let's talk science est 1993 CHALLENGE

Chemistry

2024

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Introduction to the Particle Theory of Matter

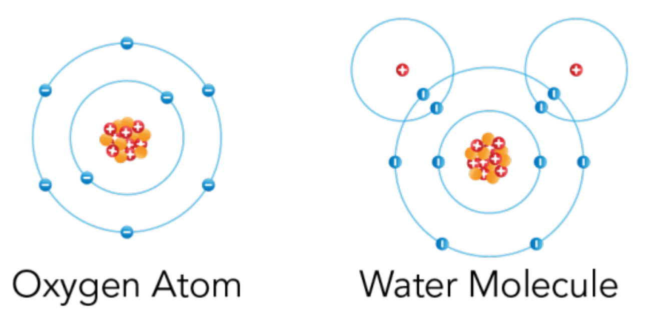
Particle Theory of Matter

Matter is anything that has mass and takes up space. It is a general name we call all the physical things around us. Matter includes things so tiny humans can't see them with their eyes.

The **Particle Theory of Matter** is a **scientific model**. A scientific model is a way of illustrating ideas, objects and processes so they're easier to understand. Scientists use models to explain things that can't be seen without special equipment. One of these things is an individual atom.

The Particle Theory of Matter helps us think about how matter behaves. It also helps us explain why different matter has different properties. It includes these key ideas:

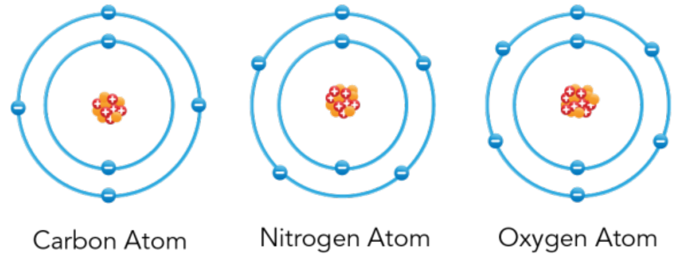
1. All matter is made of tiny particles. These particles are either individual atoms, or groups of atoms called molecules.



Left: Bohr atomic model of oxygen; Right: Bohr atomic model of water (Let's Talk Science using an image by VectorMine via iStockphoto).

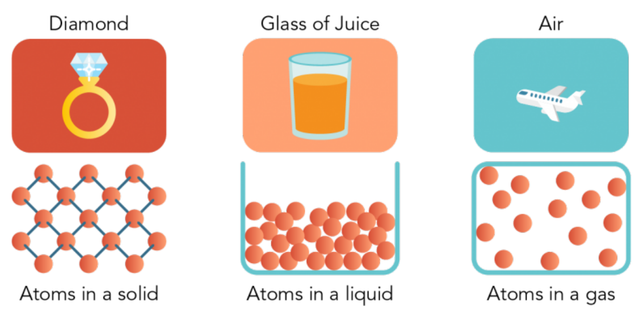
> Did you know?
> Any particle smaller than an atom is called a subatomic particle. Protons, neutrons and electrons are all subatomic particles.

2. Atoms of the same element are the same. Atoms of different elements are different. So, all of the atoms in carbon are the same. But the atoms in nitrogen and oxygen are different from carbon atoms.



From left to right: Bohr atomic models of carbon, nitrogen and oxygen (Let's Talk Science using an image by VectorMine via iStockphoto).

3. Particles are **attracted** to each other by **forces**. In some kinds of matter, like a diamond, this force is very strong. In other kinds of matter, like orange juice, the force is weaker.
4. Particles of matter have **spaces** between them. In a **gas**, there are large spaces between them. In a **liquid** they are closer together. In a **solid**, the particles are packed so close they can hardly move.

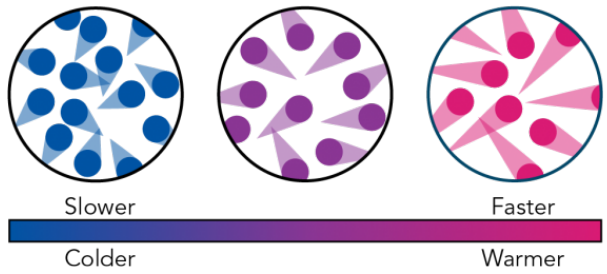


From left to right: Bohr atomic models of carbon, nitrogen and oxygen (Let's Talk Science using an image by VectorMine via iStockphoto).

5. Particles are always moving at any temperature above -273.15 degrees Celsius. But the human eye can't see them move.

> Did you know?
> -273.15 degrees Celsius is also 0 kelvin (0 K). This temperature is called absolute zero.

6. The faster particles move, the warmer they get. So, the molecules in hot water are moving faster than the ones in cold water.



The faster the speed of particles, the higher the temperature (Let's Talk Science using an image by VectorMine via iStockphoto).

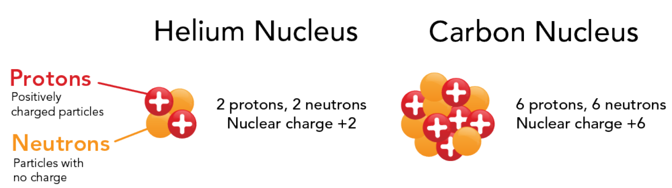
Introduction to the Atom

The Atom

According to the **Particle Theory of Matter**, all matter is made of tiny **particles**. These particles are either individual **atoms** or groups of atoms called **molecules**. There are two main parts to an atom. These are the nucleus and the electrons.

The Nucleus

In the centre of each atom is the **nucleus**. Within the nucleus there are two kinds of particles. Positively-charged particles called **protons** and particles with no charges called **neutrons**. The protons give the nucleus a positive charge. For example, a helium atom has 2 protons and 2 neutrons. It would have a nuclear charge of +2. A carbon atom has 6 protons and 6 neutrons. It has a nuclear charge of +6.



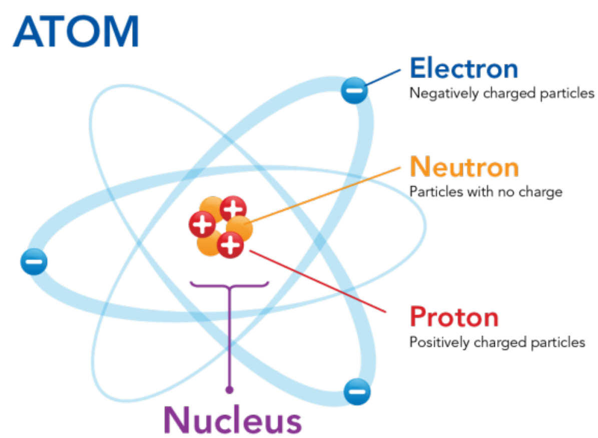
Left: Helium nucleus with 2 protons and 2 neutrons; Right: Carbon nucleus with 6 protons and 6 neutrons (Let's Talk Science using an image by VectorMine via iStockphoto).

The number of protons in the nucleus defines the type of atom. For example, all gold atoms have 79 protons and all silver atoms have 47 protons. The protons and neutrons in the nucleus are held together by a force called the **strong nuclear force**.

Did you know?
Neutrons were not discovered until 1932. They were discovered by scientist James Chadwick.

The Electrons

Moving around the nucleus are tiny, negatively-charged particles called **electrons**. Electrons are 2 000 times lighter than protons and neutrons. This means that most of the mass of an atom is found in its nucleus.

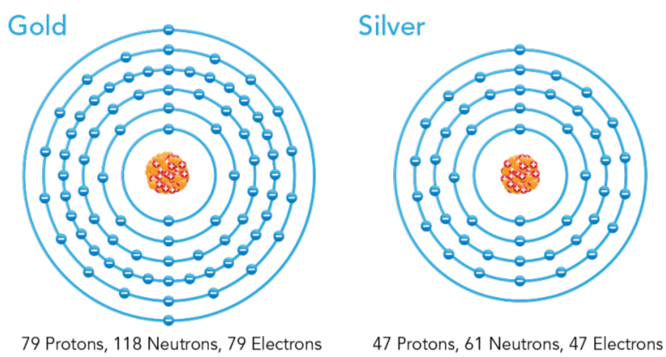


Atomic model of a helium atom which includes the protons, neutrons and electrons (Let's Talk Science using an image by VectorMine via iStockphoto).

Electrostatic forces keep electrons close to the nucleus. These are the forces that pull negatively-charged and positively-charged particles towards each other. But electrons also have **kinetic energy**. This pushes them away from the nucleus.

In a stable atom, these two forces are balanced. This keeps the electrons within certain areas around the nucleus.

In nature, most atoms are stable. A **stable atom** has the same number of electrons as protons. For example, a gold atom has 79 protons and 79 electrons. Silver has 47 positively-charged protons and 47 negatively-charged electrons. These positive and negative charges cancel each other out. This means that stable atoms have a **neutral** charge.



Atomic models of a gold atom on the left and silver atom on the right (Let's Talk Science using an image by VectorMine via iStockphoto).

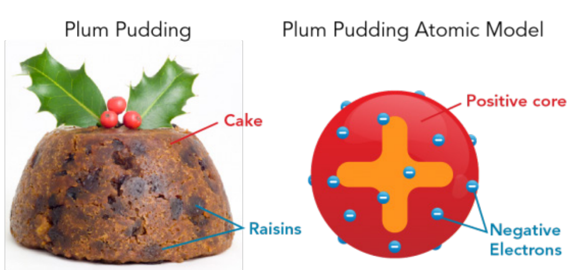
Did you know?
Any particle smaller than an atom is called a subatomic particle. Protons, neutrons and electrons are all subatomic particles.

Atomic Models

It can be tough for people to understand things they cannot see. This was the case for the atom. Over time, scientists created different **scientific models**. They did this as they performed experiments and made observations. These models helped them explain and predict how atoms behave.

Thomson Plum Pudding Model

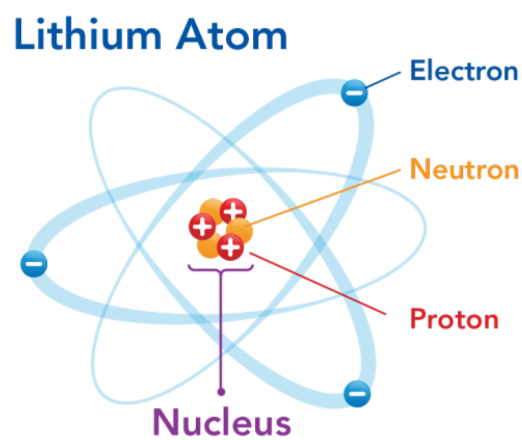
At the start of the 20th century, **J.J. Thomson** did experiments to learn about the atom. He showed that positively-charged and negatively-charged particles made up atoms. What he was not sure about was how they fit together. His idea at the time was that the negative electrons were stuck into a positive sphere. He imagined that the atom looked like a popular Christmas cake that has raisins in it. That is why this model is known as the **plum pudding model**.



Plum-pudding et plum pudding atomic model (Let's Talk Science using an image by VectorMine via iStockphoto).

Rutherford Planetary Model

Scientists' understanding of the atom changed in 1911. This was due to the **gold foil experiment** done by **Ernest Rutherford** and his team. In their work, they saw that the positive charge of atoms seemed to be concentrated at their centres. Rutherford called this the nucleus.



Rutherford atomic model of a lithium atom (Let's Talk Science using an image by VectorMine via iStockphoto).

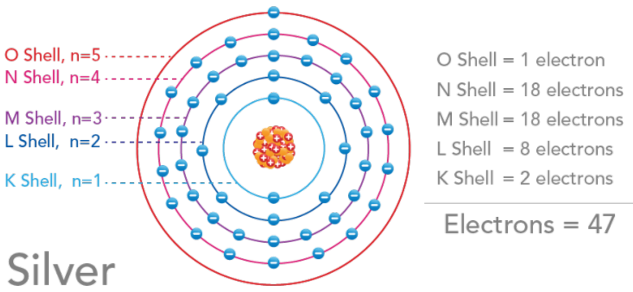
He also predicted that the electrons would orbit the nucleus, like planets around the Sun. This is why Rutherford's model is also called the **planetary model**. You have probably seen this model. Lithium atoms, like the one below, are often used as a symbol to represent science!

Bohr Model

Rutherford's planetary model explained a lot. But it didn't answer some questions that scientists still had. They wondered where the electrons actually were. Could their location be predicted? They also wondered why the orbiting electrons didn't lose energy and crash into the nucleus. Luckily, Danish scientist **Niels Bohr** was trying to find those answers.

Bohr was part of a group of scientists interested in a new field called quantum mechanics. **Quantum mechanics** is the study of how atomic particles exist and interact with each other. Bohr was particularly interested in the energy possessed by electrons.

Scientists were beginning to understand more about energy and subatomic particles. Based on this, Bohr suggested that electrons orbit the nucleus along specific paths. He called these paths electron shells.



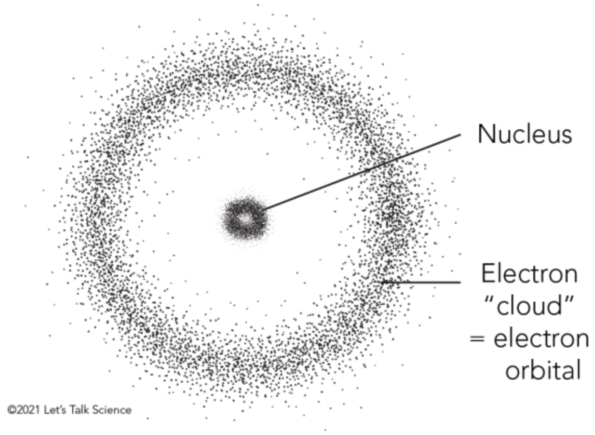
Bohr atomic model of a silver atom showing the location and names of electron shells (Let's Talk Science using an image by VectorMine via iStockphoto).

Remember the atomic models of gold and silver above? Those are Bohr models. The electron shells are labelled using either letters (K, L, M, N, O, P, Q) or quantum numbers (n=1 to n=7).

Electron Cloud Model

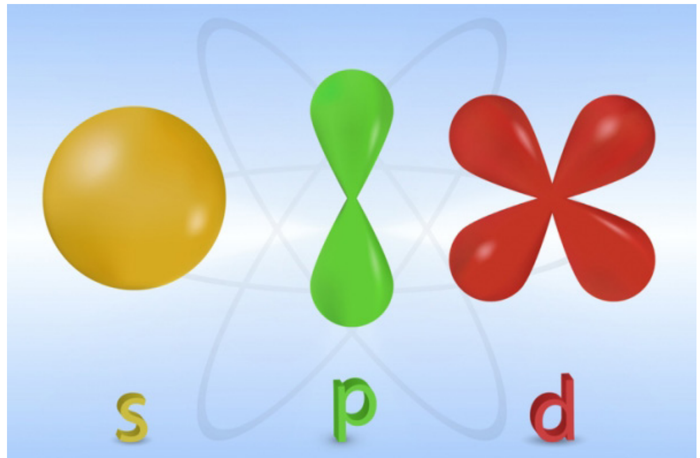
The Bohr Model quickly became popular. We still use it today because it helps us understand how and why atoms interact with each other. But scientists were not finished trying to understand how atoms look.

In 1926, Austrian physicist Erwin Schrödinger took Bohr's model a step further. He proposed a model which described the likelihood of finding an electron in a given place. This model is known as the **electron cloud model** or the **quantum mechanical model**. Drawings of electron clouds look like fuzzy shapes. Where the shape is the most dense, there is the most chance of finding an electron.



Electron cloud model (©2021 Let's Talk Science).

The area where an electron is most likely to be found is called its orbital.



Bohr atomic model of a silver atom showing the location and names of electron shells (Let's Talk Science using an image by VectorMine via iStockphoto).

Remember that the Bohr model showed the location of electrons in shells? That is still important in this model. Within each shell are subshells. Within each subshell are a specific number of orbitals. Each of the subshells can hold a certain number of electrons. They also have characteristic shapes.

These shapes can get pretty complex as the number of electrons increases. Below are the shapes of the s, p and d subshells.

Atomic models are a great example of how scientific thinking changes over time. They also show how new tools, like computer modelling, can lead to new ways of thinking about how things work.

Describing and Classifying Matter

Describing Matter

Each type of matter has its own unique properties. A **property** is a characteristic we can use to identify matter. We can use the properties of matter to know that wood is wood and gold is gold. The properties of matter fall into two categories. The first is physical properties. The second is chemical properties.

Physical Properties

A **physical property** is a way to describe the physical form of matter. We can identify some of these with our senses. **Colour** can be seen. So can **luster**. This is how shiny or reflective something is. **Odour** can be smelled. Some things, like **acidity**, can be tasted. **Texture** can be felt through touch. So can **hardness** and **temperature**. A person can try to flatten things to test their **malleability**. Or they can try to stretch things out to test their **ductility**.

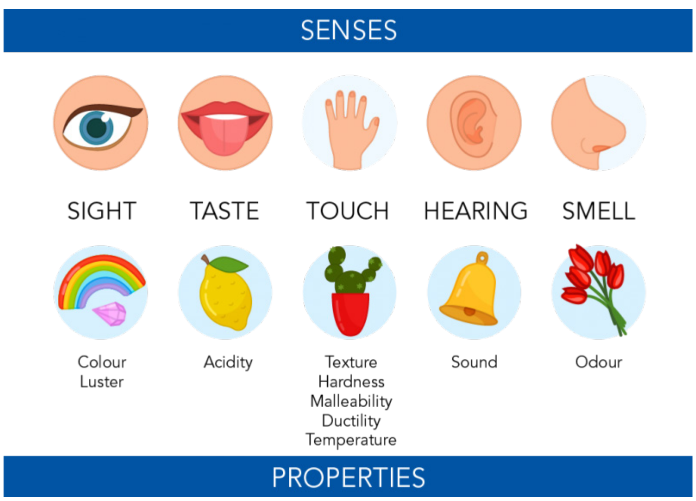


Image showing properties of matter you can identify with your senses (Let's Talk Science using an image by Alena Igdeeva via iStockphoto).

Some properties can't be identified through the senses. But they can be measured. Scientists do this without changing the matter. These properties include **boiling point**, **melting point**, **electrical conductivity**, **magnetism** and **density**.

Physical properties can be intensive or extensive.

An **intensive property** does not depend on the amount of matter. Colour, odour, density and melting point are intensive properties.

An **extensive property** depends on the amount of matter. These include things like **mass**, **volume** and **length**.

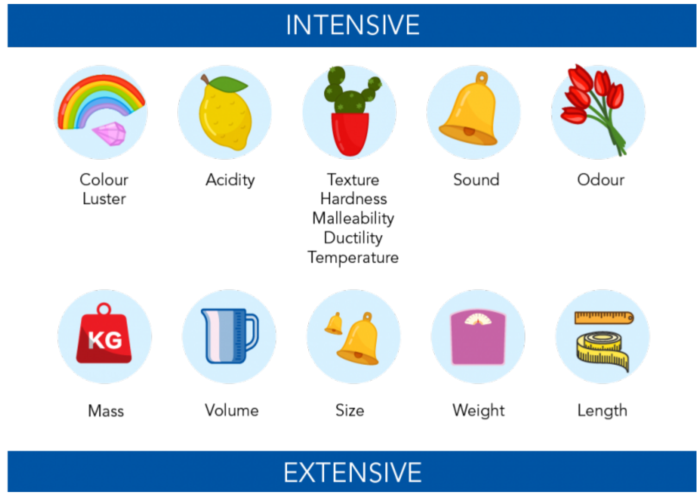


Image showing extensive and intensive properties of matter (Let's Talk Science using images by Alena Igdeeva, bortonia and erhui1979 via iStockphoto).

Chemical Properties

A **chemical property** describes how likely it is the matter will go through a **chemical reaction**. Here are some examples of chemical properties:

Flammability

Flammability Is the ability of matter to burn or combust. Things that are flammable can ignite easily and burn quickly. Flammable matter is often called **fuel**.

Wood, gasoline and wax are all flammable.

WHMIS symbol for Flammable Hazards (Source: CCOHS).

Corrosiveness

Corrosiveness is the ability of matter to 'eat away' another substance. It is important to wear safety equipment to protect your skin and eyes when using corrosive materials.

Corrosive materials include strong acids and bases. Hydrochloric acid and bleach are both corrosive.

WHMIS symbol for Corrosive Hazards(Source: CCOHS).

Toxicity

Toxicity is the ability of matter to cause damage to living things. Toxic materials cause harm when they are inhaled, swallowed or come into contact with skin.

Lead, mercury, and chlorine gas are all toxic.

WHMIS symbol for Toxic Hazards (Source: CCOHS).

Classifying Matter

There are different ways to classify matter. One way is to classify it as a pure substance or a mixture.

Pure Substances

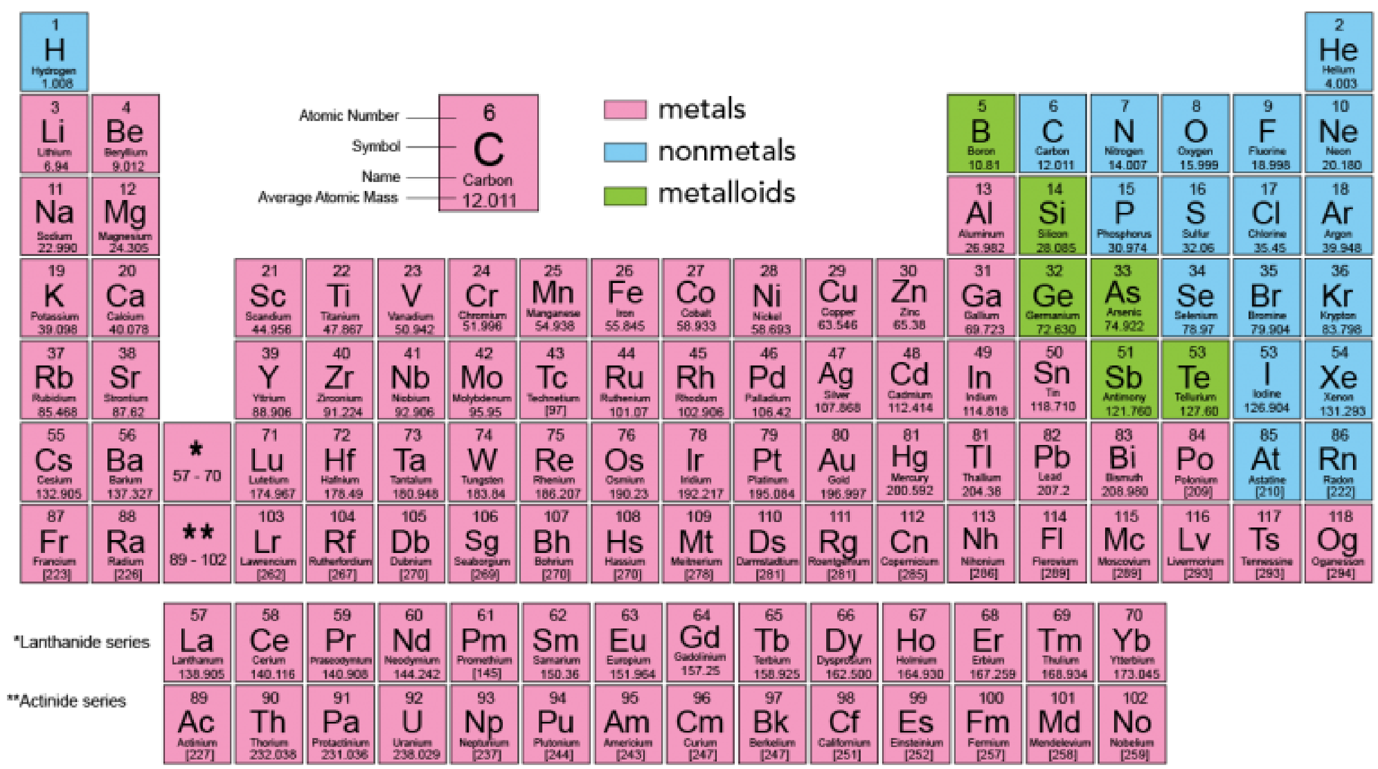
A **pure substance** is the same throughout. It can't be separated into other substances, or transformed into a new substance.

The physical properties of a pure substance never change. Water is a pure substance. So, the boiling point of water is always 100 degrees Celsius at a pressure of 101.3 kilopascals.

Pure substances only contain one type of **element** or **compound**.

Elements

Elements are a type of pure substance. They contain only one type of atom. These include carbon (C), silver (Ag) and gold (Au). Scientists have organized the elements into a chart called The **Periodic Table of Elements**.



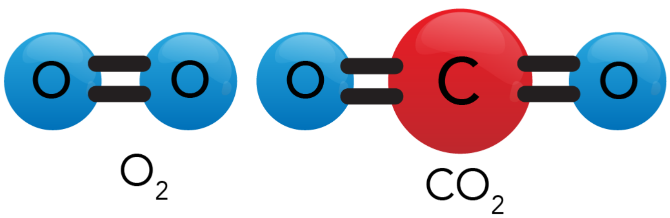
Periodic table of elements (Source: Let's Talk Science using an image by Dmarcus100 [CC-BY-SA] via Wikimedia Commons).

Each element has a specific set of properties. These are called characteristic properties. Characteristic properties are all extensive. These include density, melting point, boiling point, electronegativity and atomic weight.

> Did you know?
> Currently, there are 118 known elements. Several of these elements were discovered during your lifetime!

Compounds

Compounds are another type of pure substance. Compound molecules contain two or more elements. These are held together by chemical bonds. For example, carbon dioxide molecules have one carbon atom and two oxygen atoms.



Left: oxygen molecule; Right: carbon dioxide molecule (©2021 Let's Talk Science).

Compounds also have a fixed ratio. For example, a water molecule always has two hydrogen atoms (H) and one oxygen atom (O).

Compounds can be broken down into their individual elements. This is done through chemical reactions. For example, water can be broken down into hydrogen and oxygen using **electrolysis**.

The properties of a compound are different from the properties of each element it contains. Water has different properties than hydrogen or oxygen.

Mixtures

Mixtures are a physical combination of two or more pure substances. When they are mixed together, each pure substance keeps its own properties. For example, salt water does not have the same properties as either salt or water.

It is not a white crystalline powder like salt. And it freezes at a lower temperature than water.

Mixtures can be either **homogeneous** or **heterogeneous**.

A **homogeneous mixture** has the same composition throughout. Salt water is a good example of a homogeneous mixture. This is because dissolved salt is spread evenly through the mixture.

Another name for a homogeneous mixture is a **solution**. Solutions can be made of liquids, gases or solids. Air is a solution made of gases. Alloys are solutions made of metals. These include bronze and brass.

Examples of a liquid solution (milk), a gas solution (air) and a solid solution (brass) (Sources: cagkansayin via iStockphoto, Greg Meland via iStockphoto, and mauinow1 via iStockphoto).

A **heterogeneous mixture** is not the same throughout. The individual parts can be seen in these mixtures. Vegetable soup is a heterogeneous mixture. Each spoonful might include different vegetables, in different amounts. Heterogeneous mixtures also include things like salad dressing or mixed nuts.

Introduction to Heat Transfer

What is heat?

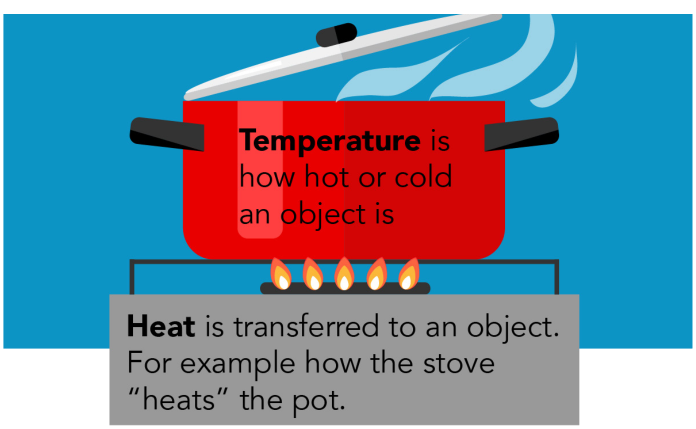
Think about all the ways that you can heat something up. You can boil water on the stove, rub your hands together quickly, or stand in front of a fire. But what is heat?

Heat is related to thermal energy. Thermal energy comes from the movement of tiny **particles** inside all matter. All solids, liquids, and gases are made up of small particles such as **atoms** and **molecules**. These particles have **kinetic energy** and are constantly moving. When these particles move more quickly, the amount of thermal energy increases.

Heat is thermal **energy** that is moving from one place to another. Heat flows from warmer objects to cooler objects. Since heat is a form of energy it is measured in **Joules** or sometimes in **calories**.

Misconception Alert
Objects don’t contain heat. They can contain thermal energy.

So what’s the difference between heat and temperature? **Temperature** tells us how hot or cold something is. Temperature is a measurement of an object’s average kinetic energy. Basically, it is a measure of the average motion of an object’s particles. Temperature is measured in degrees Celsius, degrees Fahrenheit, or using the Kelvin scale. Temperature and heat are connected. Heat is the flow of thermal energy between objects with different temperatures.



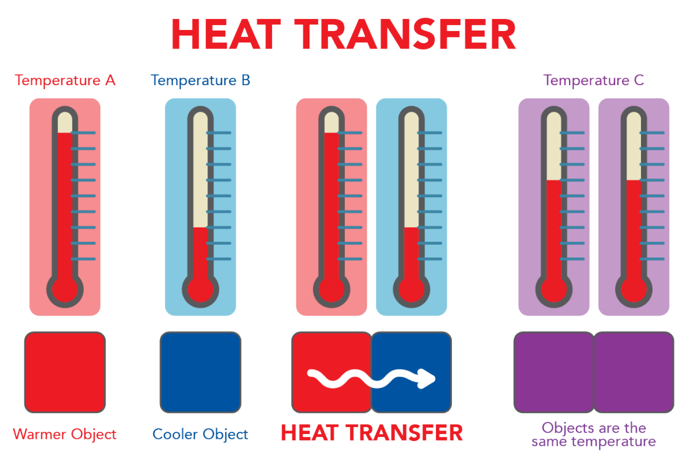
The difference between heat and temperature (Let’s Talk Science using an image by Dmitry Volkov via iStockphoto).

Did you know?
A calorie is the amount of energy required to raise the temperature of 1 gram of water by 1 degree Celsius. The energy in the food you eat is measured in calories.

How is heat transferred?

Have you ever held a cup of hot chocolate after being outside in the cold? Holding a hot cup makes your hands feel warmer. What you are experiencing is the transfer of heat from one object to another. Heat energy from the hot chocolate is transferred to your hands.

When two objects have different temperatures, heat is transferred. The cooler object gets warmer until the two objects have the same temperature. Heat energy always flows from the warmer object to the cooler object.

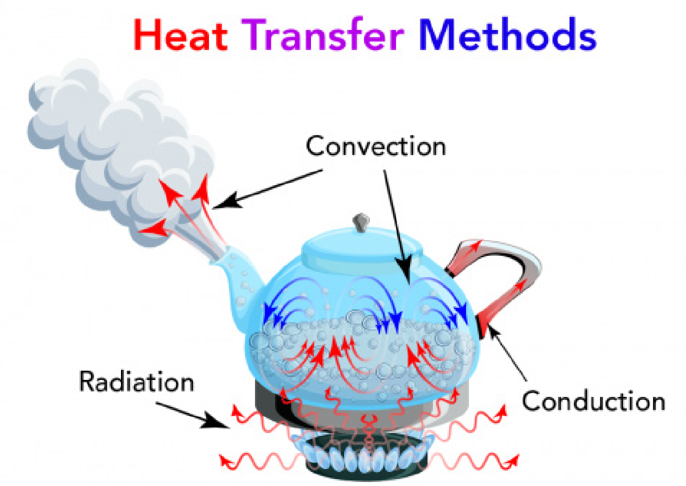


Heat always flows from a warmer object to a cooler object (Let’s Talk Science using an image by VectorMine via iStockphoto).

Heat can be transferred in three ways:

1. Conduction
2. Convection
3. Radiation

We experience these different forms of heat transfer everyday. Understanding these concepts can lead to innovative uses of heat energy. For example, a Canadian teenager created a flashlight powered by the heat of your hand. Who knows what other ways we will use our knowledge of heat in the future.

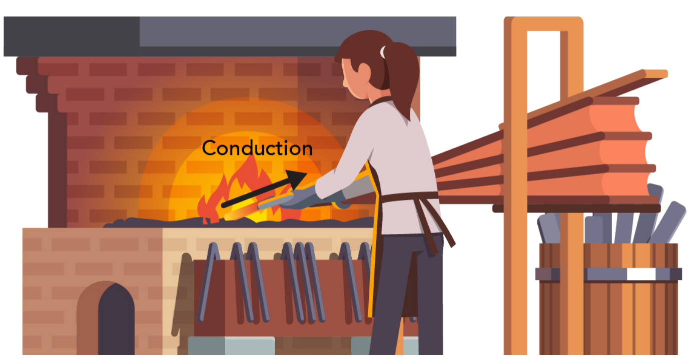


Boiling water in a kettle on the stove is a good example of the heat transfer processes of conduction, convection and radiation (Let's Talk Science based on an image from inkoly via iStockphoto).

Conduction

Conduction happens when materials or objects are in direct contact with each other. The molecules in the warmer object vibrate faster than the ones in the cooler object. The faster vibrating molecules collide with the slower molecules. This makes the cooler molecules vibrate more quickly, and the object gets warmer. For example, have you ever sat on a cool couch? Did you notice how the seat was much warmer when you stood up? Heat from your skin was transferred to the couch through the vibration of molecules.

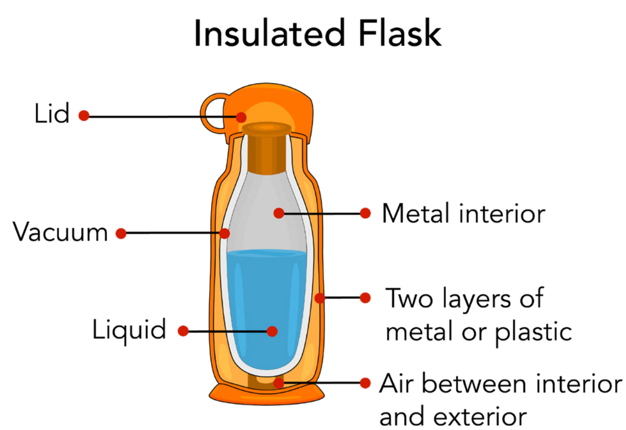
Conduction can also happen within a single object. Think of a metal rod that has just been poking around in a fireplace. The end of the rod that's been touching the hot embers becomes very hot. Energy from the hot end will move through the rod to the colder end. Eventually, the temperature of the entire rod will be the same. This is why it is important to wear a glove when handling a hot metal rod!



A person heating a metal bar at a blacksmith (Let's Talk Science using an image by IconicBestiary via iStockphoto).

Some materials are better than others at conducting heat. You might have noticed this walking around your house in the winter. Have you ever noticed that your feet get much colder walking on bathroom tile than on carpet? This happens even though both the tile and the carpet are the same temperature as your house. However, tile is a much better conductor than carpet. More heat flows from your foot to the floor when walking on tile than carpet.

Thermal conductivity is a measure of how well a material conducts heat. Materials that are good at conducting heat are known as conductors. Metals, such as silver, copper, and aluminum are conductors. Materials that are not good at conducting heat and are known as insulators. Styrofoam, snow and fiberglass are examples of insulators. Many homes have insulation. Insulation keeps homes from losing too much heat energy to the surrounding air. Many common objects also provide insulation from air such as coolers, insulated flasks and **sleeping bags**.



Cross-section of an insulated flask (Let's Talk Science using an image by KajaNi via iStockphoto).

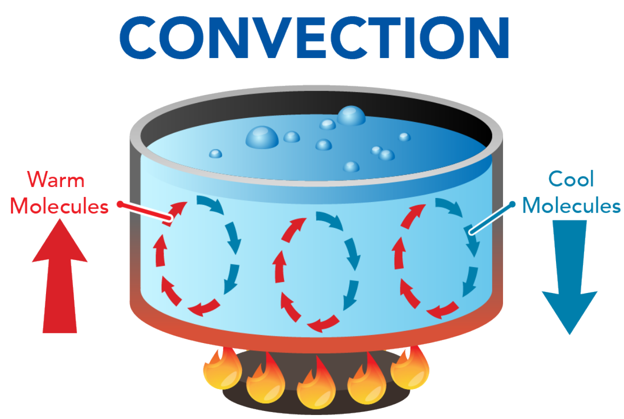
> Did you know?
> Chefs like to use wooden spoons because wood is not a good conductor of heat. This means the spoons won't heat up too quickly and burn their hands.

Conduction usually happens in solids. The particles in liquids or gases are farther apart than in solids. This makes it easier for gas and liquid molecules to move around. Thus, liquids and gases more often transfer heat through convection.

Convection

Convection is another way that heat can be transferred. Convection is motion in a gas or liquid that is caused by temperature differences. This motion transfers heat throughout the gas and liquid. The molecules in liquids and gases are farther apart and have more room to move around than in solids. Because of this, heated liquid or gas molecules can physically move. This is different from conduction, where the molecules just vibrate more quickly.

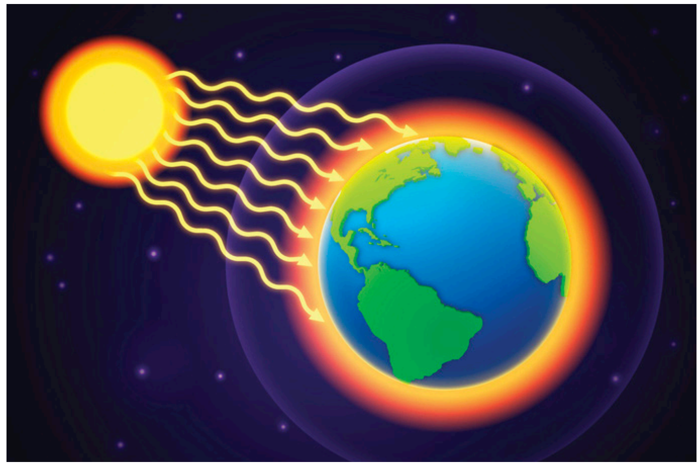
Heating a pot of water on a burner is an example of convection. Heat transfers to water molecules at the bottom of the pot through conduction. These molecules start moving faster. The water at the bottom of the pot becomes less dense. It rises above the denser, cooler water. As the water rises, it carries heat energy upwards with it. Cooler water takes its place at the bottom of the pot where it is heated. This creates a circular cycle of heat transfer. This pattern is known as convection.



Convection in a pot of water (Let's Talk Science using an image by VectorMine via iStockphoto).

Convection plays a very important role in wind and ocean currents. For example, air over land is generally warmer than air over the ocean. The warmer air heats up and rises. It is then replaced by cooler air from above the ocean. We experience this movement of air as wind.

Radiation is the third type of heat transfer. Unlike convection and conduction, no matter is needed for radiation. Thermal radiation is the transfer of energy via electromagnetic waves. Electromagnetic waves carry energy across space. Thermal radiation is the way that the Sun heats the Earth. The Sun's energy travels in waves through space, not through atoms or molecules. Other warm objects, such as a toaster or your body, also radiate heat energy. A microwave also uses radiation to heat your food.

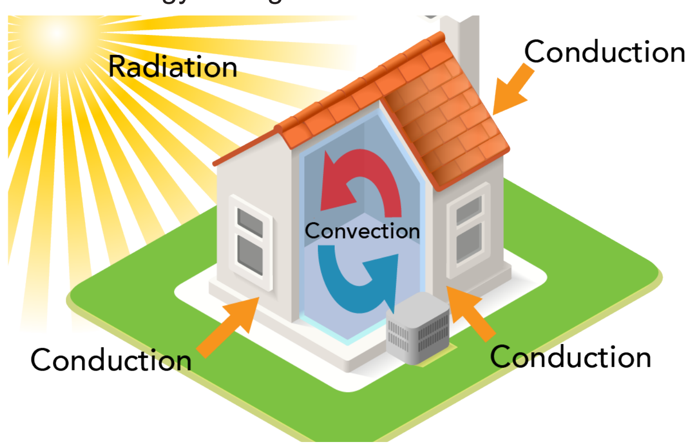


Thermal radiation on Earth comes from the Sun (Source: filo via iStockphoto).

Heat Transfer in a House

An example of all three heat transfer processes occurring at the same time is the heating or cooling of a house.

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



Conduction, convection and thermal radiation in a house (Let's Talk Science using an image by aurielaki via iStockphoto).

Introduction to Green Chemistry

Do you recycle? Compost? Turn off the lights when you leave a room? If so, you're practicing environmental **sustainability**. You recognize that our planet has limited resources. And you support its long-term health.

Chemists design all kinds of products. These include plastics, **pesticides** and **pharmaceuticals**. In the past, they focused on these products' usefulness. They didn't necessarily think about sustainability. But many products turned out to be harmful for the environment. So did the processes used to make them. Chemists who focus on the environmental impacts of products work in a growing field called **Green Chemistry**.

In green chemistry, scientists think about a chemical's impact from the laboratory, to the disposal site, to the environment. One way they can evaluate this impact is with the 12 **Principles of Green Chemistry**.

Graphic that shows the 12 guiding principles of green chemistry (© 2019 Let's Talk Science)

Let's look at four of these principles in detail.

Principle #1 : The Prevention of Waste

This principle applies to many aspects of life, inside and outside the laboratory. You might try to produce less garbage at home. Chemists try to produce less chemical waste.

You might not think of a car as something that produces waste, but it does. Inside a car's engine, fuel and oxygen from the air undergo a chemical reaction called **combustion**. This produces the energy needed to move the car. But it also produces harmful byproducts. These include **carbon dioxide** (CO_2) and **nitrogen oxides** (NO_x). Both are **greenhouse gases** that trap heat in our atmosphere. They are causing our Earth to warm and our climate to change.

Luckily, cars have something that helps reduce the harmful chemicals they produce. It's called a **catalytic converter**. This works while the car is running. It changes pollutants into less harmful molecules before they exit the car's tailpipe. The molecules emitted include oxygen (O_2), nitrogen (N_2), and water (H_2O).

Cross-section of a catalytic converter. The orange grid structures have surfaces covered in catalytic elements (Source: mipan via iStockphotos).

Did you know?
In 2021, transportation was the second largest source of greenhouse gas emissions in Canada. This sector accounted for 22% of total national emissions.

Principle #2 : Atom Economy

Imagine you're making cookies. You measure out two cups of flour. But you only end up needing one. If you threw out the other cup, that would be very wasteful!

Sadly, chemists can also cause waste when making products with chemical reactions. Green chemists try to reduce this by looking at **atom economy**. Atom economy includes questions like, "What percent of atoms from the **reactants** are incorporated into the **product**? What percent of atoms are wasted?"

For example, **photosynthesis** is a reaction that occurs in plants. This leads to two products: glucose ($C_6H_{12}O_6$) and oxygen gas (O_2). If glucose was the desired product, then oxygen gas would be a waste product.

Atom economy of photosynthesis

Step 1: Identify the reactants and products. For photosynthesis this would be:

$CO_2 + H_2O$ ---> $C_6H_{12}O6 + O_2$

Step 2: Balance the chemical equation. For photosynthesis this would be:

$6CO_2 + 6H_2O$ ---> $C_6H_{12}O_6 + 6O_2$

Step 3: Determine the masses of reactants and products based on atomic mass

CO_2 = 6(44) = 264 $C_6H_{12}O_6$ = 180
H_2O = 6(18) = 108 $6O_2$ = 6(32) = 192
Total mass of reactants = 372
Total mass of products = 372

Step 4: Determine the percentage of desired product ($C_6H_{12}O_6$) (mass of desired product/total mass of products) x 100

180/372*100 = 48.4%

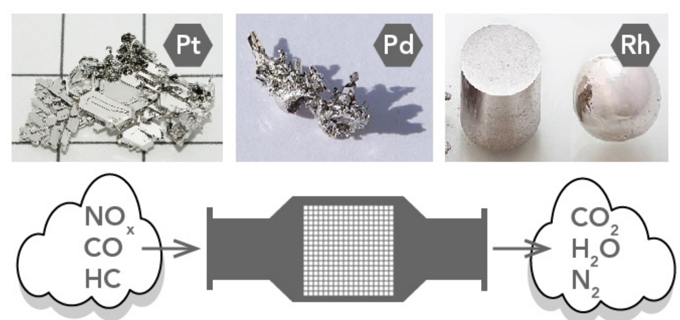
In green chemistry, products should have a high atom economy. Most of the ingredients added during the process should be used to make the final product.

You might have an example of green chemistry in your medicine cabinet: ibuprofen. This is the active ingredient in Advil and Motrin. The old method of making ibuprofen was wasteful and inefficient. Of the atoms used, only 40% made it into the final product. In the 1990s, the manufacturer developed a new method, using principles of green chemistry. Since the change, 77% of the atoms from the reactants are now in the final product! This innovation earned the manufacturer a Green Chemistry Challenge Award in 1997.

Principle #9 : Catalytic Ingredients

A **catalyst** is a substance that helps a chemical reaction happen, or makes it go faster. Catalysts can lead to reactions that produce less waste or have a greater atom economy.

Remember the **catalytic converter**? As its name suggests, the converter contains a catalyst. This catalyst helps convert some toxic gases into less harmful ones.



The elements platinum, palladium and rhodium are often used as catalysts (Let's Talk Science using photographs by Periodictableru [CC BY], Hi-Res Images of Chemical Elements [CC BY and Alchemist-hp (talk) www.pse-mendelejew. dederivative work: Purpy Pupple [CC BY-SA 3.0] Wikimedia Commons [Pt, Pd, Rh]).

As a bonus, the catalysts in the catalytic converter aren't used up in each reaction! That means they can be used over and over again.

Did you know?
Vehicles with Diesel engines use different catalytic converters than vehicles with gasoline engines.

Principle #11 : Real-Time Pollution Prevention

Imagine you have a leaky faucet. It's better to fix it right away, rather than waiting for the kitchen to flood, right? That's what real-time pollution prevention is all about. Chemists aim to fix problems before they can cause damage to the Earth.

One strategy is called **carbon capture**. The goal of carbon capture is to remove excess carbon dioxide from the air before it becomes a problem. Carbon capture technology works by:

- Collecting carbon dioxide before it can escape into the atmosphere
- Storing it safely
- Reusing or neutralising it to make it into useful materials

Did you know?
Two scientists at the University of Ottawa won Royal Society of Canada Medals for their work on carbon capture technology.

Careers in Green Chemistry

Green chemistry principles are important. They help chemists make some products less harmful to the environment. They mean more efficient processes with less waste material, less energy used, and less hazardous waste to clean up!

If you're passionate about protecting the environment and you want to be part of the solution, a career in green chemistry might be perfect for you. Here are some exciting careers options:

- **Environmental Chemist:** Finds solutions to environmental problems like pollution and climate change.
- **Chemical Engineer:** Designs processes to create products in an environmentally friendly way.
- **Sustainability Consultant:** Helps organisations become more environmentally responsible by advising them on green chemistry practices.
- **Research Scientist:** Explores new ways to make chemicals and processes more sustainable.

Even if you do not pursue a career in green chemistry, you can still apply green chemistry practices!

For example:

- Reduce the waste you produce by recycling or composting when possible
- Try to choose products made using green chemistry practices
- Be mindful of how you use transportation in your community
- Dispose of harmful waste carefully. For example, recycle batteries and electronics at designated locations. Or return unused medicine to your pharmacy instead of pouring it down the drain.

Green chemistry industry icon (Petmal, iStockphoto)

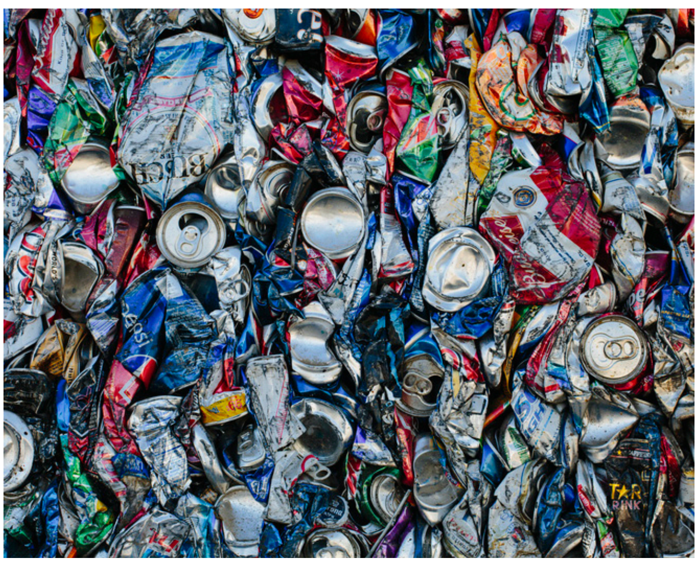
Chemistry in the Aluminum Industry

At Rio Tinto, science is everywhere. From understanding where to find minerals in the Earth to making aluminum. We use science every day. We do a lot of chemistry in our work. Especially analytical chemistry. But what is analytical chemistry? And how do we use it to make aluminum?

Let's start at the beginning!

What is Aluminum?

You have probably heard of aluminum. It is used to make many things. Aluminum foil, beverage cans, car wheels, aircraft and even satellite parts.



Crushed aluminum containers at a recycling plant (Source: Mint Images via Getty Images).

You may also know that aluminum is a **chemical element**. It is found on the **periodic table of elements**. This silvery-grey metal is the most widespread metal on Earth. It is also the third most common chemical element, after oxygen and silicon.

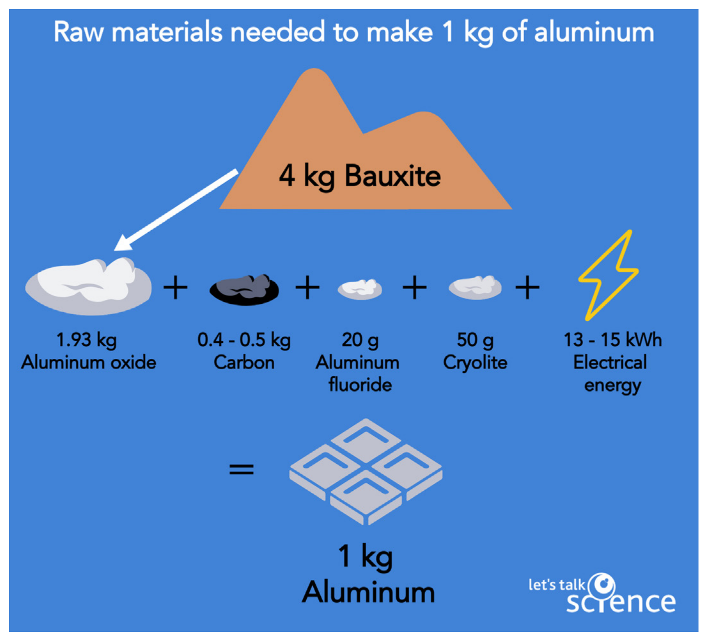
Aluminum, on its own, is very rare in nature. It almost always combines with other elements to form **compounds**.

The most common aluminum compound in nature is aluminum sulphate ($Al_2(SO_4)^3$). This is often used to make small particles clump together in **wastewater treatment plants**.

Aluminum also combines with oxygen to form aluminum oxide (Al_2O_3). This compound is called **alumina**. Alumina is often made from an ore called **Bauxite**. Alumina is usually a white powder. It is used in many different chemical and manufacturing processes.

Alumina also occurs in nature as a mineral called **corundum**. Rubies and sapphires are types of corundum.

> Did you know?
> There are at least 300 different compounds that contain aluminum.



Raw materials needed to make 1 kg of aluminum (©2023 Let's Talk Science).

Why Use Aluminum?

Physical Properties

The physical properties of aluminum make it very useful. Aluminum is not very **dense**. This means that it is light for its size.

When **evaporated** in a **vacuum**, aluminum can form a thin coating on objects. This coating reflects both heat and light. It is used on mirrors, helium balloons, packaging and toys.

Mylar balloons get their shine from a coating of aluminum (Source: psam via Getty Images).

Aluminum is a good conductor of heat. This means that heat passes easily through it. This is why it is used to make pots and pans.

It is also a good conductor of electricity. This is why it is used to make electrical transmission lines.

Electrical transmission lines (Source: NickyPe via Pixabay).

Aluminum is also very malleable and ductile. This means it can be easily formed into different shapes, such as flat sheets and thin rods. It is the second most malleable metal and the sixth most ductile.

Chemical Properties

The chemical properties of aluminum also make it useful. Aluminum does not corrode easily. This means that it is not easily damaged by reacting with water or air.

Aluminum is not very strong on its own. This is why it is often combined with other metals to form alloys. Aluminum alloys of copper, manganese, magnesium and silicon are lightweight and strong. These are often used to build aircraft and other vehicles.

Aluminum is what makes this P-51 Mustang shine (©2023 Scott Taylor. Used with permission).

Did you know?
The Convair B-36 Peacemaker bomber aircraft was so big that it was known as the "aluminum overcast."

Aluminum in Industry

Because it is so rare in nature, people were not able to get a sample of pure aluminum until 1845. This was when German chemist Friedrich Woehler isolated aluminum from aluminum oxide. But his method was very difficult and time-consuming. Scientists needed to develop new methods to produce aluminum on a larger scale.

In 1886, two scientists each found a solution. One was physicist **Paul Héroult** in France. The other was engineer **Charles Hall** in the United States. They both invented a process for breaking down alumina to produce aluminum. They didn't work together, but somehow both discovered the same process independently. They filed **patents** for their processes in the same year and became known as the "aluminum twins". Their process, called the **Hall–Héroult Process**, is the basis for the aluminum **refining** today.

The Canadian aluminium industry is the fourth largest in the world. It produces 3.2 million tonnes of aluminium every year. And it has one of the lowest **carbon footprints**.

As of 2023, Rio Tinto operates 5 aluminum smelters, 6 hydroelectric plants, and a Research & Development Center in Québec, along with a smelter and hydro facility in British Columbia. Rio Tinto employs 10,500 people across all its operations in Canada.

Where does chemistry fit in?

Chemistry is the science of matter and how it is transformed. Manufacturers transform matter a lot when they refine bauxite ore to make aluminum.

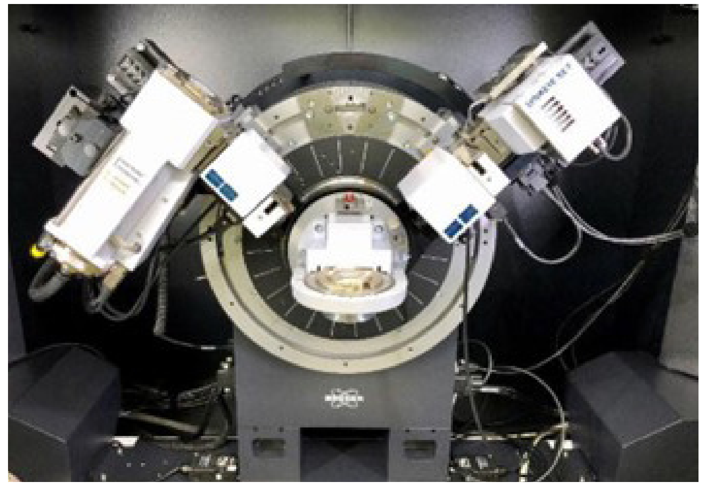
At each stage in the process, analytical chemists need to keep a watchful eye on what is happening. Analytical chemists specialize in the separation, identification, and measurement of matter.

Samples in volumetric flasks (Source: Rio Tinto. Used with permission).

Their work can include separating one type of matter from another. Like separating alumina from bauxite. It can also include Identifying the different compounds in a sample. When processing aluminum, it can include determining the quality of the finished product. To do this, analytical chemists and technicians need specialized knowledge and skills. They need to know different ways to sample and analyze data. Sometimes they even come up with totally new ways to collect data.

Analytical chemistry technicians in action (Source: Rio Tinto. Used with permission).

They also use specialized equipment and instruments. Sometimes these are simple things like beakers and volumetric flasks. Other times they are high-tech equipment.



Diffractometer (Source: Rio Tinto. Used with permission).

Chemical technicians use optical emission spectrometers to analyse the chemical elements in metals and alloys. They use x-ray diffraction analyzers to understand the physical properties and crystal structure of samples. Both of these instruments provide the measurements needed to produce aluminium at Rio Tinto.

Our teams of analytical chemists and chemical technicians help us use materials efficiently and sustainably. This cuts down on waste and greenhouse gas emissions. They also help us make sure our processes are safe. Finally, they help make sure our products are of the highest possible quality. So, the next time you pick up an aluminum can, think of all the chemistry that went into making it!

Let’s Talk Science appreciates the contributions of scientists at Rio Tinto in the development of this part of the handbook.

How can you design an insulated container?

Consider using the Design & Build Process with this challenge.

This activity will help build skills related to the Generate Ideas, Plan, Create, and Test & Evaluate phases of this process.

Materials:

- Two identical beverages in closed containers (e.g., juice boxes, cans, bottles, pouches)
  - one cold beverage (kept in the refrigerator or a cooler overnight)
  - one room temperature beverage –to be used to design the prototype
- A variety of paper (e.g., construction paper, newspapers, cardboard)
- Pieces of fabric
- A plastic container with lid (i.e., large margarine or ice cream container)
- Packing material (e.g., Styrofoam, plant-based packing peanuts, bubble wrap)
- Cotton balls
- Aluminum foil
- White glue
- Tape
- Thermometer (that can go into a liquid)

What to do!

Imagine a life-saving medication needs to be delivered to someone two hours away. The medication must stay cold while it is transported. Your challenge is to design and build an insulating device. This must keep the medication as cold as possible for two hours.

Tips and Hints

- Keep the cold beverage in the refrigerator or cooler until you're ready to test your prototype. Use the room temperature beverage to build your prototype. The cold beverage represents the "medicine" that you need to keep cold.

Think about the thermal conductivity of the different materials you have.

1. **Generate Ideas** – Think about how you could keep the "medicine" cold for two hours.
2. **Plan** – Create drawings of what you want your design to look like. Gather the tools and materials you will need.
3. **Create** – Build a prototype. This is a working model that you will test. Make sure the room temperature beverage can be taken in and out of your prototype.
4. **Test** - When you are satisfied with your prototype, it is time to test it!
   - Measure the temperature in the refrigerator or in the cooler using the thermometer. This will be the control temperature. Record this temperature.
   - Replace the room temperature beverage in the prototype with the beverage from the refrigerator/cooler.
   - Leave the prototype somewhere, not near a heat source, for 2 hours.
5. **Evaluate** - After two hours, measure the temperature of the beverage in the prototype.
   - Calculate the difference between the control temperature and the temperature of the beverage in your prototype.
     How well did your prototype keep the "medicine" cold?

What's happening?

Whenever two objects have different temperatures, heat is transferred between them.

Adult pouring a warm drink out of an insulated container for a child (Source: SeventyFour via Getty Images).

The warmer object will transfer heat to the cooler object until they reach the same temperature.

When an object is colder than air, the air will transfer heat to the cold object until they both reach the same temperature.
To keep something cold, you need to prevent heat from transferring to it. You can do this using insulation. Insulators are materials that are not good at conducting heat. If you surround a cold object with insulating materials, you can slow the transfer of heat. This keeps the object cooler longer.

Why does it matter?

There are many situations in which people want to control the transfer of heat. For example, in the winter we want to keep the heat in our homes from transferring outside. Or you might use a blanket or a sleeping bag to keep your body heat from being transferred to the cooler air around you.

Investigate further!

- How would you change your design if you wanted to keep a hot drink hot? Why?
- Try using different insulating materials. Which works best?
- Can you think of other situations where we want to control heat transfer?

Vaccine cooler bag (Michael Duff, Getty Images)

Sarah Ellis (she/her)

Senior Scientist
Via Separation

I was grew up in Halifax, Nova Scotia. I now live in Boston, Massachuetts, USA. I completed my training/education at Dalhousie University (BSc Hon, Chemistry, Certificate in Materials Science) and Queen's University (PhD, Chemistry).

What I do at work

I research and develop new technologies which fight climate change. Using chemistry, I create materials that have never been made before. I work to find solutions to complex problems. I work with people from diverse backgrounds. Together, we take an idea and turn it into a product that will help cut CO2 emissions or clean water.

My company makes water filters (or membranes) that are used to purify water. This water can come from different sources, even contaminated and dangerous industrial wastewater. I'm part of a team of chemists and engineers that is trying to make the filters work more efficiently and last longer. We have developed ways to separate materials that use less energy.

In an average day, I do hands on work in the lab using chemistry to create new materials for membranes. Once I have made the material, I use specialized equipment to figure out what exactly I made. Sometimes it's not what I expect to find! I then make the material into a membrane and test it to see how it works as a filter. My team and I analyze the data to decide what to do next.

If the membrane doesn't work well, I tweak the chemical mixture to try to make it better. (Sometimes the most interesting part of my job is when things don't work. Then, we get to figure out why!) If the membrane does works well, I work with a different team to take the membrane from a prototype to something that can be manufactured by the ton.

My team and I learn from each membrane we make. As a result, each one is better than the last. Every day is exciting and different because if I have an idea, I can go test it to see if it works. Outside of the lab, I get to mentor young scientists. I also help to make sure my company is a safe and welcoming place to work.

My career path

When I was in high school, I had no idea what I wanted to do as a career. It turns out, that's totally normal and okay! As a student, all I knew was that I wanted to do something practical and hands on that helped the environment. I had a great high school teacher who made chemistry click for me, so I pursued it in university. As an undergrad, there were a lot of opportunities to work with experts in research labs. This work was both fun and showed me that I could use chemistry to fix real problems affecting society.

After undergrad I started a master's degree doing research in chemistry. I enjoyed it so much that I decided to do a PhD instead. Even though I didn't have a plan, pursuing what I enjoyed doing and felt passionate about lead me to a career I love. Today, I'm helping to make the world a better place.

I am motivated by

Listening to the news can be downright depressing sometimes. There are forest fires raging across the prairies in the summer. There is drought and food insecurity in Africa. The icecaps in the Artic are melting. Climate change is such a big problem, and as one person we can feel helpless against it. I am motivated to go to work every day because it helps to fight climate change and save the planet as we know it.

Not only is my work important, it is also very exciting work! As a research chemist, I work in teams with extremely talented people. Every day is different! I am always learning new things and gaining new skills. I have seen the things I've worked on go from an idea in my head to a real product that I can hold in my hand, and then get made by the ton. I know that the things I work hard on every day in the lab are going to help people and protect our planet. No one person can beat climate change; we all have to do something. I love my career because it helps me do my part.

How I affect peoples' Lives

While climate change affects all of us, unfortunately, it affects poorer people and countries the most. I work at a company, Via Separations, that makes filtration systems. These systems clean water using a fraction of the energy of normal methods. Developing this technology helps to reduce CO2 emissions and fight climate change. It also makes it cheaper and easier for different industries (like dairy and paper production) to clean their wastewater. This helps reduce pollution.

Outside of work I

I enjoy running, reading, cooking, knitting, being outside, and hanging out with friends. I love speculating on what my cat does around the house when I am not around.

My advice to others

Be open to every opportunity. Failure happens to absolutely everyone, so don't let it get you down. Listen to everyone and get as much advice as you can. Be open to feedback; getting criticism is the best way to grow. Remember that above all, more than cleverness we need gentleness and kindness.

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