R1**. We put the remainder of **1** in front of (mod7).

Q13: How many elements are in set **B**? B = 4

Q14: How many elements are in set **C**? C = 5

Q15: What are the possible subsets found in the set {**1, 2, 3**}?
{1} ⊆ {1, 2, 3}, {2} ⊆ {1, 2, 3}, {3} ⊆ {1, 2, 3}, {1, 2} ⊆ {1, 2, 3}, {1, 3} ⊆ {1, 2, 3},
{2, 3} ⊆ {1, 2, 3}

Q16: Which students are **B ∩ C** in Mrs. Brown's class?
B = {**Roberta**, **Jessica**, Abdul, Yuto}
C = {Riley, Josiah, Kobe, **Roberta**, **Jessica**}
B ∩ C = {**Roberta, Jessica**}

Q17: What is **X ∩ Y?**
X = {0, **8**, 2, 100}
Y = {1, 12, 50, **8**}
X ∩ Y = {**8**}
Note: {8} is a set, even though it has only one element!

Q18: What is **Y ∩ Z?**
Y = {**1**, **12**, 50, **8**}
Z = {**8**, **12**, **1**, 42, -1}
Y ∩ Z = {**1, 8, 12**}

Q19: What is **X ∪ Y?**
X = {**0**, **8**, **2**, **100**}
Y = {**1**, **12**, **50**, 8}

X ∪ **Y** = {**0, 1, 2, 8, 12, 50, 100**}

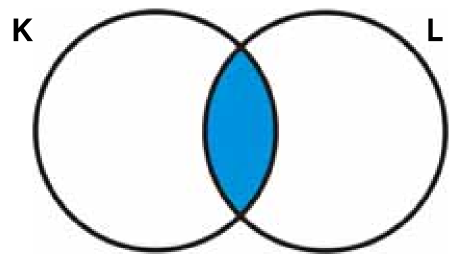
Q20: What is **Y** ∪ **Z?**

Y = {**1**, **12**, **50**, **8**}

Z = {8, 12, 1, **42**, **-1**}

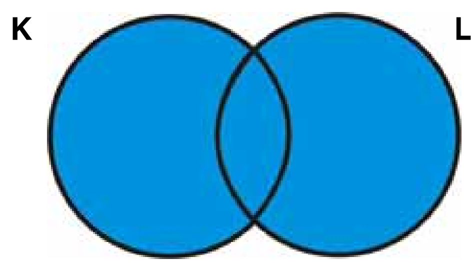
Y ∪ **Z** = {**-1, 1, 8, 12, 42, 50**}

Q21: What is **K** ∩ **L?** (What area is inside both sets?) Shade in the picture to show your answer.



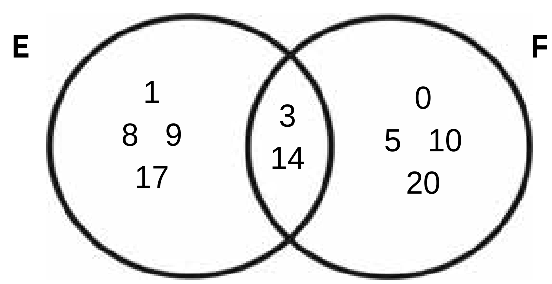
K ∩ L

Q22: What is **K** ∪ **L?** (What is the total area which is in set K, set L, or both?) Shade in the picture to show your answer.



K ∪ **L**

Q23: Use a Venn diagram to show the sets **E** and **F**.



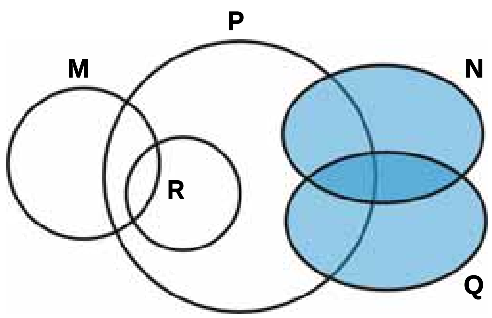
E ∩ **F** = {3, 14}

E ∪ **F** = {0, 1, 3, 5, 8, 9, 10, 14, 17, 20}

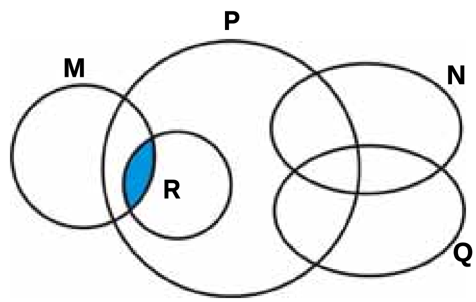
Q24: Is any set a subset (⊆) of another? Yes

If yes, which one? **R** is a subset of **P** (**R**⊆**P**)

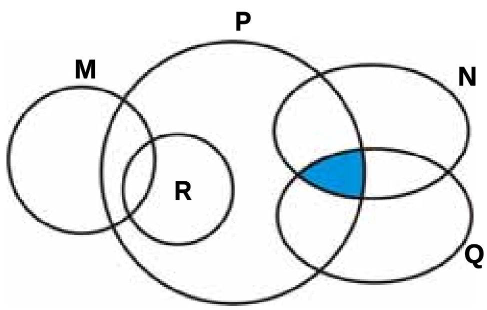
Q25: A) Shade in **N** ∪ **Q**



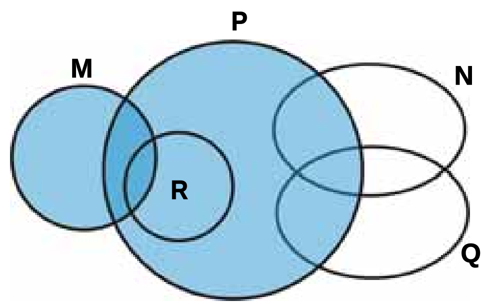
B) Shade in **M** ∩ **R**



C) Shade in **P** ∩ **N** ∩ **Q**



D) Shade in **M** ∪ **P** ∪ **R**



REFERENCES

Figure References

Figure 1: John Venn.
http://commons.wikimedia.org/wiki/File:John_Venn.jpg
(Accessed January 15, 2014)
Public domain image on Wikimedia Commons.

General References

Prime Factorization

http://www.mathsisfun.com/prime-factorization.html
(Accessed Jan. 15, 2015)
The mathisfun.com website has a page which has two methods of calculating prime factorizations.

http://www.mathsisfun.com/prime-factorization-tool.php
(Accessed Jan. 15, 2015)
The mathisfun.com website has a prime factorization tool which can calculate the prime factorization of any number you put in.

http://www.mathplayground.com/factortrees.html
(Accessed Jan. 15, 2015)
On the mathplayground.com website, you can practice prime factorization using their factor tree. You can find the prime factorization of one number or two numbers (Least Common Multiple).

Least Common Multiple (LCM)

http://www.mathsisfun.com/least-common-multiple.html
(Accessed Jan. 15, 2015)
The mathisfun.com website has a method of determining the LCM of two numbers as well as for more than two numbers.

http://www.mathsisfun.com/least-common-multiple-tool.html (Accessed Jan. 15, 2015)
The mathisfun.com has a LCM tool which can calculate the LCM of up to three numbers.

http://www.e-learningforkids.org/math/lesson/least-common-multiples/ (Accessed Jan. 15, 2015)
The e-learningforkids.org website has an online tutorial on LCM, including practice problems.

Gauss Summation

http://betterexplained.com/articles/techniques-for-adding-the-numbers-1-to-100/ (Accessed Jan. 15, 2015)
The betterexplained.com website has several strategies for adding numbers 1 to 100, including the one used in this chapter.

Modulo Arithmetic

http://nrich.maths.org/4350 (Accessed Jan. 15, 2015)
The NRICH (University of Cambridge) website has an explanation of modular arithmetic, including a 7-hour clock.

http://betterexplained.com/articles/fun-with-modular-arithmetic/ (Accessed Jan. 15, 2015)
The betterexplained.com website has a comprehensive explanation of modular arithmetic, including 'clock math' as was done in this chapter.

Set Theory

http://www.mathsisfun.com/sets/sets-introduction.html
(Accessed Jan. 15, 2015)
The mathisfun.com website has an excellent introduction to set theory including different types of sets and **set notation** (all of those funny symbols). At the bottom of the page are practice questions.

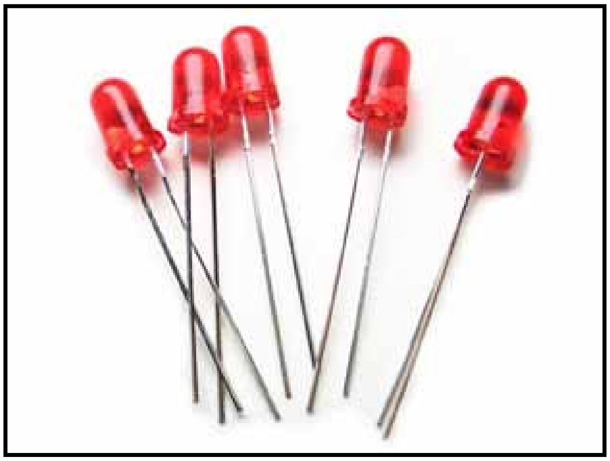
Venn Diagrams

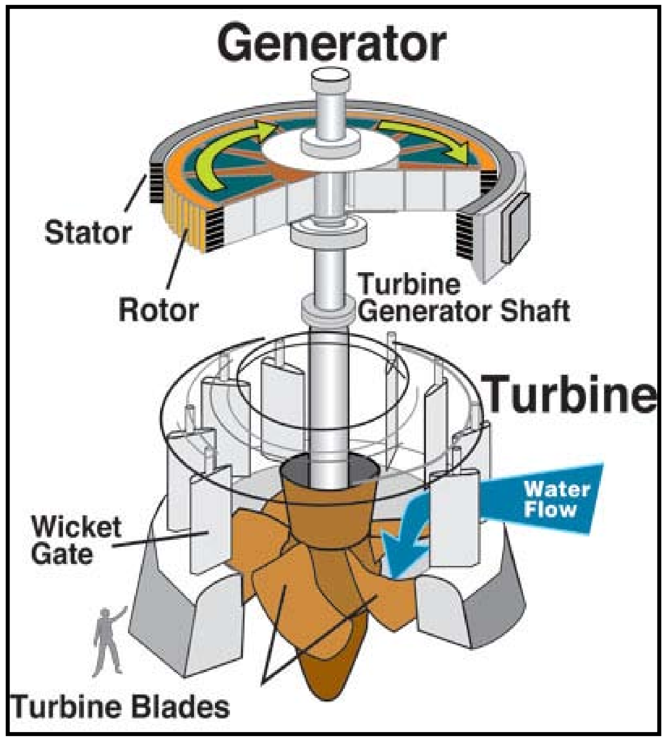
http://www.mathsisfun.com/sets/venn-diagrams.html
(Accessed Jan. 15, 2015)
The mathisfun.com website explains union, intersection and null sets using Venn diagrams. At the bottom of the page are practice questions.

http://nrich.maths.org/5721 (Accessed Jan. 15, 2015)
The NRICH website has some practice problems using Venn diagrams. You can do them online or print them off.

Chapter 7

Physics





Thank you to our Physics chapter sponsor

INTRODUCTION

Physics (from the Greek *physis*, meaning ‘nature’) is the science that examines matter, space and time. While observing the world around us we may ask questions such as: How does lightning happen? How is electricity generated? How does a TV work? What lights up a light bulb? This chapter is about finding answers to these questions.

ELECTROMAGNETISM

Electromagnetism is a part of physics which studies the **electromagnetic field**. The study of **electric charges** at rest is known as **electrostatics** and the study of electric charges in motion is known as **electrodynamics**.

Electrostatics

Electrostatics is a branch of electromagnetism that helps us learn what happens when we have two stationary or slow-moving electric charges close to each other.

There are two kinds of electric charges – **positive (+)** charges and **negative (-)** charges. Positive and negative charges are sources of electromagnetic fields. We use arrows to show how the field originates at positive charges and terminates at negative charges (see Figure 1a). If both charges are of the same type, then the field terminates VERY far away from the charges (see Figure 1b).

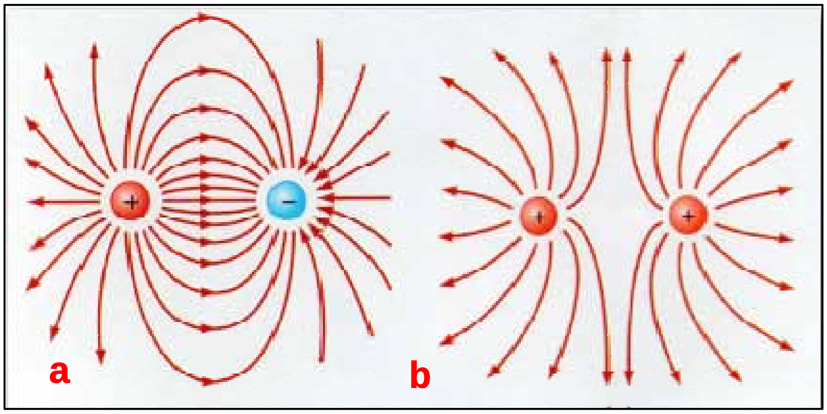


Figure 1: Electromagnetic fields.

As a result of these fields, positive and negative charges interact with each other; in other words, they can ‘feel’ each other. The intensity (strength) of this interaction is measured by the magnitude (size) of the **electrostatic force** (the force between particles that is caused by their electric charges).

This force can be **repulsive** (pushes away), which happens when the two electric charges are of the same type; for example, the two positive charges $+q_1$ shown at the top of Figure 2.

Alternatively, this force can be **attractive** (pulls toward), which happens when the two electric charges are of the opposite type; for example, the two charges $+q_1$ and $-q_2$ shown at the bottom of Figure 2.

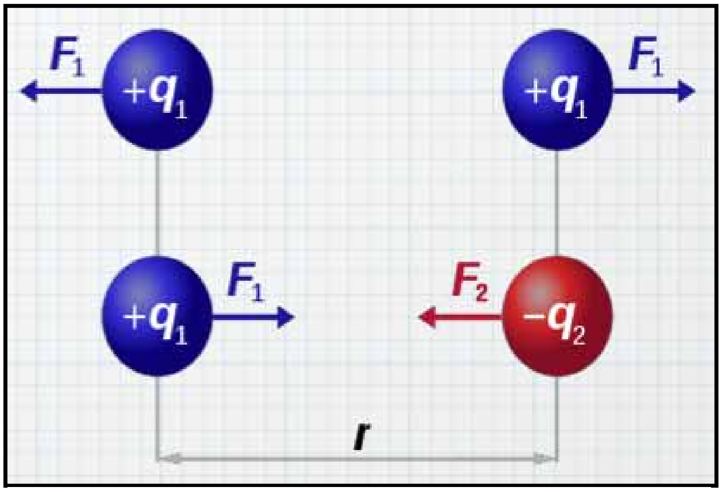


Figure 2: Electrostatic force between charges.

Static Electricity

Materials and objects are made up of **atoms** and **molecules** which are normally electrically **neutral** (have neither a positive nor negative charge) because they have an equal number of positive charges (from the **protons** in the **nucleus** of an atom) and negative charges (from the **electrons** which orbit around the nucleus).

It is possible, however, to give a normally neutral material an electric charge. One way to do this is by rubbing two objects together such as a piece of silk and a glass rod. When you rub the rod with the silk, some of the electrons will hop from the rod onto the silk which results in the rod having fewer electrons (becomes positively charged) and the silk having more electrons (becomes negatively charged).


Figure 3: Static electricity during a thunderstorm.

If two materials with opposite charges are brought close to each other, they may generate a tiny spark (movement of electrons through the air). You may have felt this when reaching for a doorknob after walking along the carpet, or when putting on a wool sweater in the winter. This little zap is **static electricity**. Zaps of static electricity also sometimes happen during a thunderstorm – only on a much larger scale!

We call these zaps **lightning**. When clouds pass by each other during a storm, they can exchange electrons, much like the rod and the silk. As a result, after much rubbing with other clouds and separation of positive and negative charges, some of the clouds can develop large electrical charges. These opposite electric charges are attracted to each other so much that they eventually 'jump' through the air and 'cancel' each other out and result in the spectacular light show that we call lightning!

Electrodynamics

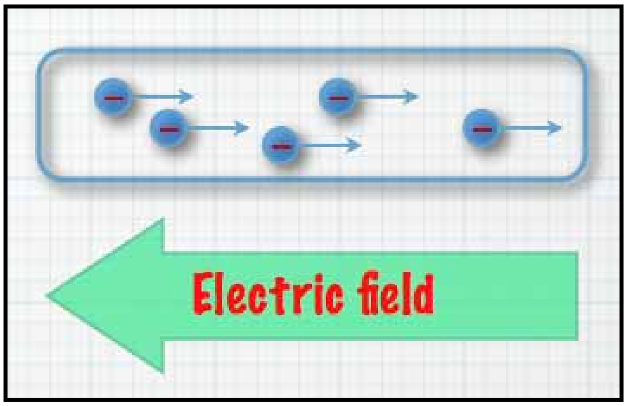


Figure 4: An electric current moving in an electric field.

Inside metals (and only metals) there are many **free electrons** (electrons which have broken away from their parent atoms). These electrons are very mobile and even a weak electromagnetic field can make them all move in the same direction. This is similar to water drops moving down a mountain and forming a river. This 'river' of moving electrons, forced to move by an electromagnetic field, is called an **electric current**. The more electrons that pass through the piece of material in a given amount of time, the greater the current.

Some materials can easily **conduct** (carry) electric current, some can do it less easily and some cannot do it at all. Materials that are <u>not good</u> at conducting electric current are called **insulators** (or **non-conductors**). Examples of insulators include rubber, plastic, glass and paper. Materials that are <u>good</u> at conducting electric current are called **conductors**. Most metals belong in this group. We also say that conductors have **low resistance**, while insulators have **high resistance**. **Resistance** describes how easily an electric current is able to pass through a material.

Finally, there is a group of materials whose conductivity is somewhere between insulators and conductors. These are called **semiconductors**. These materials are very important for the design of modern electronic circuits because we can control their conductivity! We can make them act like good conductors or good insulators depending on the situation. Most importantly, we can switch their conductivity back and forth whenever we want!

Figure 5: Insulated copper wire.

Have you ever looked closely at a piece of insulated wire like the one in Figure 5? You will see that there are fine wires of copper on the inside and a flexible plastic or rubbery material on the outside. There is a very important reason for this structure. Electrical charges always move by way of the **path of least resistance**. The current is easily able to flow along the copper wires which are good conductors, but not able to pass through the plastic shell because it is an insulator.

The human body is made mostly of water, which is a good conductor. This means that electric current will flow easily through our bodies. If a current is strong enough, it can cause severe injuries and even death to a person. If this occurs, then we say that the person received an **electric shock**. This is one reason why it is important to follow safety rules when working with electricity. Good safety practices when working with electricity include wearing clothes and gloves made of insulating materials and standing on an insulating surface. These practices provide good protection because they do not allow current to flow through a person's body.

Electric Current in Action

Electricity is very important for humans. Just imagine how difficult our lives would be if all of a sudden we were left without electric bulbs (and the whole world goes dark), if our computers, TVs and video games disappeared or if all power plants stopped working and there was no more electricity to run our air conditioners and heaters!

Electrical Resistance

When electricity passes through any material the material heats up. How hot it gets depends on the material's resistance. Low resistance materials get very hot (more than 1 000^{o}C) as soon as the electric current starts flowing. These materials can be so hot that they begin to glow! This behaviour of hot materials is used in **incandescent** light bulbs. Incandescent objects emit light when they get hot.

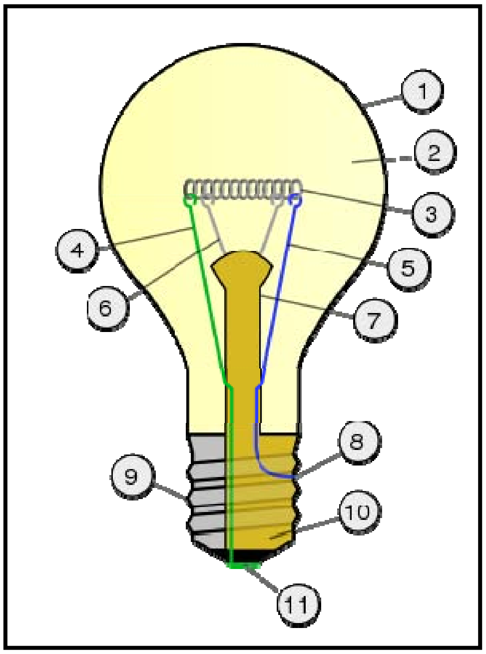


Figure 6: Incandescent light bulb.
1. Glass bulb
2. Inert gas
3. Tungsten filament
4. Contact wire (goes to foot)
5. Contact wire (goes to base)
6. Support wires
7. Glass mount/support
8. Base contact wire
9. Screw threads
10. Insulation
11. Electrical foot contact

There are two important types of electric light bulbs used today:

- Incandescent light bulbs, in which current flows through a hot metal conductor; and
- **Compact Fluorescent Lamps (CFL)**, in which current flows through a gas.

Incandescent Light Bulb

The most important innovation in the making of practical electric bulbs was the design of the **tungsten filament** (see Figure 6). Tungsten is a very good conductor which does not melt easily and glows brightly at high temperatures. To make it last longer, a tungsten wire is enclosed in a glass bulb filled with an **inert** gas (a gas which does not chemically react with the tungsten).

Compact Fluorescent Lamp (CFL)

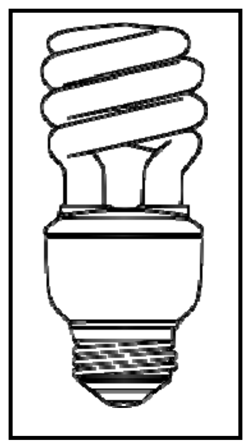


Figure 7: Compact Fluorescent Lamp (CFL).

Although incandescent electric bulbs have been used for a long time, people eventually realized that most of the energy these bulbs release is in the form of heat rather than light. Unlike in incandescent bulbs, in **compact fluorescent lamps (CFL)** the current flows through a gas instead of a metal conductor such as tungsten. CFL bulbs, therefore, release much less heat for the same amount of light, which makes them more efficient than incandescent bulbs. This also means that they have a longer **lifespan** (expected duration that the product will function). CFL bulbs are more expensive to buy than incandescent bulbs, but they save money in the end because they use less electricity and last longer. Although these bulbs use less electricity and save money, they do have one down side. CFLs contain **mercury**, a toxic substance, so they need to be handled and disposed of safely.

Light Emitting Diode (LED)

So far we have seen how an electric current can heat up a filament to produce light (incandescent light bulbs), as well as flow through a gas to produce light (CFL). There is another type of light bulb that you see every day in your digital clock, TV remote and traffic lights. These lights are called **Light Emitting Diodes**, better known as LED lights. The light from an LED is a result of the movement of electrons in a semiconductor material (remember that semiconductors have conductivity somewhere between that of a conductor and an insulator). As the electrons move across the semiconductor, they release energy in the form of **photons** (small entities which are the basic unit of light). In the early days, LEDs only emitted red light (hence all of the little red lights in alarm clocks and TV remotes), but modern versions of LEDs are now available in many different colours. The colour of light produced by an LED corresponds to the energy level of the photon being emitted. LED lights have many advantages over other bulbs, including lower energy consumption, longer lives, smaller size and better durability.

Figure 8: Light Emitting Diodes (LED).

Generating Electricity

There are many ways to generate electricity. The most common way is to use an **electrochemical reaction** in which two different chemical compounds exchange electrons, which in turn creates a current. This type of electricity generation is called **electrochemistry**. Electrochemistry is what occurs in a dry cell battery as well as in our nerve cells!

Bioelectrogenesis is the generation of electricity by living organisms. Some animals, such as jellyfish, rays and electric eels, can produce electric charges. Electric eels have three pairs of organs which can produce electricity. Together these organs make up four-fifths of the eel's body! Eels use low-voltage pulses for **electrolocation** (detect objects around them) and high-voltage pulses of up to 600 volts for hunting and self-defense. Shocks of this size can be deadly to humans.

Figure 9: Electric eel.

Light can be converted to electricity as well. When special materials called **photovoltaic** materials are exposed to light, such as sunlight, they can create an electric current. This is called the **photovoltaic effect**. **Solar cells**, such as the ones in **solar panels**, are made of photovoltaic materials. Using light to produce electricity is one of the most environmentally friendly methods, because it does not create pollution; however, it can only produce electricity on sunny days. Less than 1% of the world's electricity is currently generated using solar power.

Electromagnetic induction is the production of an electric current across a conductor moving through a magnetic field. By rotating electromagnet coils (called the **rotor**) inside a ring of North and South natural magnets (called the **stator**), we can create an electric current. A device which uses this method to generate an electric current is called a **generator**. Most large-scale electricity generation is done using electromagnetic induction, which requires **mechanical energy** to make the rotor spin within the stator. These types of generators typically have a **turbine** (drum with blades attached) which is pushed by a **fluid** (water, steam, air) to make the rotor spin. There are many different sources of this mechanical energy as you will see below.

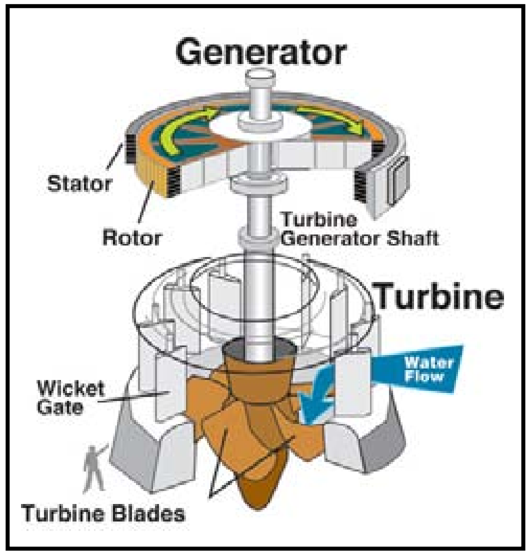


Figure 10: Generator and turbine.

Thermal Generation

Most electricity generation in the world (nearly 80%) is generated using heat. Heat is used to change liquid water into steam. In thermal generators, it is the movement of the steam that causes the turbine to spin the rotor. Globally, most of the heat (around two-thirds) used to generate electricity comes from the burning of **fossil fuels** such as **coal**, oil (**petroleum**) and **natural gas**. Fossil fuels are often used in electricity generation because fossil fuels are relatively easy to obtain, and some, like coal, are relatively inexpensive. Power plants burning fossil fuels can be constructed almost anywhere and these plants can generate large amounts of electricity in a single location. The main disadvantage of fossil fuels is that large amounts of **carbon dioxide**, a greenhouse gas, are produced as a by-product of burning the fuels.

Nuclear power plants also use thermal generation, but instead of fossil fuels, nuclear reactors use **uranium** for fuel. Uranium is a heavy, naturally radioactive element which decays through the process of **fission** (a reaction in which atoms splitting apart). When lots of atoms split at the same time, there is a huge release of energy in the form of heat. The heat from the fission reaction is used to boil water into **superheated steam**. The steam flows to the **turbines** which are connected to a shaft that spins. The shaft runs through the turbine into the **generator**. The used fuel is placed into safe storage once it has achieved its primary fission reaction, so although there are no carbon dioxide emissions for this type of electricity generation, there is radioactive spent fuel that keeps decaying for many years which must be safely stored.

Hydroelectricity

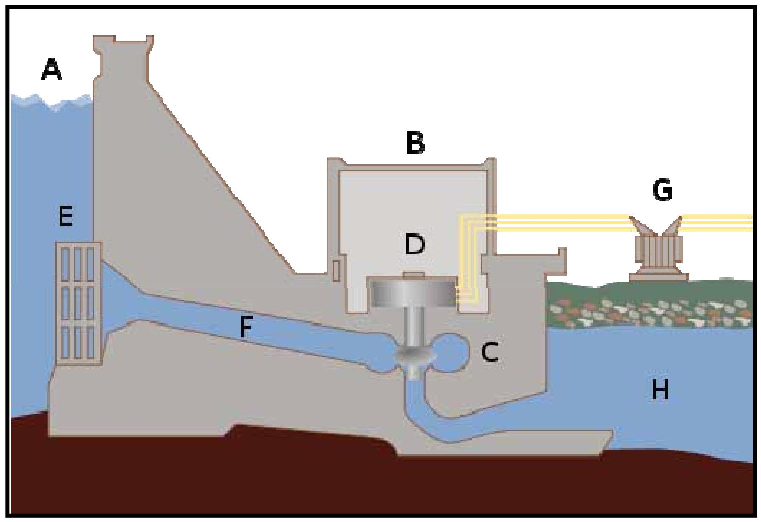


Figure 11: Hydroelectric system.
A: Reservoir; **B:** Power station; **C:** Turbine; **D:** Generator; **E:** Intake; **F:** Penstock; **G:** Long distance power lines; **H:** River

Large scale production of electricity using moving water (**hydroelectricity**) is still one of the most commonly used methods of electricity generation. In fact, nearly two-thirds of electricity used in Canada is hydroelectric and about 16% of the world's electricity is generated using hydropower. A hydroelectric system (see Figure 11) consists of pipes known as the **penstock** (**F**) (that direct the water), a turbine (**C**) and a generator (**D**); it may also include a dam. In the pipes, **potential energy** (stored energy) is converted into **kinetic energy** (energy of motion) as a result of the change of height as the water descends from the **reservoir** (**A**) through the **intake** (**E**) to the turbine. The kinetic energy of the moving water is then converted into mechanical energy when it spins the turbine. The turbine turns a shaft which is attached to the rotor in the generator (**D**) which is housed in the **power station** (**B**). The amount of energy produced depends primarily on the pressure of the water hitting the turbine and the volume of water passing by the turbine. Dams located above generators are used to increase the pressure and control the volume of water so that more electricity can be generated.

Hydroelectricity is **renewable** as it does not consume the water; however, diverting natural water systems through a turbine impacts water flow and can change the ecosystem which then affects plants and animals living in the area. If a dam is used, the **reservoir** behind the dam may provide drinking or irrigation water during dry periods as well as recreation benefits. A dam, however, can also flood land which then cannot be used for other things such as farming. Flooding can also cause ecosystem damage such as loss of habitat for animals, changes to the type of aquatic life in the area. **Methane**, another greenhouse gas, can also be produced as a result of flooding. The flooding causes plants to decay under the water which then produces methane gas. Finally, if a dam fails, the resulting damage to the nearby human and natural environments can be severe. (See the Environmental Science chapter for more information about human impacts on aquatic ecosystems.)

Wind

About 1% of the world's electricity is generated using wind power. **Wind turbines** are machines that convert kinetic (wind) energy into electrical energy using very large propeller blades and a turbine-generator system that is mounted on tall towers either on land or over water (see Figure 12). When the wind blows past the blades, it causes them to rotate, turning a shaft that runs through a generator, producing electricity. Wind power is considered to be a **renewable** source of energy since wind turbines generate electricity without significant carbon dioxide emissions from fuel use. If designed with natural habitats and migratory routes in mind, wind farms should not affect the lives of birds in a given area. You may be surprised to learn that the tallest wind turbine in Canada is located in Alberta. It is called Weather Dancer 1 and it can produce up to 2 960 megawatt-hours of power in one year. That's enough to supply around 450 homes with electricity! The disadvantage of wind turbines is that they only run when the wind is blowing. Some people are also concerned that wind turbines may affect human health as well as harm birds.

Figure 12: Wind turbine.

Biofuels

Imagine plants powering your life – that's what biofuels do. **Biofuels** are made from crops; for example, corn is grown in a field, harvested and then processed into **ethanol**. Ethanol is an alternative to gasoline and can be burned in the engine of a car just like gasoline. In fact, many countries are already using biofuels in their cars.

Figure 13: Corn field.

Biofuels are a **renewable** source of energy because new plants can be grown to take the place of the ones that were processed into fuel. While the crops are growing, they also absorb carbon dioxide. This is beneficial because it offsets the carbon dioxide released from burning the biofuel once it's processed. There is still, however, a debate about whether the costs involved in growing, fertilizing and processing the crops outweigh the benefits and whether valuable farmland should be used to grow crops for fuel instead of food.

Spotlight on Innovation in Physics

Nuclear Energy in Ontario

Canada's first day producing electricity from nuclear energy was June 4, 1962 when the **Nuclear Power Demonstration Plant** at Rolphton, Ontario, first fed power into the Ontario electricity grid. Today, nuclear power supplies Ontario with over 50 percent of its electricity.

Ontario Power Generation (OPG) owns and operates the **Pickering** and **Darlington Nuclear Power Stations**. The two stations have a combined generating capacity of about 6,600 megawatts and produce more than 30 percent of the electricity generated in Ontario.

Pickering Nuclear has been an important part of the Ontario electricity system, producing over 750 terawatt hours during its 45 years in operation – enough electricity to power the entire province for five full years at the current level of consumption.

Figure 14: Pickerington Nuclear Power Station.

In 2016, the Darlington Nuclear Power Station will undergo an important project, called a **refurbishment**. The refurbishment will allow the station to generate electricity for another 30 years!

Energy Conservation

Energy conservation is something that any of us can do every day. Energy conservation means not using energy (electricity, natural gas and petroleum) if you don't need to. Using less energy reduces our environmental impact and saves money. At home, at school or at the pool, there are always opportunities to help minimize energy use.

Little changes of habit can make big differences in how much electricity you consume. Try reading a book instead of playing video games or watching television. Keep the curtains open during the day to light a room instead of turning the lights on. When you leave a room, turn off the lights. Turning off your laptops and cell phones when you don't need them will also help reduce electricity consumption, since they won't need to be recharged as often.

Using energy-efficient devices can help cut down on your family's electricity consumption. Flat-screen televisions and computer monitors use much less electricity that older models that have cathode-ray tubes, and replacing incandescent light bulbs with compact fluorescent lamps (CFLs) or light-emitting diodes (LEDs) will really cut down on the amount of electricity used to light your home. Using energy-efficient appliances (ones that have the **Energy Star** symbol, which is an energy-efficiency seal of approval) can save your family electricity and money.

You can also help conserve electricity by using it at different times. There are two types of electricity generated for the **electrical grid** that supplies our communities with power. **Baseload** electricity is the constant, steady stream of electricity that is always consumed, day and night. This electricity is often provided by hydroelectric and nuclear power plants, which can produce large amounts of electricity efficiently and reliably. At certain times of day (from around 4:00 PM to 7:00 PM), much more electricity is consumed as people come home and turn on their televisions, computers, ovens and washing machines; the demand for electricity at these times is called **peak demand**. To meet this demand, electric utility companies turn on fossil fuel generating stations (see the Thermal Generation section above), which release large amounts of greenhouse gases into the atmosphere. You can help reduce the environmental impact of electricity generation by not only by using less electricity, but also using it at different times. Doing a load of laundry or running the dishwasher after 9:00 PM helps to reduce the demand during peak times, and means that electric utility companies don't have to use fossil fuel generating stations as much. The same goes for your laptops and cell phones – plugging them in for recharging overnight will reduce their environmental impact.

ELECTROMAGNET DESIGN CHALLENGE

Challenge:

Your challenge is to work as a team to design and build an electromagnet which can carry the greatest number of paperclips over a distance of one metre.

Materials:

- 4 iron nails
- 1 meter of copper wire
- Wire cutters
- 1 D-cell battery
- Masking tape
- Box of paper clips
- Measuring tape

Rules:

- Your design must be all attached as one piece.
- You cannot touch the paperclips as you carry them over the distance of one metre.
- Only magnetism can be used to carry the paperclips (e.g., they cannot be taped on, carried in their box, etc.).

Success

- You have created a magnet using electricity and your electromagnet is able to carry paper clips a distance of one metre.

Pushing the Envelope

- Can you carry the same number of paper clips 1.5 m, 2 m?
- Do the challenge as a race. What is the greatest number of paperclips that you can carry over a distance of one metre in one minute?

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Figure 1: Electromagnetic fields.
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Figure 2: Electrostatic force between charges.
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Figure 3: Electricity in a thunderstorm.
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Figure 4: An electric current moving in an electric field.
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Figure 5: Insulated copper wire.
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Figure 6: Incandescent light bulb.
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Figure 10: Generator and turbine.
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Electricity Generation

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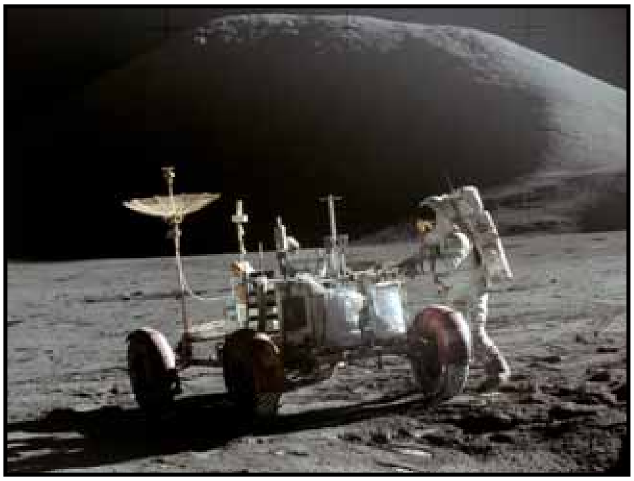
Chapter 8

Space sciences



BIRTH OF OUR SOLAR SYSTEM

Our Sun was not 'born' in the initial Big Bang which happened 15-20 billion years ago. Nearly 5 billion years ago, our Solar System was only a vast cloud of dust particles forming a pre-solar **nebula** (interstellar cloud of dust and gases) (see Figure 1, Stage 1). The dust particles in the nebula had been slowly swirling for perhaps 10 billion years, held together by their own **gravity**. Most probably, the cloud was made of 99% helium and hydrogen and less than 1% of heavier elements.

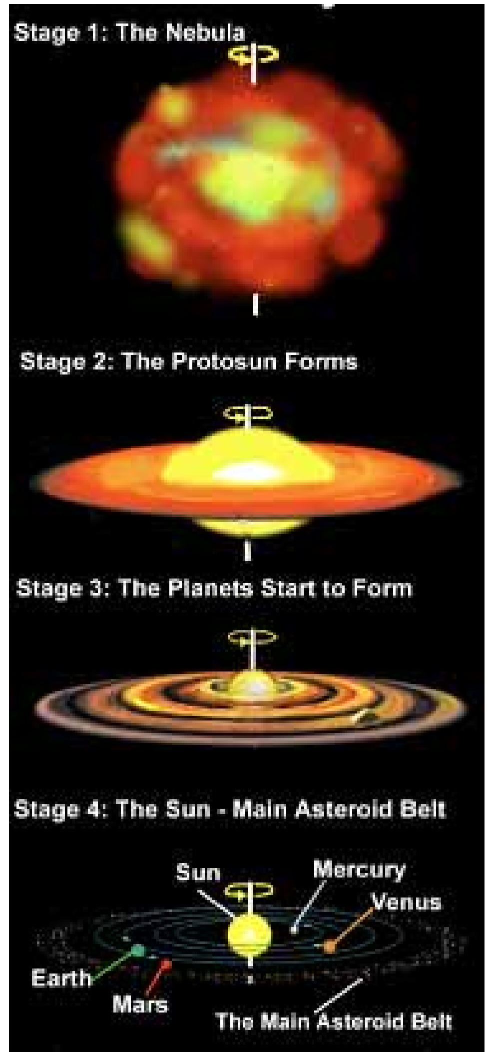


Figure 1: The formation of our Solar System.

As the gravitational pull strengthened, the gases began to come closer together and to spin more rapidly. As the nebula shrank, most of the dust particles gathered in the centre and formed a **protosun** (also called a **protostar**) (see Figure 1, Stage 2), which is the early form of a star. The protosun was a huge, tightly packed ball of gas. In the core of the protosun, the pressure became so high that the hydrogen atoms started forming helium atoms through the process of **nuclear fusion**. Eventually, due to the gravitational pull, the star was born.

Not all of the dust from the nebula formed the protosun. Away from the centre of the cloud the dust particles collected into a disk of swirling hot gasses (see Figure 1, Stage 3). As the gases cooled, they began to collect together and form **rocky planets**, **gas giant planets**, **dwarf planets**, **asteroids**, **meteoroids** and **comets** (Figure 1, Stage 4).

Figure 2: The Sun and the Earth.

The Sun

The Sun (from the Latin word *sol*), a **yellow dwarf**, is the star at the centre of our Solar System. The Earth and all other members of the planetary family orbit the Sun, which by itself accounts for about 98.6% of mass of the Solar System. The average distance from the Sun to the Earth is approximately 149 600 000 km.

So, to travel to the Sun in an airplane travelling at 900 km/h it would take you about 19 years, but it takes light (travelling at the speed of light) only about 8 minutes!

The Sun is comprised of 72% hydrogen, 26% helium and 2% other elements. The Sun 'shines' because it is constantly releasing energy as it converts hydrogen into helium in a process called **fusion**. Energy from the Sun, in the form of sunlight, supports almost all life on Earth via **photosynthesis** (the process by which plants make their own food in the form of sugar) and drives the Earth's climate and weather.

Our Sun is approximately five billion years old and it is estimated that five billion years from now the hydrogen at the Sun's **core** will run low. The Sun will then become a **Red Giant**, which is an expanded star. At the end of our Sun's life cycle, the nuclear fusion will stop. It will then become cool and collapse into a **White Dwarf** no larger than the size of the Earth, with cold dead planets orbiting around it (see Figure 3).

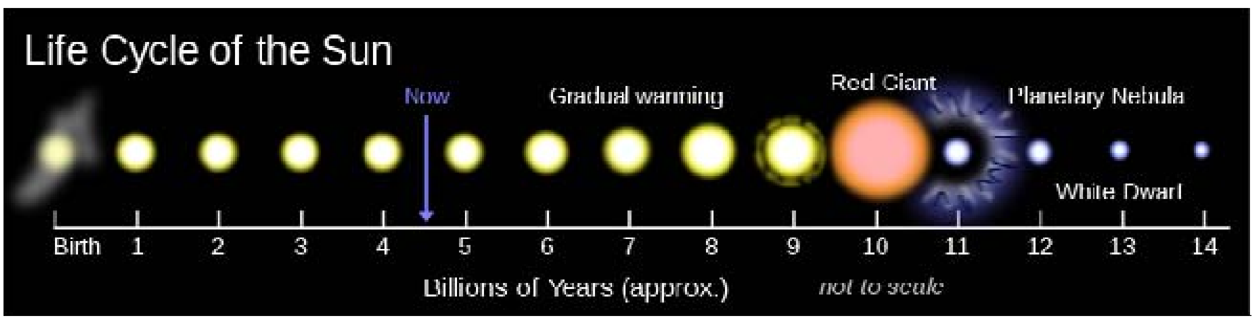


Figure 3: The life cycle of the Sun.

The Inner Solar System

The Inner Planets

The four **inner** or **terrestrial planets** - **Mercury**, **Venus**, **Earth** and **Mars** - have dense, rocky compositions, few or no **moons**, and no ring systems. They are composed largely of minerals with high melting points, such as the silicates which form their **crusts** and **mantles** and metals such as iron and nickel which form their **cores** (see Figure 4).

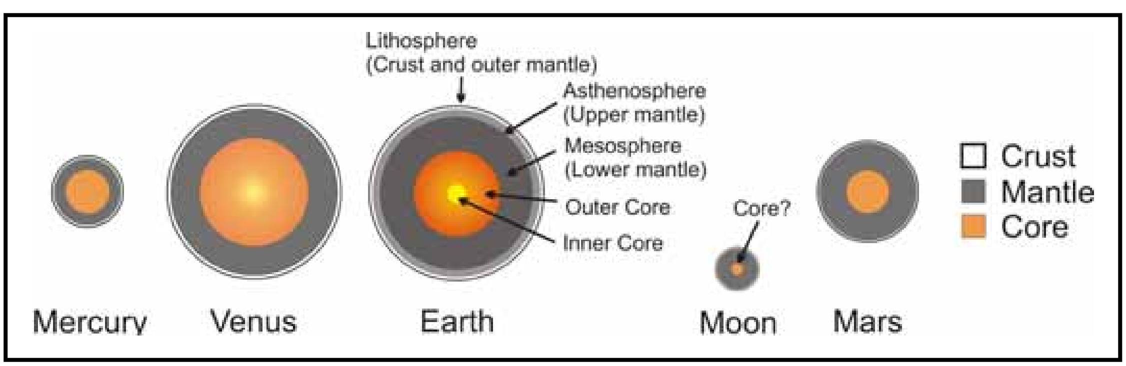


Figure 4: Composition of the inner planets.

Three of the four inner planets (Venus, Earth and Mars) have substantial **atmospheres** (gases which surround the planet) and all have impact **craters** (circular depressions on their surface) and tectonic surface features such as **rift valleys** and **volcanoes**. Mercury (named after the messenger to the gods in Roman mythology) has very little atmosphere and, much like our moon, Mercury has lots of craters from meteor impacts. Venus (named after the Roman goddess of love and beauty) has a very thick atmosphere and is actually hotter on its surface than Mercury. Our planet, Earth, is the only planet known to support life in our universe. Mars (named after the Roman god of war) is believed to have had water and methane on its surface in the past, which may have supported life.

The Asteroid Belt

The **Asteroid Belt** is the region of the Solar System located roughly between the orbits of the planets Mars and Jupiter. It is occupied by numerous irregularly-shaped bodies called **asteroids** or **minor planets**. The Asteroid Belt region is also termed the 'Main Belt' to distinguish it from other concentrations of asteroids and minor planets within the Solar System. Asteroids are not round in shape and their orbits around the Sun are not easily disturbed.

The Outer Solar System

The Outer Planets

The outer region of the Solar System is home to the planets known as **gas giants**. These include **Jupiter**, **Saturn**, **Uranus** and **Neptune** (see Figure 5) and their planet-sized **satellites** (moons). Many **short period comets** (comets which take 200 years or less to orbit the Sun), as well as the minor planets, also orbit in this region. The solid objects in this region are composed of a higher proportion of water, ammonia and methane than the rocky members of the inner Solar System.

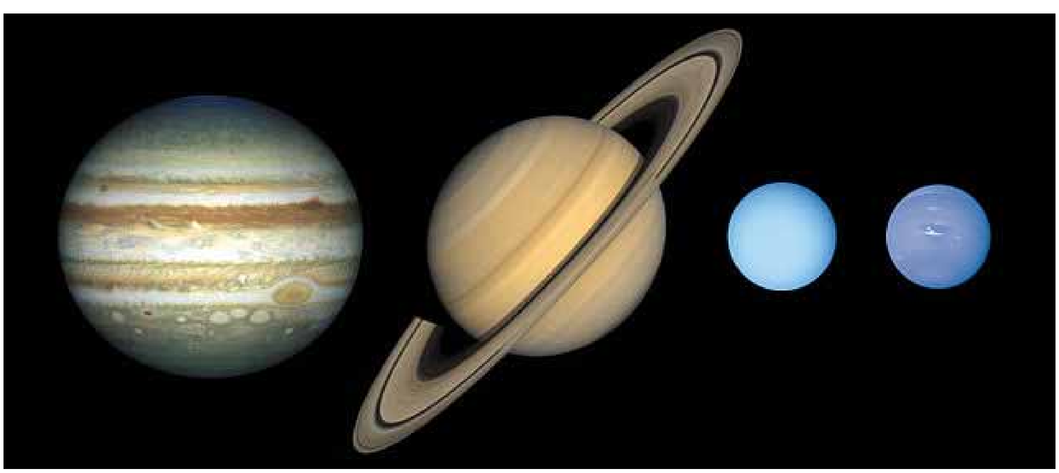


Figure 5: Outer planets (left to right: Jupiter, Saturn, Uranus and Neptune).

The four outer planets, also sometimes called **Jovian planets** (meaning 'like Jupiter'), collectively make up 99% of the mass known to orbit the Sun. Jupiter (named after the Roman king of the gods and the god of sky and thunder) and Saturn (named after the Roman god of agriculture and harvest) consist overwhelmingly of gaseous hydrogen and helium, whereas Uranus (named after the Greek god of the sky) and Neptune (named after the Roman god of the sea) possess a greater proportion of ices in their makeup. Some astronomers suggest they belong in their own category, called **ice giants**. All four gas giants have rings, although only Saturn's ring system is easily observed from Earth. The largest planet in the Solar System is Jupiter, which is 10 times smaller and is 1 050 times less massive than the Sun. Uranus is interesting in that it spins at almost a 90° angle to the plane of its orbit and Neptune has the fastest planetary winds in the Solar System!

The Kuiper Belt

The **Kuiper Belt** is a region of the Solar System beyond the planets extending from the orbit of Neptune. It is similar to the Asteroid Belt, although it is far larger - 20 times as wide and 20 - 200 times as massive. Like the Asteroid Belt, it consists mainly of small bodies which are left over from the Solar System's formation. It is home to at least three dwarf planets – Pluto, Haumea and Makemake. Unlike objects in the Asteroid Belt, which are composed primarily of rock and metal, the Kuiper Belt objects are composed largely of frozen 'ices', such as methane, ammonia and water.

Scattered Disc

Like the Kuiper Belt, the **Scattered Disc** is a region of the Solar System beyond Neptune that is full of icy bodies. Unlike objects in the Kuiper Belt that have **stable orbits** (meaning that they are not easily disturbed and will remain in their orbits over very long periods of time), objects in the Scattered Disc have **unstable orbits** which are easily disturbed by the gravity of Neptune. These objects frequently get 'scattered' around in the outer Solar System and sometimes cross into the inner Solar System.

The Dwarf Planets

In 2006, the International Astronomical Union (IAU) defined a dwarf planet as:

- being in orbit around the Sun;
- having a mostly round shape due to its own gravity;
- having not cleared its neighbouring region of debris; and
- not being a satellite of a planet.

By this definition, the Solar System has five known dwarf planets: Ceres (in the Asteroid belt), Pluto-Charon (binary system), Haumea, Makemake and Eris (in the Scattered Disk).

Figure 6: Pluto-Charon binary system.

Why is Pluto not a planet? Pluto is different than the other eight planets in several ways. It has an oval-shaped orbit that is highly inclined relative to the orbits of the other planets. One end of Pluto's orbit actually comes closer to the Sun than Neptune's! In addition, Pluto and Charon, which is half Pluto's size, orbit around each other, making a **binary system** (see Figure 6). A binary system refers to two objects in space (usually stars, but also planets, galaxies, or asteroids) which are so close that that their gravitational forces causes them to orbit around about a common center of mass.

Table 1: Characteristics of Members of Our Solar System

Name	Diameter 1= Earth	Length of Year	Known Moons	Distance from Sun 1=Earth
Mercury	0.38	88 days	0	0.39
Venus	0.95	224.7 days	0	0.72
Earth	1.00	365.3 days	1	1.00
Mars	0.53	687 days	2	1.52
Jupiter	11.2	11.9 years	63	5.2
Saturn	9.4	29.5 years	56	9.5
Uranus	4.0	84.0 years	27	19.2
Neptune	3.8	164.8 years	13	30.1
Pluto	0.2	247.7 years	3	30 – 49
Sun	109	-	-	-

EXPLORATION OF THE SOLAR SYSTEM

Before 1950, all that we knew about the Solar System was from ground-based observations with telescopes. That all changed in 1959 with the launch of the first spacecraft to fly by the Moon. Only two years later the first human was sent into space to orbit around the Earth. This new era of space travel opened the door to sending humans to the Moon and launching countless spacecraft to explore the far reaches of our Solar System.

Human Exploration – The Apollo Program

The goal of the **Apollo** program was to land humans on the Moon and bring them safely back to Earth. The program ran from 1963 to 1972 and landed six manned spacecraft on the surface of the Moon. In 1969, Neil Armstrong became the first of 12 astronauts to walk on the Moon's surface (see Figure 8).

Figure 7: Apollo 15 astronaut James Irwin with the Lunar Roving Vehicle (LRV) on the surface of the Moon, 26 July 1971.

The Apollo astronauts set up equipment to detect 'moonquakes' to learn what the Moon is like beneath its surface. They also set up a **Laser Ranging Retroreflector** array which is used to bounce light off the Moon to precisely measure how far away the Moon is from the Earth.

The Apollo program established humankind's ability to live and work in space, and returned over 300 kg of lunar rocks.

Humans have not set foot on another body in our Solar System since the Apollo program ended; however, the United States has set plans in motion for sending humans to Mars by the 2030s. Before this is possible, many challenges must be overcome. Humans can make a trip to the Moon and back in just over a week, but travelling to Mars would take over 8 months just to get there! Studies on the **International Space Station** have helped us learn about how our bodies adapt to being in a low-gravity environment isolated from the Earth. Such studies will continue to ensure humans can survive a trip to Mars and back. Technological advances must also be made to build spacecraft suitable for carrying humans on prolonged exploration missions.

Landing on Another World - Mars Exploration Rovers

Spirit and ***Opportunity*** are the names of the twin **Mars Exploration Rovers** whose mission was to look for evidence that Mars once had liquid water on its surface. If Mars had water then it is possible that it could have once supported life.

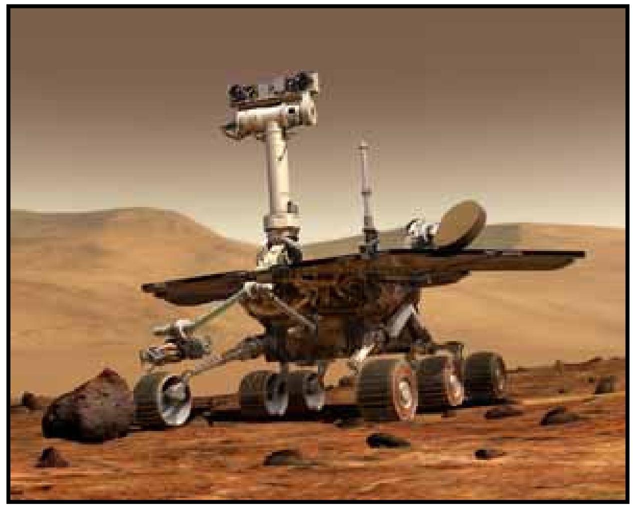


Figure 8: Mars Exploration Rover.

The Mars rovers were designed to be on-site robot geologists, equipped with scientific instruments to study the surrounding rocks and soil (see Figure 9).

They have panoramic cameras that take high-resolution 360^{o} views of the landscape so that the scientists on Earth can tell the rover where to go. They also have a robotic arm, which acts much like a human arm, reaching out to grab rocks and soil samples to analyze.

Since landing on Mars in 2004, both rovers found strong evidence that water used to exist on Mars. After five years of exploring, *Spirit* became stuck in soft soil and stopped communicating with Earth 10 months later. As of January 2012, *Opportunity* is still functional and has traveled over 34 km across the Martian surface.

Figure 9: Curiosity Rover.

Launched in November of 2011, **Mars Science Lab** will continue the search for evidence that Mars was once able to support life. It carries with it a rover named ***Curiosity*** (see Figure 10) which is heavily equipped with the instruments it needs to search for the three necessities for life: **water**, **energy** and **carbon**. *Curiosity* is four times heavier than the *Spirit* and *Opportunity* rovers and has a more sophisticated robotic arm for drilling into rocks and collecting soil samples for analyzing.

Probing the Outer Solar System

After a flyby of Jupiter, the ***Cassini*** probe arrived at Saturn in 2004 and was the first spacecraft to orbit the ringed planet. *Cassini's* mission is to study the atmosphere and rings of Saturn and also to take a closer look at some of its moons. An exciting discovery was made on the icy moon **Enceladus**, where photos taken by *Cassini* showed icy plumes, or **geysers**, shooting off the surface (see Figure 11).

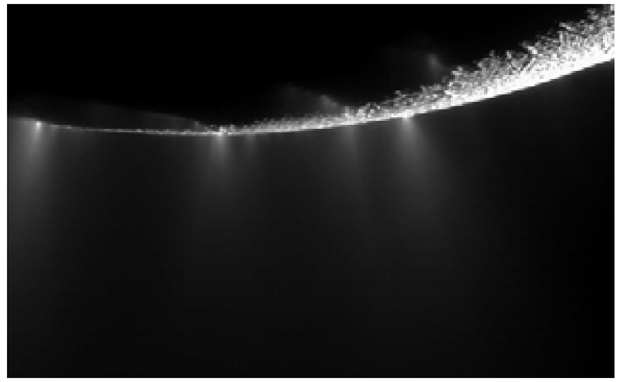


Figure 10 : Geysers on Enceladus.

The current *Cassini* mission has been extended to 2017, when NASA plans to intentionally crash *Cassini* into Saturn during Saturn's 2017 northern summer solstice.

Cassini carried with it the ***Huygens*** probe which landed on one of Saturn's moons, **Titan**. The *Huygens* probe was the first spacecraft to land on a body in the outer Solar System. Titan is Saturn's largest moon and is very interesting because it is the most Earth-like body in our Solar System. It has a thick atmosphere and resembles what Earth may have looked like billions of years ago before life began. The *Huygens* probe revealed that Titan has rivers and lakes on its surface, but instead of liquid water they are filled with liquid **ethane** and **methane** (these are carbon-based compounds that are also found on Earth in natural gas).

Figure 11: Juno probe.

Launched on August 5, 2011, the current mission to the outer solar system is called **Juno** (see Figure 12). The *Juno* probe will be the second spacecraft to orbit Jupiter when it arrives in 2016. *Juno* will study how Jupiter was formed and will provide a better understanding of how the solar system as a whole was formed. It is carrying a camera called **JunoCam** which will provide colour images of the cloud tops. *Juno* will set a record for the furthest spacecraft from the Sun to run on **solar power**.

Asteroids, Meteoroids, Meteors, Meteorites and Comets

Not all the material from our pre-solar nebula precursor was used to create the Sun and planets. There is a lot of **leftover material** (made of minerals and metals) which orbits around the Sun and, therefore, belongs to our Solar System family.

Meteoroids, Meteors and Meteorites

When **asteroids** (small rocky and metallic bodies) fall out of their orbit and wander freely in the Solar System, they are no longer called asteroids – they are called **meteoroids**. Meteoroids that fall into the Earth's atmosphere are called **meteors** and if they reach the surface of the Earth they are called **meteorites**.

Comets

Beyond our Solar System at approximately one light year distance is a region called the **Oort Cloud**. The Oort Cloud contains hundreds of billions of ice clumps which we call **comets**. Comets that come from the Oort Cloud are known as long-period comets, as they take over 200 years to orbit the Sun! There are also short-period comets, such as **Halley's Comet** which orbits the Sun every 76 years. Short-period comets are thought to come from the Scattered Disc. Once in a while a comet such as **Comet Hale-Bopp** (see Figure 13) enters our Solar System. The Sun's heat melts the ice as the comet gets closer to the rocky planets. The solar wind from the Sun sweeps this dust around the comet into a shining tail that always points away from the Sun.

Figure 12: Comet Hale-Bopp.

Meteor Showers

On any given night you can usually see a few meteors each hour; however, at certain times during the year the number of meteors per hour is much greater. This is called a **meteor shower** and it happens when the Earth passes through the debris trail left behind by a comet. The debris trail is full of tiny meteoroids, also called **cometary dust**. The meteors seen during a meteor shower all appear to be coming from the same point in the sky, called the **radiant**. Each meteor shower is named after the constellation that their radiant is closest to.

There are ten major meteor showers each year. One of the best showers is in mid-August when you can sometimes see up to 100 meteors in an hour! During this time the Earth is passing through the debris trail left behind by **Comet Swift-Tuttle**. This meteor shower is called the **Perseids**, because the radiant is in the constellation Perseus.

Spotlight on Innovation in Space Sciences

Solar Sailing

The idea of using sunlight to propel a spacecraft has been around for a long time. In 1610, Johannes Kepler described "ships or sails adapted to the heavenly breezes" in a letter to Galileo, introducing the idea of sailing on light alone. In the 400 years since, many other great minds have contributed to the goal of solar sailing.

Much like wind pushing a sailboat through water, solar sails use sunlight to push vehicles through space. Giant sails built from lightweight reflective material capture particles called **photons** that are constantly streaming out from the Sun. If enough photons push on the sail, they can propel the spacecraft at great speeds.

This technology could expand humanity's reach into the universe, allowing us to explore very distant worlds. Normally, spacecraft burn fuel to propel themselves forward through space, and so the distance and speed at which a spacecraft can travel is limited by the amount of fuel they carry. With solar sailing, on the other hand, the photons from the Sun are essentially unlimited and so could carry spacecraft at incredible speeds to very distant destinations. In fact, most scientists consider solar sailing the only reasonable way to make **interstellar** travel (travelling between stars) a reality.

Figure 13: NASA test of a solar sail.

This technology is not simple, though, and its development needs the collaboration of many countries. Space agencies of several nations are working on designing and testing solar sails, and space enthusiasts worldwide have funded independent solar sailing projects through the non-profit organization ***The Planetary Society***.

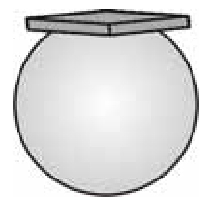
As spacecraft become smaller and lighter, solar sailing becomes more practical and could provide a way for humans to explore distant reaches of our solar system and beyond!

SPACE PROBE LANDER DESIGN CHALLENGE

Challenge:

Your challenge is to work as a team to design and build a device that will land a simulated space probe (a ping pong ball with a piece of cardboard on top to simulate solar panels) upright after a drop.

Materials:



- 1 ping pong ball or golf training ball with a 2.5cm (1") square piece of cardboard attached with tape or hot glue to one side (this is the 'top' of the ball)
- Paper clips
- Craft sticks
- Metal nuts
- Stick tack
- Erasers
- Plastic dice
- Tape

Rules:

- You may use only the provided materials to build your device.
- Your device will be dropped from a height of 1.5 metres (approx. 5') and must 'land' so that the cardboard square (simulated solar panels) on its top faces directly up.

Success

- You have created a device which will position the ball upright (with the cardboard square facing up) on the ground after a drop of 1.5 metres (approx. 5'). The drop test must be successfully repeated three times.

Pushing the Envelope

- Drop your device from a greater height or throw your device into the air.
- Drop your device onto an uneven surface, such as grass, gravel or sand. Will it still land upright?

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Authors

Pavel Abumov, M.Sc., McMaster University alumni
Stephen Adams, Level 2 Hons. Computer Science, McMaster University
Hollie Afelskie, Bachelor of Health Sciences Candidate, Carleton University
Fernando Amador, M.Sc. Candidate in Medical Biophysics, University of Toronto
Dr. Shiva Amiri, Manager, Informatics and Analytics, Ontario Brain Institute
Ariane Batic, B.Sc. Marine Biology Honours, Public Education Instructor at Bamfield Marine Science Centre
Robert Berger, Ph.D. Candidate, Psychology Neuroscience and Behaviour, McMaster University
Sarah Bishop, M.Sc. Candidate, University of Waterloo
Rich Bloch, B.Sc. Candidate, York University
Alex Bourque, Ph.D. Candidate, Dept. of Physics, McGill University
Adrian Buzatu, Ph.D. candidate, Dept. of Physics, McGill University
Jenny Campos, Ph.D. Candidate, Psychology Neuroscience and Behaviour, McMaster University
CH2M HILL staff members
Jennifer Chen, Ph.D. Candidate Dept. of Chemistry, University of Toronto
Lu Chen, Ph.D. Candidate, Dept. of Chemistry, University of Toronto
Caroline Chénard, M.Sc. Candidate, Earth & Ocean Sciences, University of British Columbia
Dr. Regina Cid, Chemical Engineer, Appreendere, Inc.
Heather Coleman, Ph.D. Candidate, Forestry (Wood Science Dept.), University of British Columbia
Lacey Corbett, B.Sc. Candidate, Memorial University
Nina Crocker, Ph.D. Candidate, Dept. Mechanical Engineering, McGill University
Adam Daily-Mcilrath, M.Sc. Candidate, Dept. of Mathematics & Statistics, McMaster University
Tara Davis, M.Sc. Candidate, Dept. of Mathematics & Statistics, McMaster University
Isabel Deslauriers, National Coordinator, Let's Talk Science Outreach, Let's Talk Science
Cate Dimitriew, Ph.D. Candidate, Dept. of Zoology, University of Toronto
Michael Ducey, B.Sc. Candidate, Memorial University
Judith Eigenbrod, M.Sc. Candidate, Dept. of Zoology, University of Toronto
Anita Elworthy, Coordinator, Evaluation & Information Management, Let's Talk Science
Adebola Enikanolaiye, M.Sc. Candidate, Department of Cellular and Molecular Medicine, University of Ottawa
Paula Estey, Formulation Chemist, Septodont
Natasha Ewing, B.Sc., K-12 Education Coordinator, Ocean Networks Canada
Sergio Fratarcangeli, Ph.D. Candidate, Dept. of Mathematics & Statistics, McMaster University
Dr. Pierre P. Ferguson, Chargé de cours, Université de Moncton
Lesley-Ann Foulds, Engineering/Applied Science Trainee - TRF (Rotation), Ontario Power Generation
Sergio Fratarcangeli, Ph.D. Candidate, Dept. of Mathematics & Statistics, McMaster University
Barbara Gadja, M.Sc. Candidate, Zoology, University of British Columbia
Marjorie Gonzalez, Ph.D. Candidate, Dept. of Physics, McGill University
Catherine Greenhalgh, Scientist, Raytheon ELCAN Optical Technologies
Karan Grewal, M.Sc. Candidate, Experimental Medicine Program, University of British Columbia
Dr. Alain Haché, Chaire de Recherche du Canada en Photonique, Professeur Agrégé, Département de Physique et d'Astronomie, Université de Moncton
Sara Harbord, M.Sc. Candidate, Medical Genetics, University of British Columbia
Dr. Christopher Hassall, Ontario MRI Postdoctoral Fellow, Carleton University, Ottawa, ON
Sarah Hirschorn, Ph.D. Candidate, Dept. of Zoology, University of Toronto
Heather Hollett, B.Sc. Candidate, Dept. of Biology, Memorial University

Dr. Andrew Horne, Instructor, Dept. of Anaesthesiology, Pharmacology & Therapeutics, University of British Columbia
Kate Howells, National Coordinator for Canada, The Planetary Society
Lesley Hymers, Environment and Education Specialist, Ontario Mining Association
Natasha Janes, B.Sc. Candidate, Dept. of Chemistry, Memorial University
Natalia Jaworska, Ph.D. Candidate, University of Ottawa
Julienne Kaiser, Ph.D. Candidate, Microbiology, Western University Canada
Nicole Kaiser, M.Sc., Assistant Coordinator, Outreach, Let's Talk Science
Catherine Kang, Ph.D. Candidate, Institute of Biomaterials & Biomedical Engineering, University of Toronto
James Karle, Ph.D. Candidate, Psychology Neuroscience and Behaviour, McMaster University
Noam Katz, M.Sc. Candidate, University of Ottawa
Jenny Kliever, Research Assistant, Department of Physics, University of Toronto
Randy Kobes, Professor of Physics, Physics Department, University of Winnipeg
Peter Kublik, Systems Consultant, Long View Systems
Laryssa Kurjewicz, Ph.D. Candidate, Department of Medical Biophysics, University of Western Ontario
Catherine Laporte, Ph.D. Candidate, Dept. Electrical and Computer Engineering, McGill University
Dr. Rebecca Lam, Faculty, CREAIT
Ivan Lee, Ph.D. Candidate, Climate Science, Western University
Dr. Kris Lehnhardt, Medical Director, Department of Emergency Medicine Training Center at George Washington Medical Faculty Associates & Professor at Centre for Planetary Science and Exploration, Western University
Gerald Li, Ph.D. Candidate, Interdisciplinary Oncology Program, University of British Columbia
Theresa Liao, Ph.D. Candidate, Experimental Medicine, University of British Columbia
Tingbin Lim, M.Sc. Candidate, Dept. of Chemistry, University of Toronto
Conny Lin, M.Sc. Candidate, Neuroscience, University of British Columbia
Ryan Marciniak, Science Entertainer, Astronomy in Action
Melissa Massey, Ph.D. Candidate, Dept. of Chemistry, University of Toronto
Patti McCarthy, Ph.D. Candidate, Faculty of Medicine, Memorial University
Lisa McDonnell, Ph.D. Candidate, Wood Science, University of British Columbia
Ann McDowall, Regional Asset Manager, BC Hydro
Alyssa Moldowan, Ph.D. Candidate, Department of Physics, University of Western Ontario
Stephanie Morgan, Coordinator, Partnership & Development, WWF Canada
Maggie Neff, Ph.D. Candidate, Dept. of Zoology, University of Toronto
Amir Nejadmalayeri, Ph.D. Candidate, Electrical & Computer Engineering Dept., University of Toronto
Jalyn Neysmith, Exhibition Developer, The Field Museum, Chicago, IL
Jeff Nicol, Ph.D. Candidate, Psychology Neuroscience and Behaviour, McMaster University
Katherine Northcott, M.Sc. Candidate, Dept. of Mathematics & Statistics, McMaster University
Denise Nunes, Mining Engineer, M.A.Sc., Department of Mineral Processing/ Mining Engineering, University of British Columbia
Constance O'Connor, M.Sc. Candidate, Department of Biology, Carleton University
Ontario Power Generation, Corporate Relations and Communications
Cathy Orlando, M.Sc., B.Ed., Science Outreach Coordinator, Laurentian University
Lance Penny, B.Sc. Candidate, Memorial University
Stephen Penny, M.Sc. Candidate, Human Kinetics and Recreation, Memorial University
Alana Plummer, M.Sc. Candidate, Department of Biology, University of Ottawa
Daniel Pohl, M.Sc. Candidate, Department of Engineering Physics, McMaster University
Damion Pollard, Level IV Chemistry, McMaster University
Randal Power, M.Sc. Candidate, Engineering, Memorial University
Khadijeh Rajabi, Ph.D. Candidate, Dept. of Chemistry, Memorial University
Amy Reckling, HB.Sc. Candidate, Dept. of Chemistry, Memorial University
Nicole Rice, B.Sc. Candidate, Dept. of Chemistry, Memorial University
Stephanie Robinson, B.Sc. Candidate, Earth Science, Memorial University
Ali Modir Rousta, Ph.D. Candidate, Dept. of Chemistry, Memorial University
Christian Rutledge, HBA Psychology & French, McMaster University
Negin Shahid, M.Sc. Candidate, University of Ottawa

Kristina Sheriden, B.Sc. Candidate, Memorial University
Sharan Sidhu, M.Sc. Candidate, Medical Genetics, University of British Columbia
Eva Simon, Ph.D. Candidate, Dept. of Chemistry, Memorial University
Beth Simpson, Ph.D. Candidate, Human Nutrition, University of British Columbia
Dr. Robert Sobot, Assistant Professor, University of Western Ontario
Guruprasad Sosale, Ph.D. Candidate, Dept. Mechanical Engineering, McGill University
Ferrinne Spector, Ph.D. Candidate, Psychology Neuroscience and Behaviour, McMaster University
Eddy St. Coeur, B.Sc. Candidate, Dept. of Psychology, Memorial University
Will Stecho, M.Sc. Candidate, University of Ottawa
Natalie Szponar, M.Sc., Environmental Consultant (G.I.T), Dillon Consulting Limited.
Susie Taylor, Special Programs Coordinator, Let's Talk Science
Kim Thorvaldson, MRT(R), RTR, BSc(Hons), CT Technologist, Thunder Bay Regional Health Sciences Center
Laura Thomson, PhD Candidate, Glaciology, University of Ottawa
Adam Vigneron, M.A.Sc. Candidate in Aerospace Engineering, Carleton University
Viengtha Vongphachan, B.Sc. Candidate, Carleton University
Sean Walkowiak, Bachelor of Health Sciences Candidate, Department of Biology, Carleton University
Alexandra Warren, B.Sc. Candidate, Department of Earth and Ocean Sciences, Faculty of Science, University of British Columbia

Final Editor

Kim Taylor, Education Specialist, Let's Talk Science

Handbook Editors

Peter Bloch, Teacher, Toronto District School Board
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Abena A. Otchere, M.Sc., M.D. Candidate, Department of Medicine, University of Toronto
Mary Quinn, Education Specialist, Let's Talk Science
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Craig White, Education Program Consultant, Grades 7-12, Let's Talk Science

Chapter Editors

Fernando Amador, M.Sc. Candidate in Medical Biophysics, University of Toronto
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Jenny Campos, Ph.D. Candidate, Psychology Neuroscience and Behaviour, McMaster University
Mike Carnate, Undergraduate in Nutritional Sciences, Department of Food, Nutrition and Health (FNH), University of British Columbia
George Chan, Ph.D. Candidate, Psychology Neuroscience and Behaviour, McMaster University
Natasha Crellin, Ph.D. Candidate, Surgery, University of British Columbia
Catherine Crouse, B.Sc. Candidate, Environmental Studies, Laurentian University
Jessi Linn Davies, Education Consultant, Creative Space
Erika Eliason, M.Sc. Candidate, Zoology, University of British Columbia
Dr. Carolyn H. Eyles, Professor, Department of Earth Sciences & Geography, McMaster University
Dr. Jeff Fletcher, Postdoctoral Fellow, Dept. of Zoology, University of Toronto

Lindsey Freeman, B.Sc., B.Ed., Teacher, Thames Valley District School Board
Dr. Phil Graniero, Associate Professor, University of Windsor
Dr. Geoffrey J. Hay, Associate Professor Geography , ISEEE Fellow, Department of Geography, University of Calgary
Monica Joch, (proofreading) Dept. of Neurology, McGill University
Kevin Jordan, Medical Physicist, London Regional Cancer Program
Michelle Kaiser, B.Sc. Psychology, McMaster University
Nicole Kaiser, Assistant Coordinator, Let's Talk Science Outreach
David Kent, Ph.D. Candidate, Genetics, University of British Columbia
Dr. Randy Kobes, Professor of Physics, Physics Department, University of Winnipeg
Dr. Louise Kuchel, Postdoctoral Fellow, Zoology, University of British Columbia
Catherine Laporte, Ph.D. Candidate, Dept. Electrical and Computer Engineering, McGill University
Theresa Yu Huan Liao, M.Sc. Candidate, Experimental Medicine Program, University of British Columbia
Sarah Manea, Astrophysics, University of Toronto
Shelley McCabe, M.Sc. Candidate, Dept. of Zoology, University of Toronto
Alyssa Moldowan, Ph.D. Candidate, Department of Physics, University of Western Ontario
Rachel Moll, Ph.D. Candidate, Curriculum Studies, University of British Columbia
Dr. David Ng, Director, Advanced Molecular Biology Laboratory, University of British Columbia
Dr. Greg Potter, Research Engineer, Borealis GmbH
Dr. Nikolas Provatas, Associate Professor, Materials Science and Engineering Department, McMaster University
Christian Rutledge, HBA Psychology & French, McMaster University
Hemanth Satish, M.Eng., Design Analyst, Beta Machinery Analysis Ltd.
Beth Simpson, Ph.D. Candidate, Human Nutrition, University of British Columbia
Robert Smith, Ph.D. Candidate, Department of Biology, Carleton University
Dr. Robert Sobot, Assistant Professor, University of Western Ontario
Susie Taylor, Special Programs Coordinator, Let's Talk Science
Dr. Christine Tenk, Assistant Professor, Department of Psychology, Brescia University College at The University of Western Ontario
Dr. Sheryl Tittlemier, Research Scientist, Health Canada
Dr. Scott Watter, Assistant Professor, Psychology Neuroscience and Behaviour, McMaster University
Dr. Paul Wiegert, Professor, Department of Physics and Astronomy, University of Western Ontario
Dr. Brea Williams, Project Manager, Halsall Associates
Michelle Zenko, M.Sc. Candidate, University of Ottawa

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Dr. Chris Valdivia, Engineering Specialist, R&D Cyrium Technologies
Jennifer Weaver, M.E.S, PhD Candidate, University of Toronto
Dr. Tabitha Woods, Assistant Professor, Department of Chemistry, University of Winnipeg
Pengcheng Xi, M.Sc. NRC Institute for Information Technology
Dr. John Yeomans, Professor, Department of Psychology, University of Toronto

Other Contributors

Arafat Aloqaily
Catherine Crouse-Dick
Nicole Husain
F. Kerton
Shawn Mansfield
Judy Shedden