let's talk science

CHALLENGE

2020 Study Handbook

Inspire your mind

with science, technology, engineering and math (STEM)!

The Let's Talk Science Challenge is made possible with generous national support from:

Boeing
GM Canada
Worley energy | chemicals | resources
Canada
Fondation Familiale Trottier Family Foundation
Roche
Scholar's Choice
3M

The Let’s Talk Science Challenge Student Handbook was created by volunteers from the following Let’s Talk Science Outreach sites:

Carleton University; Ottawa, Ontario
Laurentian University; Sudbury, Ontario
McGill University; Montreal, Quebec
McMaster University; Hamilton, Ontario
Memorial University of Newfoundland; St. John’s, Newfoundland and Labrador
University of British Columbia; Vancouver, British Columbia
University of Ottawa; Ottawa, Ontario
University of Toronto; Toronto, Ontario
University of Western Ontario; London, Ontario
University of Winnipeg; Winnipeg, Manitoba

Thank you to our national sponsors

Thank you to our regional sponsors

Quebec Event Partner

Enterprise Holdings Foundation

Let's Talk Science Visionary Donors

Mitchell A. Baran

How many hours per day do you use science, technology, engineering and math (STEM)? Nearly everything you touch today involves STEM and the amount of time you engage with STEM may surprise you!

Competing in the Let's Talk Science Challenge enables you to harness the power of those STEM hours and take an active role in your future. Through the Challenge, you develop important skills and knowledge as well as engage in experiences that help you shape Canada's future.

STEM is reshaping everything, including how we work and how we engage as citizens. We depend on science and technology innovation to address critical global challenges like climate change, sustainable clean energy, health care and providing clean water. Your ability to contribute to STEM innovation is honed at the Challenge and continues throughout your life. We can't wait to see what the future has in store, thanks to the potential that lives in your amazing brains.

At Let's Talk Science, our goal is to inspire you to think big. How will you change the world? What skills do you need? What courses will you take to help build an exciting future? Follow your dreams, keep your doors open, and you can become the researcher, entrepreneur, designer or innovator that inspires future Let's Talk Science Challenge competitors!

So, have fun, be inspired and good luck!

Bonnie Schmidt, C.M., Ph.D., FRSC
President and Founder, Let's Talk Science

Minister of Innovation, Science and Industry

Ministre de l'Innovation, des Sciences et de l'Industrie

Ottawa, Canada K1A 0H5

Message from the Honourable Navdeep Bains
Minister of Innovation, Science and Industry
Let's Talk Science Challenge

On behalf of the Government of Canada, please accept my congratulations on making it to the 2020 Let's Talk Science Challenge!

I'm so glad you're interested in the world of science. Hopefully, you will consider pursuing a career in STEM—not only because it's highly rewarding, but also because your country needs more young people like you to a have a strong, talented and innovative pool of professionals who will fuel Canada's economy in the future.

Through programs like Let's Talk Science and the #ChooseScience campaign, our government is promoting a culture where young Canadians are engaged in, and excited about, science. We also introduced programs to promote coding and digital skills in younger generations. Check out the new Citizen Science Portal and follow #ScienceAroundMe to learn more about the ways that science is transforming the world around us.

Please accept my best wishes and good luck in the days ahead. Be creative, be brave…be the next Canadian scientist!

Navdeep Bains
Minister of Innovation, Science and Industry

Canada

TABLE OF CONTENTS

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 knowledge 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 **Engineering 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 Innovation** section that features an innovative product or research from the past or present and at least one **My Career** section that introduces you to a person with a unique career. 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 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…).

Engineering Challenge

The Engineering 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 Engineering Challenges in this handbook. Each chapter (except for the Mathematics chapter) has an Engineering 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 Engineering 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 us at ecarty@letstalkscience.ca.

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

The LET'S TALK SCIENCE CHALLENGE team

let's talk science CHALLENGE | DÉFI parlons sciences

Biology
Chapter 1

2020

Thank you to our chapter sponsor: AMGEN

Introduction

Biology is the study of living things, from simple viruses and single-celled **organisms** (an organism is any form of life) to complex **multicellular organisms** (organisms made up of many cells, such as ourselves). This chapter is going to focus on a very large group of multicellular organisms – plants! From cells right up to whole organisms, we will explore the unique characteristics and **physiology** (functioning) of plants.

Plants

Plants are very important to human life for several reasons. Plants produce the oxygen that humans and animals breathe, which we require for survival. In addition, plants are a source of food for nourishment, as well as a resource for medicines, wood fiber for paper, clothes, and many other uses. Plants range in size from less than 1 centimetre to over 100 metres in height! Despite these differences, they have very similar structures, processes, and functions. What all plants have in common is the structure of their cells.

Plant Cells

The cell was first discovered in 1665 by an English scientist named Robert Hooke. While looking through a microscope, he observed tiny box-like objects in a slice of cork (bark from an oak tree) and named these boxes **cells**. Cells are the basic units of life, which make up all living things. This idea forms the basis of the **Cell Theory**.

Cell Theory

The three main parts of the cell theory are:

1. All living things are made of cells.
2. The cell is the basic unit of structure and function in all living things.
3. Cells only come from other pre-existing cells by **cell division**.

While some organisms are single-celled, others are made up of many cells. These organisms are called **multicellular** (having many cells). Cells differ in their size and complexity.

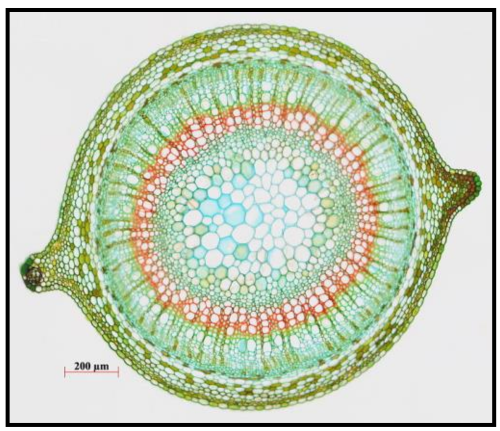


Figure 1: Cells seen in a plant stem cross-section.

Eukaryotes are organisms which are made up of large and complex cells, whereas **prokaryotes** are organisms which are made up of small and simple cells. Animals and plants are examples of eukaryotes (have **eukaryotic cells**) while bacteria are examples of prokaryotes (have **prokaryotic cells**).

Plant Cell Structure and Function

In spite of the differences in size and complexity, all cells are mostly composed of the same substances and they all carry out similar life functions. These include growth and metabolism and reproduction by cell division.

Cells are made up of subcellular structures that are responsible for different and specific functions. These structures are known as **organelles**. A number of these organelles are common to both animal and plant cells. This section will focus on those parts which plants have (see Figure 2).

Cell Structures (Cell Organelles)

❶Cell Wall: This is the rigid outermost layer of a plant cell. It makes the cell stiff - providing the cell with mechanical support - and giving it protection. Animal cells do not have cell walls.

❷Cell Membrane: This is a protective layer that surrounds every cell and separates it from its external environment. It is found just inside the cell wall and is made up of complex **lipids** (fats) and **proteins**.

❸Cytoplasm: The cytoplasm is a thick, **aqueous** (water-based) solution in which the organelles are found. Substances such as salts, nutrients, minerals and **enzymes** (molecules involved in metabolism) are dissolved in the cytoplasm.

❹Nucleus: The nucleus is the 'control center' of the cell. It contains **Deoxyribonucleic acid (DNA)**, the genetic material that directs all the activities of the cell. Only eukaryotic cells have **nuclei** (plural for *nucleus*), prokaryotic cells do not. The nucleus is separated from the cytoplasm by a specialized membrane called the ❺ **nuclear membrane**.

❻Ribosomes: These are little round structures that produce proteins. They are found in the cytoplasm or attached to the endoplasmic reticulum.

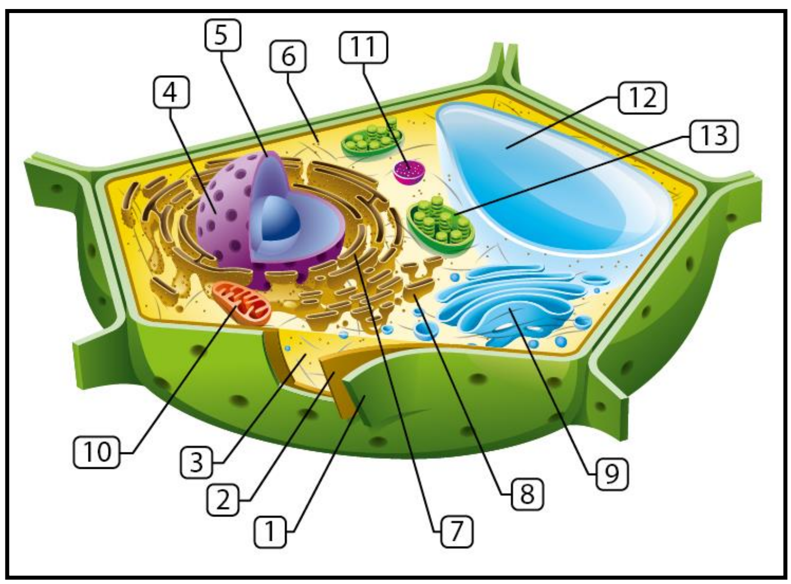


Figure 2: A typical plant cell.

Endoplasmic Reticulum (ER): The ER is a membrane system of folded sacs and tunnels. The ER helps move proteins within the cell as well as export them outside of the cell. There are two types of endoplasmic reticulum – ❼**smooth endoplasmic reticulum** and ❽**rough endoplasmic reticulum**. The rough endoplasmic reticulum is covered with ribosomes.

❾**Golgi body:** The Golgi body is a stack of membrane-covered sacs that prepare proteins for export from the cell.

❿**Mitochondrion** (plural ***mitochondria***): This is the 'powerhouse' of the cell. It converts the energy stored in food (sugar and fat) into energy-rich molecules that the cell can use (**Adenosine triphosphate** – **ATP** for short).

⓫ **Lysosome:** The lysosome is the digestive center of a cell that produces many different types of enzymes which are able to break down food particles and recycle worn out components of the cell.

⓬ **Vacuoles:** These are large membrane-enclosed compartments that store toxic wastes as well as useful products such as water. These are mainly found in plants.

⓭ **Chloroplast:** Chloroplasts contain a green pigment that traps sunlight and converts it into sugars by a process called photosynthesis (see page 7 for more). The sugars are a source of energy for the plants and the animals that eat them.

What Makes Plant Cells Unique

1. Plant cells have a cell wall.

Plant cells are different from animal cells in a number of ways. Perhaps the most obvious difference is the presence of a cell wall. The cell wall provides strength and support to the plant, much like the **exoskeleton** of an insect or spider (our skeleton is on the inside of our body, rather than on the outside like insects or spiders).

The plant cell wall is mainly made up of the **carbohydrates** molecules **cellulose** and **lignin**. Cellulose is used extensively by humans for making paper. Cellulose can also be converted into **cellulosic ethanol**, a type of **biofuel**. Some animals, such as cows, sheep and goats, can digest cellulose with the help of bacteria in their stomachs. Humans cannot digest cellulose, which passes through our bodies and is better known as dietary fiber, something that we should eat to keep our waste moving as it should! Lignin fills in the spaces between cellulose and other molecules in the cell wall. Lignin also helps water molecules move from one side of the cell wall to the other – an important function in plants.

2. Plant cells contain vacuoles.

Most adult plant cells have one large vacuole that takes up more than 30% of the cell's volume. At certain times and conditions the vacuole takes up as much as 80% of the cell's volume! In addition to storing wastes and water, the vacuole also helps to support the cell because the liquid inside the vacuole exerts an outward

pressure on the cell, much like the water inside of a water balloon. This is called **turgor pressure** and keeps the cells from collapsing inward.

3. Plant cells contain chloroplasts.
Unlike animal cells, plant cells can harness the energy of the Sun, store it in the chemical bonds of sugar and later use this energy. The organelle which is responsible for this is the chloroplast. Chloroplasts contain **chlorophyll**, the green pigment that gives leaves their colour and absorbs light energy. **Cyanobacteria**, a type of prokaryote capable of photosynthesis, are considered to be the ancestors of chloroplasts!

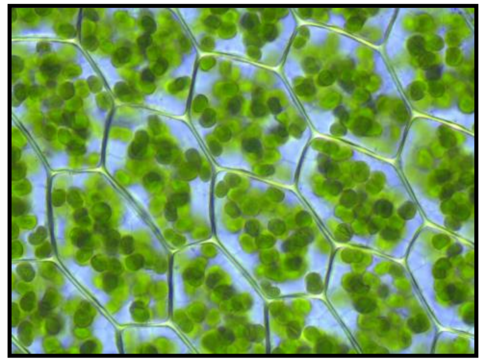


Figure 3: Chloroplasts visible in the cells of *Plagiomnium affine*, a type of moss.

Plant and animal cells also have many organelles in common, including the nucleus, cell membrane (called the **plasma membrane** in animals) endoplasmic reticulum, mitochondria and cytoplasm, as well as several others.

Did you know?
Red algae (multicellular marine algae) have chloroplasts that contain the pigment phycobilin rather than chlorophyll, which gives them a reddish, rather than green, colour.

Plant Taxonomy

Taxonomy is a method used by scientists to classify all living things in order to better understand their evolutionary relationships. Taxonomy includes species descriptions and identification. Modern taxonomy originated in the mid-1700s, when **Carl Linnaeus** established a system to classify all living organisms. He did this by giving every species a two-part Latin-based name, also known as a **scientific name**. Linnaeus categorized plants based on their **reproductive structures** (see page 12), in an attempt to better understand the evolutionary relationship between different plants.

All living things are grouped into broad categories called **kingdoms**. Plants are in the kingdom **Plantae**. Within a kingdom are many categories called **phyla** (singular is phylum). The Kingdom Plantae includes the phyla **Chlorophyta** (green algae), **Bryophyta** (mosses), **Pteridophyta** (ferns), **Coniferophyta** (conifers) and **Magnoliophyta** (flowering plants).

Chlorophyta – Green Algae

Although not technically plants, green algae are the organisms from which land plants evolved. Green algae include **unicellular flagellates** (single-celled organisms with tail-like structures) (see Figure 5), multicellular forms and macroscopic seaweeds – all of which can photosynthesize. Green algae are primarily aquatic; most commonly found in freshwater and marine habitats, but can also be found on trees and rocks. Some are also symbiotic (living in relationship) with fungi, forming what are known as **lichens**. The group of green algae most closely related to land plants is the Charophytes.

Figure 4: *Chlamydomonas* - a type of green algae.

Bryophyta – Mosses

These are the most primitive true plants. Mosses lack a **vascular system**, meaning they do not have **tissue** (group of cells that work together to perform a specific function/role) to transport water throughout the plant. Instead, mosses acquire their water, nutrients and minerals by a process called **osmosis**, where water moves from areas with a lot of water to areas with less water. Since Bryophyta cannot easily carry water and nutrients throughout a large plant, mosses grow low to the ground (usually only a few centimeters high). Mosses also lack **roots** (see 'parts of a plant' section). Instead, mosses have **rhizoids**, which are root-like threads that help anchor the plant to the ground without absorbing nutrients and water.

Mosses usually live in damp and shady areas, and grow in clumps to form dense, soft masses of vegetation. Mosses are one of the first types of plants to become established on rocky ground. Like lichens, they are able to break down the rock, allowing the early stages of soil formation, which is essential for larger plants to grow. Mosses are able to absorb many times their weight in water, and help to prevent soil erosion by capturing rainfall.

Pteridophyta – Ferns

Still primitive, but more advanced than mosses, ferns do have a vascular system to transport water and nutrients throughout the plant. The vascular system includes tissues such as **xylem** (a transport tissue which moves water around the plant) and **phloem** (a transport tissue which moves nutrients – particularly sugar – around the plant). Ferns have roots that absorb water and nutrients from the soil, which then get transported to the **stems** and **leaves** via the xylem and phloem. Ferns are also known for their **fiddleheads** – the curled-

Figure 5: *Pteridium aquilinum*, commonly known as bracken fern, occurs in temperate and subtropical regions.

up leaves of young ferns. Ferns grow in a variety of habitats, including on mountains, in the crevices of rock faces, around swamps and in moist forests. One of the most common ferns is bracken fern (see Figure 5).

Coniferophyta – Conifers

Figure 6: *Picea sitchensis*, a Sitka spruce on Vancouver Island.

Gymnosperms are the first group of vascular plants to produce **seeds** (see 'parts of a plant' section). Unlike **angiosperms** (flowering plants), gymnosperms have uncovered seeds, hence their name – *gymno,* meaning "naked," and *sperm,* meaning "seed." The most common familiar phylum of gymnosperms is coniferophyta (**conifers**), which include pines, cedars, junipers, spruces and many others.

Conifers are woody and have **cones** and **needles** (in fact the needles are actually just long, pointed leaves!). They are also generally **evergreen**, meaning they do not lose their leaves/needles over the winter, but instead gradually replace them throughout their lifetime. Pine needles have a waxy coating, allowing them to retain water throughout the winter, while still allowing them to capture sunlight for photosynthesis. Conifers are mainly found in the northern hemisphere. They thrive in areas where summers are short and winters are long, due to their ability to retain water during the winter. They are also among the tallest trees, with some species growing upward of 90 meters (see Figure 7)!

Magnoliophyta – Flowering Plants

Flowering plants (**angiosperms**) in the phylum magnoliophyta are the most evolved, most diverse and most successful group of plants. In fact, flowering plants make up approximately 90 percent of the kingdom Plantae! Angiosperms are vascular, seed-producing plants with **flowers** and **fruits** that enclose the seeds (see 'parts of a plant' section). Flowering plants have colonized nearly every land habitat conceivable – from deserts to windy alpine summits, marshes and rainforests. Flowering plants include grasses, lilies, roses, cacti and most broad-leaved trees.

Figure 7: Yellow Trout Lilies are an example of a flowering plant.

Parts of a Plant

Just as people have tissues and organs, plants also have specialized tissues and structures. The tissues and structures make up two broad systems: the **shoot system** and the **root system**. The shoot system is made up primarily of **leaves**, **stems**, and **reproductive structures** (e.g., flowers, fruit, seeds, etc.) and the root system is made up of roots (see Figure 8). Each of these structures has characteristics that help it to carry out its major function.

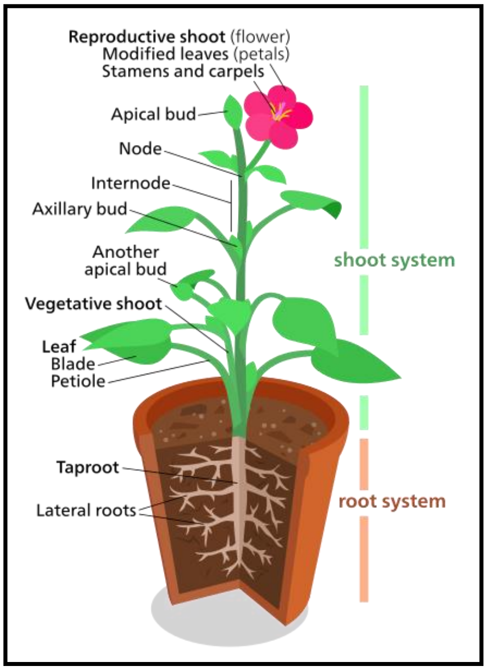


Figure 8: Parts of a plant.

Leaves

Leaves are the mostly flat green parts of plants.

The flat part of a leaf is called the **lamina** (also known as the **leaf blade**). The part of the leaf which attaches to the stem is called the **petiole** (also called a **leaf stalk**). Most, but not all, leaves have these parts.

Leaves are typically large and flat so that they can expose as many of their chloroplasts to sunlight as possible.

The role of a leaf is to:

- Provide a place for photosynthesis to occur; and
- Be involved in transpiration of water (see 'plant function' section).

Some leaves, however, have specialized functions giving them unusual shapes and colours. Some you might not even recognize as leaves! The thin needles on pine trees and other conifers are actually leaves. Their small surface area combined with a waxy covering helps these leaves to minimize water loss.

Have you ever seen a Poinsettia plant in the winter holidays like the one in Figure 9? What appear to be red flowers are actually specialized structures called **bracts**. The flowers are the little yellow things in between the red bracts. Bracts are specialized leaves which help to attract **pollinators** such as bees and birds to the flowers. Many flowers are attractive to animals, such as birds and bees, which transfer pollen (containing the sperm) from one flower to another. Due to their role in helping to spread pollen, these animals are known as pollinators.

Figure 9: Red bracts on Poinsettia plants.

Stems

The stem is a structure which forms the core of the shoot system. The stem is divided into two parts; **nodes** and **internodes**. Nodes are where buds grow into leaves, other stems, or flowers and **internodes** are the parts of the stem in between the nodes (see Figure 8). In most plants, stems are found above the ground, but for some plants, such as potatoes, stems are also found below the ground. The part of the potato plant we eat, called a **tuber**, is actually a specialized underground stem which stores nutrients for the plant.

Figure 10: Buckets for collecting maple sap on a maple tree.

The role of the stem is to:

- provide support for the plant
- provide a place for leaves, flowers and fruit to grow;
- keep leaves facing towards sunlight;
- transport **water** and **nutrients** up from the roots and transport the products of photosynthesis down from the leaves; and
- store nutrients.

Humans have many uses for plant stems. We extract sugar from sugar cane stems and make **maple syrup** from the **sap** (sugar and water) found in maple tree stems (we call tree stems **trunks**) (see Figure 10).
Paper and wood also come from tree stems, as do cinnamon and cork which are both made from the **bark** (outer layer) of tree stems.

Roots

The **root system** is the system of structures typically, but not always, found below the ground.

The role of roots is to:

- anchor the plant to the ground;
- take up water and minerals needed for growth and development;
- store food and nutrients; and
- provide a means of reproduction called **vegetative** (asexual) reproduction (see below).

Although roots are generally below ground, they do require some oxygen to stay alive. Generally, this small quantity of oxygen is found naturally between the grains of soil, but if the soil is **saturated** (filled with water), the oxygen is forced out. Without the needed oxygen underground, the plants will start to produce roots above ground. Roots can be thin and hair-like (**fibrous roots**) (see Figure 11A), short and thick (**taproots**) (see Figure 11B), or somewhere in between (e.g., **buttress roots**) (see Figure 11C).

Figure 11: A – fibrous roots (tomato plant), **B** – taproots (carrots), **C**- buttress roots (fig tree).

Plant Reproduction

Plants reproduce in a number of ways. The most primitive members of the plant kingdom, green algae, reproduce **asexually** (offspring only have one parent) by **fission** (splitting). Other plants can reproduce by the asexual process called **fragmentation** (breaking apart) (see Figure 12). The remainder of plants reproduce **sexually** (offspring with parents from each sex) by releasing **gametes** (reproductive cells). Male reproductive cells are called **sperm** and female reproductive cells are called **eggs.** Next we look at some of the different types of reproductive organs used by plants.

Figure 12: New plants a long a leaf edge.

Spores

Spores are reproductive cells that are able to develop into a new individual without fusing with another cell (in contrast, seeds are formed when male and female gametes join together). The microscopic spore cell has everything it needs to grow into a multicellular plant, and under favorable conditions the cell will divide and grow. In plants, spores can be found on non-seed bearing plants including green algae, mosses and ferns. Often, the spores are located on the underside of the leaves and are carried to a new area by wind or rain. Spores, unlike seeds, are less likely to be eaten by animals, but they are at risk of being consumed by bacteria and fungi.

Flowers

Flowers are what make flowering plants flowering plants! Flowers provide the mechanisms for sperm to find eggs, thus leading to fertilization and development of seeds (see Figure 13).

The outermost parts of the flower which typically surround the rest of the flower are green structures called **sepals**. Inside of the sepals are the **petals**, which are typically colourful. Petals on flowers are also modified leaves which serve a similar function as bracts. Next are the **stamens**, each of which contains a filament topped by pollen-producing cells.

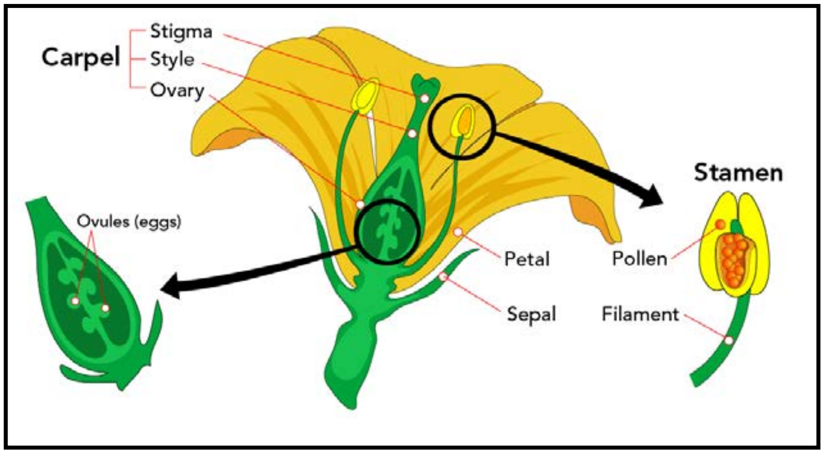


Figure 13: Parts of a flower.

The innermost part of the flower is the **carpel**, which contains the **ovary** (where the eggs are located). The pollen from another flower must enter the ovary and fertilize the ovule in order for a seed to start developing.

Seeds

Seeds are **embryonic** (immature) plants that are enclosed in protective seed coats. Seeds often contain stored nutrients in the **endosperm**, which is rich in oil, starch and protein. Seeds can be **dispersed** (sent to new places) by wind (can be lighter or structured to be air-borne), by water (can float so they can drift down rivers) or by animals (can have barbs to catch on animal's fur or can be eaten and dispersed through an animal's droppings). Seeds are a more evolutionarily advanced form of plant reproduction than spores and are present in both gymnosperms and angiosperms. In gymnosperms the seeds are covered by the **scales** of cones, while in angiosperms the seed becomes covered with a fleshy or hard fruit.

Cones

Cones are the parts of conifers which contain reproductive structures. Female cones (see Figure 14A) produce ovules. Male cones (see Figure 14B), which are much smaller and not as visible, produce pollen (which is visible as a yellowish powder). The ovule, once fertilized by pollen, becomes a seed. In most conifer species, the male and female cones appear on the same plant, with the female cones on higher branches and the male cones on lower branches. This is to improve **cross-fertilization** (being

Figure 14: Cones of *Pinus resinosa*. The cone on the left (A) is a female cone and the cones on the right (B) are male cones.

fertilized with the pollen of another plant) and avoid **self-fertilization** (being fertilized with its own pollen). The tiny, lightweight pollen of one conifer is more likely to be carried by the wind to female cones of a different conifer than upward into its own female cones.

Fruit

Figure 15: A few of the many varieties of fruit.

Fruit is the result of the maturation of one or many flowers, and is therefore only found in angiosperms. In cooking, a fruit is any sweet-tasting plant product. However in plant science (**botany**), a fruit is considered the ripened ovary of a seed-bearing plant which contains its seeds. In flowering plants, as a seed develops, its ovary begins to ripen and the ovary wall, called the **pericarp**, becomes fleshy (as in berries and apples) or forms a hard outer covering (as in nuts). Botanically, fruit also include beans, corn kernels, tomatoes, wheat grains, pumpkins, peanuts, cucumbers and rice!

Plant Functions

Plants have an important feature that makes them different from other organisms – they are **autotrophs** (self-feeding). Autotrophs are able to make their own food from inorganic materials through a process known as photosynthesis. In contrast, humans and other animals are **heterotrophs**, which means that we get our food from outside of ourselves.

Photosynthesis

Photosynthesis is the process in which plants convert the **light energy** captured by chloroplasts to **chemical energy** needed for daily survival. Chlorophyll pigments in the chloroplasts use water and **carbon dioxide** from the air to form carbohydrates which store energy in their chemical bonds. Carbohydrates are compounds including all simple **sugars** (e.g., **sucrose** or 'table sugar') as well as complex sugars such as **starch** and cellulose which store energy in plants. Carbohydrates can be stored in different parts of the plant, such as in leaves and stems (e.g., potatoes). They can also be stored in fruit as **pectin,** which is the reason that fruit can be so sweet. Roots, such as carrots, are also storage organs for carbohydrates.

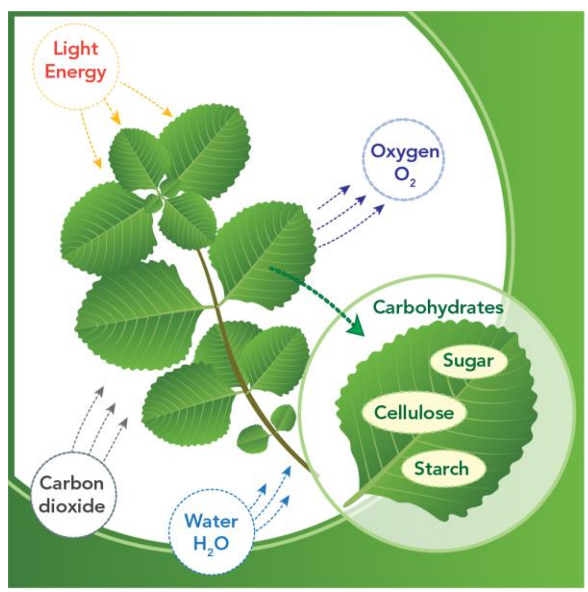


Figure 16: Process of photosynthesis.

Respiration

Respiration is essentially the opposite of photosynthesis. In the first step of this process, oxygen reacts with sugar in a plant cell, releasing the sugar's stored chemical energy. The energy released is transferred to a new molecule called **ATP (adenosine triphosphate).** The ATP molecule can then be transported throughout the cell where it can be used to complete various tasks. This process releases carbon dioxide and water. Unlike photosynthesis which can only happen when there is light, respiration can happen both in the day and at night.

Transpiration

Transpiration is the term for the **evaporation** of water from the surface of leaves and stems. Transpiration is a necessary part of photosynthesis and respiration. Water produced during respiration exits the plant through specialized structures called **stomata** (little pores in the leaf that can open and close, as needed) (see Figure 17). Through these same stomata, the carbon dioxide needed for photosynthesis can enter the plant. Water initially enters the plant through the roots by the process of osmosis. The water travels up the stem of the plant through specialized tissue called the xylem, and then can exit the plant leaf through stomata which are located on the leaves.

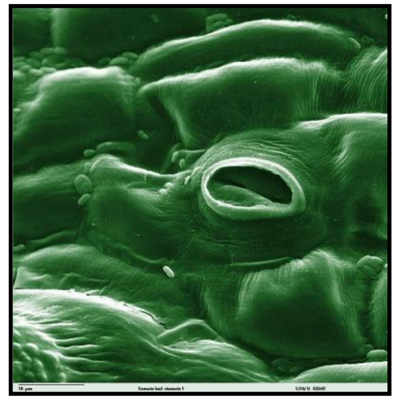


Figure 17: Stomata on the surface of a leaf.

When water availability is limited, the plant has to conserve water. It does this by closing its stomata, which decreases water evaporation, but also decreases the amount of carbon dioxide which can enter the cell. This results in decreased rates of photosynthesis which slows growth. However, at the same time it conserves water needed for survival. During this time, the plant can use its stored energy.

Since plants cannot move around to find energy and water, they have adapted several unique ways to be able to supply their needs. This happens through a balance between water and nutrient uptake through the roots and energy uptake through the leaves. The anatomy of both the plant cell and plant body allows plants to carry out special reactions to survive in a variety of habitats.

Spotlight on Innovation

Advanced Biofuels at ExxonMobil

Figure 18: Scientists completing tests in the algae greenhouse.

Global demand for energy is expected to grow by about 25 percent by 2040. ExxonMobil is a company that is finding ways to supply world energy demand while reduce emissions. One way they do this is by creating **biofuels**. Unlike most fuels which are made from petroleum, biofuels are fuels made from plants.

Biofuels used today are mainly made from agricultural crops. Sugar cane and corn are used to make the biofuel **ethanol** and vegetable oils like soy are used to make the biofuel **biodiesel**. Scientists at ExxonMobil are working to turn **algae** and **plant waste**, such as corn stalks and wheat straw, into biofuels.

There are many benefits of using algae for biofuels. Unlike corn, which is harvested only once a year, algae can be harvested repeatedly throughout the year. Algae can also be produced on land that is not suitable for other purposes. And algae can use water that can't be used for food production. Algae can even purify polluted water! Algae biofuels also have the potential to be produced on a large scale.

How does it work? Algae produce three things: protein, sugar, and fat (**lipid**). Biofuel is made from the lipid part of the algae. Most types of algae do not produce a lot of lipids. So ExxonMobil and Synthetic Genomics, Inc. (SGI) are working together to identify and modify algae to get it to make more lipids.

Biofuels can significantly reduce greenhouse gas emissions compared to today's transportation fuels. This is because plants remove carbon dioxide (CO_2) from the atmosphere while they grow. Biodiesel can be used by existing diesel automobiles without making major changes.

ExxonMobil is working to identify the best way to make these ground breaking technologies available to consumers. They combine science and engineering to develop biofuels that are affordable for customers and sustainable for the environment. ExxonMobil aims to produce 10 thousand barrels of algae biofuels per day by 2025.

My Career

Denise Hockaday
Climate Business Director Canada
Climate Corporation

Figure 19: Denise Hockaday

Denise grew up on a dairy farm in eastern Ontario where she was actively involved in her farming community. She graduated from the University of Guelph with a Bachelor's Degree in Commerce with a focus in **Agribusiness**.

Much like the rest of the world, Canada is going through a period of change in agriculture. There is an increasing interest in buying local food. And people are more interested in how and where their food is grown.

Canadians are also concerned about climate change. They want to know that farmers are taking steps to grow food today that will keep our environment healthy for future generations. But did you know that farmers will need to feed a world population of nearly 10 billion people by 2050? This will require an increase in global food production of more than 60 per cent. So how can farmers grow more food while using land, water and energy sustainably?

Increasingly, farmers today are using **digital tools** and **data science**. These technologies are enabling them to make better decisions on what, where and when to plant. This is where the Climate Corporation comes in.

The Climate Corporation's **Climate FieldView™** software is one of the most widely used platforms in the industry. Through the platform farmers can visualize and evaluate field conditions and crop performance instantaneously with weather data, satellite imagery, and field data maps. This helps them make better decisions so they can get the most out of every acre.

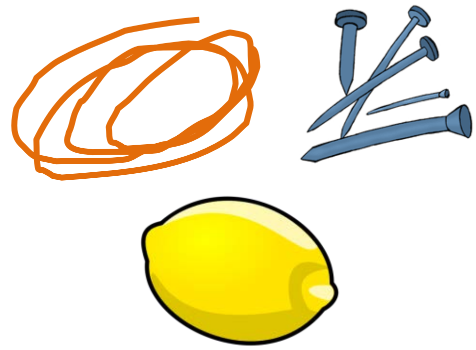
As Denise looks to the future, she believes that there will be great demand in agriculture for people that come from a variety of backgrounds. From business to communications to software development and science, all backgrounds have a role to play in the development of software such Climate FieldView™. A person interested in agriculture today does not need to have grown up on a farm or completed an Agricultural Science degree. Agriculture is a great and rewarding industry for everyone, so check it out!

Fruit Battery Engineering Challenge

Challenge:

Your challenge is to work as a team to design and build a simple battery (**electrochemical cell**) using fruit. Your goal is to get your battery to generate the largest voltage possible given the rules below.

Materials:



- Large galvanized nails (coated in zinc)
- Copper wire
- Copper pennies
- Voltmeter
- Alligator clips

Choice of:

- Fruit (lemons, apples, bananas, etc.)

Rules:

- No more than three pieces of fruit may be used. It could be three different kinds of fruit or three of the same kind of fruit.
- No more than 6 nails and/or pennies may be used.

Success

- Your group will be successful when:
  a) You have set up an electric circuit which includes the voltmeter.
  b) You have generated at least **1 volt** of electricity using the fruit.
  c) You have generated the highest voltage you can.

Pushing the Envelope

- Can you set up a circuit using fruit which can light up an LED light bulb?
- Why do you think some fruit generate more voltage than others?
- What would you need to do to generate even more voltage?

References

Figure References

Figure 1: Cells seen in a plant stem cross-section. http://commons.wikimedia.org/wiki/File:Hypericum_perforatum_stem_cross_section.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 2: A typical plant cell. Image ©2013 Let's Talk Science using an image from SMART Exchange http://exchange.smarttech.com/details.html?id=101afab2-afaa-4f37-ad0c-4bab04b79b8a (Accessed June 28, 2019)

Figure 3: Chloroplasts visible in the cells of *Plagiomnium affine*, a type of moss. http://commons.wikimedia.org/wiki/File:Plagiomnium_affine_laminazellen.jpeg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 4: *Chlamydomonas* - a type of green algae. http://commons.wikimedia.org/wiki/File:Chlamydomonas_EPA.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 5: *Pteridium aquilinum*, commonly known as bracken fern. Image ©2013 Ariane Batic. Used with permission.

Figure 6: *Picea sitchensis*, a Sitka spruce on Vancouver Island. http://commons.wikimedia.org/wiki/File:The_San_Juan_Spruce_-_the_largest_Sitka_Spruce_in_Canada.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 7: Yellow Trout Lilies https://commons.wikimedia.org/wiki/File:Yellow_Trout_Lily_-_Flickr_-_treegrow_(2).jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 8: Parts of a plant. http://commons.wikimedia.org/wiki/File:Plant.svg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 9: Red bracts on Poinsettia plants. http://commons.wikimedia.org/wiki/File:Poinsettia_2.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 10: Buckets for collecting maple sap on a maple tree. http://commons.wikimedia.org/wiki/File:Seau_%C3%A0_eau_d%27%C3%A9rable-Qu%C3%A9bec.JPG (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 11A: Fibrous roots (tomato plant) http://commons.wikimedia.org/wiki/File:Tomaat_wortels.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 11B: Taproots (carrots) http://commons.wikimedia.org/wiki/File:NRCSAZ78001_-_Arizona_(493)(NRCS_Photo_Gallery).jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 11C: Buttress roots (fig tree) http://commons.wikimedia.org/wiki/File:Buttress_roots.JPG (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 12: New plants a long a leaf edge. https://upload.wikimedia.org/wikipedia/commons/5/50/Kalanchoe_veg.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 13: Parts of a flower. Let's Talk Science using image at https://pixabay.com/vectors/diagram-flower-mature-anatomy-41571/ (Accessed June 28, 2019)

Figure 14A: Female cone of *Pinus resinosa*. http://commons.wikimedia.org/wiki/File:Pinus_resinosa_foliagecone.jpg (Accessed June 28, 2019) Public domain images on Wikimedia Commons.

Figure 14B: Male cone of *Pinus resinosa*. http://commons.wikimedia.org/wiki/File:PinusFlower.jpg (Accessed June 28, 2019) Public domain images on Wikimedia Commons.

Figure 15: A few of the many varieties of fruit. http://commons.wikimedia.org/wiki/File:Fruit_and_vegetables_basket.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 16: Process of photosynthesis. Let's Talk Science using an image by iStockphoto.

Figure 17: Stomata on the surface of a leaf. http://commons.wikimedia.org/wiki/File:Tomato_leaf_stomate_1-color.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 18: Scientists completing tests in the algae greenhouse. Photo provided by ExxonMobil. © ExxonMobil. Used with permission.

Figure 19: Denise Hockaday. © Denise Hockaday. Used with permission.

General Resources

Plant Cells

http://www.biology4kids.com/files/cell_main.html (Accessed June 28, 2019) This section, from Biology4kids, has information about cells and their organelles.

http://www.youtube.com/watch?v=9UvlqAVCoqY (Accessed June 28, 2019) This YouTube video, from Crash Course, is about plants and plant cells.

Plant Parts

http://urbanext.illinois.edu/gpe/index.cfm (Accessed June 28, 2019)
This interactive, The Great Plant Escape, from the University of Illinois, has activities about the parts of a plant and how they grow.

Photosynthesis

http://www.biology4kids.com/files/plants_photosynthesis.html (Accessed June 28, 2019) This section, from Biology4kids, has information about photosynthesis.

http://www.wonderville.ca/asset/photosynthesis (Accessed June 28, 2019)
This animation, from Wonderville.ca, is about photosynthesis.

http://www.sites.ext.vt.edu/virtualforest/modules/photo.html
(Accessed June 28, 2019)
This interactive, from the 4-H Virtual Forest, shows you how photosynthesis works.

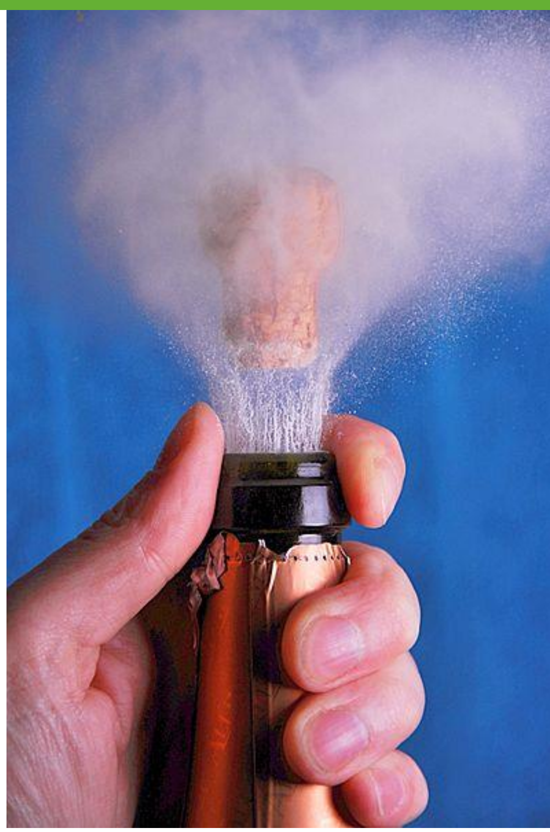
Plant Taxonomy

http://www.biology4kids.com/extras/show_plants/index.html (Accessed June 28, 2019) This section of the Biology4kids website, has a slide show of different groups in the plant kingdom.

Spotlight on Innovation

https://letstalkscience.ca/educational-resources/stem-in-context/biofuels-alternative-energy-source (Accessed January 16, 2020)
This article by Let's Talk Science talks about biofuels as an alternative energy source.

http://www.eia.gov/kids/energy.cfm?page=biofuel_home-basics (Accessed January 16, 2020)
This page from the U.S. Energy Information Administration has information about biofuels for kids.



Chemistry

Chapter 2

2020

Thank you to our chapter sponsor: FONDATION FAMILIALE TROTTIER FAMILY FOUNDATION

Introduction

Chemistry helps us understand the properties and composition of the world around us. In this section you will learn about the states of matter, as well as lots about one state in particular (three guesses – it's not solid or liquid...).

The States of Matter

Depending on **temperature**, **pressure** and a substance's properties, a substance can take on different physical forms. We call these physical forms **States of Matter**. There are 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 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).

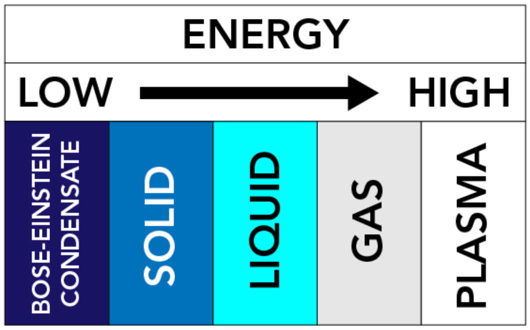


Figure 1: The states of matter.

The forces between particles and the pressure on particles keep the particles together. If we warm up matter (add **energy**), the particles start moving faster and tend to spread apart. This movement of particles has a large effect on the state of a substance.

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.

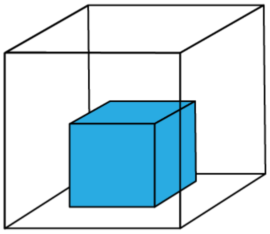


Figure 2: A solid.

Liquids

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

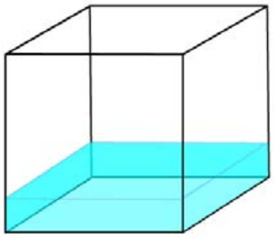


Figure 3: A liquid.

Gases

Gases are difficult to relate to because they are often invisible, but found all around. You can feel them when, for example, the wind blows. You can sometimes smell them when, for example, you smell the odour of food that is cooking, or when a skunk has been upset. Some gases are important for our health (e.g., oxygen) while others can be deadly (e.g., hydrogen sulfide and chlorine). Before surgery, you may receive an **anesthetic** gas, which contains chemicals, to relieve pain and make you unconscious during the procedure. Gases are also responsible for the force of explosions. Let's have a closer look at gases.

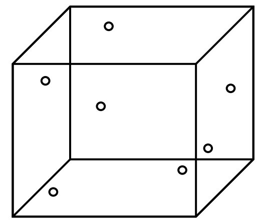


Figure 4: A gas.

Types of Gases

There are **elemental** gases (made up of a single **element**) and gases that are **compounds** (made up of more than one element). The symbols of the elemental gases can be found in any **Periodic Table of Elements**. They are summarized in the chart below.

Diatomic Gas	Chemical Formula	Monatomic Gas	Chemical Formula
hydrogen	H_2	helium	He
oxygen	O_2	neon	Ne
nitrogen	N_2	argon	Ar
fluorine	F_2	krypton	Kr
chlorine	Cl_2	xenon	Xe

A **diatomic gas** is one in which the basic unit is a molecule made of two atoms joined together. A **monatomic gas** is one in which the basic unit is a single atom. Most gases, however, are compounds with two or more different elements chemically united. The most common one is water vapour, H_2O. Here are the names, formulas and uses of some compound gases:

Common Name	Chemical Formula	Where you normally find it
Carbon dioxide	CO_2	Atmosphere, car exhaust, pop, our lungs
Propane	C_3H_8	BBQs, camp stoves, fuel for some vehicles
Methane	CH_4	Component of greenhouse gas and natural gas
Ammonia	NH_3	Used to make fertilizers, cleaning products

Kinetic Molecular Theory of Gases

Gases behave in certain ways that are described by so-called '**gas laws**.' Laws in science are not the same as how we normally think about laws. These laws simply describe behaviour; they do not offer any explanations. To provide an explanation, a **theory** is needed. The theory used to explain how gases behave is called the **Kinetic Molecular Theory of Gases**.

Kinetic Molecular Theory of Gases

This theory helps us understand the behaviour of gases. There are four **assumptions** (things we think are true) that form the basis for the theory:

1. Particles (atoms or molecules) are constantly moving in straight lines until they either collide with other particles or with the walls of their container.
2. There is no loss of energy when a particle collides with another particle or the wall of the container - this is known as an **elastic collision** in the world of molecules. In our world, collisions always result in some loss of energy due to friction. These are called **inelastic collisions**.
3. The volume of the particles themselves is so small compared to the volume of the space they occupy that it is considered to be **negligible** (can be ignored).
4. There are <u>no</u> **forces of attraction** between particles (because they are so far away from each other).

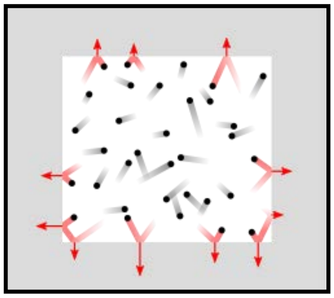


Figure 5: Pressure inside a container.

So what can this theory explain? First, it explains **pressure**. The force of many collisions by many molecules against the walls of a container is what we call pressure. In Figure 5 you can see where the molecules are exerting an outward force on the container (shown by the red arrows). If the pressure becomes stronger than the container is able to withstand, there will be an **explosion** (rapid expansion of gas). You may have had this happen if you have shaken a can of pop or seen this happen when someone uncorked a bottle of champagne (see Figure 6).

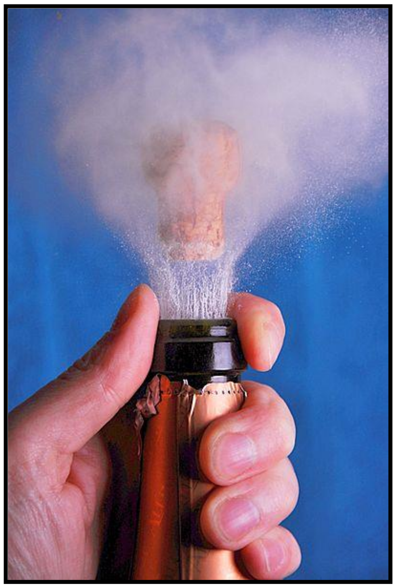


Figure 6: Release of pressure from a champagne bottle.

All of the energy of a gas is in the form of **kinetic energy** (energy from movement). Since, according to the Kinetic Molecular Theory, molecules do not lose energy when they collide, this means the average kinetic energy of the molecules stays constant. Any change in kinetic energy is accompanied by a change in

temperature (and vice versa – when there is a change in the temperature, there is a change in the kinetic energy).

Units for Measuring Gases

Before we can look at how gases behave, we need to know something about how we measure the physical properties of gases.

Volume

The amount of space a gas takes up is its volume. Volume is measured in units called **capacity units**. The most common examples of capacity units are millilitres (mL) and litres (L). Very small volumes can be measured in microlitres (μL) while very large volumes can be measured in kilolitres (kL).

Temperature

We are all familiar with the **Celsius scale**, which was named after Anders Celsius, a Swedish astronomer and physicist. We use this scale in day-to-day life for measuring the temperature outside, the temperature of swimming pool water, and our own body's temperature. Both the Celsius scale (used in the metric system) and the **Fahrenheit scale** (used in the imperial system) are based on water because originally people were interested in knowing when water changes state (e.g., its freezing point and boiling point). These scales work well for many liquids and solids, but it turns out that neither of the scales works well for describing the behaviour of gases.

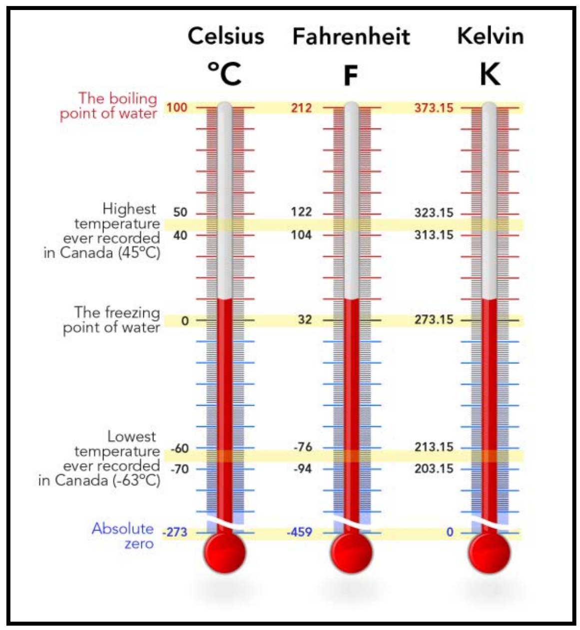


Figure 7: Fahrenheit, Celsius and Kelvin scales.

So why do the Celsius and Fahrenheit scales not work well for describing gases? If you remember from above, kinetic energy is related to temperature. A substance at a temperature of 0°C does not mean it has zero kinetic energy. As we will see below, the particles of a substance at 0°C still has a considerable amount of kinetic energy.

What is needed for gases is a temperature scale in which zero means the particles are not moving at all (i.e., have zero kinetic energy).
A temperature scale was created specifically for this purpose. It is called the **absolute temperature scale** or the **Kelvin scale**, named after its creator, Lord Kelvin of England. As you can see in Figure 7, **absolute zero**, or 0 K, is the lowest temperature. (Note that there is no degree sign when using the Kelvin scale). Thus, the freezing point of water can be written as 0°C or 273.15 K.

To convert °C to K add 273.15 to the number in °C (e.g., 3 °C would be 3 + 273.15 = 276.15 K).

Canada adopted the metric system for everyday use in the 1970's. In all countries, the metric system is the most commonly used system for scientific applications.

Pressure

As we saw above in the Kinetic Molecular Theory, pressure is caused by the collision of molecules against the walls of the container. These collisions can be thought of as a force exerted upon an area of the wall. We can express this using the equation:

$$P = F/A$$

where P stands for pressure, F stands for force and A stands for area. Force is measured in units called **newtons** (**N**) and **area** is measured in square metres (**m²**). The unit of pressure then can be stated as **N/m²**, which is called the **pascal (Pa)** after the seventeenth-century philosopher and scientist **Blaise Pascal**. In the imperial system, pressure is given in **pounds per square inch** (lb/in² or **psi**). This unit is still used in pressure gauges that measure the air pressure in car tires.

The most common unit for pressure in science is the kilopascal (kPa), which is 1000 Pa. Another commonly used unit is the **bar**, which is 100 kPa.

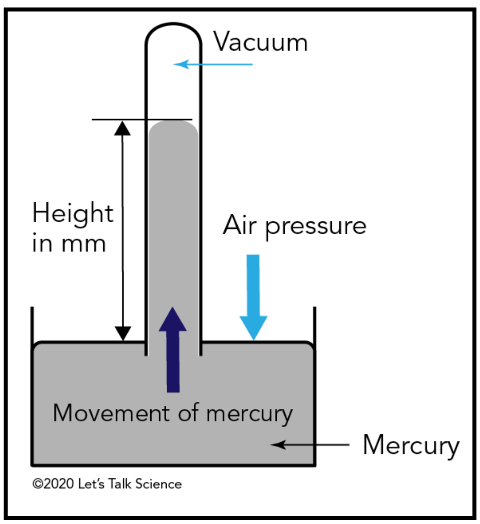


Figure 8: Mercury barometer.

One way to measure air (atmospheric) pressure is with a pressure measuring device called a **barometer**. One of the first practical barometers - a type still used today - uses an upright tube that is partially filled with **mercury** and sits in a container of mercury (see Figure 8). The tube is closed at the top and contains a vacuum, so that when air molecules from the atmosphere push down on the mercury in the container, the mercury is forced up into the tube. The mercury rises up the tube until its fluid pressure exactly matches the atmospheric pressure.

The height (in mm) to which the mercury rises in the tube (above the level of mercury in the container), is equivalent to the pressure pushing down on the mercury by the atmosphere. The unit for this type of measurement is called **mm Hg** (millimetres of mercury) or **torr** (1 mm Hg = 1 torr). In more modern commercial barometers, the mercury sits in an enclosed well at the bottom and its height is measured in millimetres by a precise scale at the top (Figure 9).

Figure 9: Modern barometer.

A baseline measurement for atmospheric pressure uses the pressure at **sea level**. At sea level, the height of mercury in a barometer is 760 mm. This can also be expressed in psi (14.696 lb/in^2) and kPa (101.325). The pressure at sea level is also known as one **standard atmosphere**, which uses the symbol **atm**. More recently, the atm has been replaced with the **bar**, which is a unit equivalent to 100 kPa (a nice round number to work with!). If you made a barometer with water instead of mercury, it would need to be more than 10 m tall to measure atmospheric pressure!

To measure the pressure of a gas inside a container, we use a different type of measuring device called a **pressure gauge**.

The pressure gauges used to measure the pressure inside bicycle or car tires work in a similar way to the mercury, but instead of the air pushing a fluid through a tube, in a tire gauge, the air pushes on a **piston** attached to a **spring** inside a tube (see Figure 10).

Like the mercury, the distance the piston travels is relative to the pressure in the tire. A **calibrated rod** (essentially a ruler) tells you the pressure in psi.

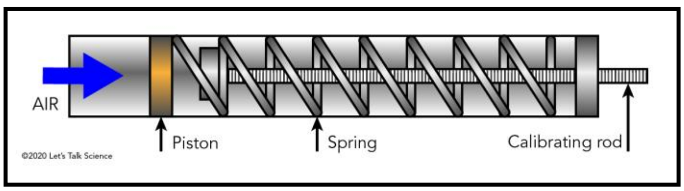


Figure 10: Inside a tire pressure gauge.

Gas Laws

There are four laws, known as **Gas Laws**, which describe how gases behave. The four laws are Boyle's Law, Charles's Law, Gay-Lussac's Law and Avogadro's Law.

Boyle's Law

Robert Boyle, a famous English chemist, discovered in 1662 that if you pushed on a gas, its volume would decrease proportionately. For example, if you doubled the pressure on a gas (increased the pressure two times), its volume would decrease by half (decreased the volume two times) (see Figure 11). The opposite is also true. If you reduced the pressure on a gas by 3.5 times, then its volume would increase by 3.5 times. This law is an example of an **inverse relationship** - if one factor increases, the other factor decreases.

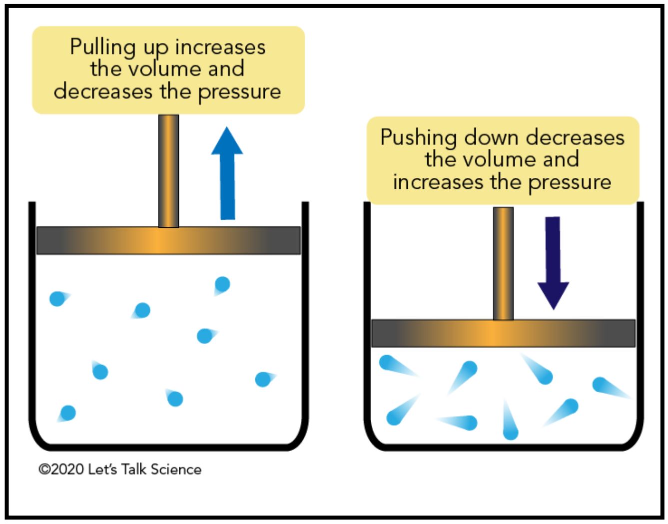


Figure 11: Relationship between pressure and volume of a gas.

Boyle's Law in Everyday Life

Here's a story from British Airways. Back when British Airways was called **British Overseas Airways Corporation (BOAC)** (before 1974), female flight attendants in the airline were finding that their uniform skirts were fitting on take-off but once they reached cruising altitude, their skirts felt too tight. This tight-skirt mystery was solved using gas laws! A spokesman for BOAC used Boyle's Law to explain what was going on. He explained that as the pressure in the cabin decreased at the higher altitude, the pressure in the flight attendants' stomachs also decreased, thus causing the volume of their stomachs to increase (making their stomachs bulge). Since then, female flight attendants wear adjustable skirts.

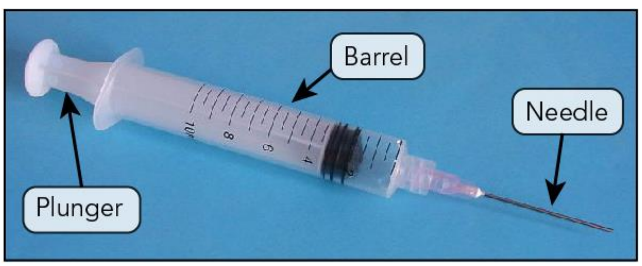


Figure 12: A syringe.

The working of a **syringe** can also be explained using Boyle's Law. When the **plunger** of a syringe is pulled out, the volume inside the **barrel** increases, resulting in a decrease in the pressure inside the barrel. Fluids (such as water) flow from a high pressure area to a low pressure area. This means that once the pressure inside a syringe is lower than the pressure outside the syringe, a fluid near the **needle** (e.g., water, medicine, etc.) will flow into the syringe.

The opposite is also true. When the plunger is pushed back in, the volume decreases and the pressure increases. Once the pressure is greater than that outside the syringe, the fluid inside the barrel will flow out.

The operation of your lungs also can be explained using Boyle's Law. When you **inhale** (breathe in), your **diaphragm** (a large muscle below your **lungs**) lowers, which increases the volume inside your lungs. This makes the air pressure inside your lungs lower than the air pressure outside your lungs (and your body); therefore, the outside air is drawn into your lungs (much like the syringe). When you **exhale** (breathe out), your diaphragm pushes upwards, reducing the volume inside your lungs, increasing the pressure and forcing the air outwards.

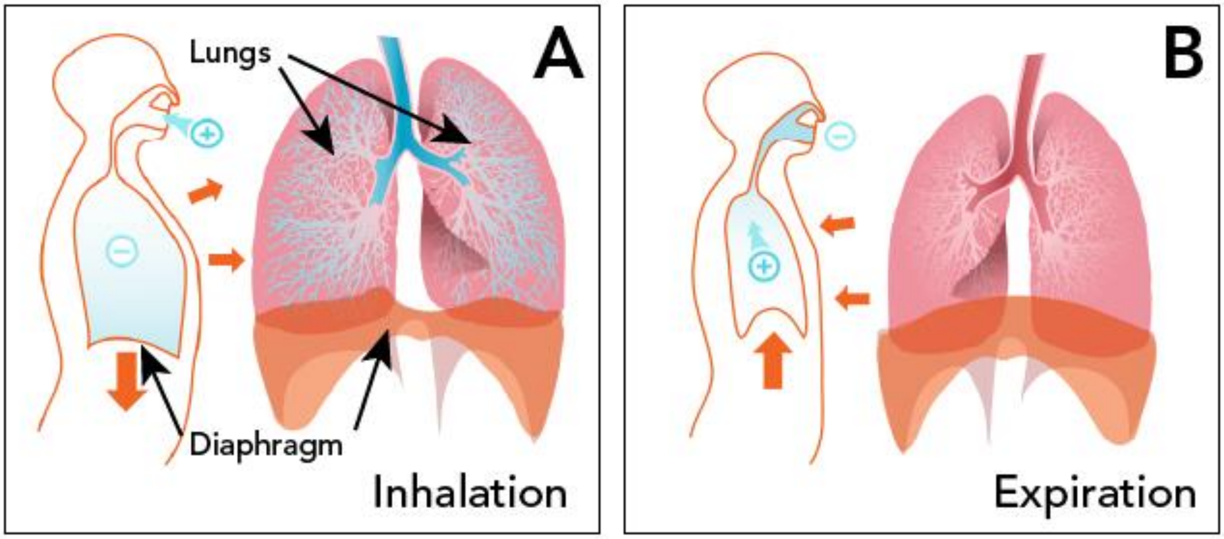


Figure 13A: Inhalation (breathing in), **13B:** Expiration (breathing out).

A **weather balloon** is a special type of high **altitude** balloon. These balloons can reach heights of 18 to 37 km above the Earth carrying instruments for measuring atmospheric pressure, temperature and wind among other things. When weather balloons are sent up, they are only partly filled with gas (typically with helium). Why don't they fill them completely? Short answer – because they would pop! At higher elevations, the air pressure outside the balloon is lower than the pressure of the helium inside the balloon. As Boyle's Law states, this causes the volume inside the balloon to increase. If the balloon was already full, this increase in volume could cause the balloon's rubber to stretch beyond its breaking point.

Figure 14: A U.S. Navy weather balloon.

My Career

Paul Fafard
Chemical Technologist
LP7 Polyethylene, Prentiss AB

Figure 15: Paul Fafard

I was born and raised in the prairies of Western Canada. I went to school in Edmonton and graduated from NAIT in Chemical Technology in 1998. I remember my instructors saying that I could go into different fields of chemistry – oil and gas, food science, environmental, manufacturing, and many others.

After graduation, I did not want to see a lab for a while, so I decided to travel across Canada. It took me about three months to explore this vast country and I know I only saw bits and pieces of it. After returning, I found a job in my field in environmental testing, then in the gas and oil sector. I was in a contract position and as it was ending, I came in one day to find a job posting on my desk for Union Carbide in central Alberta. I applied and started in February of 2000.

I was initially one of 15 lab people hired to start up the polyethylene lab. We all came from the fields of chemistry and plastics, but our wide variety of experiences made us a fantastic, well-rounded team. This team went on to successfully start up the lab in the new polyethylene plant. To this day, the team mentality is one of the most important aspects for running our 24/7 lab. We have two different type of schedule: days and shifts. Currently we have five lab techs working 12-hour rotating shifts and two working days. The day roles are what most people think of as a usual day of work (9 to 5). Shifts are when people work for 12 hour long period even during night time. We all rotate through both shift and day roles to keep us current on all aspects of our lab.

After Union Carbide merged with Dow, many of my co-workers went on to different roles in the company, ranging from Environment, Health and Safety to operations and to different levels of quality control. I am currently in the shift role in our lab, which mainly consists of routine quality control analysis of the polyethylene process. Our team is responsible for the upkeep and calibration of over 10 instruments.

We all have our roles and specialties or interests. I am also responsible for the upkeep of our site's internal webpage and am the unofficial tech support for the shift group. I have always been interested in how things work, and I tend to fix a lot of items in and around the lab when it falls in my scope, mostly electronic and electrical things. My motto is, "It's broken now, how much worse can it be?"

Charles' Law

Jacques Charles, a French physicist, discovered in the 1780s that heating a gas will cause it to expand by a certain fraction. Figure 16 shows how adding heat will make molecules move faster and hit the sides and lid with greater force, thus moving the lid up as the gas expands.

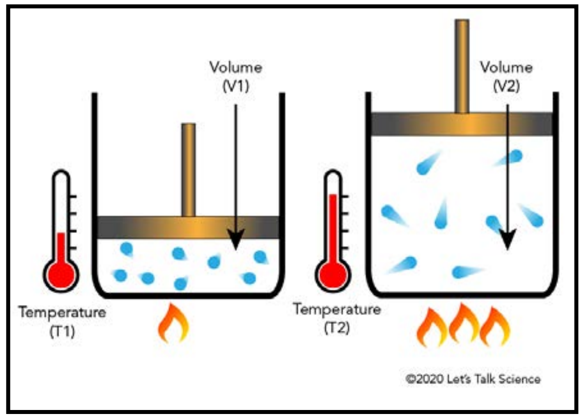


Figure 16: Charles' Law in action.

Charles' Law in Everyday Life

In order to make a hot air balloon rise, heat is added to the air inside the balloon. Adding heat causes the molecules to move further away from each other (see Figure 16). In everyday language, we would say that the air inside expands. When this happens, the total **density** (mass per unit of volume) of the balloon and the air inside it decreases. When the density of the balloon decreases to be less than the density of the outside air, the balloon rises. Conversely, the volume of a gas will shrink if its temperature decreases.

Figure 17: Burners heat up the air inside a hot air balloon.

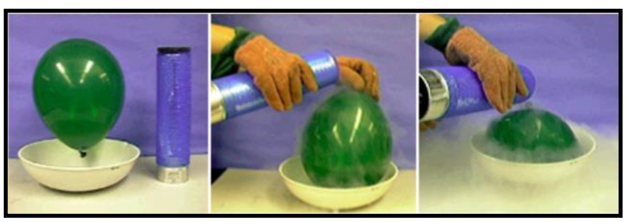


Figure 18: Liquid nitrogen poured on balloons.

In Figure 18, liquid nitrogen is poured over a green balloon. The cold liquid nitrogen cools the air inside the balloon. As a result, the molecules of air slow down causing the volume of the balloon to decrease.

During the holidays, someone you know may have used a **turkey thermometer**. A turkey thermometer is stuck into the turkey while it cooks and then pops up when the meat is cooked enough. How does this wondrous piece of technology work?

It has to do with Charles's Law, of course! Inside the turkey thermometer is a small thermometer expands. Once it reaches a certain volume, the top pops, telling the chef that the turkey is properly cooked.

Figure 19: Turkey thermometer.

Gay-Lussac's Law

Joseph Louis Gay-Lussac was a -French chemist and physicist who discovered in 1802 that if you keep the volume of a gas constant (such as in a closed container), and you apply heat, the pressure of the gas will increase. This is because the gases have more kinetic energy, causing them to hit the walls of the container with more force (resulting in greater pressure).

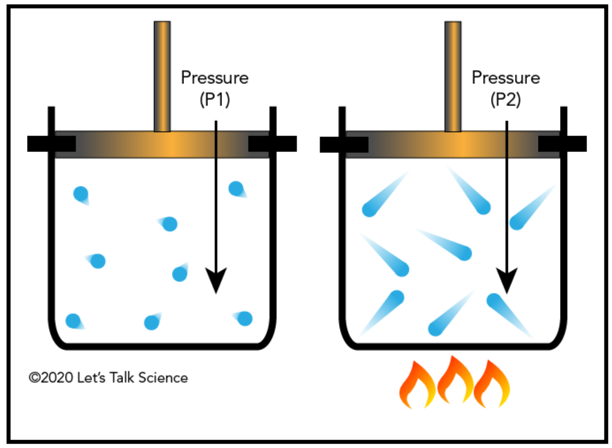


Figure 20: Gay-Lussac's Law in action.

Gay-Lussac's Law in Everyday Life

Figure 21: Pressure cooker.

Inside a **pressure cooker** (see Figure 21) the food that you want to cook sits in water. As the temperature of the liquid water is increased, **water vapour** (water in its gas state) is produced. This vapour cannot escape the pressure cooker – meaning the volume is not changing. The pressure of the water vapour keeps rising until the temperature of the water and the water vapour exceed the normal **boiling point** of water (100˚C). At this higher temperature food can be cooked much faster. Tough meat also comes out much more tender after being cooked in a pressure cooker.

Did you know that the air pressure on the inside of car tires changes when the car is driven? After driving, the air pressure in a car's tires goes up. This is because **friction** (a contact force) between the tires and road causes the air inside the tires to heat up. The air cannot expand because the tires are essentially a fixed-volume container, so the pressure increases – this is Gay-Lussac's Law!

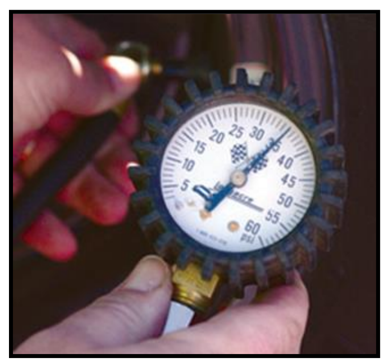


Figure 22: Measuring tire air pressure.

Try This!
Measure your car's tire pressure before and after driving somewhere to see Gay-Lussac's Law in action!

Avogadro's Law

Amadeo Avogadro was an Italian physicist who stated, in 1811, that the volume of any gas is proportional to the number of molecules of gas (measured in **Moles** – symbol **mol**). In other words if the amount of gas increases, then so does its volume. One important lesson we learn from this law is that if samples of <u>any</u> gas are compared that have <u>the same</u> volume, temperature and pressure, then they will all have the same number of molecules in them. This is illustrated in the following chart:

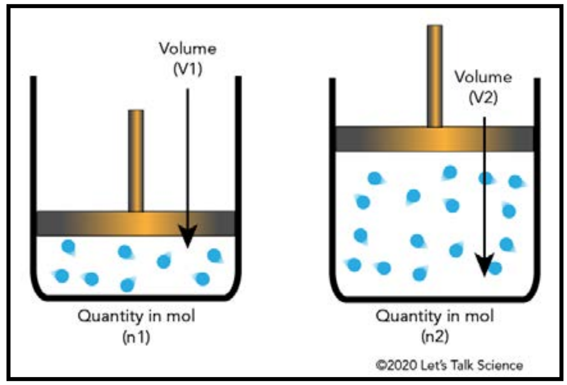


Figure 23: Avogadro's Law in action.

Argon Gas	Oxygen Gas	Nitrogen Gas
Ar	O_2	N_2
Volume: 22.4 L	Volume: 22.4 L	Volume: 22.4 L
Quantity: 1 mol	Quantity: 1 mol	Quantity: 1 mol
Pressure: 1 atm	Pressure: 1 atm	Pressure: 1 atm
Temperature: 273K	Temperature: 273K	Temperature: 273K
Mass = 40 g	Mass = 32 g	Mass = 28 g

Here are three different gases all occupying the same volume (22.4 L), at the same pressure (1 atm) and the same temperature (273 K or 0°C). Even though their masses are all different, the <u>amounts</u> of each gas are the same (1 mol). One **mole** (SI unit for the amount of a substance) of a gas (or any substance for that matter), contains the same number of molecules. So we can say that these three gases all contain the same number of molecules. The number of molecules in 1 mole is known as **Avogadro's Number**, and is immense (6.02×10^{23})! Note, we are not restricted to these conditions. For example, we could change the volume for these gases to be higher or lower and change the pressure and temperature to be equally higher or lower as well. As long as all three conditions are the <u>same for all the gases</u>, we can then say that they all have the same number of molecules! The number may not be Avogadro's number any more, but the number of molecules can still be calculated.

Figure 24: Girl blowing up a balloon.

Avogadro's Law in Everyday Life

You have probably experienced this example of Avogadro`s Law yourself (Figure 24). When you blow up a balloon, you are adding molecules of gas into it.

The result is that the volume of the balloon increases – and in order to do this, you decrease the number of molecules in your lungs (which decreases their volume)! A bicycle pump does the same thing to a bicycle tire.

Ideal Gas Law

The volume, pressure, temperature, and quantity (amount) of gas all can affect one another. Since different gases act similarly, it is possible to write a single equation relating all of these properties. The **Ideal Gas Law** combines several laws, including Boyle's Law, Charles`s Law, Gay-Lussac`s Law and Avogadro`s Law, into one neat and tidy formula! This law is commonly used to calculate how the volume of a gas will change if temperature, pressure or amount of gas is changed.

In the Ideal Gas Law, the behaviour of a gas can be summarized using the following equation:

$$PV = nRT$$

Where:

- **P** is pressure
- **V** is volume
- **n** is the number of gas molecules in moles
- **R** is a number known as the **ideal gas constant** (The value for R is often, but not always, 8.314 J/mol · K)
- **T** is temperature (which has to be in Kelvin)

The chart below shows how all the above gas laws are present in this ideal gas law.

Law	Variables	Symbols in Formula
Boyle	pressure & volume	P, V
Charles	volume & temperature	V, T
Gay-Lussac	pressure & temperature	P, T
Avogadro	volume & amount	V, n

Although in reality no gas is an 'ideal gas', some do come very close. Therefore, the Ideal Gas Law allows us to roughly predict the behaviour of a gas. This formula is often used when you want to determine the amount of gas that is present in a container. For example, you could find the mass of gas in a container by weighing the gas in the container, pumping out the gas and then reweighing the container. However, since gases have such low weight, the difference would be so small it would be hard to measure. Instead, all you need to know is the pressure - which can be obtained from a pressure gauge - the volume of the container, and the temperature of the gas. Then put these values into the formula and solve for **n**, from which the mass can be obtained.

Spotlight on Innovation

ZooShare Biogas Cooperative

A unique arrangement is underway between the animals at the Toronto Zoo, a major Canadian grocery store and non-profit renewable energy co-operative called ZooShare. ZooShare is in the process of developing North America's first zoo **biogas** plant at the Toronto Zoo using **biomass** – essentially poop – from the zoo animals along with food waste from local grocery stores. On the zoo property, ZooShare is going to build a **bioreactor**, which is a large enclosed tank where the zoo and food waste will be broken down by microorganisms. The microorganisms will be breaking down the materials in the absence of oxygen. This type of digestion is called **anaerobic** digestion. The products of the anaerobic digestion are **biogas** (made up mainly of **methane** and **carbon dioxide**) and **digestate** (the leftover solid material which can be used for fertilizer).

Figure 25: A biomass contributor at the Toronto Zoo.

Methane can be **combusted** (burned in the presence of oxygen) to release energy. The ZooShare facility will convert the heat energy from burning the methane into mechanical energy which can operate an electrical generator. Running at **nameplate capacity** (full capacity), the ZooShare electrical generator is anticipated to generate 500 kW (kilowatts) of electricity.

You could say the ZooShare project is a win-win-win. The zoo has a way to dispose of the poop generated by the animals (so that the poop does not have to go to a **landfill site**), the grocery stores have a place for their food waste (so that it also does not go to landfill sites), and Ontario has a source of electricity generation which does not come from the burning of fossil fuels.

Balloon Car Engineering Challenge

Challenge:

Your challenge is to work as a team to design and build a simple car that is propelled by a balloon.

Materials:

- 1 piece of cardboard (10 cm x 15 cm)
- 2 bamboo skewers
- 4 plastic bottle caps (with small holes punched in their centres with a nail)
- Drinking straws (2 straight and 1 bendable)
- Scissors
- Elastic bands
- Masking tape
- Balloons

Safety:

- Make sure no one in your group has a latex allergy. If so, use latex-free balloons.

The basics:

- **To make wheels and axles:** tape straws onto the cardboard and put skewers through the straws. Attach bottle caps to the ends of the skewers.
- **For the propulsion system:** slip the bendable straw into the balloon and fasten securely with an elastic band so that air does not escape. Tape the straw with the balloon onto the top side of the cardboard.
- **For the race track:** Stick two parallel lines of masking tape on the floor 50 cm apart and 5 metres in length.

Rules:

- The race is for distance, not speed. The car must remain within the lines of tape to qualify. Measure the distance travelled for each balloon car.

Success

- The car that travels the greatest distance is the winner.

Pushing the Envelope

- How can you make your balloon car go further?
- Have a race. How can you make your balloon car go faster?

References

Figure References

Figure 1: The states of matter.
Image ©2020 Let's Talk Science.

Figure 2: A solid.
Image ©2020 Let's Talk Science.

Figure 3: A liquid.
Image ©2020 Let's Talk Science.

Figure 4: A gas.
Image ©2020 Let's Talk Science.

Figure 5: Pressure inside a container.
http://commons.wikimedia.org/wiki/File:Pressure_exerted_by_collisions.svg
(Accessed June 28, 2019)
Public domain image on Wikimedia Commons.

Figure 6: Release of pressure from a champagne bottle.
http://commons.wikimedia.org/wiki/File:Champagne_uncorking_photographed_with_a_high_speed_air-gap_flash.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 7: Fahrenheit, Celsius and Kelvin scales.
Image ©2020 Let's Talk Science using an image by ttsz via iStockphoto.

Figure 8: Mercury barometer.
Image ©2020 Let's Talk Science.

Figure 9: Modern barometer.
Image ©2013 Peter Bloch. Used with permission.

Figure 10: Inside a tire pressure gauge.
Image ©2020 Let's Talk Science.

Figure 11: Relationship between pressure and volume of a gas.
Image ©2020 Let's Talk Science.

Figure 12: A syringe.
http://commons.wikimedia.org/wiki/File:Syringe2.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 13A: Inhalation (breathing in).
http://commons.wikimedia.org/wiki/File:Inhalation_diagram.svg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

14B: Expiration (breathing out).
http://commons.wikimedia.org/wiki/File:Expiration_diagram.svg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 14: A U.S. Navy weather balloon.
http://commons.wikimedia.org/wiki/File:US_Navy_040623-N-0995C-001_Aerographer%5Ersquo,s_Mate_Airman_Harley_Houston_releases_a_weather_balloon_aboard_the_conventionally_powered_aircraft_carrier_USS_John_F._Kennedy_(CV_67),_to_measure_atmospheric_conditions.jpg
(Accessed June 28, 2019)
Public domain image by the U.S. Navy on Wikimedia Commons.

Figure 15: Paul Fafard © Paul Fafard. Used with permission.

Figure 16: Charles's Law in action. Image ©2020 Let's Talk Science.

Figure 17: Burners heat up the air inside a hot air balloon. http://commons.wikimedia.org/wiki/File:Flames_from_burner_in_hot_air_balloon.JPG (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 18: Liquid nitrogen poured on a balloon.
Image © UW Madison Department of Chemistry. Used with Permission.

Figure 19: Turkey thermometer. http://commons.wikimedia.org/wiki/File:Thanksgiving_Turkey.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 20: Gay-Lussac's Law in action.
Image ©2013 Let's Talk Science.

Figure 21: Pressure cooker. http://commons.wikimedia.org/wiki/File:Pressure.cooker.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

Figure 22: Measuring tire air pressure.
http://commons.wikimedia.org/wiki/File:Tire_pressure_gauge.jpg (Accessed June 28, 2019)
Public domain image on Wikimedia Commons.

Figure 23: Avogadro's Law in action. Image ©2020 Let's Talk Science.

Figure 24: Girl blowing up a balloon. http://commons.wikimedia.org/wiki/File:Girl_inflating_a_red_balloon.jpg
(Accessed June 28, 2019)
Public domain image on Wikimedia Commons.

Figure 25: A biomass contributor at the Toronto Zoo.
http://commons.wikimedia.org/wiki/File:Giraffa_camelopardalis_-_Toronto_Zoo,_Ontario,_Canada-8b.jpg (Accessed June 28, 2019) Public domain image on Wikimedia Commons.

General Resources

Gases

http://www.youtube.com/watch?v=Ifr_gOOPRug&list=PL7FC3A2F6BA07245F&index=9 (Accessed June 28, 2019) This YouTube video, from chemistry teachers Jonathan Bergmann and Aaron Sams, is an introduction to gases.

http://www.youtube.com/watch?feature=player_embedded&v=ZcPi5t-tHIs#at=142 (Accessed June 28, 2019) This YouTube video shows you how to make a barometer.

http://www.youtube.com/watch?v=QeAp3CuGjk8 (Accessed June 28, 2019) In this YouTube video, special guest on the Almost Live! show Bill Nye explains atmospheric pressure (and makes a cloud).

http://www.youtube.com/watch?v=H2LriCHu16M (Accessed June 28, 2019) In this YouTube video, special guest on the Almost Live! show Bill Nye plays with balloons and bubbles.

Gas Laws

http://www.youtube.com/watch?v=BxUS1K7xu30 (Accessed June 28, 2019) This YouTube video, from Crash Course, is about the Ideal Gas Law.

http://www.youtube.com/watch?v=BY9VGS2eXas (Accessed June 28, 2019) This YouTube video from TedEd is about the ABC's of gas: Avogadro, Boyle and Charles.

Gas Laws in Action

http://www.youtube.com/watch?v=sUTfNEpBQYw
(Accessed June 28, 2019)
In this YouTube video, see how the gas laws help us to understand how we can get a hard-cooked egg into a bottle with a narrow opening.

http://www.youtube.com/watch?v=HUmZrtiXDik#at=391
(Accessed June 28, 2019)
This YouTube video from Veritasium is about creating the 'world's longest vertical drinking straw.'

Spotlight on Innovation

http://zooshare.ca/ (Accessed June 28, 2019) Learn more about the ZooShare program at the Toronto Zoo.

http://www.re-energy.ca/biogas-generator (Accessed June 28, 2019) On the greenlearning.ca website, learn how to build your own biogas generator.

Earth Sciences

Chapter 3

2020

Thank you to our chapter sponsor:

Introduction

This chapter is all about **geology**, which is the study of the Earth, the rock that makes it up and the processes that can change this rock. In this chapter, you'll learn about the Earth's layers and how those layers can move and change. You'll also take a closer look at rocks and minerals and will learn about how we mine them.

Structure of the Earth

The Earth's Layers

The Core

The core is in the center of the Earth. The core has two layers – the **inner core** and the **outer Core** (see Figure 1).

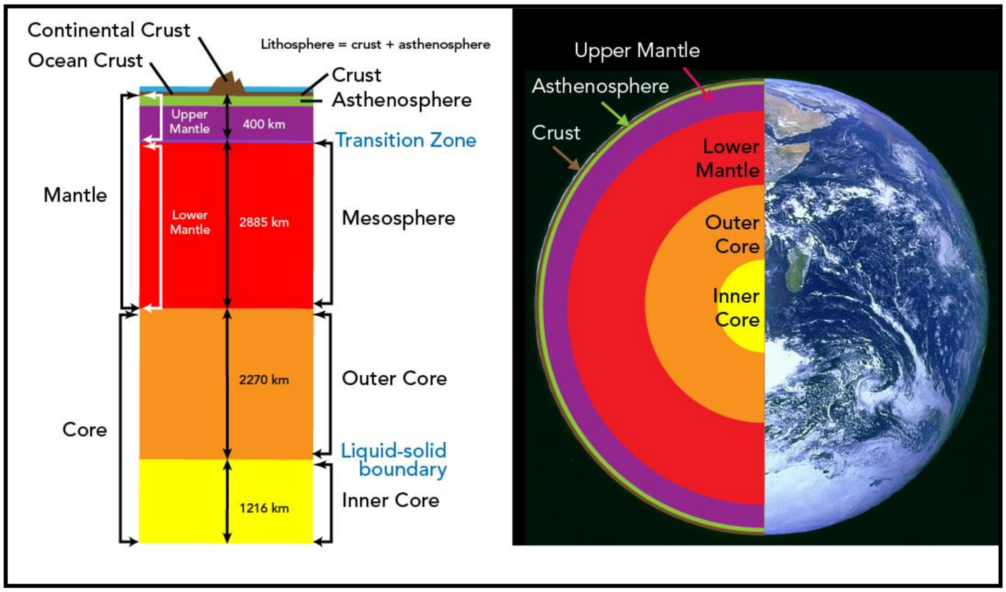


Figure 1: The layers of the Earth.

The inner core is 1 216 km thick, has a temperature of up to 4 000°C and is made of **solid** iron with some nickel. The outer core is 2 270 km thick, has a temperature of up to 3 600°C and is made of **liquid** iron with some nickel. Between these two layers is the **liquid-solid boundary**. The outer core is liquid because there is less **pressure** pushing on it than on the inner core. The solid inner core **rotates** within the liquid outer core. This giant ball of rotating solid iron and nickel generates the Earth's **magnetic field**. The core is also the Earth's source of internal heat because it contains **radioactive materials** that release heat as they break down into more stable substances.

The Mantle

Around the core is the mantle. The mantle also has two main parts – the **lower mantle** and the **upper mantle**, which includes the **asthenosphere** (see Figure 1). The mantle is made up of hot, dense, semi-solid rock.

The lower mantle is 2 885 km thick. The volume of this region is about **84%** of the Earth's total volume! The temperature of the mantle is cooler than that of the core, only reaching temperatures up to 3 000°C. The lower mantle is denser than the upper mantle. Between the lower and upper mantle lies a **transition zone** (400–660 km below the Earth's surface). Above the transition zone is the upper mantle. This area extends from the Earth's crust layer down to about 400 km.

The upper most part of the upper mantle is called the asthenosphere. The asthenosphere (from the Greek words "a" + "sthenos" meaning *without strength* and "sphaira" meaning *ball*) is made of soft, flowing rock.

The Crust

Floating on top of the asthenosphere is the solid, rigid part of our planet – the **crust** (see Figure 1). The crust is a cool layer of rigid rock, which has a thickness that varies from 5 to 80 km in depth. Together, the upper part of the asthenosphere and the crust make up the **lithosphere** (from the Greek word "lithos" meaning *rocky*) which extends down to a depth of about 100 km.

The thinnest portions of the crust are found on the **ocean floor** and form the **ocean crust**, which can be less than 5 km thick. The thickest parts of the Earth's crust lie under our continents and form **continental crust**, which can be as much as 80 km thick. The temperature of the crust closest to the mantle is about 500°C whereas the surface temperature of the crust approaches that of the temperature outside.

Human Explorations of the Earth's Crust

Humans know more about the edge of the Universe than what lies beneath the Earth's crust. Much of what we know about the world beneath our feet comes from **seismic studies**. Seismic studies give us **indirect evidence** of the composition of the layers of the Earth by studying how **waves of energy** produced by earthquakes travel through the Earth. These energy waves are called **seismic waves**.

Figure 2: An illustration from the novel Journey to the Center of the Earth

Direct evidence of the composition of the layers of the Earth can only come from digging deep into the Earth itself. In Jules Verne's 1864 classic fiction novel, Journey to the Centre of the Earth, the scientists discovered dinosaurs and other prehistoric living in the centre of the Earth (see Figure 2).

We now know that this is not true. However, the composition of the Earth's layers is not known for certain because it is very difficult to journey into the depths of the Earth – it's even more difficult than journeying to the Moon!

This doesn't mean that people have not tried to explore this mysterious world beneath our feet. During the early 1960s, at the same time as the American-Soviet race to the moon, there was a project to dig down through the Earth's crust. This project, **Project Mohole**, was named after the boundary between the crust and mantle, called the **Mohorovicic Discontinuity** (or Moho for short), named after its discoverer, geologist **Andrija Mohorovicic**. The project was the deepest offshore drilling that had ever been attempted up to that time. In the first experimental part of the project, five holes were drilled into the ocean floor, in 3 600 m of water, with the deepest hole being 183 m. Although the project didn't continue onto the next phase (in which deeper holes were planned), scientists learned much about how to do deep water drilling.

Geologists on land were going much deeper. In 1970 Soviet geologists started drilling into the **Kola Peninsula**, near Finland, hoping to drill down further into the Earth than anyone had drilled before. Their project, the **Kola Superdeep Borehole**, involved the digging of a deep vertical tube, or **bore**, into the ground (see Figure 3). Their deepest borehole, which was 12 262m deep, was completed in 1989. It is considered to be the **deepest artificial point on Earth**. At that depth, the crust was hotter than they expected (180°C instead of the expected 100°C). The rock was turning gooey, so the project had to be stopped.

Figure 3: Commemorative stamp of the Kola Superdeep Borehole,

More recently, in 2017, an oil and gas project off the Russian island of Sakhalin drilled the world's longest **extended-reach well** (long, diagonally slanted well). The length of the well with horizontal completion is 15 000 m, which as of 2019 is a world record.

With enough money and dedicated scientists, there is the belief that people may be able to drill into the Earth's mantle by the early 2020s. It may be by Japanese researchers aboard the **Integrated Ocean Drilling Program (IODP)** research ship ***Chikyu***, the largest research ship ever built, which set a new record for drilling the deepest ocean research hole (2 466 m) in 2012.

Why is it important to explore the Earth's crust and beyond through drilling? The main reason is because the assumptions we make from seismic data may not be accurate. It is possible that the indirect evidence from seismic data could be as inaccurate as the assumptions about other planets when earthbound telescopes were our only source of observation. We live on a dynamic and unpredictable planet. A greater understanding of the Earth's internal activities would allow scientists to predict more accurately geological events such as earthquakes and tsunamis.

Continental Drift and Plate Tectonics

Continental Drift

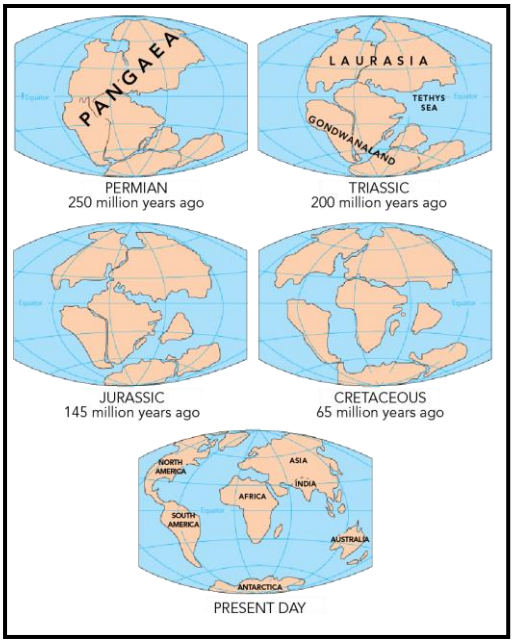


Figure 4: Movement of tectonic plates over time.

Today, most people know that landmasses on Earth move around, but people haven't always believed this. It wasn't until the early 20th century that German scientist **Alfred Wegener** put forth the idea that the Earth's continents were drifting. He called this movement **Continental Drift**. He wasn't the first or only person to think this. But he was the first to talk the idea publicly.

Wegener came up with this idea because he noticed that the coasts of western Africa and eastern South America looked like puzzle pieces, which might have once fit together and then drifted apart. Looking at all of the continents he theorized that they had once been joined together as a **supercontinent** (which was later called **Pangaea**) around **225 million years ago** (see Figure 4). The name Pangaea comes from the Ancient Greek words "pan," meaning *entire*, and "Gaia," meaning *Earth*. Pangaea is not the only supercontinent believed to have existed. Older supercontinents are also believed to have come before Pangaea.

The idea of moving landmasses seems obvious now, but Wegener's **Theory of Continental Drift** (as he called it) was not accepted for many years. Why? Well, for one thing, Wegener did not have a convincing explanation for the cause of the drifting. He suggested that the continents were moving around due to the Earth's rotation. This turned out to be wrong. Secondly, he was a **meteorologist** (someone who studies weather), not a geologist. Geologists didn't think he knew what he was talking about.

Fossil Evidence

One type of evidence that strongly supported the Theory of Continental Drift is the **fossil** record.

Fossils of similar types of plants and animals in rocks of a similar age have been found on the shores of different continents. This suggests that the continents were once joined. For example, fossils of *Mesosaurus*, a freshwater **reptile**, have been found both in Brazil and western Africa (see Figure 5). Also, fossils of the land reptile *Lystrosaurus* have been found in rocks of the same age in Africa, India and Antarctica (see Figure 5).

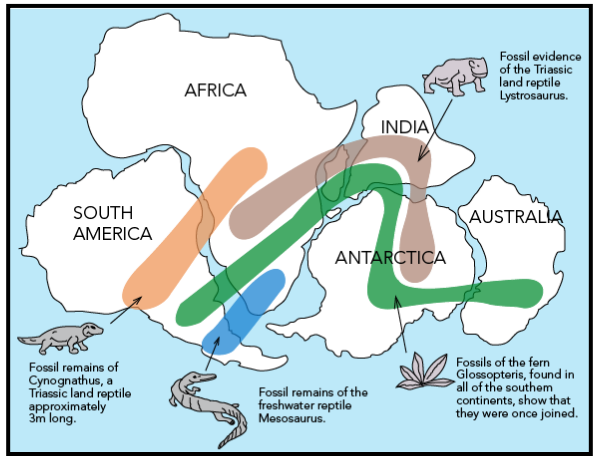


Figure 5: Map of fossil evidence.

Plate Tectonics

The **Theory of Plate Tectonics** builds on Wegener's Theory of Continental Drift. In the Theory of Plate Tectonics, it is <u>tectonic plates</u>, rather than <u>continents</u>, which are moving. **Tectonic plates** are pieces of the lithosphere and crust, which float on the asthenosphere. There are currently **seven** plates that make up most of the continents and the Pacific Ocean (see Figure 6). They are:

1. African Plate
2. Antarctic Plate
3. Eurasian Plate
4. Indo-Australian Plate
5. North American Plate
6. Pacific Plate
7. South American Plate

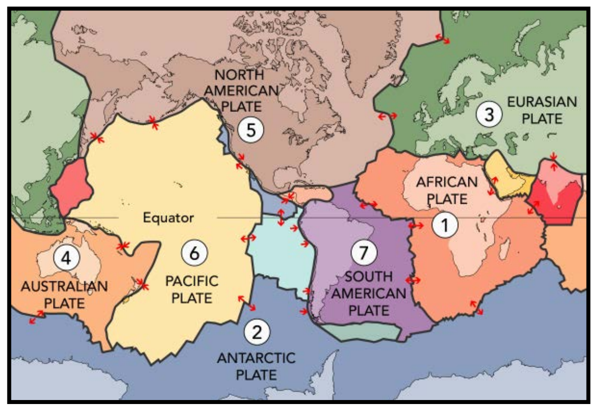


Figure 6: Tectonic Plates.

There are eight other smaller **secondary plates** as well as many other **microplates** which do not make up significant amounts of landmass. Tectonic plates not only move land masses (continental crust), but also oceans (ocean crust). Since the plates are floating on liquid rock, they are constantly moving and bumping against each other. This means that the sizes and positions of these plates changes over time.

Tectonic plates are able to move because the lithosphere, which makes up the plates, has a higher strength and lower density than the underlying asthenosphere. The solid plates above move along on the liquid rock below. You may imagine that these plates are zipping along, but in fact, they are moving VERY SLOWLY! The speed of the plates ranges from a typical 10–40 mm/year (about as fast as fingernails grow) to as fast as 160 mm/year (about as fast as hair grows). Geologists came to accept the Theory of Plate Tectonics in the late 1950s and early

1960s after coming to understand the concept of **seafloor spreading**. Seafloor spreading occurs on the seafloor where oceanic plates are moving away from each other (**diverging**). When this happens, cracks occur in the lithosphere, which allows **magma** (hot liquid rock) to rise and cool. The cool magma forms a new seafloor. The opposite of divergence is **convergence**. This occurs when plates are moving towards each other. Material may push upwards (**obduction**) forming mountains or downwards (**subduction**) into the mantle. The material lost through subduction is roughly balanced by the formation of new (oceanic) crust by seafloor spreading.

Volcanic eruptions and **earthquakes** can occur and **mountains** and **ocean trenches** can be formed when **tectonic plates** meet. Let's look at some of these processes in more detail.

Mountains and Volcanoes

What do mountains and volcanoes have in common? They are both large, steep landforms made of rock that are formed when tectonic plates are pushed and pulled. Whether you get **mountains** or **volcanoes** depends on the type of tectonic plates and where they are colliding.

To understand whether you will get mountains or volcanoes, you need to remember two things.

1. There are two major types of tectonic plates: oceanic and continental.
2. Oceanic plates are denser than continental plates.

Let's look at how tectonic plates form mountains and volcanoes.

1. When **two oceanic plates** diverge (pull apart), undersea **volcanoes** are formed. Volcanoes are caused by cracks in the Earth's crust. An example of this is the **Mid-Atlantic Ridge**, which extends from the Arctic Ocean to beyond the southern tip of Africa. There are so many volcanoes in the Mid-Atlantic Ridge, and they are so large, that it is considered the longest mountain range in the world. **Iceland** is located on this ridge (see figure 7). The red triangle on the picture show where there are active volcanoes.
2. When **two continental plates** converge on land (collide into each other), **mountains** are formed. This is because both of the plates, which are similarly dense, will push up against each other, causing the rock to get all folded and bunched up. The crust in the region of a mountain is thicker than the surrounding crust. The **Himalayan Mountains** are the result of this type of process.

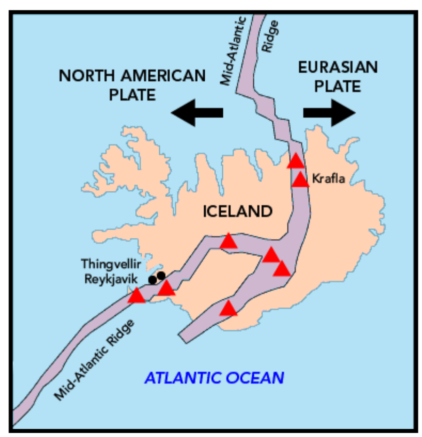


Figure 7: Iceland is located on the Mid-Atlantic Ridge.

3. When an **oceanic plate (1)** converges with a **continental plate (2)**, the oceanic plate will move under the continental plate (subduction) because it is denser **(3)** (see Figure 8). The oceanic plate may go deep enough under the continental plate and into the mantle that it melts and forms **magma (4)**. Increased pressure from beneath the Earth can build up and cause the magma to seep up through weak spots in the crust **(5)**. Magma under high pressure sometimes comes through volcanic vents in the form of flowing **lava**, forming a **volcanic cone (6)**.

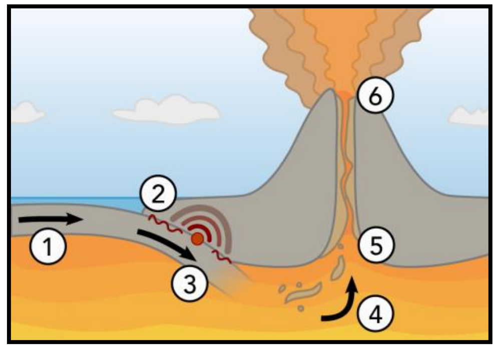


Figure 8: Subduction of an oceanic plate.

Minerals and Rocks

Minerals

Minerals are naturally occurring, solid, **inorganic** substances. They have a regular, repeating arrangement of atoms and molecules (see the **Chemistry chapter**). The study of minerals is known as **mineralogy**. People who study minerals are called **mineralogists**. Minerals can be described and classified according to their physical properties, such as as their:

- Crystal structure and shape (called their **habit**)
- Hardness (measured using the **Mohs scale of mineral hardness**)
- Lustre (the way light reflects off them)
- Colour
- Translucency (how see-through they are)
- Cleavage (how they break)
- Density (mass to volume ratio)

as well as how they react to substances such as acids or magnets. It is the properties of minerals that make them useful for important things such as manufacturing.

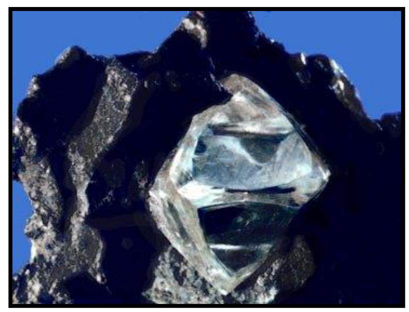


Figure 9: A rough diamond. Diamonds are the hardest minerals, with a Mohs scale hardness rating of 10.

Over 5400 different minerals have been acknowledged to exist by the **International Mineralogical Association (IMA)**. This international group is responsible for naming minerals and verifying new mineral discoveries.

Rocks

Rocks are made up of two or more minerals. Rocks containing valuable minerals are called **ore**. Minerals from ore are used to manufacture products that we use every day. This includes things like houses, stainless steel pots and pans, electronics, batteries, automobiles and fertilizer. Valuable minerals include base metals, industrial minerals and precious metals. **Base metals** are metals that do not contain iron, such as copper and nickel. **Industrial minerals** are minerals that do not contain any metals. **Precious metals** are metals of high value, such as gold, iron and platinum.

Rocks are classified as igneous, sedimentary, or metamorphic. **Igneous rocks** are rocks formed by the cooling and solidification of magma or lava. The word igneous comes from the Latin word "ignis" meaning *fire*. Igneous rock may form above or below the surface of the Earth. Igneous rock that forms below the surface is known as **intrusive igneous rock**. This type of rock cools slowly and has large crystals of different types of minerals which can be seen with the naked eye. **Granite** is a good example of this type of rock (see Figure 10A). Igneous rock that forms on the surface of the Earth is known as **extrusive igneous rock**. This type of rock cools quickly and has small crystals. Obsidian, a clear glass-like rock, is a type of extrusive igneous rock (see Figure 10B).

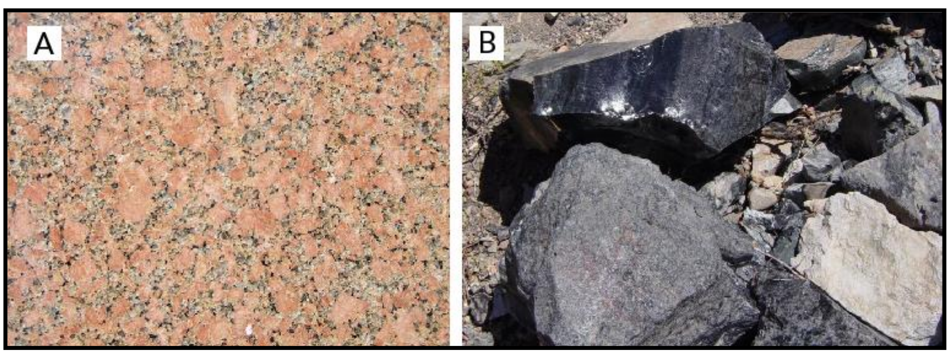


Figure 10A: Granite (quartz – gray, potassium feldspar – pink, biotite – black)
Figure 10B: Extrusive igneous rocks (counter clockwise from top - obsidian, pumice, and rhyolite).

Sedimentary rocks are formed by the accumulation of sediments. They are made up of layers of minerals, rock particles or organic materials. The layers are formed over time as materials carried by water are deposited at the bottom of lakes, rivers and oceans or are transported by wind or ice along the Earth's surface. Examples of sedimentary rocks include **conglomerate**, **shale**, **limestone** and **sandstone**.

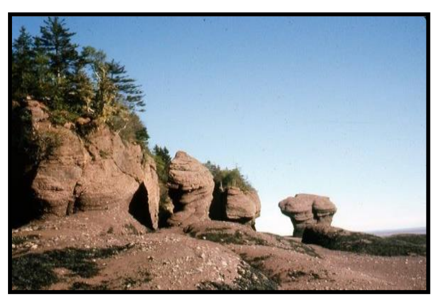


Figure 11: Sedimentary rock formations on the Bay of Fundy.

The shore of the Bay of Fundy (between

Nova Scotia and New Brunswick) is a great place to see exposed sedimentary rock (see Figure 11).

> ***Did you know…*** fossils are only found in sedimentary rock!

Metamorphic rocks are rocks, which are formed because of a physical or chemical change to an existing rock through a process called **metamorphosis**. Metamorphosis means a change in form. You may have heard this word used for the life cycle process that butterflies undergo when they change from larvae to adults. Sedimentary, igneous and metamorphic rocks can become metamorphic rocks by being exposed to extreme heat and pressure, such as deep underground. Examples of metamorphic rocks include **gneiss**, **marble**, **quartzite** and **slate**. Marble is very strong, durable and beautiful. It has been a rock of choice for sculptors and builders for thousands of years.

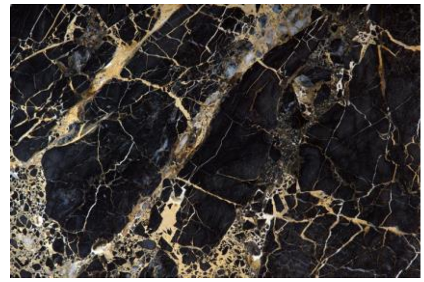


Figure 12: Marble comes in many different colours and patterns.

Rock Cycle

Rocks can change from one form to another (igneous ↔ sedimentary ↔ metamorphic). This is known as the **Rock Cycle** (Figure 13). Rocks begin as magma deep underground **(1)**. The magma cools **(2)** to form igneous rocks **(3)**. Exposed rock can be worn away by wind, water and ice. This is known as **weathering (4)**. The weathered material can move (**erosion**) and eventually settle at the bottom of a body of water (**sedimentation**)**(5).** Over time the layers of materials can be cemented together (**lithified**) to form sedimentary rocks **(6)**. The layers can be shifted, folded and buried as a result of plate tectonics. This exposes them to heat and pressure **(7)**. The heat and pressure transforms them into metamorphic rocks **(8)**. Some of these rocks become so hot that they melt and form magma **(9)** and then the cycle starts again. The cycle may, however, be interrupted and follow any of the paths as shown in Figure 13. It can take millions of years for a rock to cycle through the rock cycle.

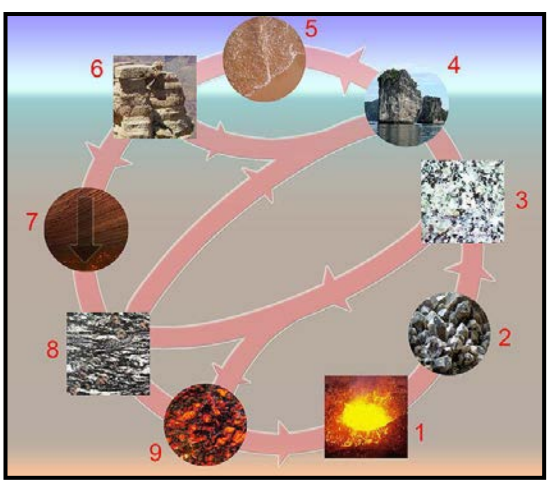


Figure 13: The rock cycle.

1. Magma
2. Cooling
3. Igneous rocks
4. Weathering and erosion
5. Sedimentation
6. Sediments & sedimentary rocks
7. Tectonic burial & metamorphism
8. Metamorphic rocks
9. Melting

Weathering, Erosion, and Sediment Deposition

Wind and **water** can change the shape of the Earth over time. **Weathering** involves both the physical and chemical breakdown of rock. **Physical weathering** involves breaking the rock into smaller pieces. Freezing water can cause rock to become physically weathered. Since water expands as it freezes, water that freezes in a crack in a rock can split the rock apart. **Chemical weathering** involves chemical reactions that change the composition of the rock fragments. For example, **acid rain** can dissolve some types of sedimentary rock.

Erosion involves the transport of rock particles, sediments, and soils by water, wind, or **glaciers**. Eroded material that is transported from one place to another, such as from the upstream portion of a river to the downstream portion, will eventually be **deposited** (put down) on the river bed. Rock particles and sediment can be transported very dramatically in **a landslide**, which is the rapid downward sliding of a mass of soil and rock. Many kinds of events can trigger a landslide, such as erosion associated with rivers, glaciers, waves, heavy **snowmelt** or even **earthquakes**. **Canada's deadliest rockslide** occurred April 29th, 1903. On this day, 82 million tonnes of rock fell from the summit of Turtle Mountain, into the Crowsnest River valley below. The landslide buried mining buildings, homes, and the railway line, killing 90 people. You can still see rubble from the rockslide today (see Figure 14).

Figure 14: Rubble from the rockslide near the town of Frank, Alberta.

Mine and Mining

Mining is the process of removing minerals from the Earth. A **mine** is the facility where mining occurs. There are two types of mines. **Surface mines** (see Figure 15A) are used to remove minerals found naturally near the surface of the Earth. In surface mines, minerals (**ore**) are accessed by digging a big open pit. **Underground mines** are used when minerals are located deep beneath the Earth's surface. A series of tunnels are used to access the ore (see Figure 15B).

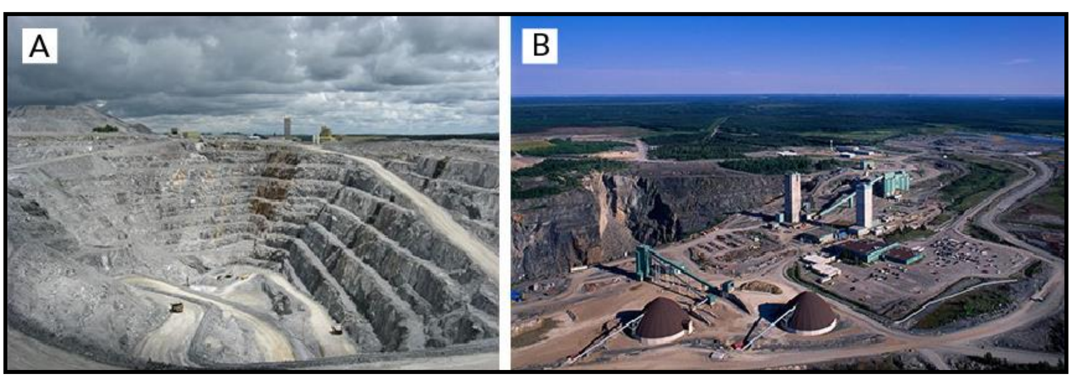


Figure 15A: A typical surface mine showing the open pit (Williams Open Pit Mine).
Figure 15B: An underground mine illustrating the surface footprint (Kidd Operation-Kidd Mine).

In both surface and underground mines, rock that contains the ore is blasted into pieces small enough to be loaded onto trucks. The ore is then transported to the **mill**. A mill is a type of processing plant where the ore is crushed. Valuable minerals are then separated out from the non-valuable rock.

Mine Life Cycle

There are many stages to mining. These stages are called the **mine life** cycle. The stage are: exploration, development, operation and closure/reclamation.

Figure 16: A geoscientist looks for minerals in a rock core.

1. **Exploration** is the first stage of the cycle. It involves research, field investigations, and analyzing information to find out where the minerals are. **Prospectors** and scientists go out on the land to search for rocks and minerals. If valuable minerals are discovered and scientific analysis shows that these minerals occur in a large enough quantity, additional work will be completed. Only a small number of these mineral finds will go on to become mines.
2. **Development** involves further research and analysis. This includes:
    - **a.** developing a plan for the mine
    - **b.** discussions with government and communities located near the proposed mine to make sure that their needs and requirements are addressed
    - **c.** applying for government permits and licenses
    - **d.** final evaluation of the proposed mine. Depending on the outcomes of this step, the decision can be made to build the mine.
3. Once the mine has been constructed, it moves into the **operation** stage. In this stage, rock is **excavated** (dug) from the ground. The valuable mineral is separated from the surrounding rock and processed. The length of this stage depends on how much mineral ore is present at the mine.
4. The final stage of the mine life cycle involves **closure and reclamation**. This includes ending the operation of the mine, removing all buildings and reestablishing the vegetation on the land (**reclamation**).

Figure 17: Drills are used in underground and surface mines to prepare the rock face for blasting.

Mining Across Canada

Canada is a large country where many rocks contain valuable minerals.

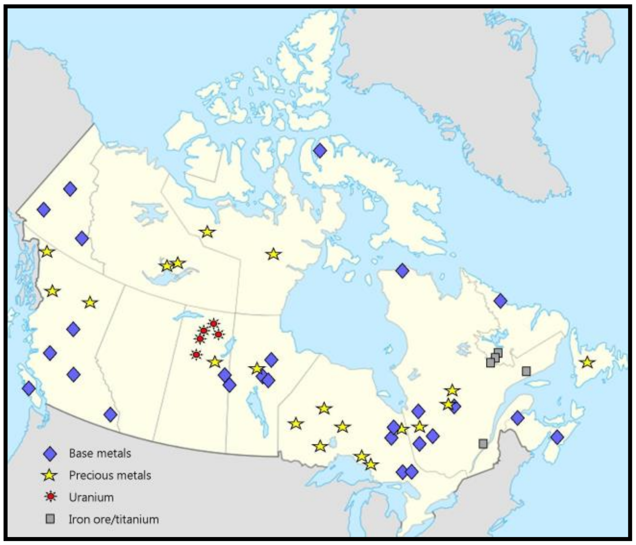


Figure 18: Map of Canada illustrating the location of metals mines across the country.

Mining takes place in 12 provinces and territories across the country (everywhere except for **Prince Edward Island**). Canada is a global leader in mining, producing more than 60 minerals and metals. The map on the left (Figure 18) shows the location of mine types by province and territory. Base metal (metals such as iron, nickel, lead, zinc and copper) mines are located in many provinces and territories. Precious metals, such as gold and silver, mines are located in British Columbia, Northwest Territories, Saskatchewan, Manitoba, Ontario, Quebec, Nunavut, Yukon, Alberta as well as Newfoundland and Labrador. **Uranium**, used to generate energy, is mined only in Saskatchewan. **Iron ore**, used to make steel, is mined in Quebec, Nunavut as well as Newfoundland and Labrador.

Gold, copper, zinc, nickel, and diamonds are mined in Canada. British Columbia produces the most **copper** in Canada. Ontario mines produce the most **gold** and nickel in the country. Manitoba mines produce the most **zinc**. More **diamonds** are mined in the Northwest Territories, Ontario and Quebec.

Figure 19: Ekati Diamond Mine. You can see three open pit mines on the left side.

Gold conducts electricity and is used to manufacture electronics and computers. Gold is also used to make jewelry, in dentistry and in medicine. Copper also conducts electricity and heat and is used in power generation and transmission (e.g., copper wiring), automobiles, plumbing and in the manufacturing of cooking utensils like pots and pans. Zinc is mixed with other metals to make **brass**. It is also used to manufacture musical instruments and housewares and is a key part of automobile components. Zinc can also be added to fertilizers to increase crop yield. Zinc (in the form of zinc oxide) is mixed with other chemicals to make sunscreen. Adding thin layers of zinc to iron or steel, in a process called **galvanization**, is used to prevent rusting. **Diamond** is a very hard mineral that is resistant to chemicals. It is used as an abrasive, to make strong drill bits and in jewelry. Canada became a diamond producer in October 1998 when the Ekati Diamond Mine opened about 300 kilometres northeast of Yellowknife (see Figure 19). By 2003, Canada was the world's third largest diamond producer on a value basis, after Botswana and Russia.

Spotlight on Innovation

Aluminium Smelting in Canada

What metal is lightweight, does not rust and can be infinitely recycled? **Aluminium**! Aluminium is one of the most widely used metals across all industries. It is used to make everything from pop cans to jet engines.

Aluminium is the most abundant metal in the Earth's crust. **Bauxite ore** is a reddish-brown rock found in Africa, South America and Oceania. Bauxite ore, which is also called aluminium ore, is the world's primary source of aluminium. Bauxite ore is mined using **strip mining**. Strip mining is a type of surface mining in which soil and rock are removed in strips. Prior to mining, the **topsoil** is removed and stored. Bauxite ore is then dug from the ground. Next, the ore is cleaned and crushed. It is then transported to a **refinery**. At the refinery, the crushed bauxite is transformed into **alumina** through the Bayer chemical process. The alumina is then shipped to **smelters** around the world for processing into aluminium. Finally, during reclamation, the stored topsoil is put back into its original place.

One company that is a global leader in aluminium production is Rio Tinto. In Canada, they have one alumina refinery and six smelters. As an organization, they are very concerned about the environment. That is why they use electricity generated by water (**hydroelectricity**) to run their refinery and smelters. This means that they can produce aluminium with one of the lowest **carbon footprints** in the world. Also, new technologies are being developed that will eliminate all **greenhouse gas** emissions from the aluminium smelting process. In Canada alone, if this technology were to be used at every smelter, it could eliminate the equivalent of 6.5 million metric tonnes of greenhouse gases. That's roughly the same as taking 1.8 million cars off the road.

Another useful product that comes from the aluminium process is **anhydrite**. This is a by-product of refining alumina. Anhydrite can be used in **fertilizer** for local growers and farmers. For example, in the Saguenay-Lac-St-Jean region of Quebec, where the Vaudreuil alumina refinery is located, anhydrite is used to fertilize neighboring blueberry crops. The people at Rio Tinto believe that innovation and sustainable development are key to responsible mining. With new technologies, improved processes and good relationships with local communities, companies such as Rio Tinto can produce important metals, like aluminium, while having the least amount of impact on the environment.

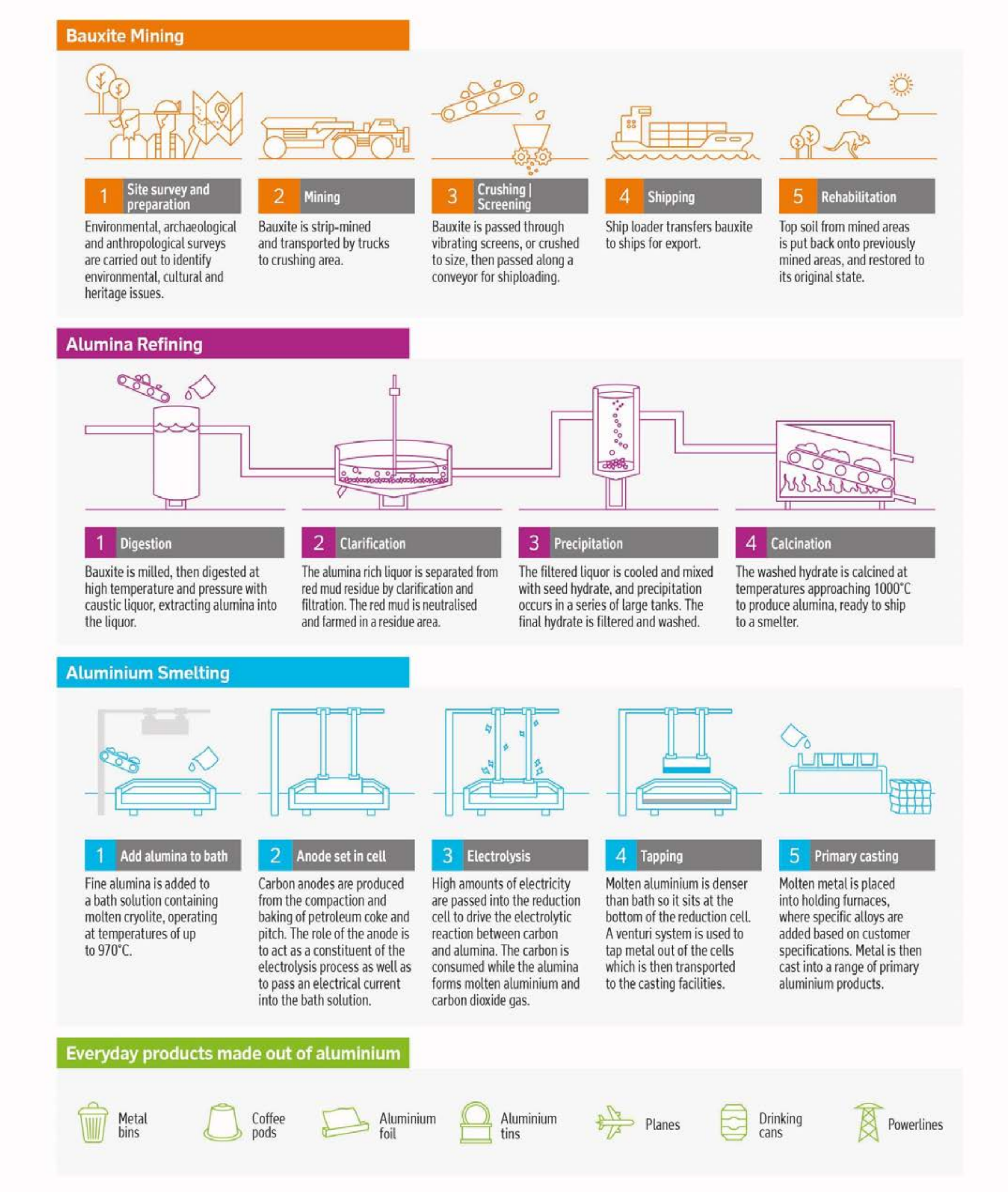


Figure 20: Three-step process to making aluminium.

My Career

Figure 21: Adam Brumwell at work.

Adam Brumwell
Autonomous Solutions Manager, Finning Canada

As an autonomous solutions manager I work with mining companies to help them with the specialized equipment needed to automate their operations. This involves training operators and helping companies design the technology-based solutions to make their operations run faster and better than before.

One of the biggest concerns in mining is safety. By automating processes previously done by people, we can increase the safety of workers by taking them out of situations that could cause them harm. It also gives mines better control over processes and the ability to work more effectively. They can remotely monitor their equipment to identify maintenance and repair issues. By closely monitoring their mining operations, our customers can expose their workers to fewer potential hazards which helps to reduce the risk of injury. Reducing potential harm to workers is possible with today's technology. Instead of sending in workers to address hazards, we can now send a drone onto the customer's mine site to survey it.

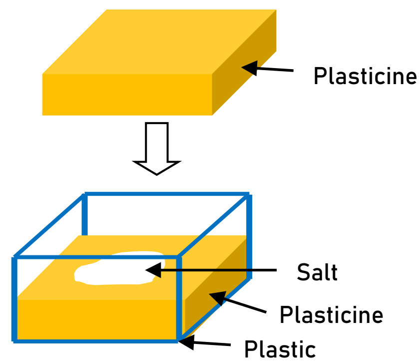
Every day I get to show customers these new autonomous technologies. I help them understand what they can do to help keep their workers safe, increase the speed of production and lessen the impact on the environment. I find it extremely rewarding to share my expertise and see the evolution of the mining industry first hand. Our autonomous technologies help identify opportunities in their current operations, as well as assist with planning a project and showing companies how to install, operate and maintain the equipment. It is very satisfying to watch a customer realize the impact of technology, and how they can use it to improve their operations and keep their workers safe. I have a Degree in International Business and Supply Chain Management. I also worked at a mine operation when I finished my education so I have a strong understanding of how mines function. My education and work experience help me to support customers by identifying how these technologies can transform their mining operations.

Mineral Extraction Engineering Challenge

Challenge:

Your challenge is to work as a team to design and construct a mining system so that you will be able to **extract** (remove) salt from a 'salt deposit' found in rock (plasticine). Your task is to extract the most salt while removing/moving the least plasticine.

Materials:



- 1 plastic container (sandwich-sized or larger)
- Plasticine (enough to fill container)
- 100 mL table salt
- Weigh scale

Excavation and extraction tools

- Craft sticks
- Drinking straws – straight and flexible
- Plastic spoons
- Twist ties

Set-up:

- Push half of the plasticine into the bottom of the plastic container. Make a small indentation in the center of the plasticine. Pour the salt into the indentation.
- Place the other half of the plasticine over top and press down (salt will form a deposit in the centre of the plasticine).

Rules:

- You may use only the provided tools for excavating (digging) and extraction (taking salt out).
- You may not push the plasticine sideways (form hills) or return any plasticine that has been extracted back into the container.
- When the time is up, both the salt and the plasticine you have extracted will be weighed.

Success

- You have extracted as much salt as you can during the extraction period.
- You have a high salt to plasticine ratio (more salt than plasticine)

Pushing the Envelope

- How else could you have removed the salt?
- Did you use surface mining or underground mining? Why?

References

Figure References

Figure 1: The layers of the Earth. Image ©2013 Let's Talk Science using a public domain image from Wikimedia Commons.
http://commons.wikimedia.org/wiki/File:The_Blue_Marble.jpg (Accessed January 22, 2020)

Figure 2: An illustration from the novel Journey to the Center of the Earth by Jules Verne by Édouard Riou (1864).
http://commons.wikimedia.org/wiki/File:%27Journey_to_the_Center_of_the_Earth%27_by_%C3%89douard_Riou_02.jpg (Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 3: Commemorative stamp of the Kola Superdeep Borehole, 1987, USSR (Union of Soviet Socialist Republics).
http://commons.wikimedia.org/wiki/File:Soviet_Union_stamp_1987_CPA_5892.jpg (Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 4: Movement of tectonic plates.
http://pubs.usgs.gov/gip/dynamic/historical.html (Accessed January 22, 2020)
Public domain image from the U.S. Geological Survey.

Figure 5: Map of fossil evidence.
https://commons.wikimedia.org/wiki/File:Snider-Pellegrini_Wegener_fossil_map.svg
(Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 6: Tectonic Plates.
http://commons.wikimedia.org/wiki/File:Plates_tect2_en.svg (Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 7: Iceland is located on the Mid-Atlantic Ridge.
http://commons.wikimedia.org/wiki/File:Iceland_Mid-Atlantic_Ridge_Fig16.gif
(Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 8: Subduction of an oceanic plate.
http://commons.wikimedia.org/wiki/File:Destructive_plate_margin.png
(Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 9: A rough diamond.
http://en.wikipedia.org/wiki/File:Rough_diamond.jpg (Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 10A: Granite.
http://commons.wikimedia.org/wiki/File:Fj%C3%A6regranitt3.JPG (Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 10B: Extrusive igneous rocks.
http://commons.wikimedia.org/wiki/File:Different_rocks_at_Panum_Crater.jpg
(Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 11: Sedimentary rock formations on the Bay of Fundy. http://commons.wikimedia.org/wiki/File:Bay_of_Fundy_rock_formations.jpg (Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 12: Marble comes in many different colours and patterns. https://www.istockphoto.com/ca/photo/black-marble-with-beautiful-yellow-streaks-called-new-portoro-gm1135153686-301886595 (Accessed January 22, 2020)
Elena Mordasova from iStockphoto.

Figure 13: The rock cycle. http://commons.wikimedia.org/wiki/File:Rockcycle.jpg (Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 14: Rubble from the rockslide near the town of Frank, Alberta. http://commons.wikimedia.org/wiki/File:Frank_Slide,_Canada.jpg (Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 15A: A typical surface mine showing the open pit (Williams Open Pit Mine).
Image © Lesley Hymers. Used with permission.

Figure 15B: An underground mine illustrating the surface footprint (Kidd Operation-Kidd Mine).
Image © Glencore Canada Operations. Used with permission.

Figure 16: A geoscientist looks for minerals in a rock core.
Image ©Northgate Minerals. Used with permission.

Figure 17: Drills are used in underground and surface mines to prepare the rock face for blasting.
Image © Triple Boom Jumbo Drill - Sandvik Mining and Construction. Used with permission.

Figure 18: Map of Canada illustrating the location of metals mines across the country.
©2014 Let's Talk Science based on an image from Natural Resources Canada.

Figure 19: Ekati Diamond Mine. http://commons.wikimedia.org/wiki/File:Ekati_mine_640px.jpg (Accessed January 22, 2020)
Public domain image from Wikimedia Commons.

Figure 20: Three-step process to making aluminium. © Rio Tinto. Used with permission.

Figure 21: Adam Brumwell at work. © Adam Brumwell. Used with permission.

General Resources

Plate Tectonics

http://education.nationalgeographic.com/education/encyclopedia/continental-drift/?ar_a=1
(Accessed January 22, 2020)
This page from National Geographic Education is about Continental Drift.

https://letstalkscience.ca/educational-resources/stem-in-context/plate-tectonics (Accessed January 22, 2020)
Information and video about Plate Tectonics.

http://pubs.usgs.gov/gip/dynamic/dynamic.html (Accessed January 22, 2020)
This website, This Dynamic Earth – the Story of Plate Tectonics, by the U.S. Geological Survey, has a number of different sections about plate tectonics.

Minerals & Rocks

http://www.mineralseducationcoalition.org/minerals-elements (Accessed January 22, 2020)
The Minerals Education Coalition website is full of information about minerals, including how we use minerals in everyday life.

http://www.pdac.ca/mining-matters/school-programs/students/rock-and-mineral-identification-guides (Accessed January 22, 2020)
On the Prospectors and Developers Association of Canada Mining Matters website, you can access rock and mineral identification guides.

http://bayoffundytourism.com/sea-cliffs-fossils/ (Accessed January 22, 2020)
Learn more about the Sea Cliff and Fossils Ecozone of the Bay of Fundy on this Bay of Fundy tourism website.

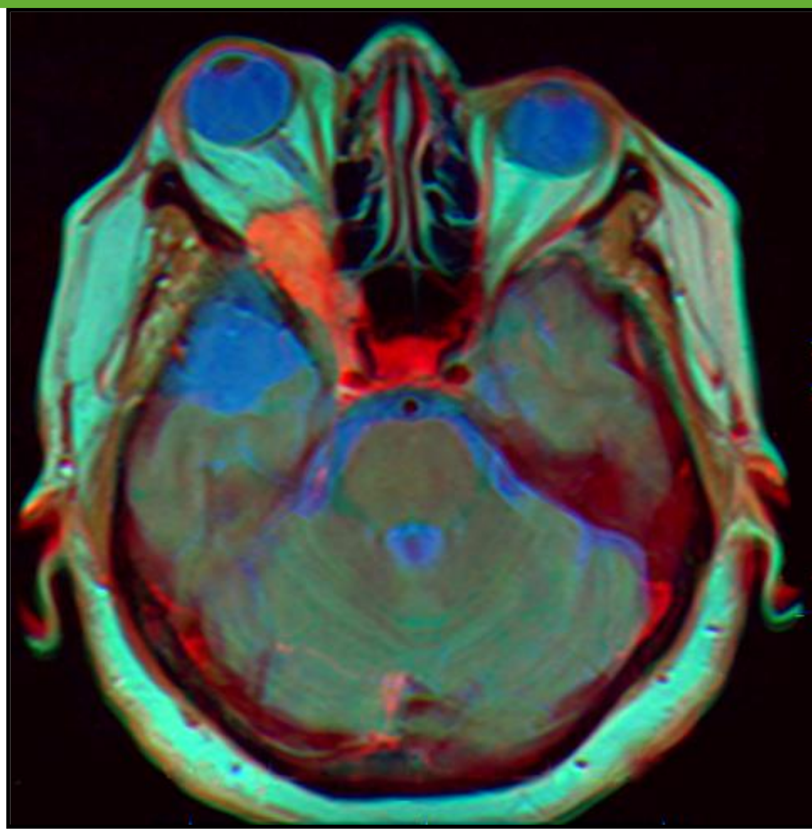
https://frankslide.ca/learn (Accessed January 22, 2020)
This page, from the Frank Slide Interpretive Centre, has more about the story of Canada's deadliest rockslide.

Mining

https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/20507 (Accessed January 22, 2020)
This page, from Natural Resources Canada, has links to information about the minerals and metals mined in Canada.

http://www.nrcan.gc.ca/mining-materials/mining (Accessed January 22, 2020)
This section of the Natural Resources Canada website is about mining in Canada.

http://www.oma.on.ca/en/ontariomining/Mining101.asp (Accessed January 22, 2020)
The Ontario Mining Association's Mining 101 section has information about the mine life cycle. The website also includes maps, photos and videos.



Engineering and Technology

Chapter 4

2020

Thank you to our chapter sponsor:

Imaging Technology

This chapter showcases some amazing forms of **imaging technology**. Imaging technology involves using various materials and types of technologies to create images. An **image** (from the Latin word *imago,* meaning 'a picture,' or 'likeness') is a visual representation of a person, place or thing. It can be two-dimensional, such as a photograph, or three-dimensional, such as a statue. Some images are very short-lived, such as the image of your face in a mirror or the images on a TV screen. Other images are more permanent. Permanent images are known as **fixed images** or **hard copies**. Telescopes, cameras, microscopes and other optical devices are all used to capture images. We will be looking in depth at some of the devices that enable us see and record amazing images, such as images of structures deep inside the human body.

Radiography

Radiography is the creation of images using **x-ray energy**. Images created using this technique are called **radiographic images** (or **radiographs**). **X-ray images** are still pictures similar to photographs. **Fluoroscopic images** are moving pictures similar to movies. **Tomographic images** are visualized 'slices' of the body.

Medical Radiation Technologists (MRTs) are the professionals who create radiographic images. Several types of radiographic imaging are used in health care. MRTs need a good understanding of both biological sciences and physical sciences. The biological sciences they study are primarily human anatomy and physiology, including **osteology**. Osteology is the study of the bones that make up the human skeleton. They also study physical sciences, such as physics and chemistry. Through their studies they learn how x-rays are produced. They learn how the x-ray beam changes when it interacts with the tissue of a body to create an image. They also learn how the image is captured and how the image is stored.

Next we'll explore some of these different radiographic imaging methods.

X-ray Imaging

Imagine you were playing your favourite sport and right when you were about to be the star of the day, a kid from the other team crashes into you! After rushing to the hospital, where you get an **x-ray** of your bone, you might ask yourself, "What is an x-ray?"

History

Figure 1: The first medical x-ray.

X-rays were discovered on November 8th 1895 by German physicist **Wilhelm Conrad Roentgen** while he was experimenting with **cathode ray tubes**. A cathode ray tube is a sealed tube with all of the air removed. At one end of the tube is an **electron gun** and at the opposite end of the tube is a screen on which images can be viewed. Roentgen noticed that photographic plates made using a chemical called barium platinocyanide would **fluoresce** (glow) even when the cathode rays were blocked. What he discovered was a new type of **electromagnetic radiation** (see the **Physics chapter** for more about the electromagnetic spectrum), which he called **x-radiation**. He used the letter "x" because he didn't in mathematics "x" represents an unknown quantity. The term was later shortened to x-rays. The x-rays that Roentgen discovered are a highly penetrating form of electromagnetic radiation. He found that the rays could pass through soft human tissue, but could not pass easily through hard tissue, such as bone, or through metal, such as his wife's ring (see Figure 1). He also found that the rays could make images on photographic film. For his pioneering work, Roentgen received many honours, including the **first Nobel Prize for Physics** in 1901. The unit that was used for a long time for measuring exposure to x-rays, **R** (**roentgen**), was named in his honor. Exposure to x-rays is now measured in Coulombs per kilogram (C/kg).

How it Works

An x-ray machine is essentially a specialized type of camera. Instead of having visible light expose the film and create an image, x-rays expose the film and create an image. Bone tissue, which contains a lot of **calcium**, absorbs many x-rays, whereas soft tissues such as fat and skin do not. In an X-ray image, areas that contain less dense tissue appear darker while areas that contain denser tissue appear lighter. This is why bones and metal objects look white in x-rays (see Figure 2). This is the opposite of what we see in Figure 1. This is the opposite of what we saw in Roentgen's first x-ray image. That image was a **positive image** (image transferred from photographic film to paper) whereas the image at right is a **negative image** (image on photographic film).

Figure 2: X-ray showing person with metal pins and bars used to support broken leg bones.

Uses

X-rays are not just for checking for broken bones. Your dentist uses x-ray imaging to check for cavities in your teeth. **Mammographers** use low-energy x-rays to do **mammograms**, which help doctors check the health of breast tissue. Airport security uses x-ray machines to check luggage for dangerous objects (see Figure 3). X-rays are also used as a form of **non-destructive testing** (way of testing for weaknesses without destroying the object). X-ray images can show hidden flaws such as tiny cracks or flawed welding in items such as pipelines.

Figure 3: Airport x-ray of a backpack. Can you guess what is inside?

Benefits & Risks

The benefit of x-ray imaging is that it is a very useful tool for looking at bones, as well as other hard tissues. This includes **gallstones**, which are crystals sometimes formed in the **gallbladder**. It also includes kidney stones, which are crystals sometimes formed in the **kidneys**. Other hard objects include cancerous tumors and accidentally swallowed objects, such as keys, coins and safety pins. On the negative side, x-rays are a form of **ionizing radiation**. This means that they can increase the risk of developing cancer. However, the amount of radiation exposure we get from dental x-rays or x-rays of broken bones is very small.

Computed Tomography (CT)

X-ray Computed Tomography (**x-ray CT** or **CT**) uses x-rays and a computer to generate images that look like thin slices of tissue. The word **tomography** comes from the Greek words *tomo,* meaning 'to slice', and *graphia,* meaning 'to write' (writing with slices).

History

The invention of CT is generally credited to **Sir Godfrey Hounsfield** and **Allan McLeod Cormack**. One day in 1967, Hounsfield came up with the idea that you might be able to determine what was inside a box by taking x-ray readings at all angles around the outside of the box. In order to test his idea, he built a prototype CT machine. It included a computer that could take input from x-rays at various angles to create an image of the object in 'slices' (see Figure 4). He tested his prototype first on a preserved human brain, then on a fresh cow brain from a butcher shop, and later on himself. At the time, Hounsfield was not aware of the work that Allan

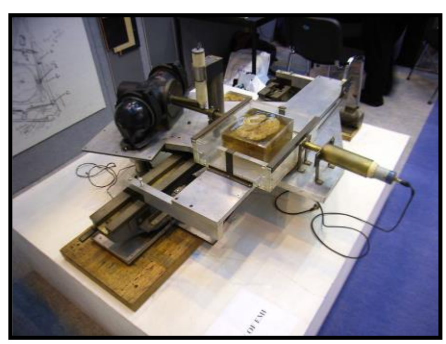


Figure 4: The first CT machine prototype.

Cormack had done on the mathematics of such a device. Together their work led to a shared **Nobel Prize in Physiology or Medicine** in 1979. The first CT machine (called a **CT scanner**) was located in England and the first scan of a patient's brain was on October 1, 1971. These first images took about five minutes to record and 2½ hours for the computers to process. The scanner had a single detector and used a single beam of x-rays.

How it Works

Modern CT scanners work by rotating an x-ray tube paired with a digital x-ray detector around a part of the body (see Figure 5). The scanner takes many images. These are then processed using computers and mathematical calculations, creating a series of images from one end of an object to the other (see Figure 6).

Figure 5: Modern CT scanner.

Since these images are all taken along one **axis** (i.e., along the of the body), this process was originally called **Computed Axial Tomography** or **CAT**. You may have heard the term CAT scan before or have known someone who has had a CAT scan. CAT scans and CT scans are two different terms for the same process. CT scan is the preferred term today. This is because images can be combined using computer software to form a 3-dimensional (3D) image.

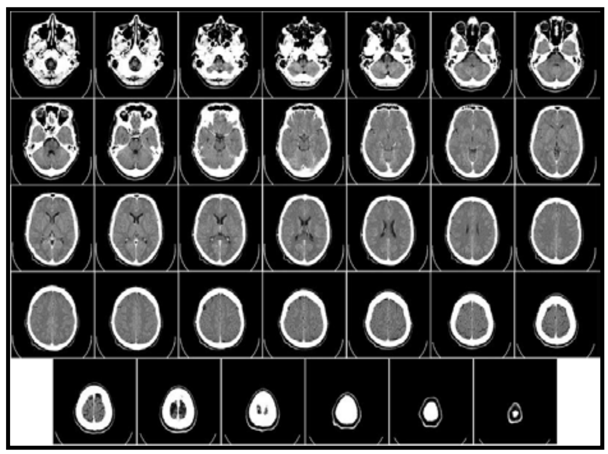


Figure 6: CT scans of a human brain from the base of the skull (top left) to the top of the head (bottom right).

Uses

Like x-rays, CT scans are often used to look for injuries or **pathology** (abnormalities) in the body. They are most commonly used on the neck, chest, abdomen and pelvis. CT scans are often used to look for brain tumors and blood clots in the brain because their rays can go through the skull. CT scans are also used to look at tissues in the heart and lungs. In some cases, a patient may go back for a series of CT scans so that the doctor can monitor how something, such as a tumor in the lungs, grows and changes.

Benefits & Risks

The greatest benefit of CT scans is that they generate 3-dimensional images. This allows doctors to look at a body part from many different angles. Also, since doctors can look at one thin slice at a time, they can pinpoint issues in very small areas (see Figure 6). Other advantages of CT scanners over regular x-ray machines is that CT scanners can vary the **intensity** (energy level) of the x-rays. This allows the person looking at the images to see the various body parts with better precision. The drawback of CT scans is that they expose the patient to more radiation than regular x-rays. Over time, this can lead to higher risks of cancer, but most people do not get enough CT scans in their lifetimes for this to be an issue.

Magnetic Resonance Imaging (MRI)

Another powerful imaging technique is **Magnetic Resonance Imaging (MRI)**. MRI is one of the most important ways we see details of tissues inside the body. Unlike CT scans, MRIs can show both how tissues look as well as how they function. There are estimated to be more than 25 000 scanners in use worldwide.

History

In the 1930s, **Felix Bloch** and **Edward Purcell** discovered **nuclear magnetic resonance** (NMR). They worked at different American universities. But they were both able to show how magnetic fields and radio pulses can cause atoms to give off tiny radio signals. And by detecting these **radio signals**, you can create an image. This makes it possible to look inside objects without taking them apart or destroying them.

In the early stage of MRI many people did experiments. Herman Carr produced the first one-dimensional MRI image in 1952. In 1972, the physicist **Peter Mansfield** found a way to make images clearer. He also found a way to reduce scanning time from hours to minutes. In 1974, **Paul Lauterbur** created the first sectional images of a mouse. On July 3, 1977, Raymond Damadian, Larry Minkoff and Michael Goldsmith performed the first full body scan. In 2003, Lauterbur and Mansfield won the **Nobel Prize in Physiology or Medicine** for their contributions to MRI technology.

How it Works

MRI scanners use strong **magnetic fields** and **radio waves** to form images of the body. Over half your body is made of water. Each water molecule (H_2O) contains two hydrogen atoms and one oxygen atom. The magnet in an MRI scanner causes the **nuclei** of the two **hydrogen atoms** to line up. Next, short pulses of radio signals cause the nuclei go back to their original positions. When this happens the nuclei emit weak radio signals that are detected by a receiver. The receiver then sends the information to a computer. The computer then creates an image. MRI images capture a lot of details and can be colour-enhanced so that the

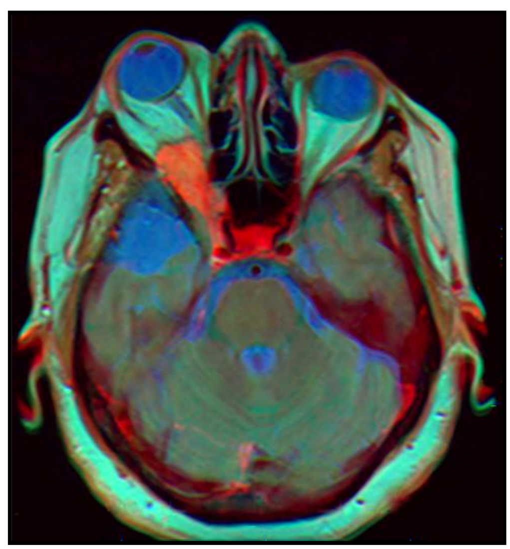


Figure 7: Colour-enhanced MRI image of the brain, optic nerves and eyes.

various parts stand out even more (see Figure 7).

Uses

Like CT scans, MRI scans are used to detect **structural** problems, such as tumours, blood clots, or damage caused by accidents and disease. One unique type of MRI is a **Functional MRI (fMRI)**. An fMRI measures changes in blood flow within the brain. This technique allows doctors to visualize the living brain and observe changes to the brain as it undergoes different functions. CT scanners tend to be used more than MRI machines because they are less expensive to buy. However, as the price of MRI machines comes down, they will likely get used more often.

Benefits & Risks

The greatest benefits of MRI machines are that they do not use x-rays. X-rays can be damaging to tissues and cause cancer). MRI machines are also better than CT scanners for taking images of soft tissues, like tumours. Unfortunately, MRI scans are slow. It can take anywhere from 10 minutes to an hour to produce an image! The machines can also be scary for patients who are **claustrophobic** (afraid of small, enclosed spaces).

> ***Did you know?***
> Since the introduction of fMRI in 1990, more information about the brain has been collected than in the previous 100 years!

Ultrasonography

Ultrasonography uses **ultrasound** to create images of soft tissues such as tendons, muscles, joints, blood vessels and internal organs. Unlike CT scans which use x-rays and MRI machines which use radio waves, ultrasound devices use **sound waves** to create the images.

History

Two researchers are particularly important in the history of medical ultrasound. **Doctor Karl Theodore Dussik** of Austria published the first paper on medical ultrasound in 1942. It was based on his research about the transmission of ultrasound through the brain. **Professor Ian Donald** of Scotland developed some of the first practical technology and applications for ultrasound in the 1950s.

Figure 8: NASA astronaut Chris Cassidy performs an ultrasound on European Space Agency astronaut Luca Parmitano for the Spinal Ultrasound investigation.

How it Works

Ultrasound imaging devices take pictures using sound. Ultrasound are sound waves that have a very high **frequency** (see the **Physics Chapter**). The frequency of sound waves is measured in **Hertz** (**Hz**). Humans are able to hear sounds between a frequency of 20 to 20 000 Hz. Ultrasound uses frequencies between 2 000 000 and 17 000 000 Hz. Unlike sound waves that we normally hear which travel through air, ultrasound waves are **mechanical waves** that travel through a solid or liquid. This is why a gel is applied when a person gets an ultrasound. The gel helps the sound to travel into the person.

One of the main parts of an ultrasound-imaging device is the **transducer**. The transducer is the instrument that the **sonographer** holds on the patient's body. A sonographer is the technician doing the ultrasound imaging. A sound wave is produced by the transducer, which then travels through tissue at a constant speed of 1 540 m/s. Body tissues and structures will absorb, reflect or refract the sound wave (see the **Physics chapter** for more about reflection and refraction).

Once the sound wave returns back to the transducer, it is converted from sound energy into electrical energy. The electrical energy is converted into **pixels** by the ultrasound machine and displayed as a video on a monitor. Soft tissue or organs show up on the monitor as shades of grey. Fluid and blood are black and bone is white. There are different types of transducers than can be used depending on the internal tissue or organ being imaged. A **high frequency transducer** is used to image surface structures with greater detail. A **low frequency transducer** is used to image structures deep within the body, but these images have less detail.

> ***Did you know?***
> A pixel is the smallest element of an image.

Uses

Ultrasound is used to image many internal structures – even babies (see Figure 9)! Ultrasound imaging is widely used on pregnant women. This is called **obstetric sonography**. Ultrasound is also used as a form of treatment. Ultrasound can help sprains and strains to heal faster. Focused high-energy ultrasound pulses is used to break up kidney stones and gallstones through a process known as **lithotripsy**. In addition to medical uses for humans, ultrasound has many other uses, such as in veterinary medicine for diagnosing and treating animals. They are used in **motion-sensors**, jewelry cleaners, humidifiers and many other devices. Who knew ultrasound technology was used for so many things!

Figure 9: Ultrasound image of a fetus in the womb (12 weeks of pregnancy).

Benefits & Risks

Ultrasound imaging is very safe to use and does not appear to cause any negative effects. It is also relatively inexpensive and quick to perform. Ultrasound scanners are portable and can be taken into places such as intensive care units. This avoids potential danger caused by moving critically ill patients to the **radiology department** where x-ray machines, CT scanners and MRI machines are located. The real-time moving images are also very useful in terms of diagnosing and treating illnesses.

Ophthalmic Imaging

How well we see depends on the health of our eyes (see the **Physics chapter** for more about eyes). The study of eyes is called **ophthalmology**, which comes from the Greek words *ophthalmos,* meaning 'eye,' and *logia,* means 'the study of'.

The Fundus

Have you ever seen a photograph in which a person has '**red-eye**?' The Red-eye effect occurs when light from the camera flash reflects off the back of the eye. The back of the eye is called the **fundus**. The fundus includes the **retina**, **fovea**, **optic disc** and **macula** (see the **Physics chapter** for more about these parts and what they do). The many blood vessels in the fundus cause more red light to be reflected, which is why we sometimes get that red-eye in photos. We tend to get the worst red-eye when pictures are taken in a dark room because our pupils are wide open. So how can you avoid getting 'red-eye?' Don't look directly at the flash! A healthy fundus is important to overall eye health (see Figure 10). Eye doctors can see and record images of your fundus using ophthalmic imaging tools.

Figure 10: A healthy fundus.

Ophthalmoscope

The health of the eye is very important for quality of life. The tools described here, and other imaging tools used by healthcare professionals, can help catch diseases early enough to treat or prevent damage to the eye and vision. The **ophthalmoscope** was one of the first devices invented to look into the eye and help understand how it functioned.

History

The first ophthalmoscope was made in 1847 by **Charles Babbage**. It was independently invented in 1851 by **Hermann von Helmholtz**. Within 50 years of the first ophthalmoscope, there were at least 140 different models. Several examples are shown in Figure 11. Early ophthalmoscopes used a candle for their light source. Oil and gas lamps were also popular light sources before Thomas Edison invented the incandescent bulb in 1879. Initial designs that used light bulbs

Figure 11: Several different handheld ophthalmoscopes.

only worked for a short period. Nowadays, handheld battery-operated devices work for a long time with very little energy consumption.

How it Works

An ophthalmoscope has several parts (see Figure 12). The light is focused and directed into the patient's eye with lenses and mirrors. The light that is reflected from the back of the eye is directed through a one-way mirror into the observer's eye (often the **optometrist**). If the image is blurry, a focusing lens can be used (just like in eyeglasses) to make images clearer. Handheld ophthalmoscopes can see only a small part of the fundus at once.

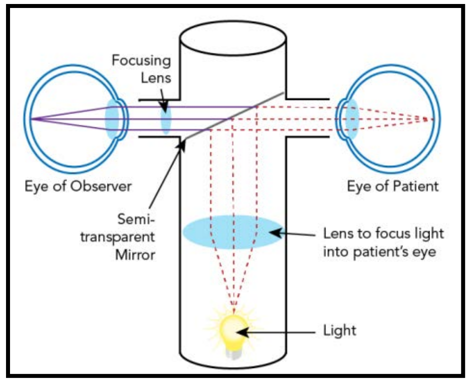


Figure 12: How an ophthalmoscope works.

Modern Ophthalmoscopes

Fundus cameras are ophthalmoscopes that can see a larger area of the fundus as well as take pictures (Figure 13). Before these digital cameras, pictures had to be recorded on film. **Scanning Laser Ophthalmoscopes (SLO)** use a single wavelength of light from a laser instead of a light source like a light bulb. The laser beam is focused to a small spot and motorized mirrors move the spot across the fundus very quickly. A computer stores data from every point and then makes a 2D picture. **Optical coherence tomography (OCT)** takes pictures at many depths in the back of the eye (like the slices of a CT scan) and then creates a 3D image.

Figure 13: A fundus camera.

Uses

Diseases can change the way the fundus looks and therefore the way we see. Medical professionals examine the fundus for signs of swelling of the retina, changes in blood vessels and damage to the nerve tissue as these are signs of eye disease. The shape and colour of the optic nerve can help diagnose **glaucoma**. Glaucoma is a disease in which damage to the optic nerve can lead to blindness (see Figure 14B). Complications from **diabetes** can cause damage to the retina called **diabetic retinopathy** (see Figure 14C). Diabetics need fundus examinations regularly to catch signs of diabetic retinopathy so it can be corrected with surgery before it causes permanent vision loss.

Figure 14A: Normal vision, **B**: Severe glaucoma, **C:** Diabetic retinopathy.

Benefits & Risks

Ophthalmic imaging is a very safe technique. Although shining bright lights and lasers into your eye can be harmful, the imaging tools described here are designed and tested to be very safe and effective when used by professionals.

Thermal Imaging

There are parts of the electromagnetic spectrum that the human eye can't see. This includes **thermal infrared** radiation. This is radiation with long wavelengths.

Everything emits thermal radiation - even humans. Objects such as a stove element on high, emit radiation in the visible spectrum when it glows 'red' hot. Humans are not as hot as stove elements. We emit radiation in the infrared part of the spectrum. The intensity and distribution of wavelengths changes with temperature. If we can record the energy emitted by the thermal radiation, we can use it to look for temperature differences across an area.

The design of a thermal camera is similar to a regular camera. You need lenses to collect and focus the energy as well as a detector. Infrared wavelengths do not transmit through regular camera lenses. Lenses must be made from special materials such as the chemical element **germanium**. Specialized detectors such as **microbolometers** or cooled detectors are also needed. A thermal camera displays an image called a **heat map**. On heat maps, cooler temperatures appear purple and blue and warmer temperatures appear orange and yellow. The image below shows a regular camera image (left) and a thermal camera image (right). Notice that emitted radiation passes through the black plastic bag, but not through the eyeglasses.

Figure 15: Visible image (left) and thermal image (right).

There are a number of Industrial uses of thermal imaging. Thermal imaging can show where heat is escaping around windows and doors. Thermal imaging can also help firefighters to see through smoke to find victims. In the scientific field, thermal imaging can help researchers to observe chemical processes.

Thermal imaging is **non-invasive**. This means that nothing breaks the skin or enters the body. This makes it very safe and painless. Scientists are now beginning to explore thermal imaging for medical applications. For example, thermal cameras are used in airports in countries like China and Mexico. They help to detect people who have high fevers. in places such as airports. This monitors and prevents the spread of diseases. Researchers in Montreal are also developing a way to use thermal imaging to help evaluate the severity of a burn. Other current research explores how thermal images of the hands and wrists may reveal **carpal tunnel syndrome**. While hot spots on a thermal image of the neck could indicate a **thyroid** condition.

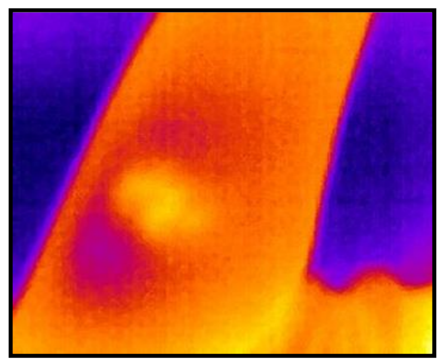


Figure 16: Arm with a burn. The bright spot is the burn. The dark around the burn is cold from an ice pack on the arm. Only the brightest spot of the burn could be seen with a regular camera.

Thermography provides a way to look at the heat distribution of an object. It has many industrial and medical applications. Thermography is not used as much as other medical imaging techniques currently. However, it may become more popular as scientists understand more about human heat mapping and ways it could be used to diagnose illnesses.

Spotlight on Innovation

The Canadian Light Source Synchrotron

A synchrotron is a source of brilliant light that scientists can use to gather information about the structure and chemical properties of molecules in a given material.

Figure 17: The experimental facility of the Canadian Light Source Synchrotron.

A synchrotron produces light using radio waves and powerful electro-magnets to accelerate electrons to nearly the speed of light. Energy is added to the electrons as they accelerate. When the magnets alter the course of the electrons, they naturally emit a very brilliant, highly focused light. Different spectra of light (see the **Physics Chapter**), such as Infrared, Ultraviolet, and X-rays, are directed down channels for the light called **beamlines**. Researchers can choose the desired wavelength to study their samples. The researchers observe the interaction between the light and matter in their sample at the **end stations** (laboratories).

The synchrotron can be used to investigate matter and analyze physical, chemical, geological, and biological processes. Information obtained by scientists can be used to help design new drugs, examine the structure of surfaces to develop more effective motor oils, build smaller, more powerful computer chips, develop new materials for safer medical implants, and help with the clean-up of mining wastes, to name just a few applications.

The Canadian Light Source is Canada's national centre for synchrotron research and is located at the University of Saskatchewan in Saskatoon.

Text from the Canadian Light Source.

My Career

Ning Zhu
Associate Scientist, Canadian Light Source Inc.
Biomedical Imaging and Therapy Beamline (BMIT)

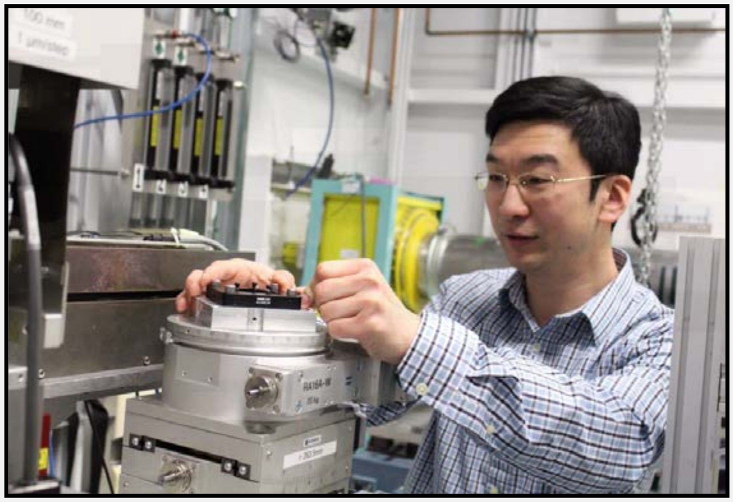


Figure 18: Ning Zhu at work in a laboratory.

The Canadian Light Source (CLS) is a national research facility located at the University of Saskatchewan. It is one of the largest science projects in our country's history. It is also the brightest light in Canada – millions of times brighter than the Sun! Over 1 000 scientists from around the world use the CLS every year to conduct ground-breaking research in health, environment, materials and agriculture. The Biomedical Imaging and Therapy Beamline (BMIT) at the CLS enables researchers to use advanced X-ray imaging techniques to answer questions into anatomy and disease. For example, researchers could combine computed tomography with chemical mapping.

My role is to use my expertise in biomedical engineering to help researchers. I help them to plan their experiments, select the best imaging technique, set up the equipment, prepare the samples, and interpret data. Researchers who use BMIT are experts in medicine or biology, but often not experts in imaging processes or synchrotron equipment. That is why my assistance is essential to finding solutions for their research questions. For example, surgeons rely on medical imaging to help them plan precise operations. I worked with researchers from Ontario to develop a database of highly detailed images to plan **cochlear implant** surgeries. Cochlear implants are placed in a patient's inner ear to help them hear.

My favourite thing about my job is being able to 'see' new things. "We have eyes, but when looking at science and nature, we are quite blind. Using cutting edge technology like the CLS, we can see things we've never seen before and it's exciting to see such magnificence."

Pinhole Camera Engineering Challenge

Challenge:

Your challenge is to work as a team to design and build a simple pinhole camera.

Materials:

- Shoebox (or other small, light-proof container with removable lid) (the **camera**)
- Sun-sensitive paper (this is the **film**) (available from craft stores)
- Aluminum foil
- Masking tape
- Pin or sharp nail
- Hammer (optional)
- Self-adhesive notepaper (1 piece)

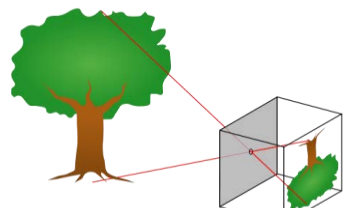


Figure 19: How a pinhole camera works.

Set-up:

- Cut a hole in the middle of one side of the box. Make sure that there is a way that you can open and close the box.
- Tape the piece of aluminum foil securely over the hole that you cut in the box. Poke a very small hole in the centre of the aluminum foil.
- Cut a piece of sun-sensitive paper the size of the back of your camera. Keep it in darkness until you are ready to take your picture.

Operation:

- In a dark room, tape the sun-sensitive paper to the inside of the box, opposite the pinhole and close the box. Place a cover over the side with the pinhole.
- Place the camera on a flat, stable surface, so the side with the pinhole is facing what you want to take a picture of (hint: it should be something well-lit and not moving). Uncover the pinhole and let sit for 1-2 minutes (this is called "exposing" the film).
- Cover the pinhole back up and take the camera to a dark place, then open the camera and remove the sun-sensitive paper. When viewed inside the camera, the image on the paper should appear upside-down (see picture above).

Success

- You have captured an image on the piece of sun-sensitive paper.

Pushing the Envelope

- Change the length of exposure. How does that affect the image?
- Can you figure out a way to see your image without using film?

References

Figure References

Figure 1: The first medical x-ray.
http://commons.wikimedia.org/wiki/File:First_medical_X-ray_by_Wilhelm_R%C3%B6ntgen_of_his_wife_Anna_Bertha_Ludwig%27s_hand_-_18951222.jpg (Accessed July 2, 2019)
Public domain image from NASA.

Figure 2: X-ray showing person with metal pins in legs.
http://commons.wikimedia.org/wiki/File:Medical_X-Ray_imaging_KFF05_nevit.jpg
(Accessed July 2, 2019)
Public domain on Wikimedia Commons.

Figure 3: Airport x-ray of a backpack.
http://commons.wikimedia.org/wiki/File:Xray-verkehrshaus.jpg (Accessed July 2, 2019)
Public domain on Wikimedia Commons.

Figure 4: The first CT machine prototype.
http://commons.wikimedia.org/wiki/File:RIMG0277.JPG (Accessed July 2, 2019)
Public domain on Wikimedia Commons.

Figure 5: Modern CT scanner.
http://commons.wikimedia.org/wiki/File:CAT_scanner.jpg (Accessed July 2, 2019)
Public domain on Wikimedia Commons.

Figure 6: CT scans of the brain from base of the skull to the top of the head.
http://commons.wikimedia.org/wiki/File:Computed_tomography_of_human_brain_-_large.png (Accessed July 2, 2019)
Public domain on Wikimedia Commons.

Figure 7: Colour-enhanced MRI image of the brain, optic nerves and eyes.
http://commons.wikimedia.org/wiki/File:Brain_MRI_133441.png (Accessed July 2, 2019)
Public domain on Wikimedia Commons.

Figure 8: NASA astronaut Chris Cassidy performs an ultrasound on European Space Agency astronaut Luca Parmitano.
http://commons.wikimedia.org/wiki/File:ISS-36_Luca_Parmitano_and_Chris_Cassidy_in_the_Columbus_lab.jpg (Accessed July 2, 2019)
Public domain image by NASA on Wikimedia Commons.

Figure 9: Ultrasound image of a fetus in the womb (12 weeks of pregnancy).
http://commons.wikimedia.org/wiki/File:CRL_Crown_rump_lengh_12_weeks_ecografia_Dr._Wolfgang_Moroder.jpg
(Accessed July 2, 2019)
Public domain image by Wolfgang Moroder on Wikimedia Commons.

Figure 10: A healthy fundus.
http://commons.wikimedia.org/wiki/File:Fundus_photograph_of_normal_right_eye.jpg (Accessed July 2, 2019)
Public domain on Wikimedia Commons.

Figure 11: Several different handheld ophthalmoscopes.
http://commons.wikimedia.org/wiki/File:9_Ophthalmoscop_front.JPG
(Accessed July 2, 2019)
Public domain on Wikimedia Commons.

Figure 12: How an ophthalmoscope works.
Image ©2020 Let's Talk Science based on an image from http://www.yorku.ca/eye/ophthal.htm
Used with permission.

Figure 13: Fundus camera.
http://commons.wikimedia.org/wiki/File:2010-12-07-funduskamera-by-RalfR-03.jpg (Accessed July 2, 2019)
Public domain image by Ralf Roletschek on Wikimedia Commons.

Figure 14A: Normal vision.
http://commons.wikimedia.org/wiki/File:Eye_disease_simulation,_normal_vision.jpg (Accessed July 2, 2019)
Public domain image by the National Institutes of Health on Wikimedia Commons.

Figure 14B: Severe glaucoma.
http://commons.wikimedia.org/wiki/File:Eye_disease_simulation,_glaucoma.jpg (Accessed July 2, 2019)
Public domain image by the National Institutes of Health on Wikimedia Commons.

Figure 14C: Diabetic retinopathy.
http://commons.wikimedia.org/wiki/File:Eye_disease_simulation,_diabetic_retinopathy.jpg (Accessed July 2, 2019)
Public domain image by the National Institutes of Health on Wikimedia Commons.

Figure 15: Visible image (top) and thermal image (bottom).
http://coolcosmos.ipac.caltech.edu/cosmic_kids/learn_ir/
Image courtesy of NASA/JPL-Caltech.

Figure 16: Arm with a burn.
Image ©2014 Catherine Greenhalgh. Used with permission.

Figure 17: The experimental facility of the Canadian Light Source Synchrotron
© the Canadian Light Source. Used with permission

Figure 18: Ning Zhu at work in a laboratory.
© the Canadian Light Source. Used with permission

Figure 19: How a pinhole camera works.
http://commons.wikimedia.org/wiki/File:Pinhole-camera.png?uselang=en-gb
(Accessed July 2, 2019)

General Resources

X-rays

http://science.howstuffworks.com/x-ray.htm (Accessed July 2, 2019)
This section of the How it Works website explains how x-rays and x-ray machines work.

CT Scans

http://science.howstuffworks.com/cat-scan.htm (Accessed July 2, 2019)
This section of the How Stuff Works website explains how CAT scans work.

http://www.youtube.com/watch?v=Tx-0emi4m8s (Accessed July 2, 2019)
This YouTube video, by OUlearn, explains what happens during a CT scan.

MRI

http://science.howstuffworks.com/mri.htm (Accessed July 2, 2019)
This section on the How Stuff Works website explains how MRIs work.

http://www.youtube.com/watch?v=pGcZvSG805Y (Accessed July 2, 2019)
This YouTube video, by the Edison Tech Center, explains how an MRI works.

http://www.youtube.com/watch?v=DZTXa4qerI4 (Accessed July 2, 2019)
This YouTube video, by the Via Christi Health Centre, shows you what it is like to have an MRI.

Ultrasounds

http://www.timetoast.com/timelines/the-history-of-ultrasound (Accessed July 2, 2019)
This timeline, from timetoast, is about the history of the ultrasound.

Thermal Imaging

http://coolcosmos.ipac.caltech.edu/cosmic_kids/learn_ir/index.html (Accessed July 2, 2019)
This page, from Cool Cosmos (by NASA), is about infrared radiation.

http://electronics.howstuffworks.com/gadgets/high-tech-gadgets/nightvision2.htm (Accessed July 2, 2019)
This page, on the How Stuff Works website, provides a good overview of how thermal imaging works.

http://www.youtube.com/watch?v=2M-xRye03vI (Accessed July 2, 2019)
This video, by FLIR Systems, gives a history of thermal imaging, as well as how thermal imaging works.

https://phys.org/news/2009-05-thermal-imaging-cameras-flu-fevers.html (Accessed January 24, 2020)
This article, from Phys.org, shows how thermal imaging is used in airports.

https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0206477 (Accessed January 24, 2020)
This research paper, in PLoS ONE, studied thermal imaging and burn wounds.

https://link.springer.com/chapter/10.1007/978-3-642-30668-6_23 (Accessed January 24, 2020)
This webpage includes an excerpt from *Aspects of Computational Intelligence: Theory and Applications* about evaluating Carpal Tunnel Syndrome with thermal imaging.

https://academic.oup.com/jcem/article/99/12/4600/2834415 (Accessed January 24, 2020)
This research paper, in The Journal of Clinical Endocrinology & Metabolism, studied thermal imaging for detecting thyroid eye disease.

Spotlight on Innovation

https://www.lightsource.ca/inside_the_synchrotron (Accessed July 2, 2019)
Canadian Light Source website providing information about the Synchrotron and research performed at the facility.

Pinhole Camera Design Challenge

http://www.pinhole.cz/en/pinholecameras/ (Accessed July 2, 2019)
This page, from David Balihar's pinhole.cz website, has a history of and a good explanation of how pinhole cameras work.

http://www.diyphotography.net/23-pinhole-cameras-that-you-can-build-at-home (Accessed July 2, 2019)
This page, from the DIYPhotography website, has lots of fun pinhole camera designs.

Environmental Sciences
Chapter 5

2020

Thank you to our chapter sponsor: 3M

The Terrestrial Biomes

The **terrestrial** world can be divided into areas called **biomes**. A biome is a large area of land classified by its distinct plants and animals. The characteristics of each biome are dependent on its temperature and the amount of precipitation the area receives. The plants and animals found in each biome are adapted to the particular environment of the biome.

A biome is made up of many **ecosystems**. An ecosystem is the interaction of living and nonliving things in an environment. However, a biome is the specific geographic area in which ecosystems can be found. For the purpose of this chapter, we will identify eight major terrestrial biomes of the world based on the Whittaker classification scheme: **tropical rainforest, savanna, grassland, chaparral, desert, temperate deciduous forest, boreal forest/taiga**, and **tundra**. It is interesting to note that not everyone agrees on the number and types of biomes.

Distribution of the Earth's Major Biomes

Figure 1 shows where each of the eight major terrestrial biomes are located in the world. Canada contains four biomes: temperate deciduous forest, grassland, boreal forest/taiga, and tundra. A biome has the same characteristics in any part of the world when it can be found. Therefore, the boreal forests of Canada look like the boreal forests of Russia. The characteristics of each biome are dependent on its climate, particularly temperature and the amount of precipitation the area receives. In this chapter we are going to explore five of the biomes – tropical rainforests, savannas, deserts, boreal forests/taiga and tundra.

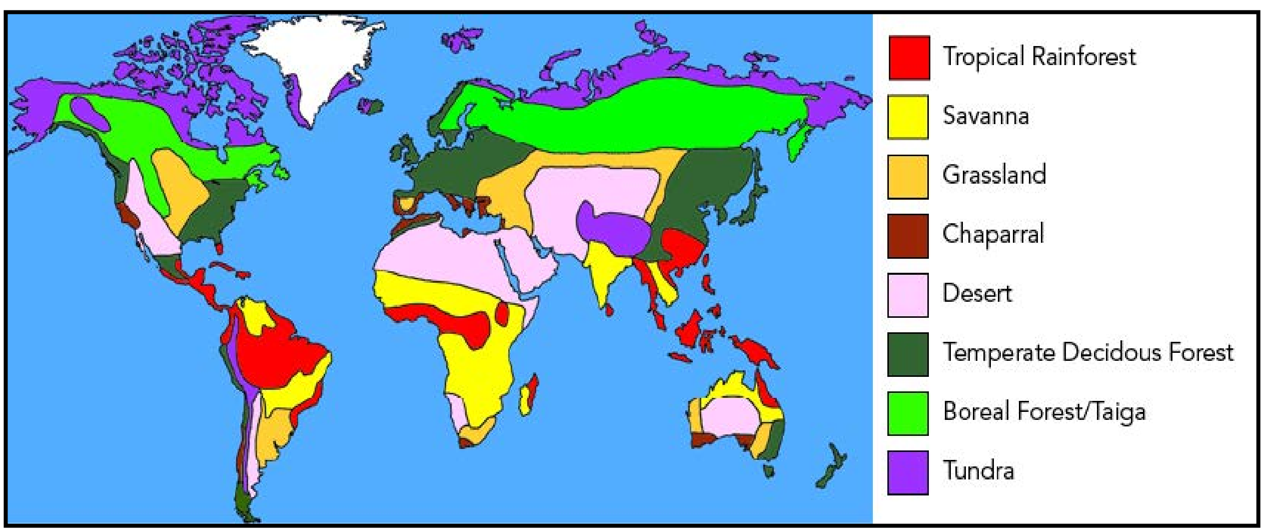


Figure 1: Major terrestrial biomes.

Tropical Rainforests

Location

Tropical rainforests are found in the equatorial zone in Central America, South America, Africa, Asia and Australia (see Figure 1).

Description

Tropical rainforests have warm temperatures and high **humidity**. Humidity is the proportion of water vapor in the air. Tropical rainforests typically receive between 1.5m to 4m of rainfall each year. That's a lot of moisture! This consistently warm and humid climate makes tropical rainforests a great habitat for plants and animals. Rainforests are one of the most **biodiverse** biomes on Earth. Biodiversity is a measure of the number of living things. As many as half of the Earth's terrestrial species are found in this one biome!

Plants & Animals

For plants in tropical rainforests, it's all about competition. These forests are very **dense**. This means that the trees stand close to each other. Their branches and leaves overlap greatly, creating what is known as a **tree canopy**. This canopy prevents much of the sunlight from getting to the forest floor. Only 2% of the Sun's rays pass through! Some plants have adapted to the small amount of light they receive by growing tall while others have adapted by growing over top, covering other plants.

Figure 2: Canopy trail in Puerto Viejo de Sarapiqui, Costa Rica.

Figure 3: Blue poison dart frog (*Dendrobates tinctorius azureus*).

Animals in the rainforest are also very diverse. Most animals live in the trees. There they can find everything they need, so they rarely come down to the floor of the forest. Insects make up most of the living creatures in the tropical rainforest. Many amphibians and insects are poisonous to their potential predators. This is because they absorb harmful chemicals called **toxins** from plants, usually by eating them. You can tell when a species has adapted in this way because it has very brightly colored markings that warn predators not to eat it (see Figure 3).

On the other end of the colour spectrum, mammals such as big cats and monkeys **camouflage** into their surroundings. Jaguars, tigers and boars move quietly along the forest floor in search of food. Monkeys, lemurs and sloths use the abundant branches to their advantage. They stay away from predators by finding food high up above in the trees.

Human Impacts & Conservation

Local human populations in tropical rainforests harvest fruit, wood and medicinal plants as well as hunt animals. The biggest threat to tropical rainforests is **deforestation**. Deforestation is the cutting down of trees. Humans cut down the trees for wood. They also often burn the land where the trees had been to prepare the soil for farming. Brazil and Indonesia have lost over 46% of their rainforest area. In many places, such as deforested areas, the soil damage makes it difficult for rainforests to regrow, and the lost biodiversity is irreplaceable.

Figure 4: Orang-utan (*Pongo pygmaeus*) in the Semenggok Forest Reserve, Malaysia.

Many of the plants found in rainforests are being used to make medicine, including anti-cancer drugs, along with beauty products and foods. An example of deforestation that has put many species of plants and animals at serious risk is in **Malaysia**. Thousands of acres of forest have been cut down to accommodate oil palm plantations. **Palm oil** from palm trees is used in many products, from soap and shampoo to chocolate bars. One endangered species that suffers from deforestation in this area is the **orang-utan** (meaning '*man of the forest in Malay*').

For many years, individuals, environmental organizations and other stakeholders have pressured governments to protect tropical rainforests. There has been success in many places, but deforestation is still a major problem. One way to prevent further destruction is to develop and encourage **sustainable farming** methods in regions that have already been cleared in order to discourage further deforestation. Farmers can be taught new farming methods that require less land and less water. They can also be encouraged to maintain the forests themselves. Projects are also underway in many regions to replant trees in cleared areas.

It is important for tropical rainforests to be preserved so that they can **mitigate** (make less severe) climate change, because they act as '**carbon sinks**.' Similar to how we take in oxygen when we breathe, plants take in **carbon dioxide** and release **oxygen**, when they make their food (through the process of **photosynthesis**). By taking in carbon dioxide from our atmosphere, the rainforest helps to slow down the effects of climate change.

Savannas

Location

Savannas are found all around the world. There are five different types of savannas:

- **Tropical and subtropical savannas:** found near the equator and bordered by tropical rainforests and deserts (e.g., the **Serengeti** in Africa)

- **Temperate savannas**: found in mid-latitude regions (e.g., temperate savanna of **Southeast Australia**)
- **Mediterranean savannas**: also found in mid-latitude regions, but in the Mediterranean (e.g., the **Alentejo region** in Portugal)
- **Flooded savannas**: found in the **tropics** (e.g., the **Pantantal** in South America)
- **Montane savannas**: found in high altitude regions (e.g., the **mountains of Angola** in equatorial Africa)

Description

If you were to climb a tree in the middle of a savanna, you would see kilometres of flat land covered in tall and short **grasses** and spotted with **low-lying shrubs** and scattered trees. Savannas are usually a **transitional zone** between a forest and a grassland. This means that while there are still tall trees, like a forest, they are spread out and the ground is covered in grasses, like a grassland. The climate is also transitional with rotating dry periods, like a desert, and wet periods, like a rainforest. During the winter, no rain falls, and the land is very dry. In the summer, it usually rains quite a lot. This is called **seasonal rainfall** because it only rains in a certain season.

Figure 5: Acacia tree in the Serengeti, Tanzania.

Plants & Animals

Due to the large amount of grass found in savannas, many types of **grazing mammals** can be found there. Grazing animals are animals that feed on grasses. These include **zebras**, **wildebeests**, **elephants**, **giraffes**, **ostriches**, **gazelles**, and **buffalo**. **Herds** (groups) of grazing animals are commonly seen in the African savanna. The savanna biome of sub-Saharan Africa also has the highest diversity of **ungulates** on Earth. Ungulates are hoofed mammals like rhinoceroses, giraffes, camels, hippopotamuses, and elephants.

Many **rodents** live in savannas. Rodents are a mammal group which includes mice and rats. Rodents are often found in holes leading to intricate underground homes called **burrows**. In their burrows, the rodents can hide from predators and keep cool.

Savannas are also home to very specialized predatory mammals and birds. The mammals, both **feline** (e.g., **lions** and **cheetahs**) and **canine** (e.g., **African wild dogs**), have colouring that allows them to blend into the grasslands. **Raptors** (birds of prey), such as **vultures**, **eagles** (see Figure 6) and **goshawks**, have incredible eyesight, able to spot even a well-camouflaged grassland creature from high above.

The plant-eating animals have developed ways at avoiding predators. Some animals, like the gazelle and ostrich, use speed to try and outrun predators. The giraffe uses its height to spot predators from far off and the elephant uses its shear size and strength to keep predators away.

Figure 6: Tawny eagle (*Aquila rapax*).

Human Impacts & Conservation

Savannas are subject to natural **wildfires** during the dry seasons, but humans often cause fires as well. Many savanna plants are adapted to thrive after fires. However, if fires happen too often, it can be damaging to the ecosystem. Savannas are also often used for farming, which is disruptive to the wildlife. This is a big problem for animals if large farms take over grazing or hunting lands. Developing farmland typically involves clearing trees, which destroys the habitats of animals and other plants that rely on those trees. Farmers also allow their domesticated livestock to graze on savannas, which can mean that there is not enough food for wildlife. This over-grazing can have negative effects on the native plants as well.

Figure 7: Elephant with missing tusk.

For wildlife, **poaching** is a major threat, especially in Africa. Poaching is the term for hunting animals illegally. Large grazers like **elephants** (see Figure 7) and **rhinoceros** are hunted for their ivory tusks and horns. This is putting these animals at risk. When animals are lost due to poaching, it can alter the entire ecosystem.

In addition to providing on-the-ground protection for animals, many countries make poaching an offense punishable by prison or heavy fines. However, a better way to stop poaching is the ongoing effort to decrease demand for illegal wildlife and wildlife parts. If no one's buying the products, there will be no need to kill these animals!

As with all biomes, climate change is a huge threat to savannas. As the average global temperature rises due to the emission of greenhouse gases, extreme weather events, such as **droughts** (extremely dry conditions) have become increasingly severe. Furthermore, when the landscape is altered by the human uses described above, savannas are more likely to flood and burn in an uncontrolled manner.

Sustainable farming methods can be put into place to protect the land and wildlife of savannas. This may involve growing more than one crop on a piece of land so that less space is used. Or it may mean growing native species, such as trees, on farmland instead of cutting them down. To keep grazing livestock from competing with wildlife, some farmers feed their animals in stalls rather than letting them graze out on the savanna. There are also environmental organizations and governments that are taking serious action against poaching and illegal wildlife trade.

Deserts

Location

When looking at a world map, the majority of **deserts** are found along two lines of latitude. These two lines are called the **Tropic of Cancer** (30 degrees North) and **the Tropic of Capricorn** (30 degrees South).

Around these latitudes, dry air coming from the **equatorial regions** (around 0 degrees) dries out the land. Some deserts are found in **landlocked** regions. These are places not bordered by an ocean. One example of this is the **Great Basin Desert** in North America. This is the largest desert in The United States. **Coastal deserts** form near the coasts of continents. As cool air moves from west to east across oceans, it can create cold foggy weather instead of rainfall along the western coasts of continents. Two deserts that fit this pattern are the **Namib Desert** in southwestern Africa and the **Atacama Desert** in South America (see Figure 8).

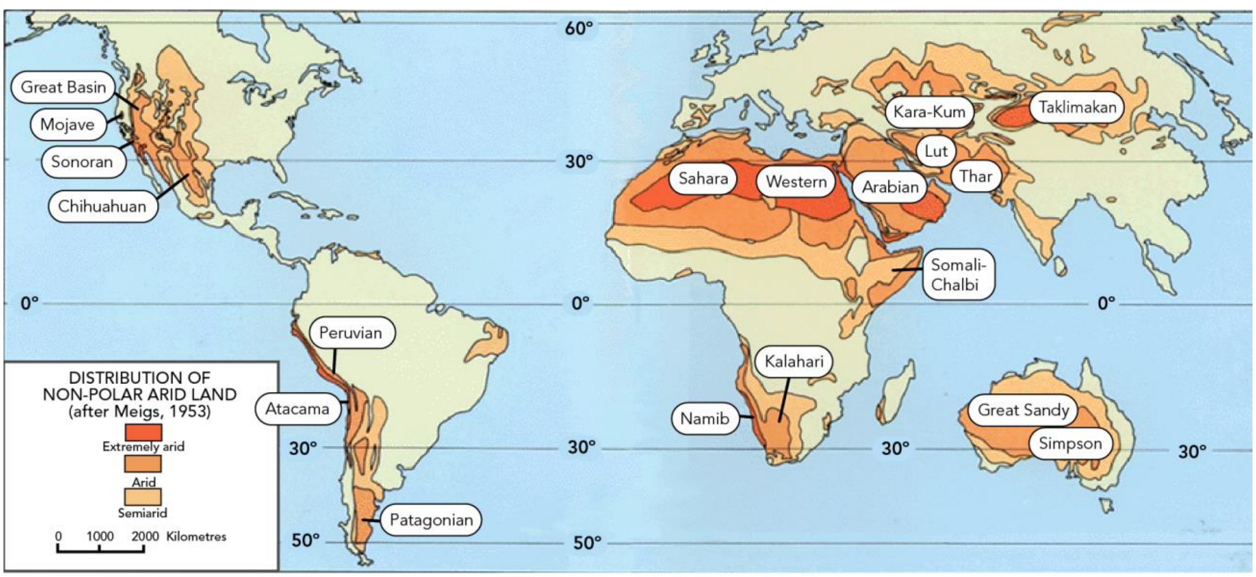


Figure 8: Deserts of the world.

Description

Deserts differ based on where they are and the type of climate found there. Deserts are regions of land that receive less than 25 cm of rain each year. We usually think of deserts as being very hot, but some deserts can be very cold. **Cold deserts** can be found in the Antarctic as well as Greenland. What defines a desert is rainfall, not temperature. Some deserts receive more rain than others, but even when a desert does receive rain, the water evaporates quickly. With few plants, little water and extreme swings in daily temperatures, the soils in deserts tend to be rocky or sandy and have very little **organic matter** (from dead plants). These soils are known as **aridisols** or desert soils. Many deserts also experience a lot of **wind**.

Plants & Animals

A desert is often thought of as a windy expanse of sand. But there is more going on in **hot deserts** than meets the eye. The plants and animals in deserts have special adaptations which help them to live in this sometimes harsh biome.

Plants found in hot deserts have developed ways to reduce the natural evaporation from their leaves. They also have ways to protect themselves from desert **herbivores** (plant-eating animals). Plants reduce evaporation by having small leaves and **waxy cuticles**. The cuticle is a protective covering on leaves. Because the sunlight is so intense, plants have small or no leaves. Some desert plants only grow leaves in response to rainfall and then have no leaves during most of the year when it is dry. Other plants, in the **cacti** family, do not have any leaves. Instead they have hairs or spines covering them. Theses hairs/spines have a double benefit. Not only do they help to reduce evaporation, they also discourage animals from eating them. Like **camels**, cacti can store water in their tissues to use later (see Figure 9).

Figure 9: Golden barrel cacti.

Animals in hot deserts are good at avoiding the heat. When it is very hot, many animals will only come out at night, when the Sun has gone down. During the day, most animals will seek shelter in shady areas. An example of this is the **desert scorpion**, which hunts at night and spends the day hidden. Several different desert animals, such as rodents, burrow underground to keep cool during the day, similar to the rodents in the savanna biome. In the Sonoran Desert in the United States, **ground squirrels** spend large amounts of time in burrows built underground. The burrows they dig provide shelter from the Sun and from predators. When temperatures are moderate, the ground squirrels will venture above ground to look for food.

Human Impacts & Conservation

Human activities, such as allowing livestock to graze on grasslands, are turning other biomes into deserts. This is called **desertification**. Population growth and greater demand for land is making this a difficult problem to solve. Climate change is also making these hot dry places even hotter and drier. Off-road vehicles such as **dune buggies**, **oil and gas production** and **urbanization**, such as building towns and cities, are all causing damage to desert plants which take a long time to grow. For example, the **saguaro cactus** takes 200 years to grow to full size!

Some proposed solutions include planting bushes and grasses that keep the sand from blowing around and digging ditches that can store rain as well as wind-blown seeds. People are encouraging to use off-road vehicles only on designated trails and people living in desert resort cities, such as **Palm Springs**, California (in the Sonoran Desert), are encouraged to replace their water-loving grass lawns with native desert plants which do not require watering. This is known as **xeriscaping**.

Boreal Forests/Taiga

Location

The boreal forest, also known as the taiga, covers about 11% of the land mass of this planet. This makes it the world's largest terrestrial biome! It is located in the northern hemisphere, approximately between the latitudes of 50˚ N – 65˚ N. The term "boreal forest" tends to mean the more southern part of the biome, while the term "taiga" tends to mean the more northerly part of the biome where it transitions to the tundra (see the next section).

Description

Figure 10: Boreal forest in northern Quebec.

This biome is known for its **coniferous** (cone-bearing evergreen) forests and many freshwater bodies in the form of rivers, lakes, bogs, fens and marshes. Overall, the soil has relatively **low fertility**, which means that it is not good for growing plants. Most of the nutrients occur in the upper layer of the soil where organic matter is found. The soil also tends to be slightly **acidic** because of the breakdown of evergreen needles when they fall to the ground and decompose. The boreal forest has cold winters and relatively warm summers. Typical temperatures range from 21 ˚C in summer down to -54 ˚C in winter. Precipitation is moderate, averaging around 200–600 mm per year, and droughts are relatively rare.

Plants & Animals

Vegetation found in this biome is adapted to a cold climate and low nutrient availability. Many of the plants have shallow root systems which work together with **mycorrhizal fungi** (see the **Biology chapter**) to get the most nutrients they can out of the organic matter in the soil. Southern boreal forests have a thick tree canopy formed by fully grown trees. This is called the **closed canopy forest**. In open spaces called **clearings** there are some shrubs and wildflowers.

On the floor of this type of forest are mainly **mosses** (see the **Biology chapter**). Northern boreal forests have trees which are more spread apart. This is called the **lichen woodland**. Here, lichens, which are fungi which live in partnership with algae, form most of the ground cover. Some of the common trees found in this biome include conifers such as **spruce**, **fir**, **hemlock**, **larch** and **pine** and deciduous trees such as **aspen**, **birch** and **willow**. The mix of trees varies depending on which part of the world the forest is found in. The boreal forest of North America is mostly made up of spruces. The boreal forest of Eastern Siberian taiga is basically one large larch forest. Larch trees don't follow the common evergreen rule and keep their needle-like leaves year-round. These trees are actually deciduous. The needles of larch trees turn a brilliant yellow in autumn and then drop off.

Figure 11: Wood bison (wood buffalo) at Wood Buffalo National Park (the largest national park in Canada!).

Similar to the vegetation, the animal life in the boreal forest is adapted to the cold climate. Common animals found in the boreal forests of Canada include large herbivores such as **caribou** (called **reindeer** outside of North America), **moose**, **elk** and **wood bison** (also called wood buffalo) (see Figure 11). Large predators found here include the **Canada lynx**, **gray wolf**, **black bear** and **brown bear**. Smaller mammals, such as **beavers**, **raccoons** and **voles** also live here. Many species of birds use this biome for their nesting grounds. Many freshwater bodies provide a unique habitat for many migratory fish such as the **North American Atlantic salmon**. Finally, the forests, bogs and marshes of this biome are home to a large variety of insect life.

Human Impacts & Conservation

Humans have had a long history of interacting with boreal forests. One way we know this is through art. Cave paintings and rock drawings that are thousands of years old show people hunting boreal forest animals for food (see Figure 12). However, human impact on the boreal forest has been relatively minor since the unfavourable climate makes it difficult for people to live there.

Figure 12: Rock drawings of humans hunting reindeer from Alta, Norway (dated 4000 BC).

In more recent times, as the number of humans living in this biome has increased, and so has our impact. In general, humans have looked towards the boreal forest as a source of **natural resources**. At the beginning, this meant cutting down trees for wood and mining the land for various metals. More recently, this has expanded into **oil and gas exploration** and extraction. Human-induced **climate change** is predicted to have a large impact on the population and ranges of both plants and animals living in boreal forests. For example, warmer, drier conditions associated with climate change will likely cause more trees to die during the summer and insect populations to increase. However, conservation groups, such as the **Canadian Boreal Initiative** are working hard to help others create sustainable solutions for Canada's boreal forests.

Arctic Tundra

Location

The **arctic tundra** biome is the northernmost biome. It covers the lands north of the Arctic Circle up to the **polar ice cap**. It reaches as far south as the Hudson Bay area of Canada and the northern part of Iceland. It covers approximately 11.5 million km^2. There is also an **alpine** tundra, which is found on mountains and **Antarctic** tundra, which is found on Antarctica and the surrounding Antarctic islands.

Description

The arctic tundra is a vast, dry, rocky place that is noted for its lack of trees. In fact, the word "tundra" comes from the Finnish word *tunturi*, meaning 'treeless plain.' One important characteristic of the tundra is the **permafrost**. The word permafrost is short-form for the permanently frozen soil, which starts within a meter of the soil surface. In the winter almost all of the soil is frozen. In the summer the soil near the surface thaws, but the permafrost at lower depths remain frozen. The permafrost limits how far roots of plants can extend down into the soil. It also is what prevents trees from growing. The ground in the arctic tundra tends to be rocky and the soil has few nutrients. This is because the decomposition rates of plants tends to be low. Despite the lack of trees, this biome is still considered a major carbon sink as there are large amounts of organic matter found in deposits of **peat** and **humus**. Peat is decayed sphagnum moss and humus is organic matter.

Figure 13: Typical arctic tundra landscape in Nunavut.

Due to its northern position, the arctic tundra has a very cold climate. Temperatures range from 15.5 ˚C in summer to -90 ˚C in winter. Summers are also much shorter than the winters. The northernmost part of this biome receives close to 24 hours of sunlight during parts of the summer. And it receives close to 24 hours of darkness during parts of the winter. Annual precipitation is around approximately 200 – 600 mm. Most of this precipitation does not evaporate due to the low temperatures. Rivers and lakes often form soil tends to be very soggy in the summer.

Plants & Animals

Due to the cold climate and short growing season, most vegetation in the tundra tends to be **herbaceous**. Examples of herbaceous plants found there include grasses, mosses such as **reindeer moss**, **liverworts** and lichens. The few woody plants which live in the tundra, such as **dwarf willows**, tend to be short and spread across the ground. This is an adaptation to the high winds that are common in this biome. Plants in this biome also tend to go **dormant** during the long winters. This means that they slow down their normal life functions. Most of their **biomass** (mass of their parts) is below ground. And they have relatively high growth rates in the short summers.

Figure 14: Arctic hare in winter.

Many large mammals, such as caribou, **polar bears**, **arctic foxes**, and **musk ox**, are found in this biome. There are also several smaller mammals, such as **lemmings** and **arctic hare** (see Figure 14) which are prey to the larger mammals. These prey animals have brown fur in the summer and white fur in the winter to help them camouflage with the changing landscape. During the summer many migratory birds, such as **loons**, **snow geese** and **terns**, come to the tundra to breed. Although there is low insect biodiversity, the insects that live in the arctic tundra, such as mosquitoes, can have large populations.

Human Impacts & Conservation

In the past, humans have had relatively little impact on the arctic tundra. Recently this has begun to change as more and more people have come to the north to extract various natural resources such as oil. Climate change has also begun to, and will continue to have a large impact on this biome. Higher global temperatures are melting the sea-ice and permafrost. This is altering and sometimes destroying the habitats of plants and animals. In an effort to protect this unique biome, efforts to reduce human impacts are being undertaken. This includes efforts to reduce levels of **greenhouse gases** as well as the creation of protected areas where human interference and hunting are limited.

Spotlight on Innovation

Prescribed Burns

Fire can be a very destructive force both in populated areas and wilderness areas. One such fire caused billions of dollars in damage in Fort McMurray, Alberta in 2016.

Despite the devastation that fire can cause, fires are very important parts of Canada's **ecosystems**. Fires recycle decomposing forest materials, such as dead leaves, into nutrient-rich soil. Fires can also open the tree canopy which can allow more sunlight to get through. This helps seedlings and small plants and the forest floor as well as create new habitat for insects, etc. Some trees, such as **lodgepole pine** and **jack pine** can only reproduce after a fire. This is because only fires can open their cones and release their seeds. Fires also help to maintain ecosystems such as open grasslands by keeping trees and shrubs from growing there. Finally, fires can maintain biodiversity by creating many different types of habitats for wildlife to live in.

Wildfires are suppressed in Canadian parks. However, because they are important for some ecosystems, parks may use **prescribed burns** (see Figure 15). These are closely controlled forest fires. To begin a prescribed burn, fire specialists create detailed plans in order for the burn to be effective and safe. For example, they will define specific boundaries for the fire to make sure that the fire does not go beyond where it is supposed to go. Once the proper weather conditions are met, the prescribed burn can take place.

Figure 15: A prescribed burn in a pine forest.

In Canada, many of the ecosystems found in national parks are **fire-adapted**. This means that controlled burns are necessary to maintain and/or restore the environmental health of the park and the organisms that inhabit it. Fires can have a regenerating effect on ecosystems and can help ecosystems stay around in the future. The history of a particular ecosystem can actually be determined by examining the effects and occurrence of fires there. Each ecosystem's unique fire history can mean that it can be home to some unique plants and species not be seen in other locations!

My Career

Anne-Claude Pépin
Fire Management Technician
Parks Canada

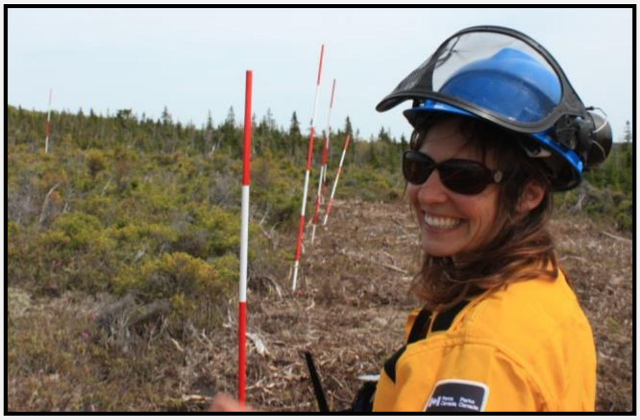


Figure 16: Anne-Claude Pépin at work in the field.

I grew up near Quebec City and I have a bachelor's degree in forestry from the University of Moncton, New Brunswick. I also have a Master's degree in Geography from Laval University. At the moment, I am working at Cape Breton Highlands National Park, in Nova Scotia.

My role involves planning controlled burns. This practice helps certain species of trees to grow. In fact, some trees need fires in order to grow. It's true! I start fires to help the forest!

Before burning, you have to prepare a very detailed burning plan. I first have to spend some time in the forest assessing the site. I use aerial photographs, and maps of the forest, watercourses and roads. I make sure that I am very familiar with the area. What type of vegetation is present? Are there any cliffs, streams or lakes? I collect all of this information to include in my plan.

When I prepare the burning plan, I use specialized software to analyze all of the information collected in the field. This software can predict fire behaviour. A fire doesn't burn the same way on flat ground as it does on a slope. And a hardwood forest does not burn the same way as a coniferous forest. I then try to identify the best weather conditions in which to conduct the burn safely. I consider factors such as wind, moisture and temperature to determine the ideal conditions for the burn. If it is too hot, too dry, or too windy, it could be dangerous. Safety is our top priority! On the other hand, if it is too wet, we would not be able to get the fire started. So weather forecasting tools play a very important role.

On the day of the burn, we start the fire in the locations that were identified in my burning plan. We use helicopters, which drop small balls that catch fire, and manual burners. This work keeps us in shape, because you have to walk quickly if you are carrying a lit torch through the forest! At the end of the day, we usually let the fire burn freely, but continue to monitor it until it is completely extinguished.

As you can imagine, I love my job with Parks Canada. I am lucky to have a job that gives me so much pleasure and excitement. You have to like variety to be a fire management technician, because every day is different. You also have to enjoy team work and working outdoors.

Keeping Warm Engineering Challenge

Challenge:

Your challenge is to work as a team to design and build a device which keeps a container of hot water, which represents a person or animals in the **arctic tundra**, as warm as possible using the materials provided.

Materials:

- 1 glass or plastic jar with lid
- Hot water (from a kettle)
- Kettle
- Thermometer
- Freezer (or cooler with ice)

Choice of:

- Cotton balls
- Plastic bags
- Foam packing chips
- Cardboard
- Pieces of cloth or knit fabrics

Preparation:

- Boil water using the kettle. Fill the jar ¾ full of water.
- Measure and record the temperature of the water using the thermometer.

Rules:

- Using no more than three different materials, design and build a sleeve for the jar of water.
- To test, put the lid on the jar and put the jar in the freezer (or cooler with ice). After 10 minutes, take out of the freezer (or cooler), open the lid and measure and record the temperature again.

Scoring:

- Starting with **20 points**, subtract **one point** for every one degree of temperature the water drops.

Success

- You have a score as close to 20 points as possible (which means that the temperature of the water did not drop very much).

Pushing the Envelope

- How could you change your design so that the temperature dropped even less?
- Learn more about how people and animals in the arctic tundra keep warm.

References

Figure References

Figure 1: Major terrestrial biomes. http://www.physicalgeography.net/fundamentals/9k.html (Accessed January 30, 2020)
Adapted from: H.J. de Blij and P.O. Miller. 1996. Physical Geography of the Global Environment. John Wiley, New York. Pp. 290.

Figure 2: Canopy trail in Puerto Viejo de Sarapiqui, Costa Rica. Notice the humid air.
http://commons.wikimedia.org/wiki/File:Costa_rica_santa_elena_skywalk.jpg (Accessed January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 3: Blue poison dart frog (*Dendrobates tinctorius azureus*).
http://commons.wikimedia.org/wiki/File:2009-03-29Dendrobates_tinctorius_azureus108.jpg (Accessed January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 4: Orang-utan (*Pongo pygmaeus*) in the Semenggok Forest Reserve, Malaysia.
http://commons.wikimedia.org/wiki/File:Orang_Utan,_Semenggok_Forest_Reserve,_Sarawak,_Borneo,_Malaysia.JPG?uselang=en-gb (Accessed January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 5: Acacia tree in the Serengeti, Tanzania.
http://commons.wikimedia.org/wiki/File:Acacia-tree.jpg (January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 6: Tawny eagle (*Aquila rapax*).
http://commons.wikimedia.org/wiki/File:2011-tawny-eagle-closeup.jpg
(Accessed January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 7: Elephant with missing tusk.
http://commons.wikimedia.org/wiki/File:2010-Kabini-single-tusk-tusker.jpg?uselang=en-gb (Accessed January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 8: Deserts of the world.
http://pubs.usgs.gov/gip/deserts/what/world.html (Accessed January 30, 2020)
Public domain image from the U.S. Geological Survey.

Figure 9: Golden barrel cacti.
http://commons.wikimedia.org/wiki/File:Golden_Barrel_cactus,_Huntington_Desert_Garden.jpg?uselang=en-gb
(Accessed January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 10: Boreal forest in northern Quebec.
http://commons.wikimedia.org/wiki/File:Taiga_Landscape_in_Canada.jpg
(Accessed January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 11: Wood bison (wood buffalo) at Wood Buffalo National Park.
http://commons.wikimedia.org/wiki/File:Wood-Buffalo-NP_Waldbison_2_98-07-02.jpg?uselang=en-gb
(Accessed January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 12: Rock drawings of humans hunting reindeer.
http://commons.wikimedia.org/wiki/File:Alta_rock_carvings_01.jpg?uselang=en-gb (Accessed January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 13: Typical arctic tundra landscape in Nunavut.
http://en.wikipedia.org/wiki/File:Nunavut_tundra_-c.jpg (Accessed January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 14: Arctic hare.
http://commons.wikimedia.org/wiki/File:Arctic_Hare.jpg?uselang=en-gb
(Accessed January 30, 2020)
Public domain image on Wikimedia Commons.

Figure 15: A prescribed burn in a pine forest.
https://commons.wikimedia.org/w/index.php?curid=11192497 (Accessed July 2, 2019) Public domain image on Wikimedia Commons.

Figure 16: Anne-Claude Pépin at work in the field.
© Parks Canada. Used with permission.

General Resources

http://kids.nceas.ucsb.edu/biomes/index.html (Accessed July 2, 2019)
The Kids Do Ecology website has a section on terrestrial biomes including information, games and web links.

http://www.ucmp.berkeley.edu/glossary/gloss5/biome/ (Accessed Sept. 1, 2015)
This series of web pages from UC Berkeley is about The World's Biomes.

Tropical Rainforests

http://www.youtube.com/watch?v=YUuA-C_I3DE (Accessed July 2, 2019)
This YouTube video by IMAX has amazing views of tropical rainforests and some of the plants and animals found there.

https://www.nationalgeographic.com/environment/habitats/rain-forests/
(Accessed August 20, 2019)
This webpage, from National Geographic, is about tropical rainforests.

Savannas

http://www.youtube.com/watch?v=Tuk-JW-wng0 (Accessed July 2, 2019)
This YouTube video is all about tropical savannas.

https://www.ducksters.com/science/ecosystems/savanna_biome.php
(Accessed January 2020)
This series of webpages, from Ducksters Education site, has information on Savannas, including animal predators.

https://www.nationalgeographic.com/animals/reference/poaching-animals/
(Accessed August 20, 2019)
This webpage, from National Geographic, discusses animal poaching.

Deserts

http://www.ucmp.berkeley.edu/exhibits/biomes/deserts.php (Accessed July 2, 2019)
This web page, from the University of California, Museum of Paleontology, has information about the desert biome including the different types of deserts.

http://www.desertmuseum.org/books/nhsd_desert_soils.php (Accessed July 2, 2019)
This web page, from the Arizona-Sonora Desert Museum, has information about desert soils.

http://www.desertmuseum.org/books/nhsd_squirrels.php (Accessed July 2, 2019)
This web page, from the Arizona-Sonora Desert Museum, has information about ground squirrels. There are also links to information about other desert animals.

http://environment.nationalgeographic.com/environment/habitats/desert-threats/ (Accessed July 2, 2019)
This web page, from National Geographic, discusses threats to deserts as well as potential solutions.

Boreal Forests/Taiga

Molles Jr., M.C. and J.F. Cahill Jr. Ecology: Concepts & Applications. Toronto: Mcgraw-Hill Ryerson.

Zhang, J. (2013). Boreal Forest and Taiga. In R.W. Howarth (Ed.), Biomes and Ecosystems. (pp. 127-130). Amenia: Grey House Publishing, Inc.

Shipignia, E. and W.G. Rees (2013). Analysis of human impact on boreal vegetation around Monchegorsk, Kola Peninsula, using automated remote sensing technique. Polar Record. 48(244): 94 – 106.

http://www.youtube.com/watch?v=DuRxklojz54&feature=player_embedded
(Accessed July 2, 2019)
This YouTube video, from the Pew Charitable Trust and the Canadian Boreal Initiative, has a virtual view of Canada's boreal forest.

https://www.thecanadianencyclopedia.ca/en/article/boreal-forest (Accessed January 23, 2020)
This web page, from the Canadian Encyclopedia, is about taiga (boreal forest) including plants and animals.

Arctic Tundra

Chen, Z. (2013). Tundra Ecosystems. In R.W. Howarth (Ed.), Biomes and Ecosystems. (pp. 197-200). Amenia: Grey House Publishing, Inc.

Molles Jr., M.C. and J.F. Cahill Jr. Ecology: Concepts & Applications. Toronto: Mcgraw-Hill Ryerson.

Peacock, E., Derocher, A.E., Thiemann, G.W. and I. Stirling (2011). Conservation and Management of Canada's polar bear (Ursus martimus) in a changing Arctic. Can. J. Zoo. 89: 371 - 385.

http://www.ucmp.berkeley.edu/exhibits/biomes/tundra.php
(Accessed July 2, 2019)
This web page, from the University of California, Museum of Paleontology, has information about the tundra biome including the different types of tundra.

http://blog.cwf-fcf.org/index.php/en/santas-got-company/ (Accessed January 23, 2020)
This web page, from the Canadian Wildlife federation, is about plants and animals in the arctic tundra.

Spotlight on Innovation

https://www.pc.gc.ca/en/nature/science/conservation/feu-fire (Accessed January 23, 2020)
This series of web pages, from Parks Canada, explains the general importance of fire and its effects on forest health and structure. It also provides an overview of prescribed burning and its purpose.

Mathematics

Chapter 6

2020

Thank you to our chapter sponsor:

Scholar's Choice

Introduction

Mathematics, in a very basic sense, describes **relationships** between numbers and other measurable quantities. It is called the "language of science." A strong understanding of mathematics is essential in order to develop a deep understanding of science.

At the heart of any domain of science is the testing of a theory. This can only be done when comparisons can be made in a language all scientists understand. This language is mathematics. Mathematics enables groups of scientists who don't necessarily speak the same oral language to work on a common problem and talk in a way that they can all understand.

There are many different branches in mathematics, each with many unique and fascinating aspects. In this chapter you will explore ways in which we use mathematics to understand how things can be arranged (**combinatorics**), how mathematics can help us to predict what might happen (**probability**), and how mathematics can help keep our data safe (**encryption**). We hope this gets you to think of mathematics in a whole new light!

Combinatorics

Combinatorics is a branch of mathematics that counts the number of ways we can arrange certain objects into sets and subsets.

Multiplication Principle

The **multiplication principle** is all about counting the different ways that things can be combined, without worrying about the order things are in. Here is a typical question:

> *A deli has 5 kinds of soup and 4 different sandwiches. How many different lunches can you have at the deli consisting of one soup and one sandwich?*

The multiplication principle says: If one event (such as choosing a type of soup) can occur in x # of ways and a second event (such as choosing a type of sandwich) can occur in y # of ways, then the two events can occur together in x times y # of ways. In other words, we just multiply the possibilities!

So to answer the question above, you have five choices for soup (x = 5) and four choices for sandwiches (y=4), so there are x·y or 5x4=20 possible lunch combinations consisting of one soup and one sandwich (see Figure 1).

(*Note: a dot like this · can be used instead of the multiplication symbol "x." The dot is good to use when you are using letters like "x" to represent unknown quantities.*)

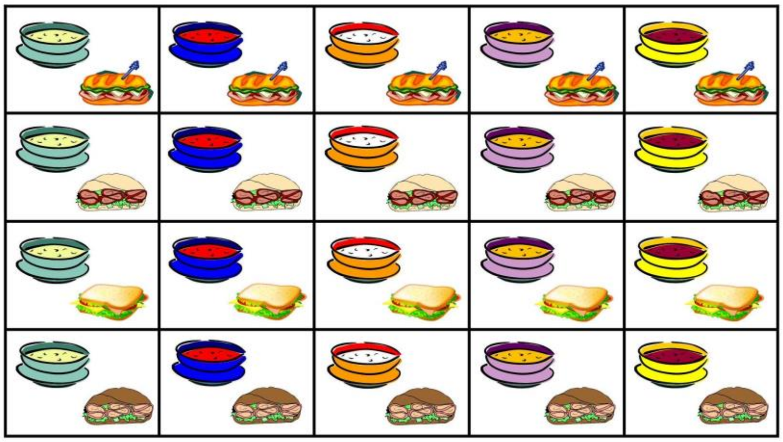


Figure 1: All the possible combinations of soup and sandwiches.

If there are more than two **events**, we can still use the multiplication principle. For example:

Q1: Suppose the deli also has 7 different drinks. How many different lunch combinations can you make that have one soup, one sandwich, and one drink?

Show your work. The answer is at the end of the chapter.

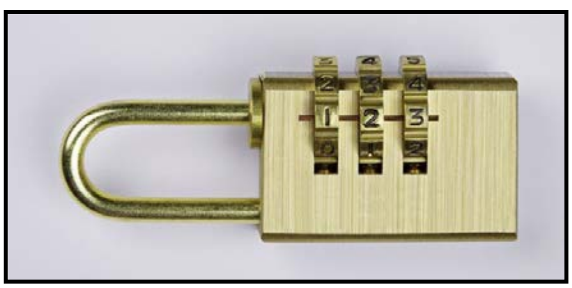


Figure 2: Lock with three-digit number to unlock.

Here's another example. Suppose you had a lock like the ones found on suitcases or used on some bicycle chains. It has a tumbler with three numbers (see Figure 2). Each of the three spinning dials has the numbers 0 through 9. How many different three-digit numbers can be made using such a lock?

The first dial, or event, has 10 possible choices (0 through 9) (x=10), while the second dial also has 10 possible choices (y=10), as does the third dial (z=10). Using the multiplication principle, and assuming that any digit can appear on any dial, you have $x \cdot y \cdot z = 10 \cdot 10 \cdot 10 = 1\ 000$. There are 1 000 different possible combinations, which is another way of saying 1 000 different three digit numbers – which makes it tough for thieves to come up with the correct three-digit number using only trial and error!

Q2: How many different licence plates can you make if the first three positions have letters of the alphabet and the second three positions have numbers? (Note: I, O and Q are not used).

Show your work. The answer is at the end of the chapter.

Here's another example. Suppose Abdul, Bianca, Cho, and Dave make up a team of students in the Let's Talk Science Challenge. There are four questions (1, 2, 3, 4), and each student must answer exactly one question. How many different ways can they take turns answering these questions?

As one possibility, they might go in order; so Abdul will answer question 1, Bianca question 2, and so on. As another possibility, Cho might go first, then Bianca, etc. Listing all the possibilities could quickly become boring!

Here's a quicker way to figure it out: for question 1, there are four possible students who can answer it (Abdul, Bianca, Cho, and Dave). Once the team decides who will go first, that person cannot go again. This means there are three students left to answer question 2. Then, there will be two students left who can answer question 3, and the last remaining student is forced to answer the last question. Using the multiplication principle, there are $4 \cdot 3 \cdot 2 \cdot 1 = 24$ ways the students can answer the questions.

But wait, there is a pattern here. For instance, what if you were keen on planning what you were going to wear for school for the upcoming week. You had five favourite shirts. How many different ways could you lay out your shirts so that you wore one for Monday, a different one for Tuesday, a third for Wednesday, and so on through Friday? Using the multiplication principle, there are $5 \cdot 4 \cdot 3 \cdot 2 \cdot 1 = 120$ ways to lay out your favourite shirts for the week. And you thought you had nothing to wear!

Now that you've got the idea, here is a little mathematical notation. Products that look like $9 \cdot 8 \cdot 7 \cdot 6 \cdot 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1$, with all of the numbers in descending order to 1, are called **factorials**. Instead of writing out $9 \cdot 8 \cdot 7 \cdot 6 \cdot 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1$, we can write **9!**, which means the same thing (and takes up less space on the page). It's also easier to say "nine factorial" than to say "9 times 8 times 7 times…," So in our example with Abdul, Bianca, Cho, and Dave there are $4! = 24$ ("four factorial") possibilities. In our last example with five shirts, there were $5! = 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1 = 120$ possibilities.

Probability

Take a coin and flip it. What side would you expect to land facing up? If the coin is fair (hasn't been rigged to land on a specific side), you would probably say that there is an equal chance of it being heads or tails. We can phrase this statement in terms of **probabilities**. The probability of the coin landing head side up is one in two (1/2). It can only be one of two possible choices. The probability of it landing tail side up is also one in two (1/2). Note that the sum of the probabilities of all possible outcomes is 1 (= 1/2 +1/2 or 0.5 + 0.5). The outcome of adding to 1 is a fundamental property of probability.

A question you might ask is "how do you know that these probabilities are correct?" One way to do this is to flip the coin lots of times, record the result each time, and then infer the probabilities from the results. Suppose we flipped the coin 10 times, and obtained the results H,T,H,H,T,T,T,H,T,T (where T stands for "tails" and H for heads). We got four heads and six tails. From this, we might conclude that the probability of getting a head is 4/10 = 0.4 and the probability of getting a tail is 6/10 = 0.6. These values are close to the expected probability of 0.5, but don't exactly agree. Why is this? It's because you will only get the expected probabilities if you flip the coin an extremely large number of times. The more times you test, the closer to the expected probability you will get. You can try this with your class!

It is interesting to consider questions that involve **combining probabilities**. This means we use combinatorics and probability together. For example, suppose we flipped the coin twice, and asked what the probability is of getting tails up two times in a row. For this, we take the probability of the first coin being a tail (1/2) and multiply it by the probability of the second coin being a tail (1/2), leading to a final result of 1/2 x 1/2 = 1/4.

We can see this by examining all possible outcomes of flipping the coin twice:

Figure 3: Possible combinations from flipping two coins.

From this we can see that, of the 4 possible outcomes, only one leads to two successive tails, so the probability is 1/4.

Q3:	A farmer breeds a white cow and a black cow. The calves (baby cows) have an equal chance of being either all white, all black, black with white faces or white with black faces (assume these are the only four possibilities for offspring). a) What is the probability that a calf will be all black? b) What is the probability that three calves in a row will be all white? Show your work. The answer is at the end of the chapter.

A famous example of probability is known as the **Birthday Problem**. What are the chances, in your class, that two students have the same birthday? The answer depends on how large the class is. The chance that this is true is likely a lot higher than you think.

To figure this out, it is actually easier to calculate the probability of two students *not* having the same birthday. Since the sum of the probability of two students having the same birthday and the probability of two students not having the same birthday is 1, calculating one of these probabilities easily allows us to infer the other. We would just subtract the probability from 1, to get the other probability. In the following example we'll assume that there are 365 days in a year (so not a leap year).

Let us start with a class of two students. The first person can have any birthday, while the probability that the second person does not have the same birthday is 364/365, because their birthday could be any day *except* the first person's birthday. The probability of these two people not having the same birthday is 365/365 x 364/365 = 0.9973, or 99.73%. Thus, the chances of these two students having the same birthday is 1 - 0.9973 = 0.0027, or 0.27% - so, pretty unlikely.

How about 3 students? As before, the first person can have any birthday, and the probability that the second person does not have the same birthday as the first person is 364/365. The probability that the third person does not have a birthday on either of dates of the first two students is 363/365. Thus, the probability that, of these three students, <u>none of them</u> share a common birthday is 365/365 x 364/365 x 363/365 = 0.9918. Thus, the probability that, of these three students, at least two of them <u>do share</u> a common birthday is 1 - 0.9918 = 0.0082, or 0.82%.

You may see the pattern developing – for 4 students, the probability of none of them having the same birthday is 365/365 x 364/365 x 363/365 x 362/365, leading to a probability of at least two of them having the same birthday of about

0.0164, or 1.64%. You might ask "How large must a class be in order for the probability to be 50% of finding two people with the same birthday?" Having seen how this goes, you might want to try calculating it yourself – the answer is that you need only a class of about 23 students!

Q4: Given the number of students in your class, what is the probability that two people in your class have the same birthday?

Do any two people in your class have the same birthday?

Show your work. The answer is at the end of the chapter.

Try testing this out in your school with various classes to see what the probabilities are. The results will probably amaze most of your classmates, and likely even your teachers! Probabilities may require thinking through a lot of possibilities, but chances are, the results may surprise you.

My Career

Figure 4: Anna Szuto.

Anna Szuto
Genetic counsellor
Division of Clinical and Metabolic Genetics
The Hospital for Sick Children

The Hospital for Sick Children is a specialized hospital for children and their families. Doctors there perform complex surgeries and treat children with cancer. In the Clinical and Metabolic Genetics division, we evaluate and treat children who have, or may be at risk of having, a genetic condition such as Down syndrome or Cystic fibrosis.

Genetic conditions are caused by **mutations**, which are variations in a person's DNA. Mutations can cause the cells in our body to not work properly. Different mutations can cause many different genetic conditions. Each condition has certain symptoms and certain ways of being passed down to the next generation (**inheritance**). Each has a certain prognosis, which is what will likely happen to a patient who has the condition.

As a genetic counsellor, I use probabilities when I answer patient's questions about genetic conditions. This may be about the possibility that a genetic condition might explain their symptoms. Or it could be about the probability that they will have a child with a genetic disorder. Or even the probability that they have inherited a condition that is present in a family member. To do this, I collect and analyze my patients' personal medical histories. I also take a detailed account of the health of their family members, which is known as a **family history**. I then provide information about the different genetic tests that can be used to establish if my patients have a disease-causing mutation. We talk about disease management as well as about the risks and benefits of genetic testing.

I use the information I've collected about the family history and genetic test results to determine the probabilities that my patients might carry mutations. I might also determine the probabilities that their children or other family members could also have inherited the mutation.

My favourite aspect of being a genetic counsellor is meeting new families and helping them to understand the impacts of having a genetic condition on their families and even on their culture.

Encryption

Whether you are a secret agent or a student buying stuff over the Internet, it is important to keep your information secret while you are transmitting it. For example, if you wanted to send a message about a surprise birthday party to a friend by email, it would be good to re-write it in a secret way that only you and your friend understand. **Encryption** is the term for creating secret messages. **Decryption** is the term for reading the secret messages. Encryption and decryption have been vitally important during wartime. For example, in World War II, encryption and decryption centres were set up across many countries. One such centre was **Bletchley Park** in England. There **cryptologists** worked hard to decrypt messages from the countries they were fighting.

A famous German **cryptography machine** created during World War II was called the **Enigma machine** (see Figure 5). Enigma machines used a keyboard, a set of rotating disks and electric circuits to create the secret codes. The electrical pathway from each letter on the keyboard to the output letter was changed often, so it was a tough code to break. Eventually, information about the machines and the hard work of Allied cryptologists enabled the Allies to read the German coded messages. This ability to find out what the Germans were up to, without their knowledge, helped the Allies win the war.

Figure 5: An Enigma machine in use, 1943.

Substitution Codes

The Enigma machine worked by substituting one letter with another. This is called a **substitution code**. A substitution code is a code in which each letter in a word gets replaced by a different letter or symbol. For example, if you wanted to send your bank password - "hotdog" - to a friend in a secure way, you could use a substitution code and rewrite it as "©¢¿£¢>" before sending it to your friend. Your friend would only be able to decode this message if he or she knew how you were substituting the letters.

Q5: Given the example above ("hotdog" is coded as "©¢¿£¢>"), what would your friend need to know in order to break the code (known as the **encryption key**)?

Show your work. The answer is at the end of the chapter.

Another way to do a substitution code is to replace each letter of the message with a letter that is located a fixed distance from that letter in the alphabet. For example the word DANGER becomes GDQJHU if we use the corresponding letter located three positions further along in the alphabet. This kind of encryption is called the **Caesar Shift Cipher** because Julius Caesar used it in Ancient Rome in relaying his messages.

Q6: Create a Caesar Shift Cipher for "The troops are approaching" and get a friend to solve it by giving him/her your encryption key.

Show your work. A potential answer is at the end of the chapter.

In the "hotdog" example, if someone intercepted the message, that person would have to figure out what substitution code you were using. For example, which letter does "¢" stand for? The person might have to try all the possible combinations before finding one that makes sense. However, there are some tricks that could make the job easier. A clever interceptor could use clues like the number of times a symbol appears in the secret message. Since the letter "e" is the most common letter in the English language, the most common symbol in a secret message probably stands for "e". Figuring out a message this way is called **Frequency Analysis**. The trouble with frequency analysis is that it only works when the message is long.

So, how can you prevent someone from using frequency analysis to decode your secret messages? One possible solution to this problem is to use different substitution codes for different parts of the message. For example, in the first sentence of the message, "e" could be coded to "%", and in the second sentence, "e" could be coded to "*." If you change codes often enough, as the Germans did with the Enigma machine, it will be very difficult to find patterns.

Encryption Keys

The information that only you and the person reading your code know is called the **encryption key** of the code. This is because it allows you to 'unlock' its secrets. For example, in a substitution code, the key is the substitution pattern you agree on with your friend.

One simple type of encryption using keys is called **Symmetric Key** encryption. In this method, a key is used to encrypt the message and the <u>same</u> key is used to decrypt the message (see Figure 6). The simplicity of this type of encryption is a drawback of this method.

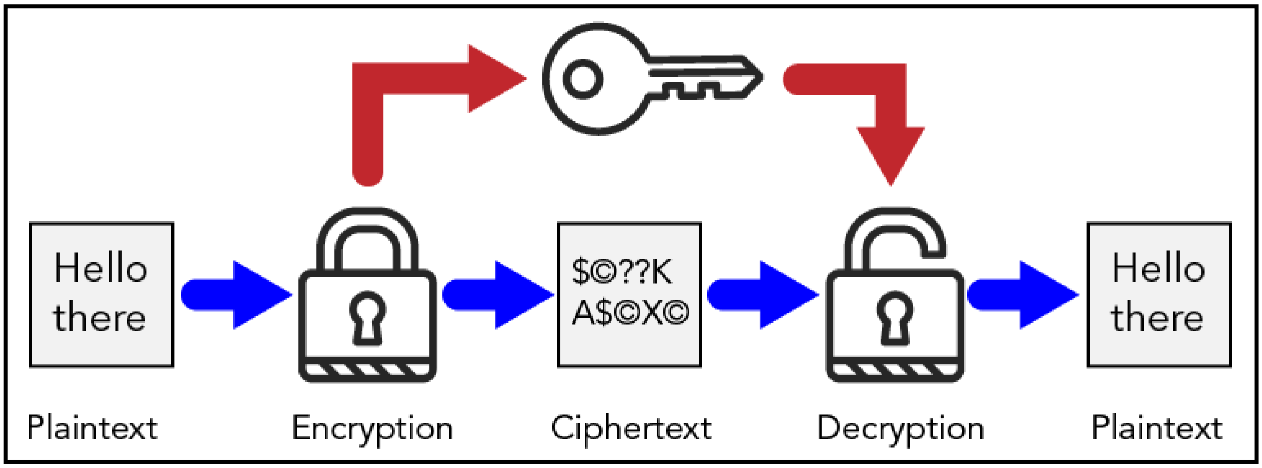


Figure 6: Symmetric key encryption.

A more tricky method is **Public-key Encryption**. In this method, two different keys are used, one key to encrypt the message and a different key to decrypt the message. The key used to encrypt the message is called the **public key**. The key used to decrypt the message is called the **private key** (see Figure 7). These keys are mathematically linked in such a way that it is virtually impossible to guess the private key given the public one. Public-key is a safer and preferable method for encryption than symmetric-key because only the intended reader knows the private key.

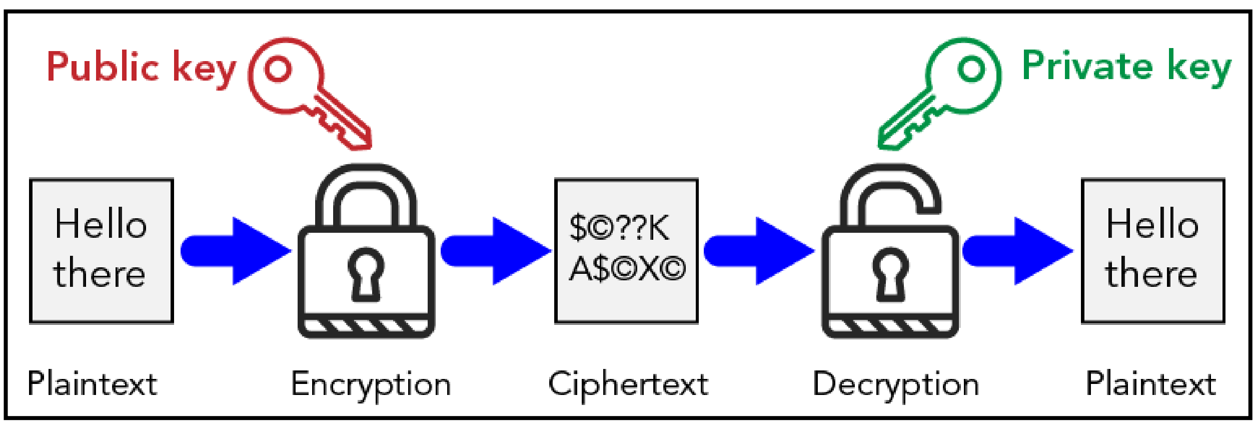


Figure 7: Public-key encryption.

Compression Codes

Another type of code studied by cryptologists is the **compression code**. Compression codes are ways to re-write information using fewer characters, so that it takes less space to store on a computer. Compression codes also help to transmit things more quickly over the Internet. Take the following English message, for example:

Welcome to New Brunswick!

We could probably remove some of the characters in this message and still be able to read it. For example, if we remove all of the vowels in the message,

Wlcm t Nw Brnswck!

we get a shorter message whose meaning is still fairly clear. This message only needs two-thirds of the original space to store on a computer. So, removing all of the vowels in an English message is a simple kind of compression code. Other kinds of compression codes have been developed for other kinds of data; for example **JPEG** is a method for compressing images. JPEG is an acronym for **Joint Photographic Experts Group**, which is the name for the group who created this method of compression.

Morse Code

The **Morse code** is a code that allows us to transmit text electrically. It was first demonstrated by **Samuel Morse**, its inventor, in 1844. He used it with his **electric telegraph machine** to transmit information over **telegraph lines**, which are wires for transmitting electrical signals. **International Morse Code** is a modern variation of Morse's original code. In it, each letter of the alphabet is encoded as a different pattern of dots and dashes. Common letters are represented by short sequences, for example a single dot stands for "E". Less common letters are represented by long sequences, for example "dash-dash-dot-dash" stands for "Q" (see Figure 8).

This is one way of making the transmission as short as possible, since the short sequences will be used a lot, and the long sequences only rarely. Therefore, the Morse code is a kind of compression code.

Q7: Decode this word in International Morse code (see Figure 7).

•••• • •-•• •-•• ---

Show your work. The answer is at the end of the chapter.

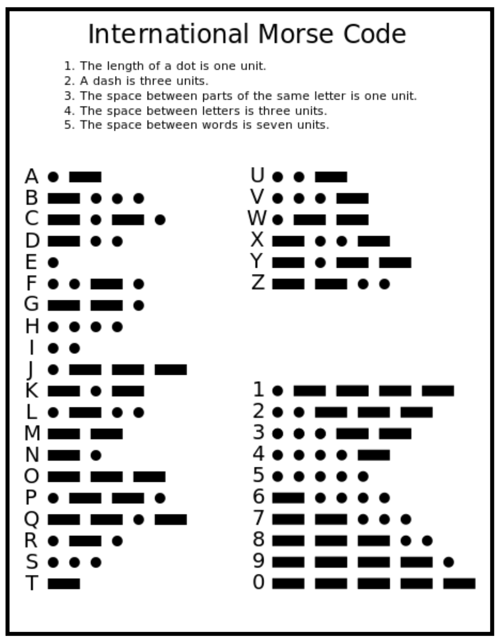


Figure 8: International Morse Code.

Run-length Coding

Figure 9: A fax machine from the 1990s.

Have you ever seen a **fax machine** (short for **facsimile machine**) (see Figure 9)? There is probably one in the office at your school or you may have seen one in an office building. A fax machine is a machine that is able to scan images and text and then send that information digitally over a telephone line. Since the images and text sent by a fax machine consist of black and white parts, a fax machine essentially divides the image into a fine grid (see Figure 10), and then sends information indicating whether each square in the grid is black or white.

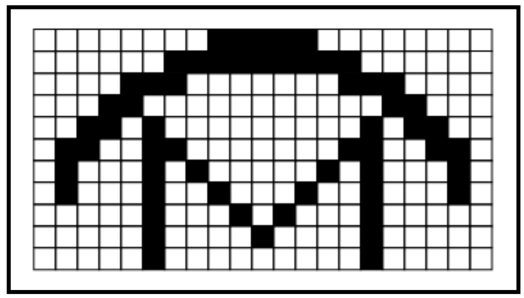


Figure 10: Section of the Arecibo Message.

For example, let's say you wanted to send the image in Figure 10. It is actually part of a message, called the **Arecibo Message** that was sent into space using a radio telescope (see the **Space chapter**). Let's say 0 represents a white square, and 1 represents a black square. To send the first line of the picture in Figure 10, we would send a message saying 000000001111100000000, which is 21 characters long. Let's say each character takes one second to transmit. The description of the first line of the picture would take 21 seconds to transmit. But, is there a shorter way to transmit a description of this line of the picture? Since the pictures sent by fax machines often contain alternating long blocks of either white or black pixels, we can send a description of these blocks. We only need to send a message saying how many pixels are contained in each block. This is called **run-length coding**. In picture above we could encode the first line as 8,5,8 which takes only 3 characters. Assume that you always start with white.

Q8: Encode the rest of the picture in Figure 10 in both regular coding (0s and 1s) and run length coding.

Regular coding | Run-length coding

Show your work. The answer is at the end of the chapter.

Spotlight on Innovation

Probability and Wind Energy

For thousands of years, energy from the **wind** has been used by people to propel ships, grind grain and pump water. More recently, it has been used to generate electricity using **wind turbines**. Since the speed and direction of the wind varies from place to place and from day to day, wind speed data is vital to understanding how much energy a wind turbine could produce at a particular site. Wind engineers use tools such as anemometers, which are wind speed measuring devices. They also use data logging systems to collect data about the wind speed at a site before they install a large **wind farm**. A wind farm is a site with multiple wind turbines.

A **wind speed probability graph** shows the percentage of time the wind blows at a given wind speed. The **wind speed** is on the **x-axis** and the probability that the wind will blow at that speed (given in percentages) is on the **y-axis** (see Figure 11). As with other probabilities, the sum of all of the probabilities equals 1, or 100%. When reading the graph, it is important to note that the taller the bar, the more likely it is that the wind will blow at the speed of that bar.

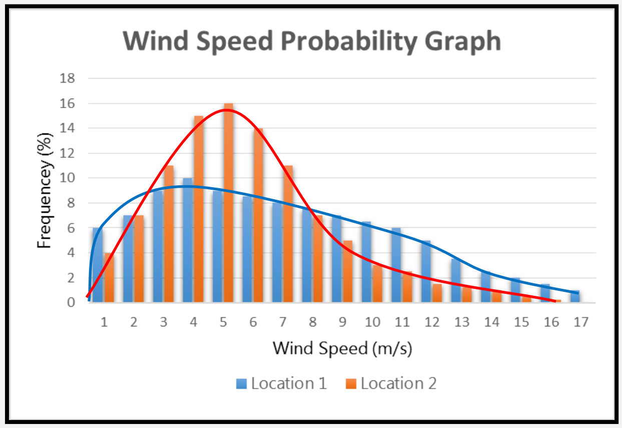


Figure 11: Wind speed probability graph.

Understanding the frequency of wind speeds is important when choosing a site for a wind turbine. Notice the wind patterns at location 1 (blue) and location 2 (orange) on the graph above. The two locations have the same average wind speed (5.8 m/s), but very different distributions of frequency. Even though the locations have the same average wind speed, a wind turbine at location 1 is likely to generate more electricity over time because the probability is greater that the wind will blow at higher wind speeds, which enables the turbine to generate more electricity.

To find out more about wind speed patterns in your area, check out the **Canadian Wind Energy Atlas** at http://www.windatlas.ca/index-en.php.

Answers

Q1: How many lunches consist of one soup, one sandwich, and one drink?

x = number of types of sandwiches = 4
y = number of types of soups = 5
z = number of types of drinks = 7
Number of possible combinations = x▪y▪z (x times y times z) = 4▪5▪7 = 140
There are 140 different lunch combinations (so a hungry student can visit the deli 140 times and never have the same lunch twice!).

Q2: How many different license plate combinations can you make if the first three positions have letters of the alphabet and the second three positions have numbers?

Using the English alphabet (with the letters I, O and Q removed), you would have:
x = 23, y = 23 and z = 23
x▪y▪z = 12 167 combinations of letters.
You can use what you know from the combination lock, that for three positions of numbers (from 0 to 9) = 10▪10▪10 = 1 000
To find the overall number of combinations, multiply the possible letter combinations by the possible number combinations.
12 167▪1 000 = 12 167 000

Q3: A farmer breeds a white cow and a black bull. The calves (baby cows) have an equal chance of being all white, all black, black with white faces or white with black faces.

a) What is the probability that a calf will be all black?
There is a one in four chance (1/4) that a calf will be all black.

b) What is the probability that three calves in a row will be all white?
There is a one in four chance (1/4) that a calf would be all white. To have three in a row that are all white you would multiple the chances of each being white
1/4 x 1/4 x 1/4 = 1/64 or 0.016 (1.6%) chance

Q4: Given the number of students in your class, what is the probability that two people in your class have the same birthday?

This will depend on the number of people in your class. Just keep multiplying further fractions of a year as was done in the sample.

Q5: Given the example above ("hotdog" is coded as "©¢¿£¢>"), what would your friend need to know in order to break the code (known as the encryption key)?

Your friend would need to know that h = ©, o = ¢, t = ¿, d = £ and g = >.

Q6: Create a Caesar Shift Cipher for "The troops are approaching" and get a friend to solve it by giving him/her your encryption key.
This will depend on the encryption key used. If you used a Caesar Shift Cipher that was a shift of three letters, the ciphertext would read, "Wkh wurrsv duh dssurdfkloj."

Q7: Decode this word in International Morse code (see Figure 7).
●●●● ● ●-●● ●-●● ---
•••• = h, • = e, •-•• = l, --- = o, therefore the word is "hello"

Q8: Encode the rest of the picture in Figure 9 in both regular coding (0s and 1s) and run length coding.

	Regular coding	Run-length coding
Line 2:	000000111111111000000	6, 9, 6
Line 3:	000011100000001110000	4, 3, 7, 3, 4
Line 4:	000110000000000011000	3, 2, 11, 2, 3
Line 5:	001101000000000101100	2, 2, 1, 1, 9, 1, 1, 2, 2
Line 6:	011001100000001100110	1, 2, 2, 2, 7, 2, 2, 2, 1
Line 7:	010001010000010100010	1, 1, 3, 1, 1, 1, 5, 1, 1, 1, 3, 1, 1
Line 8:	010001001000100100010	1, 1, 3, 1, 2, 1, 3, 1, 2, 1, 3, 1, 1
Line 9:	000001000101000100000	5, 1, 3, 1, 1, 1, 3, 1, 5
Line 10:	000001000010000100000	5, 1, 4, 1, 4, 1, 5
Line 11:	000001000000000100000	5, 1, 9, 1, 5

References

Figure References

Figure 1: All the possible combinations of soup and sandwiches. Image ©2014 Let's Talk Science.

Figure 2: Lock with three-digit number to unlock. Photobvious via iStockphoto.

Figure 3: Possible combinations from flipping two coins.
Image ©2014 Let's Talk Science.
Using images from the Royal Canadian Mint.

Figure 4: Anna Szuto. © Anna Szuto. Used with permission.

Figure 5: Enigma machine in use, 1943.
http://commons.wikimedia.org/wiki/File:Bundesarchiv_Bild_183-2007-0705-502,_Chiffriermaschine_%22Enigma%22.jpg (Accessed July 2, 2019).
Public domain image on Wikimedia Commons.

Figure 6: Symmetric key encryption. Image ©2020 Let's Talk Science.

Figure 7: Public-key encryption. Image ©2014 Let's Talk Science.

Figure 8: International Morse Code. http://commons.wikimedia.org/wiki/File:International_Morse_Code.svg (Accessed July 2, 2019).
Public domain image on Wikimedia Commons.

Figure 9: A fax machine from the 1990s.
http://commons.wikimedia.org/wiki/File:Samfax.jpg (Accessed July 2, 2019).
Public domain image on Wikimedia Commons.

Figure 10: Section of the Arecibo Image ©2020 Let's Talk Science.

Figure 11: Wind speed probability graph.
Image ©2020 Let's Talk Science based on images in WindWise Education

General Resources

Combinatorics

Weisstein, Eric W. "Multiplication Principle."from *MathWorld*--A Wolfram Web Resource.
http://mathworld.wolfram.com/MultiplicationPrinciple.html (Accessed July 2, 2019)
This page defines the multiplication principle.

http://www.youtube.com/watch?v=sEul6TMYDY0 (Accessed July 2, 2019)
This YouTube video explains the multiplication principle using the examples of a combination lock and licence plates.

Encryption

http://www.bletchleypark.org.uk/
(Accessed July 2, 2019)
On this website, run by the museum that has converted Bletchley Park into a museum, learn how the Government Code and Cypher School (GC&CS) cryptographers worked to break the Enigma code.

http://www.pbs.org/wgbh/nova/military/how-enigma-works.html (Accessed July 2, 2019)
On this page from the show NOVA on PBS, learn more about how the Enigma Machine works.

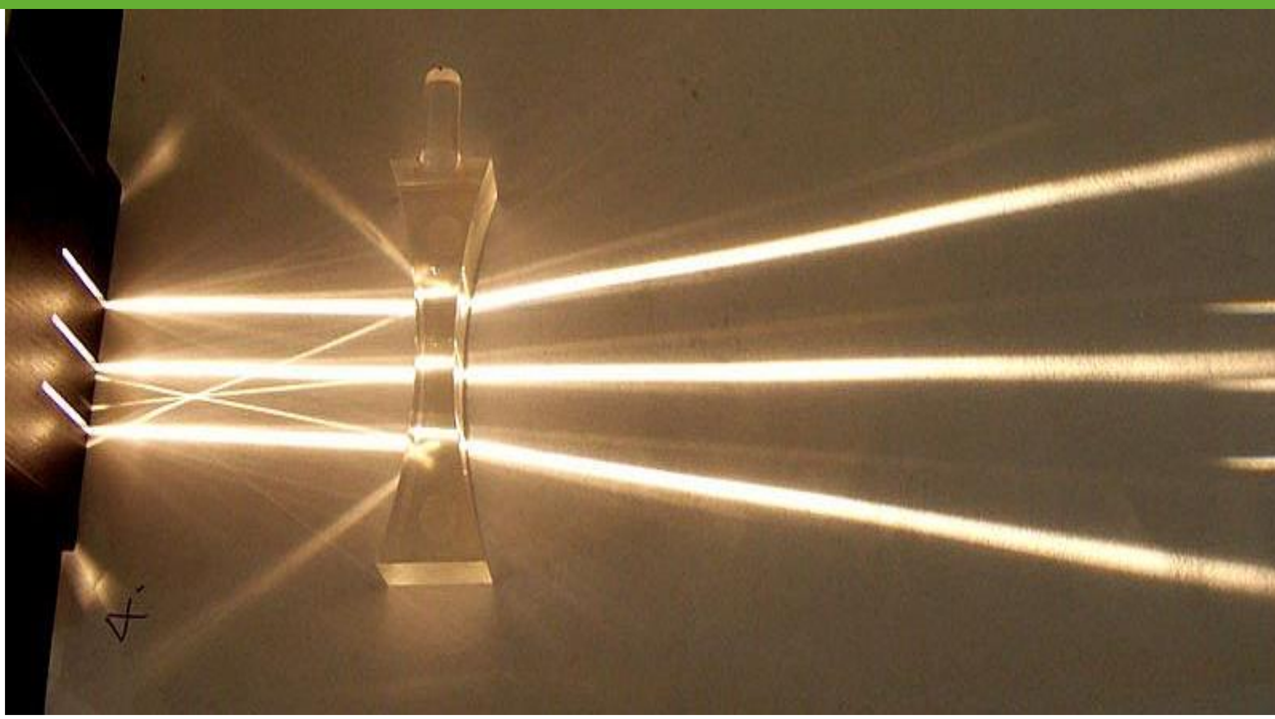
http://www.pbs.org/wgbh/nova/military/secret-code.html Accessed July 2, 2019)
This interactive activity on the NOVA website lets you send an encrypted message to a friend.

http://www.pbs.org/wgbh/nova/military/cryptography.html
(Accessed July 2, 2019)
This interactive activity on the NOVA website shows how three different ciphers work – the Caesar Cipher, the Rail Fence Cipher and the Route Transposition Cipher.

http://www.cryptomuseum.com/index.htm (Accessed July 2, 2019)
The Cryptomuseum (a virtual museum in The Netherlands) is a wealth of information about cipher machines, such as Enigma machines, from around the world.

http://www.history.com/topics/telegraph (Accessed July 2, 2019)
This set of pages on the History.com website includes information and video about Morse code and the first telegraph message sent by Samuel Morse.

http://electronics.howstuffworks.com/gadgets/fax/fax-machine.htm
(Accessed July 2, 2019)
This set of pages, on the How Stuff Works website, explains how fax machines work.



Physics
Chapter 7

2020

Thank you to our chapter sponsor:

Introduction

Light is all around us. It not only lets us see in the dark, but the properties of light are important to many aspects of our lives. Reflections in rear-view mirrors of cars help to keep us safe. Refraction through lenses of eye glasses or contact lens' helps some people see better. More generally, **electromagnetic waves** (of which visible light is one example) are transmitted as a signal that our radios pick up so we can listen to music. Pulses of infrared light are transmitted as signals so we can communicate with our TVs. This chapter is all about visible light and how we interact with it.

Light and its Properties

In a vacuum (a container with no air), **light** travels at the speed of approximately 299 792 458 metres per second (m/s). This is known as the **speed of light**. It is the fastest that anything in the universe is able to move! For comparison, the **speed of sound** is only approximately 300m/s. This is why during a storm you always see lightning before hearing thunder.

An important thing to know about light is that it travels in a straight line through a material.

Waves and the Spectrum of Light

Light has the properties of waves. Like ocean waves, light waves have crests and troughs. The distance between one crest and the next, which is the same as the distance between one trough and the next, is called the **wavelength** (see Figure 1). The **frequency** of a wave is the number of crests (or troughs) that pass a point in one second. The wavelength multiplied by the frequency equals the speed at which the wave travels.

The colours of visible light are red, orange, yellow, green, blue, indigo, and violet. These different colours of light have different wavelengths and frequencies. Red light has the longest wavelength, and the lowest frequency of the visible spectrum. Violet has the shortest wavelength, and the highest frequency of the visible spectrum. Look at the two waves in Figure 1. You can imagine how, if they were both moving to the right at the same speed, the number of violet crests passing the edge of the box in one second would be higher than the number of red crests.

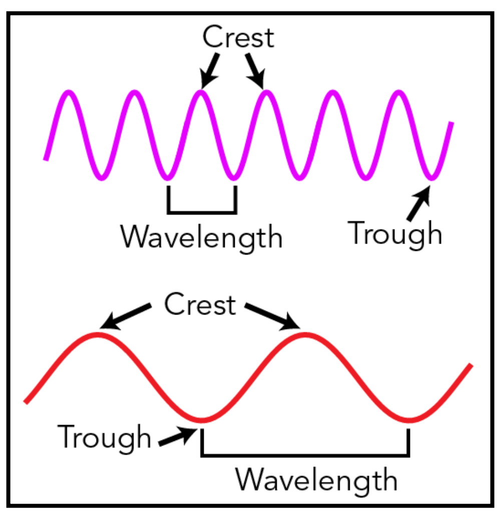


Figure 1: Red and violet light waves.

Figure 2: Chrysanthemum flower as seen using visible light (top), ultraviolet light (middle) and infrared light (bottom).

There is also light that is not visible to humans. **Ultraviolet light** (see Figure 2) and **x-rays** are also light, but have too small a wavelength and too high a frequency to be visible to us. **Infrared light** (see Figure 2) which can be detected by night-vision goggles, and **radio waves**, which are picked up by your radio so you can hear music, have wavelengths which are too long and frequencies which are too low to be seen by the human eye. Visible light, together with these invisible types of lights, make up what is known as the **electromagnetic spectrum** (EMS) (See Figure 3).

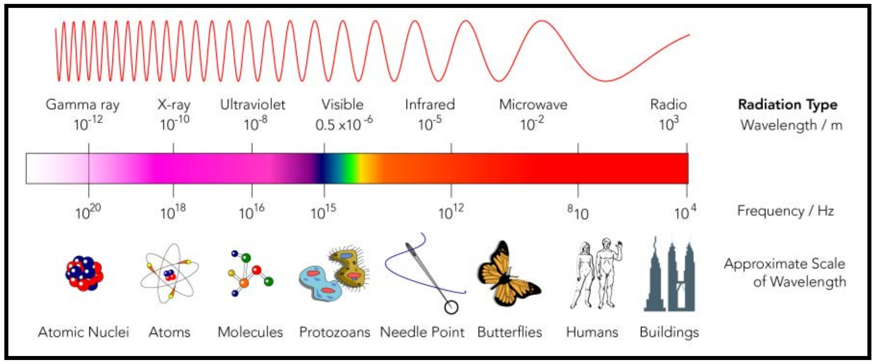


Figure 3: The electromagnetic spectrum.

Primary Colours of Light

You will remember from art class that the primary colours are red, yellow and blue. These can mix to form the secondary colours orange, green and purple. Light has primary colours as well. But these are different colours than the colours we use in paint and markers. The primary colours of light are **red, green,** and **blue**. The secondary colours of light are **cyan** (made by combining blue and green), **magenta** (made by combining blue and red) and **yellow** (made by combining green and red) (see Figure 4). Computer screens use various amounts of red, blue, and green light to make all the colours that you see. When the primary colours of light are combined, they make **white light** (see Figure 4). The human eye perceives colour using three types of **photoreceptor cells** which are sensitive to long, medium, and short wavelengths of visible light. Yellow wavelengths of light, for example, are perceived the same as a combination of red and green light, as in Figure 4. This is because they stimulate the cells in the eye in the same

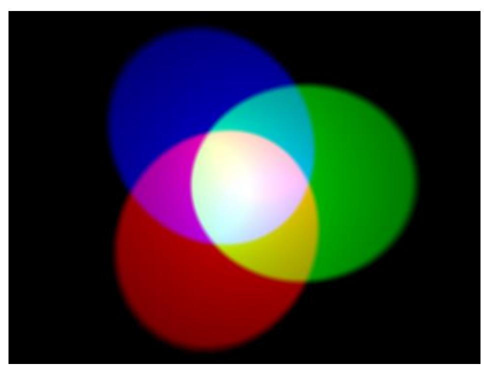


Figure 4: Primary colours of light. Blue, green, and red lights are shone on a black wall to show the secondary colours, with white light in the middle.

way. In other words, pure yellow light is physically different from a combination of red and green light, but they are both perceived by us as yellow. Did you know that two shades of green are easier for the human eye to differentiate, than the other colours? If you go into a paint shop and lay down all the red and all the green paint options, you will be able to more easily differentiate between the green shades than red. This is due to the fact that green is in the middle of the visible spectrum.

Reflection

Reflection occurs when light traveling through one material bounces off a different material. The reflected light still travels in a straight line, only in a different direction. The light is reflected at the same angle that it hits the surface (see Figure 5). The **angle of incidence** is equal to the **angle of reflection**. The angle of incidence is the angle between the incoming light and a line perpendicular to the surface called the **normal**. The angle of reflection is the angle between the reflected light and the normal. The symbol θ means 'angle' and arrows represent **rays** of light.

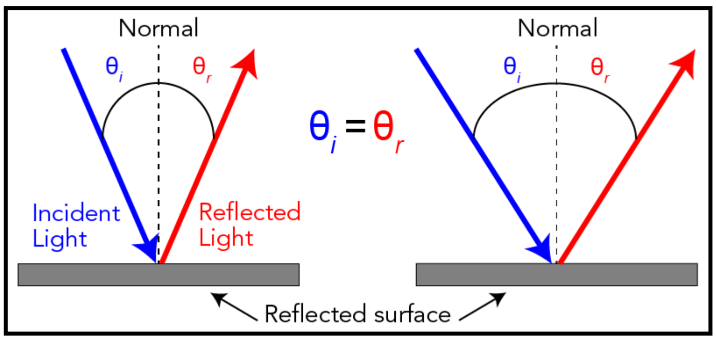


Figure 5: Light reflecting off two surfaces. Although the light hits the surface at different angles, the angle of incidence always equals the angle of reflection.

Light reflecting off a smooth surface, where all of the light is reflected in the same direction, is called **specular reflection**. Along a smooth surface, the normal always points the same way. This means that all of the light is reflected in the same direction (see Figure 6A) and the image that is reflected looks the same as the original image. Figure 6B shows light reflecting off a rough surface. This is called **diffuse reflection.**

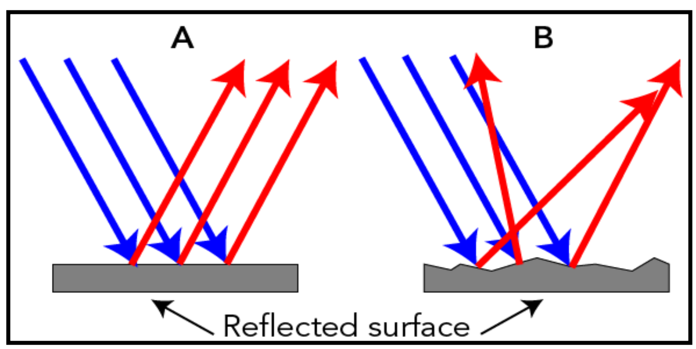


Figure 6:
A: Specular reflection (reflection off a smooth surface)

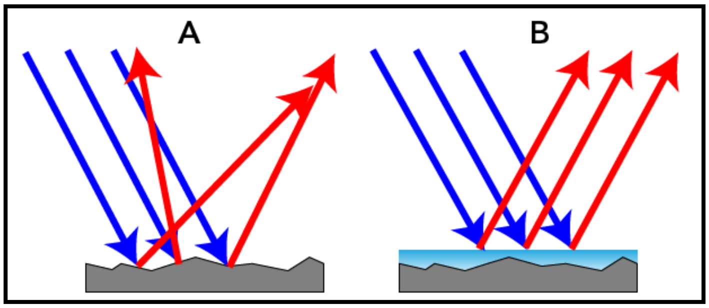


Figure 7A: Reflection on a dry road and **B:** reflection on a wet road.

The normal at different spots along the rough surface points in different directions, which causes the reflected light to go in different directions. The arrows show in which direction the reflected image will appear. The headlights of a car shine onto the road at night. If the road is dry, the light is diffusely reflected (see Figure 7A), since the pavement is very rough. If the road is wet, the water makes the road surface smoother. There is more specular reflection of the light from the car's headlights (see Figure 7B), which can cause a **glare** (light reflected off the surface like a mirror) that makes it hard for drivers to see.

Refraction

When light traveling through one material reaches a second material, some of the light will be reflected, and some of the light will enter the second material (see Figure 8) At the point at which the light enters the second material, the light will bend and travel in a different direction than the incident light. This is called **refraction**. Refraction happens because the speed of light is different in different materials (though always less than the speed of light in a vacuum).

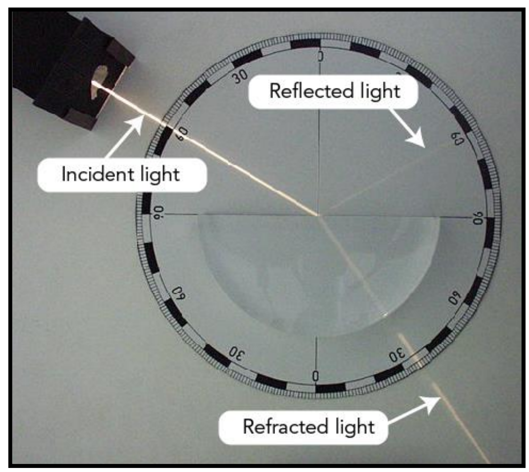


Figure 8: Refraction through a lens.

Think about pushing a shopping cart along cement, and then reaching grass, like in Figure 9. It's harder to push the cart in the grass, so each wheel slows down when it reaches the grass. The wheels on the pavement are still moving faster, so it causes the cart to change directions (in this case, turn to the right).

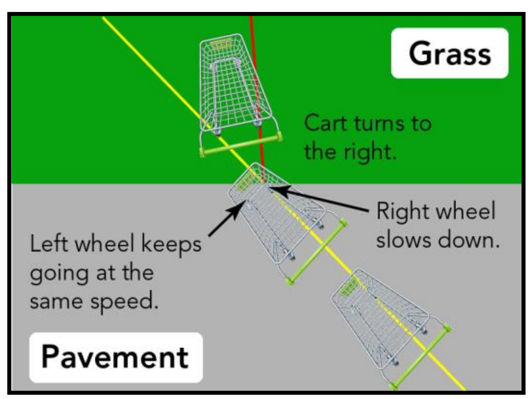


Figure 9: Shopping cart example of refraction.

Index of Refraction

Materials have a property called the **index of refraction**, which is symbolized using the letter **n**. The index of refraction of a material is equal to the speed of light in a vacuum, divided by the speed of light in the material.

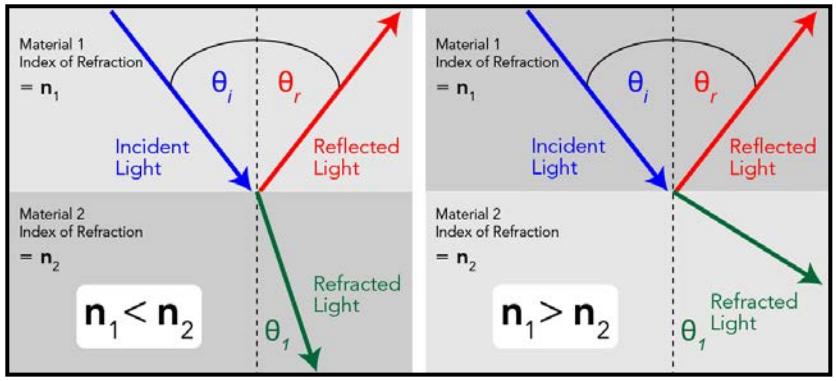


Figure 10A: Light bends towards normal when $n_1 < n_2$. **B**: Light bends away from the normal when $n_1 > n_2$.

The higher the index of refraction, the slower light travels in that medium. If light is traveling in one material and then refracts in a second material, it will bend towards the normal if the index of refraction of the second material, $\mathbf{n_2}$, is greater than the index of refraction of the first material, $\mathbf{n_1}$ (the light travels slower) ($\mathbf{n_1 < n_2}$) (Figure 10A). If the second material has a lower index of refraction, the light will bend away from the normal as it travels faster in the second material ($\mathbf{n_1 > n_2}$) (Figure 10B). Unlike reflection, the angle of incidence is not equal to the angle of refraction.

The angle of incidence and angle of refraction are mathematically related to the index of refraction of each material through the law of refraction, also called **Snell's Law**.

Converging and Diverging Light

A **lens** is an optical device made of plastic or glass. When light passes through a lens, it can be refracted in predictable ways depending on the shape of the surfaces of the lens. The surface of a lens may be **convex** (curved outward) or **concave** (curved inward). When parallel beams of light strike a lens that is convex on both sides (**double convex lens**) the light is refracted inwards and is said to be **converging** (see Figure 11A). The beams of light cross at a point called the **focal point** which is behind the lens (to the right of the lens). When light strikes a lens that is concave on both sides (**biconcave lens**), the light is refracted outwards and is said to be **diverging** (see Figure 11B). In this case, the **focal point** is actually in front of (to the left of) the lens.

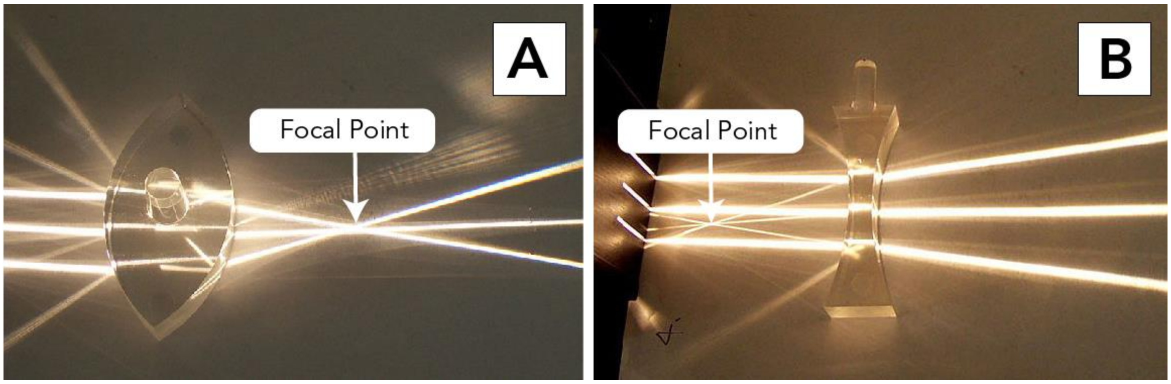


Figure 11A: Light passing through a biconvex lens. Notice how the light converges on a point behind the lens. **10B:** Light passing through a biconcave lens. Notice how the light converges on a point in front of the lens.

Light through a Prism

Light entering a plastic or glass **prism** (usually a triangular prism), refracts first as it enters the prism and again as it exits the prism. When white light passes through a prism, it is refracted into all of its colours. If you project this light onto a white surface, you see what looks like a rainbow (see Figure 12). All of the colours that make up white light are separated at different angles since each individual colour refracts by a different amount through the prism.

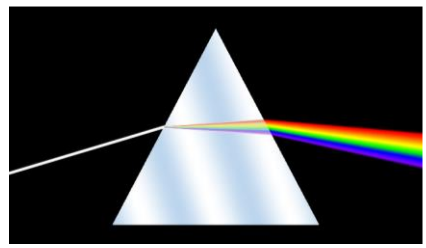


Figure 12: Light refracted through a prism.

My Career

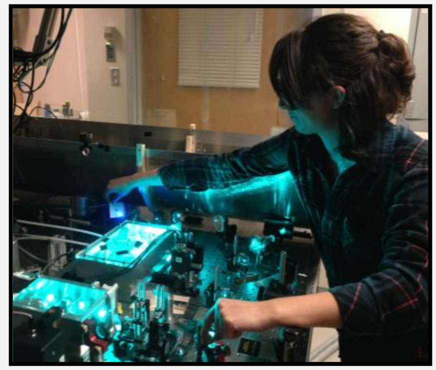


Figure 13: Emily Altiere.

Emily Altiere
PhD student in Physics,
University of British Columbia

For my PhD research project, I am using short wavelength **lasers**, known as ultraviolet lasers, to learn more about atoms. Lasers cannot produce ultraviolet light directly, so I built one. I first converted a red laser light source to a green laser. Then I converted the green laser to an ultraviolet laser (almost purple). When I fire the ultraviolet laser at atoms, they absorb the energy from the light and get excited (with more energy). As a result, the atoms start emitting light of certain colours. By observing this process we can learn more about the fundamental properties of atoms. If the atoms are placed in a new environment, such as between two magnets, the atoms will behave a little differently. We can track this difference by how the atoms absorb the laser light. This can help us learn about the magnetic field surrounding these atoms.

Lasers have many applications, and learning about atoms is just one example of how we can use the light and energy from the laser to learn new things about the world that surrounds us. Some common examples of laser uses are laser eye surgery, tattoo removal lasers, and lasers used by the department of defense to track flying aircrafts. I use science and technology every day to do my research. For example, I use mirrors to bounce light back and forth on itself, in order to build up power in the laser light. I use electronics to keep the mirrors in very precise locations. In addition, I often engineer circuits or build mechanical parts to support my experiments. Before I perform any experiment, I use math to predict the results. What I love most about my job is that there are always new challenges and puzzles to solve. When I have a new idea or question, I design and perform an experiment to find the answer, thereby adding new knowledge that can be used by me or other scientists to solve other important research questions.

How We See

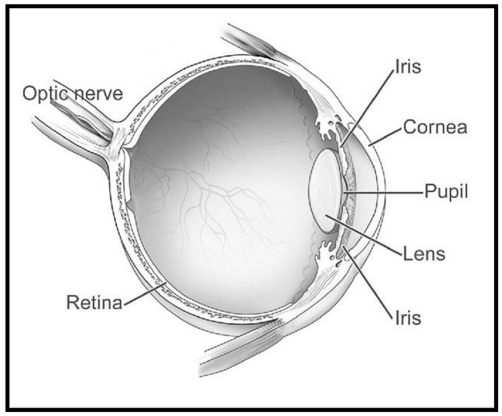


Figure 14: Cross-section of the human eye.

Vision is the sense we know the most about, but how do we see? Most people would say, "That's easy, our eyes see for us!" In truth, it is more complicated than that. It involves our brains as much as it does our eyes (if not more). Let's take a look at how this works from the beginning (see Figure 14).

Energy in the form of light enters the eye through the **cornea.** This light passes through the **pupil,** which can contract (close) and expand (open). This controls the amount of light that enters the eye. The light then passes through the lens, which helps to focus the image. Finally, the light hits the **retina** at the back of the eye, which is made of several different types of cells. There are two main types of cells - **cones** and **rods**. Cones are heavily involved in colour vision. They are found mainly in the **fovea**, which is at the center of the retina. The fovea is the area of the retina where an image falls when the viewer is looking directly at something. Rods are very important for seeing movement, but only transmit information to the brain in black and white. Rods tend to be found more at the edge of the retina. So, when you want to determine if a car is red or blue, your cones are at work. When you want to catch a baseball, your rods get really involved, even though in truth, both are active at any given time.

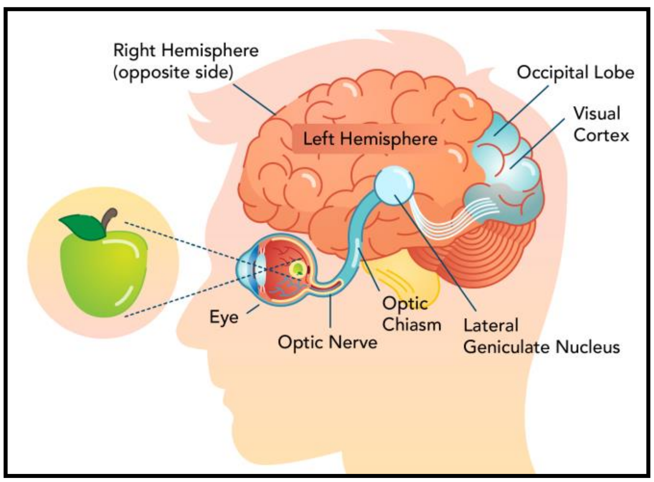


Figure 15: Sight and brain pathway.

All of the information from the rods and cones leaves each eye through the **optic nerves**, which cross at the **optic chiasm**. This is so that both sides of the brain (**left** and **right hemispheres**) get information from each eye. From the optic chiasm, the information passes through the **lateral geniculate nucleus**, or **LGN**. Then it goes to the **primary visual cortex** (also known as V1), which is located in the occipital lobe (see Figure 15).

So, why do we need a brain to see? Well, for one thing, when an image in the form of light energy hits the lens, it is flipped upside down and reversed from left to right. Information in this form wouldn't be very helpful to us. One of the first things the brain does is to take the information sent from the eye and flip it upright and right to left. The **occipital lobe** in the brain can then process the now corrected information. Eventually, this information gets to a part of the brain where you become consciously aware of it. When it gets to this point, you can see! You have now experienced **perception**! This may not seem exciting because you achieve this complicated process continually and rapidly, but it really is quite amazing. Vision is incredibly complex and this section just scratches the surface of a widely studied, yet still very exciting research area.

Near-sighted (Myopia)

Individuals with **myopia** are commonly known as being short-sighted or near-sighted. This is because they are able to focus on close objects but distant objects are out of focus. Myopia occurs when the light that enters the eye converges to a point in front of the retina instead of directly at the level of the retina as a normal eye would do (see Figure 16). Myopia can occur if the eye is too long front to back (**axial myopia**) or the power of the refractive tissues (cornea and lens) are too high. This causes the image to be focussed in front of the retina, resulting in distant objects appearing blurry.

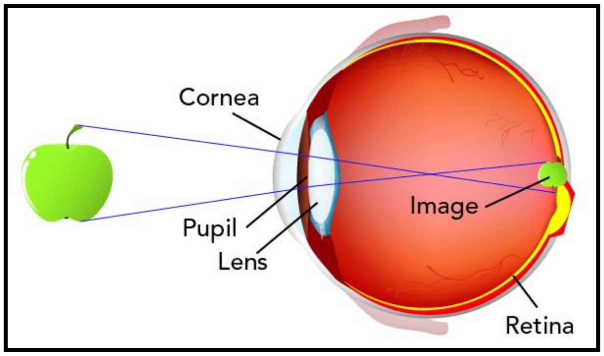


Figure 16: Eye with normal vision.

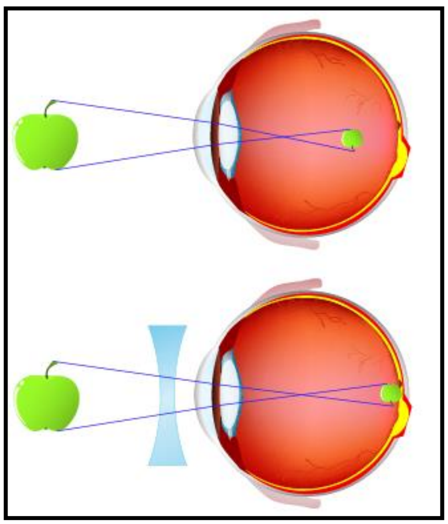


Figure 17: Diagram of myopia and lens correction with a biconcave lens.

If a person is found to have myopia, the **optometrist** will issue a prescription for corrective lenses based on the person's degree of myopia. Myopia is corrected using a negative (**biconcave**) spectacle lens. When the concave spectacle lens is placed in front of the eye, it acts to **diverge** (spread out) the light and push the focal point further back onto the retina. This re-focuses the image onto the retina, causing the individual to see clearly (see Figure 17).

Far-sighted (Hyperopia)

Individuals with **Hyperopia** are commonly known as being far-sighted. This condition occurs due to the eye being too short, or the power of the refractive tissue being too low. The condition results in the light converging to a focal point behind the retina. This causes nearby objects to be out of focus (see Figure 18). In extreme cases, distant objects can also appear blurry.

Hyperopia can easily be corrected using **refractive lenses**. For an individual with hyperopia, the prescription issued by an optometrist will be for a positive (biconvex) spectacle lens. When placed in front of the eye, the convex lens acts to **converge** (bring together) the light and pull it further forward onto the retina, allowing the individual to see clearly at all distances.

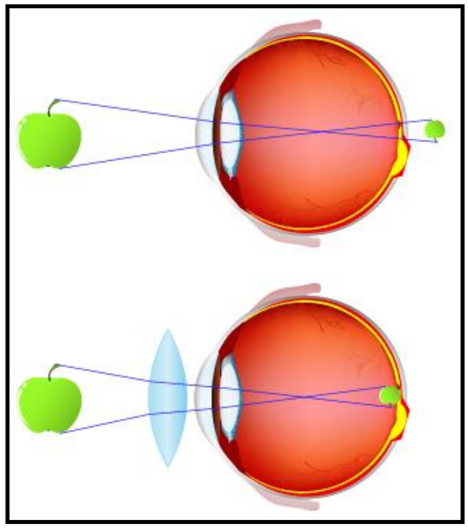


Figure 18: Diagram of hyperopia and lens correction using a biconvex lens.

Presbyopia

During the aging process, the eye gets weaker ad becomes less able to focus on nearby objects. **Presbyopia** usually begins in the 5th decade of life. This is when it is common for individuals to notice that close objects become increasingly difficult to see, especially in dim light or if there is fine detail. This **natural aging process** occurs as a result of the **crystalline lens** (the structure just behind the surface of the eye which helps refract (bend) light onto the retina) becoming less flexible. Presbyopia, which gradually deteriorates, can be easily corrected with positive (convex) spectacle lenses or contact lenses.

Contact Lenses

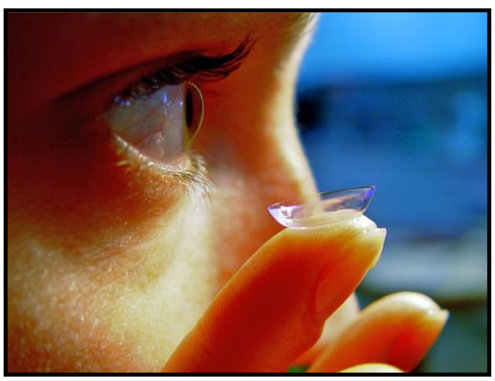


Figure 19: A person putting in a contact lens.

An alternate method for the correction of both myopia and hyperopia is **contact lenses**. These are thin lenses that are placed directly on the eye. When an individual has a special contact lens fitting, the lenses can be extremely comfortable to wear.

Some contact lenses are thrown away and replaced after one use. There are also contact lenses that can be cleaned and stored in a special solution overnight before being re-inserted the next day. Typically these re-usable contact lenses need to be thrown away after two weeks or a month, depending on their material.

There are a number of different reasons why individuals choose to wear contact lenses. These reasons include playing sports, not liking the appearance of glasses, and not wanting to limit peripheral vision. Contact lenses are a good alternative to glasses for many people, although often contact lenses cannot totally substitute for glasses. Most people choose to correct their vision with a combination of both types of lenses.

Spotlight on Innovation

Optogenetics

Optogenetics is a field that combines **genetics** (the study of genes) and **optics** (the study of light). Researchers in this field study how light can be used to control cells in a body. It offers a way for **neuroscientists** (people who study the brain and nervous system) to map out the network of specialized cells in the brain called **neurons**. It also gives neuroscientists a better understand of what neurons do, how they communicate and how they behave.

To communicate with one another, neurons send chemical and electrical signals to other neurons close by. Once one neuron receives a chemical or electrical message, it can become **activated** (turned on) and pass on this message to other neurons.

By using the methods of optogenetics, scientists can turn neurons that they are interested in on and off. The process typically begins by finding genetic material called a **gene** from an organism that produces molecules that can convert light into electrical signals (see Figure 20A). One group of molecules that can do this are the proteins called **opsins.** The genetic material is then placed into neurons of the scientist's choosing (see Figure 20B). Once this is done, the neuron will now be able to produce these molecules. As a result, when light is shined at the neuron (see Figure 20C), the light sensitive molecules will produce an electrical signal. This signal will activate it and allow it to send out chemical and electrical messages to communicate with other neurons around it.

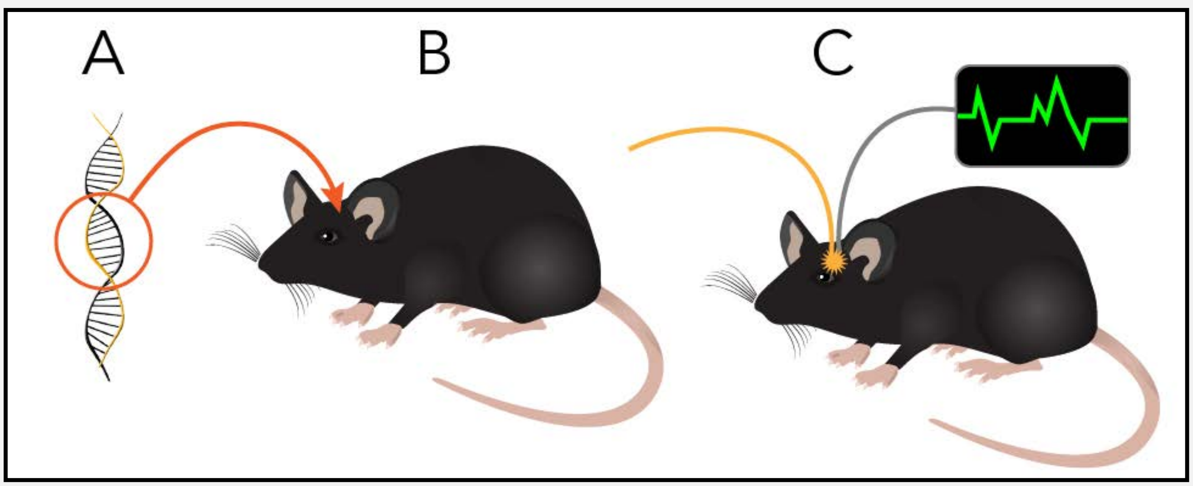
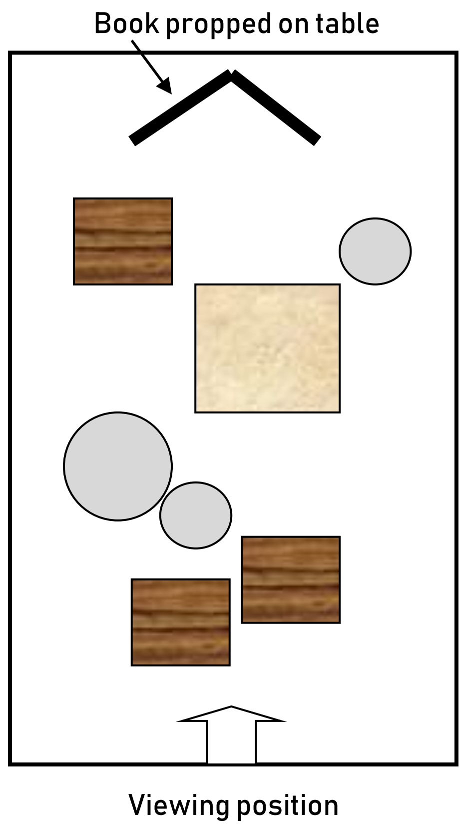


Figure 20: The process of optogenetics.

Research in optogenetics can provide scientists with an understanding of neurological disorders and illnesses.

Mirror Engineering Challenge

Challenge:
Your challenge is to work as a team and use your understanding of mirrors and reflection in order to see a book that is behind a number of objects.



Materials:
- Small mirrors (several)
- Sticky tack (to hold up the mirrors)
- Book
- Various objects (boxes, cans, binders, etc.)

The basics:
- Stand up a book at the end of a table.
- Set up the objects in front of the book. At table height, a person should not be able to see the book when looking straight across.
- Use the mirrors in order to read the words on the pages of the book from the viewing position.

Rules:
- Each mirror must have one edge touching the top of the table.
- You must look towards the book at table height.

Success:
- You can read the text on the pages of the book (in the proper orientation – not backwards!).

Pushing the Envelope
- What is the fewest number of mirrors you have to use to see the text on the pages of the book?
- If the print is too small to read, what type of lens could you put in front of it to make the text appear larger?
- Rearrange the objects on the table and try again. Did you use more or fewer mirrors this time?

References

Figure References

Figure 1: Red and violet light waves. Image ©2020 Let's Talk Science. Adapted from Levine, S., & Johnstone, L. (1998) The Optics Book, Sterling Publishing Company, Inc., USA, page 27.

Figure 2: Chrysanthemum flower as seen using visible light, ultraviolet light and infrared light (bottom). http://commons.wikimedia.org/wiki/File:Chrysanthemum_quill_flower_1_Spectral_Comparison_Vis_UV_IR.jpg (Accessed July 2, 2019) Public domain image from Wikimedia Commons.

Figure 3: The electromagnetic spectrum. Let's Talk Science using an image by Inductiveload via Wikimedia Commons https://commons.wikimedia.org/wiki/File:EM_Spectrum_Properties_reflected.svg

Figure 4: Primary colours of light. http://commons.wikimedia.org/wiki/File:Additive_color_mixing_simulated.png?uselang=en-ca (Accessed July 2, 2019) Public domain image from Wikimedia Commons.

Figure 5: Light reflecting off two surfaces. Image ©2020 Let's Talk Science. Based on a drawing by L. Kurjewicz, Department of Physics, University of Western Ontario.

Figure 6: Specular and diffuse reflection. Image ©2020 Let's Talk Science.

Figure 7: Reflection on a wet and dry road. Image ©2020 Let's Talk Science.

Figure 8: Refraction through a lens. http://commons.wikimedia.org/wiki/File:F%C3%A9nyt%C3%B6r%C3%A9s.jpg (Accessed July 2, 2019) Public domain image from Wikimedia Commons.

Figure 9: Shopping cart example of refraction. Image ©2020 Let's Talk Science based on an image from How Stuff Works: "How Rainbows Work" http://science.howstuffworks.com/nature/climate-weather/storms/rainbow.htm (Accessed July 2, 2019)

Figure 10: Refraction in different materials. Image ©2020 Let's Talk Science. Based on a drawing by L. Kurjewicz, Department of Physics, University of Western Ontario.

Figure 11A: Converging light. Image ©2020 Let's Talk Science using images from Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Large_convex_lens.jpg

Figure 11B: Diverging light.
Image ©2020 Let's Talk Science using images from Wikimedia Commons.
http://commons.wikimedia.org/wiki/File:Concave_lens.jpg
(Accessed July 2, 2019)

Figure 12: White light refracted through a prism.
http://commons.wikimedia.org/wiki/File:Dispersion_prism.jpg (Accessed July 2, 2019)
Public domain image from Wikimedia Commons.

Figure 13: Emily Altiere at work in her laboratory. © Emily Altiere. Used with permission.

Figure 14: Cross-section of the human eye.
http://commons.wikimedia.org/wiki/File:Human_eye_diagram-sagittal_view-NEI.jpg (Accessed July 2, 2019)
Public domain image from Wikimedia Commons.

Figure 15: Sight and brain pathways. Let's Talk Science using an image by VectorMine via iStockphoto).

Figure 16: Diagram of a healthy eye. Let's Talk Science using an image by ttsz via iStockphoto).

Figure 17: Diagram of myopia correction with a concave lens.
Let's Talk Science using an image by ttsz via iStockphoto).

Figure 18: Diagram of hyperopia and lens correction using a convex lens.
Let's Talk Science using an image by ttsz via iStockphoto).

Figure 19: Person putting in a contact lens.
http://commons.wikimedia.org/wiki/File:Contact_Lens_Ayala.jpg (Accessed July 2, 2019)
Public domain image from Wikimedia Commons.

Figure 20: The process of optogenetics. Image ©2020 Let's Talk Science.

General Resources

Electromagnetic Spectrum

https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum2.html (Accessed January 23, 2020)
This page, on NASA's Imagine the Universe website, explains about the different types of electromagnetic radiation.

http://www.youtube.com/watch?v=cfXzwh3KadE
(Accessed July 2, 2019)
This YouTube video, from NASA Best of Science, is an introduction to electromagnetic radiation.

http://www.bbc.co.uk/schools/gcsebitesize/science/edexcel/electromagnetic_spectrum/electromagneticspectrumact.shtml
(Accessed July 2, 2019)
This interactive, from BBC Bitesize Science, is about the electromagnetic spectrum. It has activities and quizzes.

Reflection and Refraction

http://www.upscale.utoronto.ca/PVB/Harrison/Flash/Optics/Refraction/Refraction.html (Accessed July 2, 2019)
This interaction, from the University of Toronto, lets you change the angle of incidence and refractive index of glass in order to see how the light is reflected and refracted.

http://www.youtube.com/watch?v=gDA_nDXM-ck (Accessed July 2, 2019)
This YouTube video has lots of cool experiments about reflection and refraction that you can try at home.

Vision

http://science.howstuffworks.com/life/human-biology/eye.htm (Accessed July 2, 2019)
This series of pages, on the How Stuff Works website, explains how our vision works.

http://www.youtube.com/watch?v=gBdyU1b0ADQ (Accessed July 2, 2019)
This short video on YouTube, from Island Retina, has an animation which explains how we see.

https://www.childrensuniversity.manchester.ac.uk/learning-activities/science/the-brain-and-senses/how-the-eye-works/ (Accessed January 23, 2020)
This interactive, from the University of Manchester, helps you learn about vision. It includes a quiz to test your knowledge.

http://www.childrensuniversity.manchester.ac.uk/learning-activities/science/the-brain-and-senses/how-the-eye-works/ (Accessed July 2, 2019)
This series of pages, on the How Stuff Works website, explain how corrective lenses work.

Spotlight on Innovation

https://www.youtube.com/watch?v=Nb07TLkJ3Ww (Accessed July 2, 2019)
This Youtube video from the Massachusetts Institute of Technology (MIT) provides an overview of optogenetics.

Space Sciences
Chapter 8

2020

Thank you to our chapter sponsor:

Astronomy

Astronomy comes from the Greek words *"astron"* meaning 'star' and *"nomos"* meaning 'law.' It is the study of everything that exists beyond the Earth. It is really all about the study of light. Whether you are doing research, or just gazing up at the night sky, everything that you learn comes in the form of light. On a clear dark night, there is a lot to see! Long ago, astronomers used to try to document it all with the naked eye. But the human eye is not good at seeing details of dim and distant objects. There is much we cannot see with our eyes alone.

The Telescope

A **telescope** is a tool that makes far off things look up-close and bright. The invention of the first telescope is a little sketchy. Most people believe that **Galileo Galilei** invented the first telescope in 1609. But people knew how to build telescopes before that. We just do not have any evidence before Galileo. The earliest telescopes we know of were made in 1608 by various optical craftsmen in the Netherlands. One of them, Hans Lippershey, publicized his design well enough that news reached Galileo in Italy in 1609. When Galileo heard of the existence of a telescope, he built his own. Within a year he had improved Lippershey's design. And his name became associated with the first telescope. Galileo's used his telescope to make observations of Jupiter's largest moons.

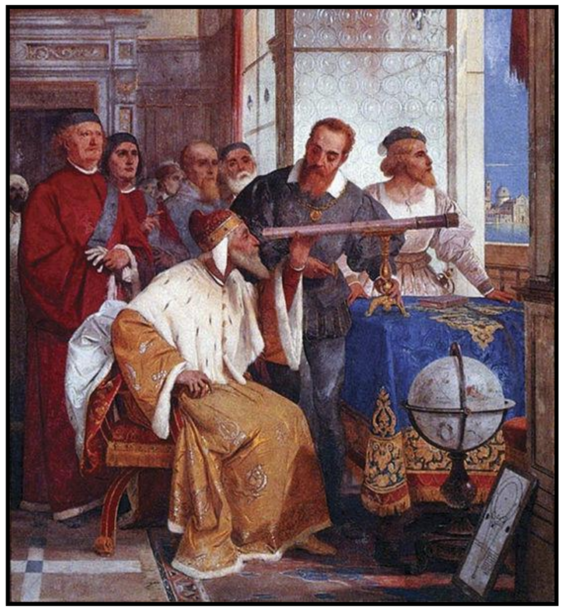


Figure 1: Fresco of Galileo Galilei showing the Doge (duke) of Venice how to use his telescope (Bertini, 1858).

In 1923, **Edwin Hubble** used the most powerful telescope on Earth at the time to look at the Andromeda Galaxy. He is the person after whom the famous space telescope is named. Astronomers knew that the Andromeda Galaxy was made up of stars. But it was Hubble who was able to measure how far away it is. Astronomers had already figured out the rough size of the Milky Way. Hubble used that data to calculate that the Andromeda Galaxy was at least ten times further away than the edge of our galaxy. This discovery led to further observations that helped astronomers find other galaxies. It also helped to expand our ideas about the Universe.

How Do Telescopes Work?

So how exactly do telescopes work? Let's consider a basic telescope. If you were looking to buy a telescope, a knowledgeable friend might tell you that there are two basic designs. There are **refracting telescopes (refractors)** and **reflecting telescopes** (**reflectors**).

Refracting Telescopes

Refracting telescopes are the long, tube-shaped telescopes which you imagine astronomers, like Galileo, using. Refractors use **lenses** to **refract** (bend) incoming light through a tube to a **focal point** (see the **Physics chapter** for more about refraction). The **objective lens** is the lens at the front of the telescope through which the light initially passes. The **eyepiece or lens** is the lens, which magnifies the image (see Figure 2).

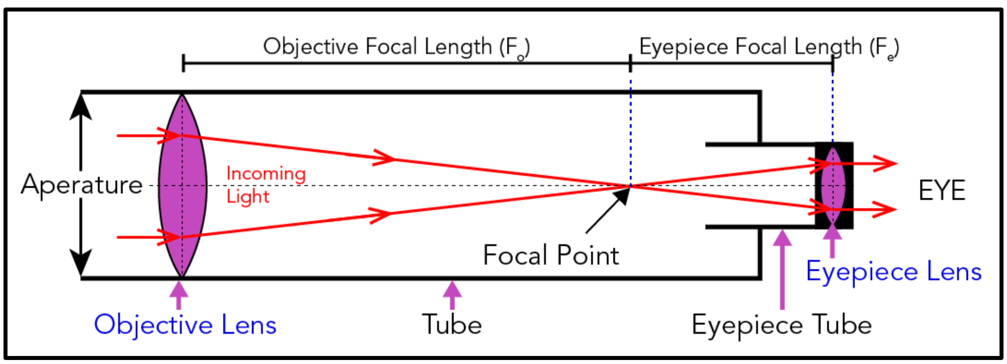


Figure 2: Parts and function of a refracting telescope.

Reflecting Telescopes

Reflecting telescopes use **mirrors** instead of lenses to **reflect** light to a focal point (see the **Physics chapter** for more about reflection). Reflectors have two mirrors. The **primary mirror** is the big curved mirror at the back that starts to focus the light. The **secondary mirror** is the smaller mirror at the front that redirects the light towards your eye. Reflectors also have eyepiece lenses (see Figure 3).

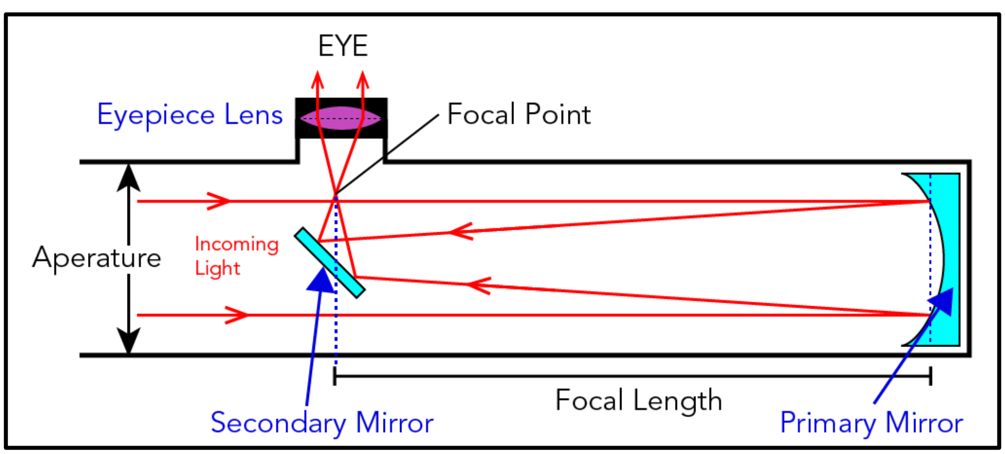


Figure 3: Parts and function of a reflecting telescope.

It's not really fair to say which type of telescope is 'better'. They both have their advantages and disadvantages. It depends on what you want to look at. Whether you want to take pictures, if you want portability, etc. Most modern **observatories**, which are buildings containing telescopes, use reflectors. This is because their telescopes are so huge! Their size allows for a lot of light to pass through them/ For telescopes that size, the weight of the lenses and the length of the tube makes refractors impractical.

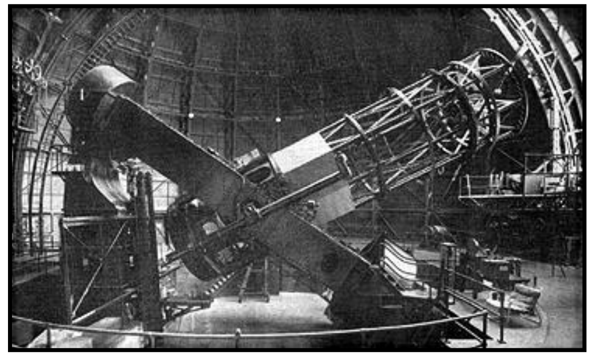


Figure 4: The 2.54 m diameter Hooker telescope at Mount Wilson Observatory, California, a reflector, was completed in 1917.

Aperture

There are two other important aspects of telescopes. These are the aperture and focal length (see Figures 2 and 3). The **aperture** of the telescope is the diameter of the opening on the front. The bigger the aperture the greater the amount of light that can enter the telescope. The pupil in your eye is your body's aperture. It can only open a few millimetres. Optical telescopes rarely have apertures smaller than 8 cm. Large telescopes in observatories can have apertures that are greater than 10 m in diameter! Since the dimmest objects in the universe do not give us a lot of light to work with, we need telescopes with big apertures to collect enough light from the object to see them!

Figure 5: The Canada-France-Hawaii Telescope, located at the Mauna Kea Observatory in Hawaii.

Focal Length

Focal length is the length from the aperture to the focal point in the telescope. The longer the focal length, the smaller the patch of sky you can see. The upside is that longer focal lengths allow for greater possible magnification. Focal length is another advantage for reflectors. Since refractors bend light down their tube, the tube has to be at least as long as the focal length. Reflectors, on the other hand, use mirrors to reflect light. This means that they can be shorter than their focal length. The light still travels the full focal length, but the tube itself does not need to be as long (see Figure 3). The eyepiece is near the focal point of the primary mirror to magnify the image.

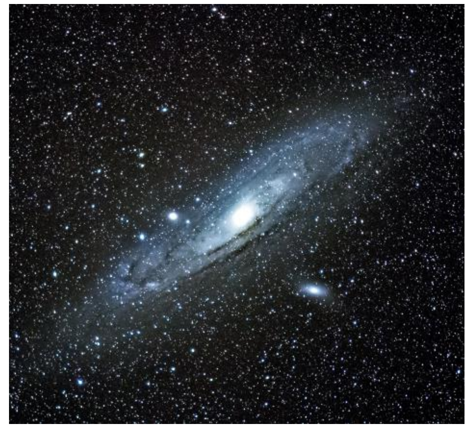


Figure 6: Andromeda Galaxy.

Therefore, you might be thinking that every telescope should have the biggest aperture and longest focal length possible. Aside from limitations such as cost and storage space, there are other reasons why this is not a good idea. First, for anyone who studies our solar system, aperture really is not that important. Most of the planets are visible using even the smallest telescopes. Objects like the Moon are so bright that too large an aperture may be an issue. Secondly, even smaller-sized telescopes, such as ones with apertures of 20 cm, are capable of seeing hundreds of **galaxies** and **nebulae**, some of which are almost a hundred million light-years away! Galaxies are large systems of stars, gases and dust and **nebulae** are interstellar clouds of dust and hydrogen gas. It can actually help to use low magnification for these types of objects. Objects, such as star clusters and galaxies can be too large to 'zoom in' on. The Andromeda Galaxy (see Figure 6), for example, appears to be larger than the full moon in the night sky!

Astronomical Cameras

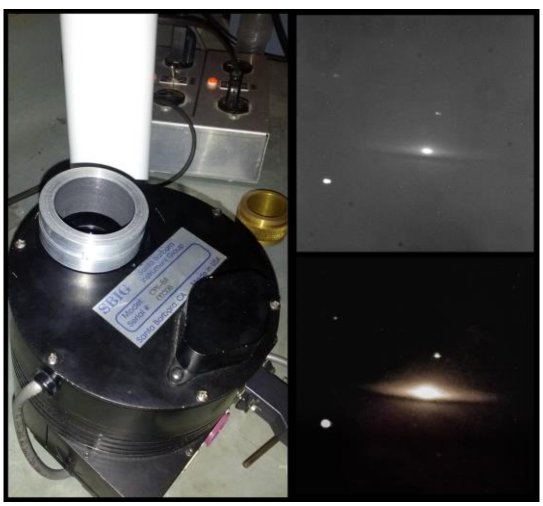


Figure 7: Left: An astronomical camera. Top right: A raw image taken with the camera. Bottom right: A processed version of the same image.

Nowadays, most astronomical work is done with cameras and computers. It is probably not surprising that astronomical cameras are more sensitive to light than the human eye. Your eyes might tell you "that galaxy kind of looks bright in the centre, and maybe has a spiral structure." A camera will tell you exactly how bright every part of the image is, and how it changes over time. Astronomers can learn a lot from this highly precise data.

An astronomical camera can have an attachment called a **spectrograph** that works like a prism (breaks up white light – see the **Physics chapter**). The spectrograph allows the camera to pick up small changes in colour. So why does colour matter, aside from making pictures of objects in space look pretty? Well, different colours represent different wavelengths of light.

If you think of a wave, you might imagine stretching it to make gradual crests, or compressing it to make very sharp crests. The **wavelength** of a wave is the distance from crest to crest. We see the colours of a rainbow go from red to violet, but that isn't the entire picture. That is just the picture we can see with our eyes. Red light has longer wavelengths than violet light. Light can have wavelengths much, much longer than red, and much, much shorter than violet. We can only see a tiny fraction of all light. We call the entire possible range of light the **electromagnetic spectrum (EMS)** (see Figure 8).

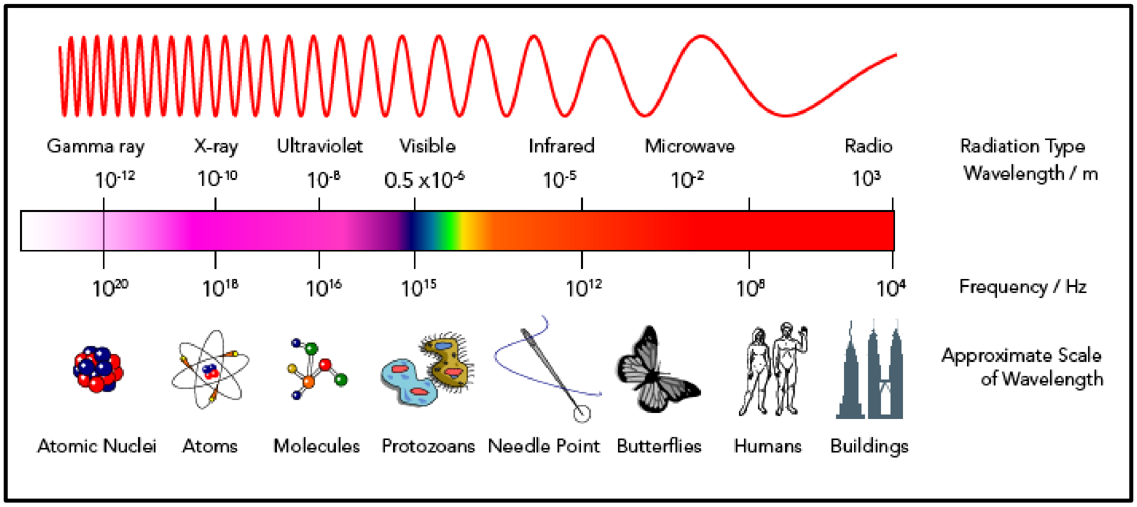


Figure 8: The electromagnetic spectrum.

We give different names to the different ranges of radiation. From the longest to the shortest wavelength they are: **radio waves**, **microwaves**, **infrared**, **visible light**, **ultraviolet light, x-rays**, and **gamma rays**. The visible part of the spectrum is actually very small. It is the part that people are most familiar with because it is the part that we see. So what does this have to do with astronomy?

Everything. Just because humans can only see visible light, that doesn't mean that everything in the universe emits visible light. There are events and objects that can only be detected in different parts of the EMS. Some details of visible objects, like the Sun, can only be detected when viewed at these other wavelengths. So what do astronomers do to see these non-visible things? They build telescopes that can see these wavelengths.

Radio Astronomy

Radio astronomy is a field of astronomy that studies objects in space using **radio frequencies**.

Figure 9: Full-scale replica of Karl Jansky's radio telescope at the US National Radio Astronomy Observatory.

This means we can use radio waves instead of using visible light to see stars and planets.

The discovery of radio waves, like so many great discoveries in science, happened by chance. **Karl Jansky** was an engineer with Bell Telephone Laboratories. In 1931, he was investigating static that might interfere with radio-telephone service. He was using a large, rotating antenna which he built himself! He recorded signals from all directions for several months. He noticed an unknown type of static which repeated every 23 hours and 56 minutes. He discussed this puzzling static with a friend who was an astronomer. His friend pointed out that the time between the peaks of the strange static was the same as that of a **sidereal day**. That is the time it takes for an object in the sky to come back to the same location after one rotation of the Earth. This led Jansky to think that his strange static came from beyond the Earth. Jansky looked at **astronomical maps** and compared them to his observations. Astronomical maps are maps which show where celestial objects are located. He concluded that the static was coming from the **Milky Way Galaxy** and in the direction of the constellation **Sagittarius**. Not long after, an amateur radio operator named **Grote Reber** built the first dish-shaped radio telescope in his backyard in Illinois in 1937. **Reber** was one of the pioneers of what became known as radio astronomy.

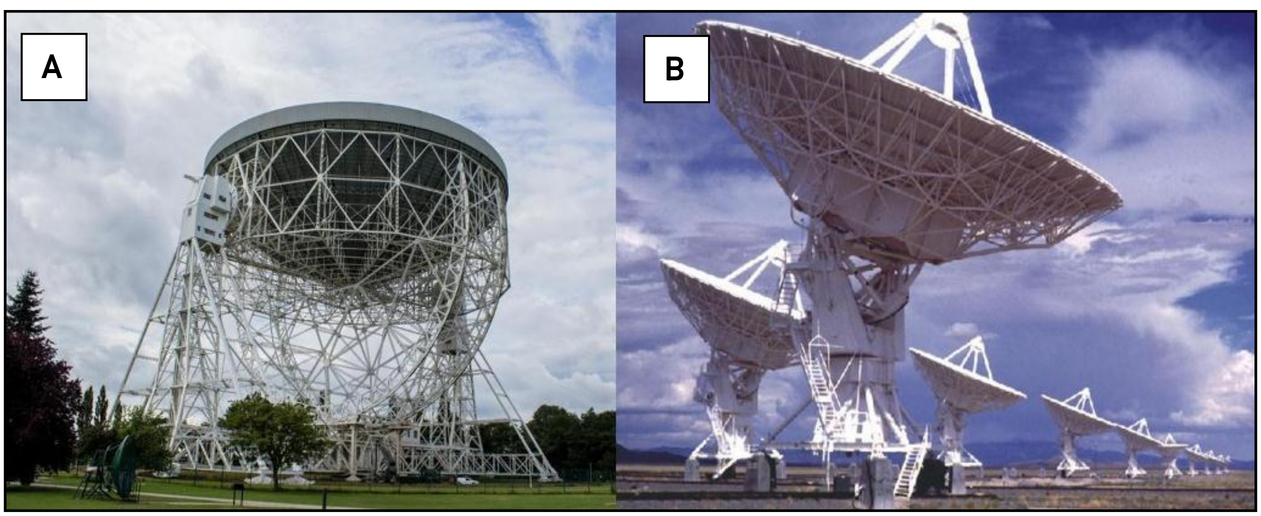


Figure 10A: The 76-metre wide Lovell telescope at the Jodrell Bank Radio Observatory.
Figure 10B: The Very Large Array (VLA) in New Mexico.

Reber and others found that since radio waves have a wide range of wavelengths (3 m to 30 m), radio telescopes need to come in different shapes and sizes. You may have seen these giant dish-shaped antennae in the movies (see Figure 10A).

More recently, radio observatories have been able to connect (**network**) different dishes together so that they can all operate as if they were one giant dish. This process is called **interferometry**. The **Very Large Array (VLA)** in New Mexico (see Figure 10B) is a good example of interferometry. Their array consists of 27 - 25m diameter radio antennas set up in a Y-shaped pattern.

How do Radio Telescopes Work?

Radio telescopes work very differently than the tube-based reflecting and refracting telescopes we have seen so far, although they do have some features in common with reflecting telescopes.

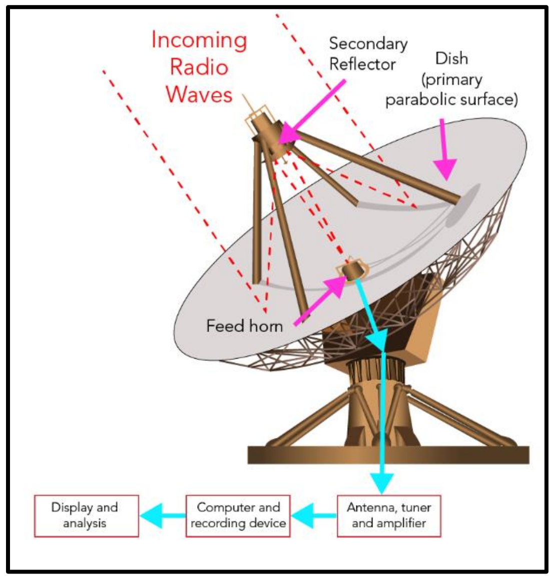


Figure 11: Parts of a radio telescope.

The big bowl-shaped part of a radio telescope is called the **dish**. The dish is a giant **parabolic** (concave-shaped) reflector. The dish takes incoming radio waves and brings them to a focus, like a mirror in a reflecting telescope. The telescope in the diagram below has a **Cassegrain** design. This type of telescope uses a **secondary reflector**, like the secondary mirror in a reflecting telescope. It also has a **feed horn** to bring the radio waves to a sharp focus. At the feed horn is an **antenna**. The antenna converts the radio waves into an electric current. This happens because the radio waves cause electrons to move in the antenna. The electronics in the radio telescope are often cooled with liquid nitrogen or liquid helium. This helps to reduce random electrical currents, or **noise**. The less noise there is, the easier it is to detect weak signals.

The other main parts are the tuner, the amplifier and the computer system. The **tuner** is like the dial on a radio. It allows the astronomer to focus on a single radio signal from the thousands that come into the antenna. Telescopes used by SETI are set up so that they can listen to more than one radio signal at a time. The **amplifier** is a device that increases the strength of the weak electrical current caused by an incoming radio signal. Finally, radio telescopes are hooked up to **computer systems**. These are used to record and store the electronic signals, analyze data and control the telescope's movements.

SETI – The Search for Extraterrestrial Intelligence

Some astronomers are not looking for stars, planets or galaxies. They want to know if there is other intelligent life in the universe. This field of study is known as **SETI** (**Search for Extraterrestrial Intelligence**).

Scientists think one way we might find life beyond Earth is with radio waves. We have been sending out radio and television waves from Earth for more than a century. Anybody in the Universe with a sensitive enough receiver could listen in on what we have been sending to each other. Even though radio waves travel at the speed of light, it could take millions of years for these messages to be received.

The Universe itself makes a lot of electronic 'noise.' That is what radio astronomers listen to. SETI works to filter out artificially-produced radio waves from the noise of the Universe. All human-made radio waves are **narrow-band**. This means they are transmitted on a narrow part of the electromagnetic spectrum. It is like when you want to tune in to a radio station. You turn the dial and hear static until the signal comes through clearly. That's what SETI researchers are doing. But they don't know what the signal they are listening for will sound like. They predict that any signal would be repeated, so other stations could tune in to the signal. This would show that a signal wasn't a random noise. A repeating signal could have been created by an intelligent life form. Without a repeated signal, people will not be convinced that extraterrestrial intelligence has contacted us.

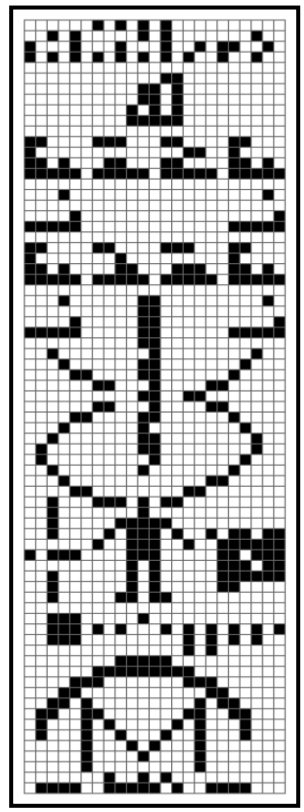


Figure 12: The 'Arecibo Message,' sent on November 16, 1974.

It's hard to know what a message from an extraterrestrial intelligence would be like. Did you know that we humans have tried to write one ourselves? In November 1974, a message was sent from the **Arecibo radio telescope** in Puerto Rico. The message was aimed at a group of stars called M13 that are about 21 000 light-years away. The message was made up of 1 679 binary numbers. It was arranged in a 23-column by 73-row **run-length coding** image. The message contained information about us humans. The picture showed the numbers 1-10, DNA, a human, the solar system, and the radio telescope that sent the message. If you look at the message, you can see how hard it might be to decipher alien radio signals. Even if the Arecibo Message is heard and a reply is sent, we won't get it for at least 42 000 years! If we ever do find somebody else in the Universe, it's going to be hard to have a conversation.

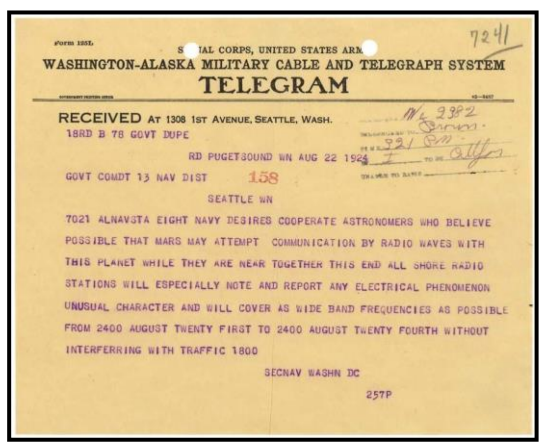
The Universe is an awfully big place. So is the electromagnetic spectrum. There are billions of radio frequencies. However, there is one part of the electromagnetic spectrum, in the 1-10 gigahertz (GHz) range, where there is very little natural background noise. SETI researchers think any extraterrestrials would also know this and send signals in that range. Almost all SETI research looks at those wavelengths. There are still billions of wavelengths in that range, though. Searching for a needle in a haystack is easy compared to SETI!

Figure 13: The 305 metre radio telescope at the Arecibo Observatory in Puerto Rico.

There are only a few radio telescopes in the world. This means that it is hard to get time on them. SETI searches often 'piggyback' on other radio astronomy. For example, they may search through data gathered by other researchers. SETI researchers do get some observing time on large radio telescopes like the giant 305 m dish in Arecibo. The **SETI Institute** is building the **Allen Telescope Array** at the University of California-Berkeley. These are the first radio telescopes that are used only for SETI research.

Before radio telescopes had been invented, some scientists wondered whether radio receivers might pick up transmissions from space. In 1899, **Nikola Tesla** heard some strange signals on his Tesla Coil receiver. He thought those signals came from the planet Mars. **Guglielmo Marconi** and **Lord Kelvin** also thought radio signals could be used to communicate with beings on Mars.

In August 1924, Mars passed closer to Earth than at any time in more than a century. Astronomers on Earth wanted to use this chance to listen for radio messages from beings on Mars. Astronomer David Peck Todd convinced the United States government to declare a "**National Radio Silence Day**." This happened over 36 hours from August 21-23, 1924. For five minutes every hour, high-powered radio transmitters were supposed to shut down. This would make it easier to pick up any signals sent by Martians. **Cryptologists** (see the **Math** chapter) waited to decipher any messages that might come in. Sadly, no signals from Mars were heard then. Today there are so many radio and television signals in the air that filtering out human-



Form 1251

7241

S IAL CORPS, UNITED STATES ARM

WASHINGTON-ALASKA MILITARY CABLE AND TELEGRAPH SYSTEM

TELEGRAM

RECEIVED AT 1308 1ST AVENUE, SEATTLE, WASH.

18RD B 78 GOVT DUPE

RD PUGETSOUND WN AUG 22 1924

GOVT COMDT 13 NAV DIST 158

SEATTLE WN

7021 ALNAVSTA EIGHT NAVY DESIRES COOPERATE ASTRONOMERS WHO BELIEVE POSSIBLE THAT MARS MAY ATTEMPT COMMUNICATION BY RADIO WAVES WITH THIS PLANET WHILE THEY ARE NEAR TOGETHER THIS END ALL SHORE RADIO STATIONS WILL ESPECIALLY NOTE AND REPORT ANY ELECTRICAL PHENOMENON UNUSUAL CHARACTER AND WILL COVER AS WIDE BAND FREQUENCIES AS POSSIBLE FROM 2400 AUGUST TWENTY FIRST TO 2400 AUGUST TWENTY FOURTH WITHOUT INTERFERRING WITH TRAFFIC 1800

SECNAV WASHN DC

257P

Figure 14: Telegram asking US Navy units to support efforts to listen to radio messages from Mars, August 22, 1924.

made 'noise' is a big part of SETI searches. The quiet airwaves those astronomers had in 1924 is something that modern SETI researchers can only dream of!

Modern SETI began in 1960. In that year, astronomer Frank Drake conducted **Project Ozma**, which was named after the ruler of Oz. Drake pointed a 26 m radio telescope at two nearby stars for about four months. They listened to the 1.4 GHz frequency for signals. No signals were heard, but Drake's work inspired many SETI research projects over the past 60 years.

You can even help out with SETI in your own home! One of the biggest challenges for SETI researchers is analyzing all the data gathered. In 1999, the University of California at Berkeley launched the **SETI@Home** program. This lets the public help with SETI. You can download a program that lets your computer analyze data with its unused power. The results are then sent back to SETI researchers.

Telescopes for Other Wavelengths

There are other telescopes that study phenomena in other wavelengths. **Microwave telescopes** have given us insight into the cosmic microwave background, a radiation field that permeates the entire universe, created shortly after **the Big Bang.** **Infrared telescopes** are good for peering through the dust in our galaxy that blocks visible light, allowing us to see things that might otherwise have remained invisible. **Ultraviolet telescopes** have given us insight into the chemical composition of our galaxy, which helps us understand how it changes over time. **X-ray** and **gamma ray telescopes** can detect high energy particles from objects such as neutron stars and black holes, giving us plenty of data with which to study these objects.

Airborne Telescopes

Some telescopes are located on Earth. Instead, they are sent high into the air above most of the atmosphere. Some, such as the **Kuiper Airborne Observatory** and the **Stratospheric Observatory for Infrared Astronomy (SOFIA)** (see Figure 15) are mounted on airplanes. They take measurements mid-flight at around 12 km up where there is not much **water vapour**. Not only does water vapour produce clouds, it also absorbs infrared radiation. This is exactly what these telescopes were designed to observe.

Figure 15: Stratospheric Observatory for Infrared Astronomy.

Figure 16: BLAST on its launch vehicle, in 2005.

Other airborne telescopes are mounted on high altitude balloons. The two **Stratoscopes** were used from the 1950s to the 1970s. The Balloon-borne Large Aperture Submillimeter Telescope (**BLAST**) had three science flights between 2005 and 2010 (See Figure 16).

The **Sunrise telescope** is taking a look at our Sun. To date, it is the largest solar telescope to leave the Earth. This telescope was designed to take off and land during the arctic summer. This was so that it could make uninterrupted observations of the Sun for several days. Both of its scientific flights, which took place in 2009 and 2013, provided astronomers with important data about the Sun's magnetic field. For all of these airborne telescopes, high altitude balloons have enabled them to reach higher altitudes than airplanes, with Sunrise even reaching up to three times higher!

Space Telescopes

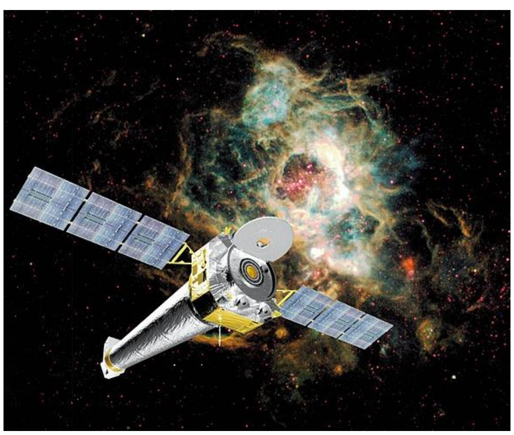


Figure 17: Chandra X-ray Observatory.

Telescopes have changed how we see the universe. They allow us to learn about the cosmos long before we will be able to explore it in person. But not all telescopes do their work from the ground. At ground level, telescopes need to look up through the Earth's atmosphere. Our atmosphere can make astronomy difficult. The gases that make up the Earth's atmosphere can distort images as well as absorb some wavelengths of light. As a result, many telescopes are actually launched into space to do their work in orbit. Most famously, the **Hubble Space Telescope** has been peering at the near-infrared and visible wavelengths for over 25 years. The **Chandra X-Ray Observatory** observes x-rays. The **James Webb Space Telescope** is scheduled to be launched in 2021. Both of these telescopes can only do their work outside the atmosphere. In the end, it takes a lot of different telescopes observing a lot of different wavelengths to get a complete picture of our universe. But regardless of what part of the spectrum you observe, there's always something new out there to look at and study. So whether you are looking through online images from NASA, or your friend's backyard telescope, new sights are only a peep away!

Spotlight on Innovation

Saving the Night Sky

If you were to travel beyond a city and look back at it, you may see a glow in the sky. This is called **sky glow**, which is an example of **light pollution.** Light pollution is the brightening of the night sky caused by artificial light. Scientists are very concerned with the negative impacts of light pollution. It has been shown to disrupt wildlife patterns, and prevent astronomers from studying stars, galaxies, and planets. Not to mention that it keeps us from seeing the scenic beauty of our night sky!

In 2007, in response to the concerns of light pollution, the **International Dark-Sky Association** (IDA), established the world's first international **dark sky reserve**. It is located around the Mont-Mégantic Park in the province of Quebec. The purpose of a dark sky reserve is to protect the starry nights and nocturnal environment. It also there to promote and support the study of astronomy and space sciences. An area can be designated as a dark sky reserve if it is a large area of very dark sky that is actively protected for scientific, educational, cultural and environmental reasons.

The Royal Astronomical Society of Canada also recognizes several areas across the country as dark sky preserves. These include Wood Buffalo National Park (AB), Point Pelee National Park (ON) and Fundy National Park (NB), just to name a few.

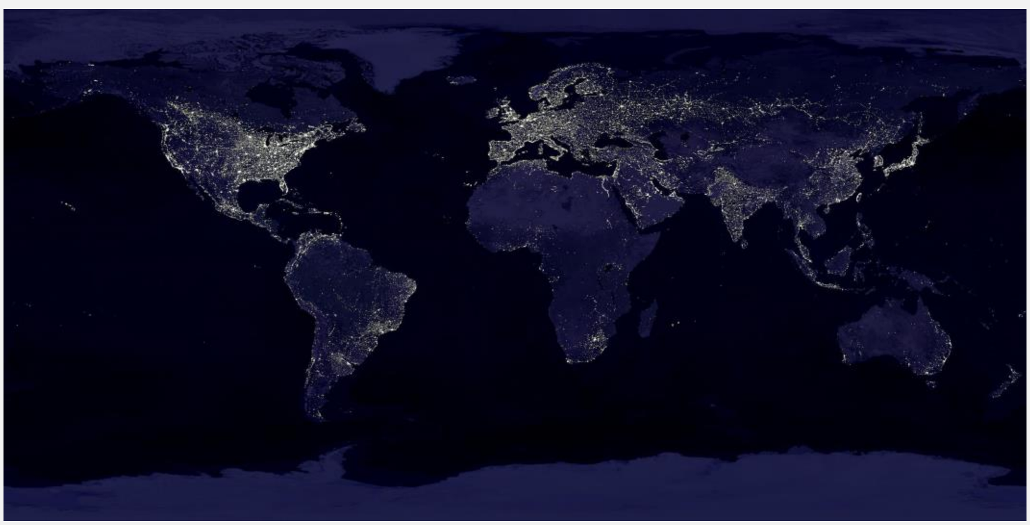


Figure 18: Composite image of Earth at night showing light pollution.

My Career

René Doyon
Astronomer and professor at the Université de Montréal

To become an astronomer, I completed an undergraduate degree in physics at the Université de Montréal, and a Master degree in astronomy. I completed my PhD in astronomy at Imperial College London, in England.

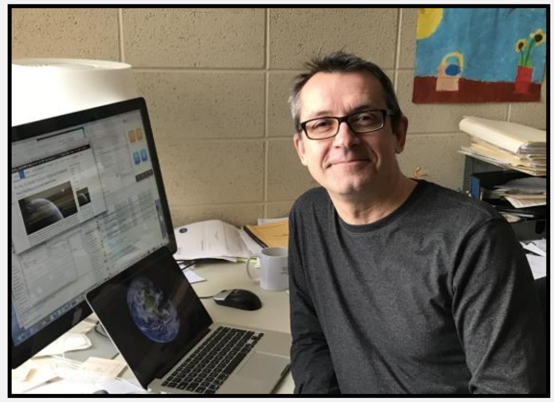


Figure 19: René Doyon at work.

I am interested in studying exoplanets, which are planets that orbit stars other than our Sun. To study them, my team and I are building specialized instruments that are installed on the best telescopes in the world. For example, I am currently working on an instrument called the Near-Infrared Imager and Slitless Spectrograph (NIRISS). This instrument will be installed on the James Webb Space Telescope, which will be launch in space in 2021. With this instrument, we hope to determine if there are exoplanets with Earth-like atmospheres, on which life as we know it could have developed.

I also work on two other instruments called SPIRou and NIRPS. SPIRou was installed in 2018 on the Canada-France-Hawaii Telescope in Hawaii. The NIRPS will be installed in 2020 on the ESO 3.6 metre telescope in Chile. One of the most important missions of these two instruments will be to find potentially habitable planets around stars that are smaller and less bright than the Sun called **red dwarfs**.

On these projects, I need to work in a team with people who are just as passionate that I am. This includes astronomers, engineers, technicians, administrative assistants, etc. This is why I decided in 2014 to create the **Institute for research on exoplanets** (iREx). Here more than 40 people work towards the same objective - to find potentially inhabited planets.

I am also the director of the Observatoire du Mont-Mégantic (OMM) which houses the largest telescope in north-eastern America. Many instruments built for the largest telescopes in the world are first tested here in Canada. As well, many great Canadian astronomers now work around the world, thanks to the unique training they got at OMM.

I really like my work as an astronomer. I consider myself very lucky to live in a time when we have the technology necessary to have reasonable hope of answering one of humanity's greatest questions, "Are we alone in the Universe?"

Build a Telescope Engineering Challenge

Challenge:
Your challenge is to work as a team to design and build a simple **refracting telescope**. Your goal is to make a device that will let you see things that are far away (see this video on YouTube for hints: http://www.youtube.com/watch?v=0eZ2o4WNtJU).

Materials:
- Concave and convex lenses (out of a science kit, old pair of binoculars or reading glasses)
- Cardboard or paper towel tube
- Scissors
- Tape
- Stick tack

Rules:
- No more than two lenses can be used.

Success
- Your group will be successful when:
    - Things at a distance look bigger
    - What you see through the telescope is in focus

Pushing the Envelope
- Can you set up the telescope so that you can see something even further away?
- Can you set up the telescope so that the image you see through the telescope is in the same orientation as the original?

References

Figure References

Figure 1: Fresco of Galileo Galilei showing the Doge (duke) of Venice how to use his telescope (Bertini, 1858). http://commons.wikimedia.org/wiki/File:Bertini_fresco_of_Galileo_Galilei_and_Doge_of_Venice.jpg (Accessed July 2, 2019)
Public domain images on Wikimedia Commons.

Figure 2: Parts and function of a refracting telescope.
Image ©2013 Let's Talk Science.

Figure 3: Parts and function of a reflecting telescope.
Image ©2013 Let's Talk Science.

Figure 4: The 2.54 m diameter Hooker telescope at Mount Wilson Observatory, California, a reflector, was completed in 1917.
http://apod.nasa.gov/apod/ap950701.html (Accessed July 2, 2019)
Public domain image from Mount Wilson Observatory via NASA.

Figure 5: The Canada-France-Hawaii Telescope, located at the Mauna Kea Observatory in Hawaii.
http://commons.wikimedia.org/wiki/File:Canada-France-Hawaii_Telescope_with_moon.jpg
(Accessed July 2, 2019)
Public domain images on Wikimedia Commons.

Figure 6: Andromeda Galaxy.
Image ©2013 Richard Bloch. Used with permission.

Figure 7: Astronomical camera and images taken using such a camera.
Image ©2013 Richard Bloch. Used with permission.

Figure 8: The electromagnetic spectrum. Let's Talk Science adapted from an image by Inductiveload, NASA https://commons.wikimedia.org/wiki/File:EM_Spectrum_Properties_edit.svg

Figure 9: Full-scale replica of Karl Jansky's radio telescope.
http://en.wikipedia.org/wiki/File:Jansky_Karl_radio_telescope.jpg (Accessed July 2, 2019)
Public domain images on Wikimedia Commons.

Figure 10A: The 76-metre wide Lovell telescope at the Jodrell Bank Radio Observatory.
Image ©2013 Richard Bloch. Used with permission.

Figure 10B: The Very Large Array (VLA) in New Mexico.
http://apod.nasa.gov/apod/ap020528.html (Accessed July 2, 2019)
Public domain image by NASA.

Figure 11: Parts of a radio telescope.
Image ©2020 Let's Talk Science using an image by Elena Mykhailenko via iStockphoto.

Figure 12: The 'Arecibo Message,' sent on November 16, 1974.
http://commons.wikimedia.org/wiki/File:Arecibo_message_bw.svg (Accessed July 2, 2019)
Public domain image on Wikimedia Commons.

Figure 13: The 300 metre radio telescope at the Arecibo Observatory in Puerto Rico.
http://www.nsf.gov/news/special_reports/astronomy/images/photos/full_size/21.jpg (Accessed July 2, 2019)
Public domain image by National Science Foundation.

Figure 14: Telegram asking US Navy units to support efforts to listen to radio messages from Mars, August 22, 1924.
https://io9.gizmodo.com/us-armed-forces-listened-for-messages-from-mars-30944693 (Accessed July 2, 2019)
Public domain image from the National Archives.

Figure 15: Stratospheric Observatory for Infrared Astronomy.
http://commons.wikimedia.org/wiki/File%3A446826main_ED10-0080-03c_946-710.jpg
(Accessed July 2, 2019)
Public domain image by NASA on Wikimedia Commons.

Figure 16: BLAST on its launch vehicle, 2005.
http://commons.wikimedia.org/wiki/File:BLAST_on_flightline_kiruna_2005.jpeg (Accessed July 2, 2019)
Public domain image on Wikimedia Commons.

Figure 17: Chandra X-ray Observatory.
http://commons.wikimedia.org/wiki/File:Chandra_X-ray_Observatory.jpg
(Accessed July 2, 2019)
Public domain image by NASA on Wikimedia Commons.

Figure 18: Composite image of Earth at night showing light pollution.
Data courtesy Marc Imhoff of NASA GSFC and Christopher Elvidge of NOAA NGDC.
https://commons.wikimedia.org/wiki/File:Earth%27s_City_Lights_by_DMSP,_1994-1995_(large).jpg
Public domain image on Wikimedia Commons.

Figure 19: René Doyon. © René Doyon. Used with permission.

General Resources

Optical Telescopes

https://www.bbc.com/bitesize/guides/zq6kv9q/revision/4 (Accessed July 2, 2019)
This page, on the BBC Bitesize Science website, has information about types of telescopes.

http://science.howstuffworks.com/telescope1.htm (Accessed July 2, 2019)
This section of the How Stuff Works website explains how different types of telescopes work.

http://www.youtube.com/watch?v=m9QcQGoOjbI (Accessed July 2, 2019)
This YouTube video, from Orion Telescopes, explains how telescopes work.

http://www.youtube.com/watch?v=4X6tNJpJY_A (Accessed July 2, 2019)
This video, from the Discovery Channel series "How It's Made," shows how a reflecting telescope is made.

Radio Telescopes

http://www.vla.nrao.edu/ (Accessed July 2, 2019)
This page, on the National Radio Astronomy Observatory website, has information about the Very Large Array. It connects to other pages on the basics of radio astronomy as well as who uses the Very Large Array.

https://public.nrao.edu/telescopes/radio-telescopes (Accessed July 2, 2019)
This page, on the National Radio Astronomy Observatory website, has information about radio telescopes and how they work.

SETI – The Search for Extraterrestrial Intelligence

http://www.seti.org/ (Accessed July 2, 2019)
This is the website for the SETI Institute, the leading SETI research organization.

http://science.howstuffworks.com/seti.htm (Accessed July 2, 2019)
This page, on the How Stuff Works website, has a good overview of SETI research.

http://www.news.cornell.edu/stories/1999/11/25th-anniversary-first-attempt-phone-et-0 (Accessed July 2, 2019)
This page from Cornell University tells the story of and explains the content in the Arecibo message.

http://ferriter.blogspot.ca/2008/04/capt-john-ferriters-martian-mystery.html (Accessed December 20, 2016)
This page tells a fascinating personal story of the August 22-24, 1924 National Radio Silence Day (although the story erroneously talks of National Radio Silence Day as being in October of that year).

http://setiathome.berkeley.edu/ (Accessed July 2, 2019)
This is the website for the SETI@Home project.

Space Telescopes

http://www.jwst.nasa.gov/ (Accessed July 2, 2019)
This page, on the NASA website, is all about the James Webb Space Telescope.

http://chandra.harvard.edu/ (Accessed July 2, 2019)
This page, on the NASA website, has information about the Chandra x-ray observatory.

http://hubblesite.org/ (Accessed July 2, 2019)
The Hubble site has extensive information about the Hubble Space Telescope, including an amazing photo gallery.

Spotlight on Innovation

http://darksky.org/idsp/reserves/ (Accessed July 2, 2019) International Dark Sky Association website

https://www.rasc.ca/dark-sky-site-designations (Accessed July 2, 2019) Royal Astronomical Association of Canada website with informational on dark sky preserve areas in Canada.

http://ricemm.org/en/ (Accessed July 2, 2019) Mont-Mégantic Dark Sky Reserve website.

ACKNOWLEDGEMENTS

Let's Talk Science wishes to acknowledge the contribution of all of the writers and editors who contributed their expertise to the creation of the three of the Let's Talk Science Challenge Student Handbooks.

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
Robert Berger, Ph.D. Candidate, Psychology Neuroscience and Behaviour, McMaster 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
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
Sarah Eaton, M.Sc. P.Geo, Project Officer, Directorate of Nuclear Cycle and Facilities Regulation, Canadian Nuclear Safety Commission
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
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
Joann Greeley, Construction Electrician, Red Seal Construction Business Owner
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
Natalie Hirsch, Project Officer in Operational Space Medicine, Canadian Space Agency
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
Natasha Janes, B.Sc. Candidate, Dept. of Chemistry, Memorial University
Natalia Jaworska, Ph.D. Candidate, University of Ottawa
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
Michelle Kunimoto, Ph.D, candidate, Department of Physics and Astronomy, University of British Columbia
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
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
Malcolm McKee, M.Sc., Lead Technical Advisor, Directorate of Environmental and Radiation Protection and Assessment, Canadian Nuclear Safety Commission
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
Marie-Eve Naud, Ph.D. Institute for research on exoplanets (iRex), Université de Montréal
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
Amanda Obodovsky, M.Sc. Astronomy (Planetary Science), Seismic Processor, Divestco
Constance O'Connor, M.Sc. Candidate, Department of Biology, Carleton University
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
Kimberly Reynolds, Education and Interpretation Officer, Canada Aviation and Space Museum
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
Allison Rumbolt, IFR First Officer, Cougar Helicopters Inc.
Christian Rutledge, HBA Psychology & French, McMaster University
Jedd Sardido, B.Ed. Candidate, University of Western Ontario
Negin Shahid, M.Sc. Candidate, University of Ottawa
Kristina Sheriden, B.Sc. Candidate, Memorial University
Ian Sidders, B.A Sc. Development Chemist, H.L. Blachford Ltd.
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.
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

Profile Authors 2020

Denise Hockaday, Climate Business Director Canada, Climate Corporation
Paul Fafard, Chemical Technologist, LP7 Polyethylene
Adam Brumwell, Autonomous Solutions Manager, Finning Canada
Ning Zhu, Associate Scientist, Canadian Light Source Inc., Biomedical Imaging and Therapy Beamline
Anne-Claude Pépin, Fire Management Technician, Parks Canada
Anna Szuto, Genetic counsellor, Division of Clinical and Metabolic Genetics, The Hospital for Sick Children
Emily Altiere, PhD student in Physics, University of British Columbia
René Doyon, Ph.D., Astronomer and professor at the Université de Montréal

Final Editor

Kim Taylor, Education Specialist, Let's Talk Science

Handbook Editors

Peter Bloch, Teacher, Toronto District School Board
Laura Brown, Education Specialist, Let's Talk Science
Christina Carnovale, LTS Challenge and Events Coordinator, Let's Talk Science
Rosanna Deo-DiScipio, Education Specialist, Let's Talk Science
Desiree Newhook, Communications Officer, Let's Talk Science
Darla O'Reilly, Education Program Consultant, Let's Talk Science
Abena A. Otchere, M.Sc., M.D. Candidate, Department of Medicine, University of Toronto
Mary Quinn, Education Specialist, Let's Talk Science
Scott Taylor, Education Specialist, Let's Talk Science

Chapter Editors

Fernando Amador, M.Sc. Candidate in Medical Biophysics, University of Toronto
Dr. Shiva Amiri, Science and Innovation Officer, British High Commission
Dr. Darren Anderson, Academic Program Coordinator, Institute for Optical Sciences
Pauline Barmby, Assistant Professor, Department of Physics and Astronomy, University of Western Ontario
Dr. Yvonne Beckham, Research Scientist, University of Chicago
Jenna Bishop, Ph.D. Candidate, Microbiology & Immunology, University of British Columbia
Adrian Buzatu, Ph.D. Candidate, Dept. of Physics, McGill University
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
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
Monica Joch, (proofreading) Dept. of Neurology, McGill University
Kevin Jordan, Medical Physicist, London Regional Cancer Program
Michelle Kaiser, B.Sc. Psychology, McMaster University
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
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
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

Expert Reviewers

Dr. Seema Bissoon-Haqqani, Patent Examiner, Canadian Intellectual Property Office
Dr. Patricia A. Chambers, A/Director, Aquatic Ecosystem Impacts Research Division, Environment Canada
Steve Clemens, Research Technologist, NOVA Chemicals
Dr. Stéphane Courteau, Associate Professor, Department of Physics, Engineering Physics & Astronomy, Queen's University
Dr. Maria DeRosa, Assistant Professor, Carleton University
Dr. Jean Deslauriers, Ph.D. Physics
Dr. Elaine Dodge, Postdoctoral Fellow, Memorial University of Newfoundland
Dr. Mark Fry, Assistant Professor, Department of Biological Sciences, University of Manitoba
Dr. Ravinder Goyal, Lethbridge AB.
Dr. Edward Grant, Professor and Head of Chemistry, University of British Columbia
Dr. Elizabeth Haack, Environmental Scientist
Dr. Mary Louise Hill, Professor, Department of Geology, Lakehead University
Dr. Shirin Kalyan, Postdoctoral Fellow, Faculty of Medicine, University of British Columbia
Dr. Joe McCann, Pharmaceutics Scientist, GlaxoSmithKline Canada Inc.
Dr. Alison McGuigan, Postdoctoral Fellow, Stanford University Physics
Lauren O'Bryant, Electrical Engineering Technologist Staff 2, COM DEV
Dr. Jeff Orchard, Assistant Professor, University of Waterloo
Dr. Gavin Pereira, Senior Research Scientist, Kinectrics Inc.
Dr. John Preston, Professor, Department of Engineering Physics
Laura Reynolds, M.Sc., Biology, University of British Columbia
Dr. Mark Samuels, Professeur Agrégé, Centre de Recherche de Ste-Justine, Université de Montréal
Dr. Maria Strack, Assistant Professor, Department of Geography, University of Calgary
Dr. Ray Syvitski, Research Officer, Institute for Marine Biosciences - National Research Council of Canada

Titus Tao, M.Sc., Biologist, Health Canada
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
Rana Amache
Nadia Bragagnolo
Camila Santander
Sierra Rosiana

Let's Talk Science

1510 Woodcock Street, Unit 12, London, Ontario, Canada N6H 5S1

letstalkscience.ca