BIOZONE

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42 Covalent Networks

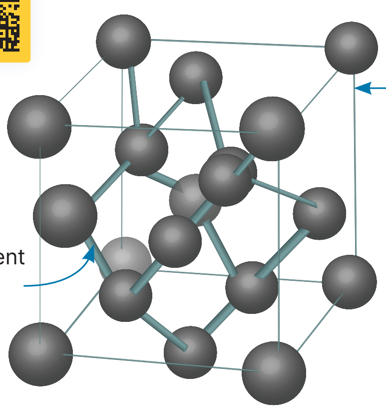
Key Question: How do the different structures of covalent network structures affect their properties?

What are covalent network solids?

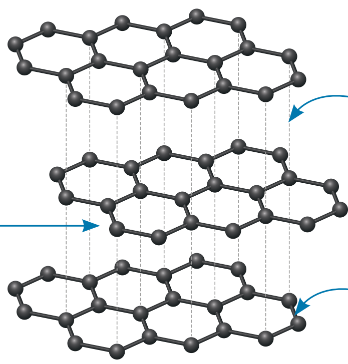
In **covalent network** solids such as carbon (C) and silicon dioxide (SiO_2), **atoms** are held together by strong **covalent bonds**. Examples include:

- **Diamond** (C): a 3-dimensional covalent network structure where atoms are held together by strong covalent bonds in all directions.
- **Graphite** (C): a covalent network structure with 2-dimensional sheets. Within these layers, there are free-moving **electrons** from the **valence energy level** of the carbon atoms.
- **Silicon dioxide** (SiO_2): a 3-dimensional covalent network structure that is the main component of sand and manufactured glass.

Diamond C



Graphite C



Cut and polished diamond

Graphite 'lead' pencil

Diamonds, graphite, single-layered graphene, nano-sized carbon structures e.g. buckyballs (C60), and amorphous carbon forms such as charcoal are all **allotropes** of carbon. These are different forms of the same element, bonded together in various ways.

Conductivity in covalent network solids

- **Diamond** (C) and other 3-dimensional covalent network structures, such as silicon dioxide (SiO_2), have all their atoms held together by strong covalent bonds. Since there are no free-moving charged particles, they cannot conduct electricity.
- **Graphite** is a covalent network structured in 2-dimensional sheets. Between and through these layers, there are free-moving electrons from the valence electrons of the carbon atoms. These free-moving electrons can carry a current, allowing graphite to conduct electricity.

Comparing hardness in carbon allotropes

- **Diamond:** Every carbon atom in a diamond is held together by strong covalent bonds, which require a large amount of energy to break. This makes diamond very hard, making it useful for applications such as drill bits.
- **Graphite:** The atoms in graphite are held together by strong covalent bonds within 2-dimensional layers. However, the forces holding these layers together are very weak, allowing them to slide over one another easily. This makes graphite soft. Pencils utilize this property, as the graphite layers are left behind on paper when drawing.

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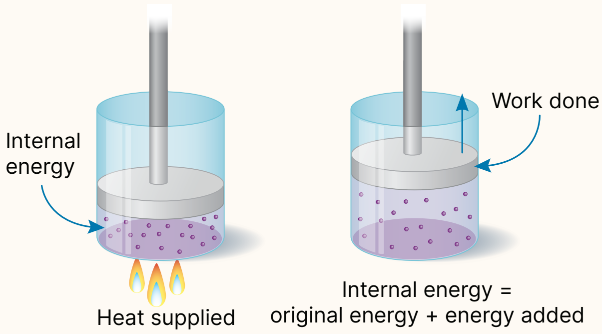
68 Thermodynamic Laws and Thermochemistry

Key Question: How can the laws of thermodynamics be applied to the concepts of thermochemistry?

The Laws of Thermodynamics in the context of thermochemistry

- Thermodynamics is mainly used in physics to study energy, heat, work, and how they interact in different systems. However, the laws and principles of thermodynamics are also used in chemistry to explain and control how energy is transferred. In chemistry, the focus is often on how these processes happen at the particle level.
- In **thermochemistry**, the laws of thermodynamics are used to understand and predict energy changes during chemical reactions and **phase changes** (changes of state). These laws help chemists figure out the energy changes and determine whether a chemical reaction will happen and in which direction it will go. Below, are the key laws of thermodynamics that are important for thermochemistry:

First Law of Thermodynamics (Law of Conservation of Energy):
This law states that energy cannot be created or destroyed, only transferred or converted from one form to another. In thermochemistry, it implies that the total energy change in a chemical reaction is equal to the heat absorbed or released.
In the context of substances, it also includes the work done by or on the system to expand or contract.



Second Law of Thermodynamics:
This law states that the total disorder (**entropy**) of an isolated system increases over time. In thermochemistry, it means that chemical reactions usually move in a direction that increases the overall disorder of the system and its surroundings, making the processes more likely to happen on their own.
Entropy is a measure of the disorder or randomness in a system. Heat flowing into an ordered, colder solid substance will result in a warmer, more disorganized liquid, and eventually gas: entropy increases.

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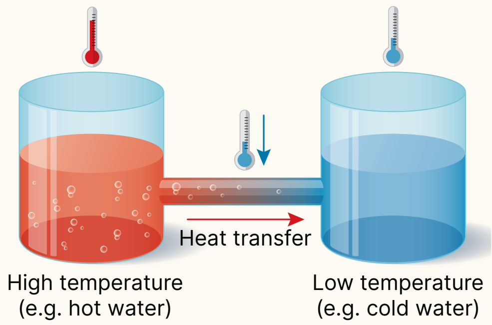
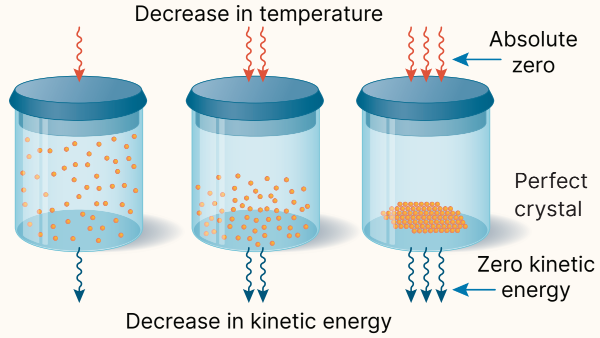
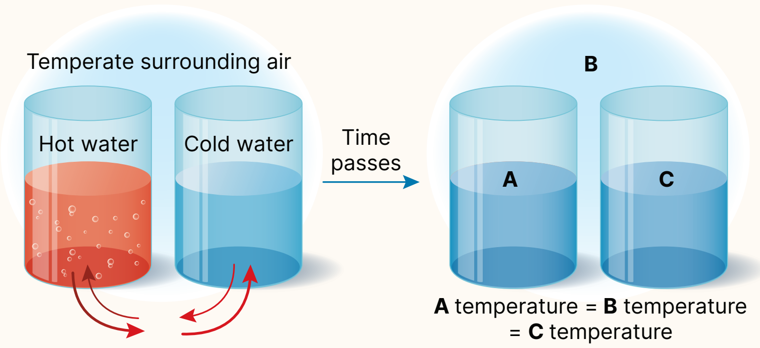


Third Law of Thermodynamics:
The third law of thermodynamics states that, as the temperature of a system gets closer to absolute zero, the disorder (entropy) of a perfect crystal becomes zero. In thermochemistry, a perfect crystal is a completely ordered structure where all atoms or molecules are arranged in a perfectly regular and repeating pattern, with no movement. Although absolute zero is a theoretical temperature, it helps in understanding particle behavior and movement.



Zeroth Law of Thermodynamics:
This law states that if two systems (A and B) are each in thermal equilibrium (balance) with a third system (C), then A and B are also in thermal equilibrium with each other. In thermochemistry, this law supports the concept of **temperature** and allows us to consistently measure temperature changes during chemical reactions for reactants and products.



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Standing on the shoulders of giants

James Prescott Joule

- The laws of thermodynamics were developed by a series of scientists. 1st Law: James Prescott Joule in the 1840s and Rudolf Clausius in the 1850s; 2nd Law: Rudolf Clausius publishing his work in 1850 and Lord Kelvin; 3rd Law: Walther Nernst formulated this law in 1906; and the zeroth Law: Formulated by Ralph H. Fowler in the 1930s.
- These developments spanned nearly 100 years, reflecting the collaborative and evolving nature of scientific discovery.
- The phrase 'standing on the shoulders of giants', often attributed to Sir Isaac Newton, refers to the idea that current achievements and discoveries are built upon the work of those who came before. It suggests that progress is made by using the knowledge and insights of previous generations to reach new heights of understanding and innovation.

1. How does the First Law of Thermodynamics apply to chemical reactions?

2. Why is entropy important in predicting the direction of chemical reactions?

3. Compare and contrast the roles of kinetic energy and potential energy in chemical reactions:

4. Discuss the significance of the phrase 'standing on the shoulders of giants' in the context of the development of the laws of thermodynamics:

5. Elaborate on one area in daily life in which the laws of thermodynamics play a key role. Continue writing on blank paper and attach to the page:

Wireless charging of phones

Wireless charging allows you to charge your smartphone without plugging in a cable. Instead, you place your phone on a special charging pad.

In wireless charging, electrical energy is converted into an electromagnetic field and then back into electrical energy in your phone. This is governed by the first law of thermodynamics.

Not all the energy transferred is used to charge the battery. The second law of thermodynamics explains that during energy transfer, some energy will always be lost as heat. This is why your phone and the charging pad might get warm during wireless charging.

Engineers use thermodynamics to design wireless chargers that minimize energy loss and manage heat effectively. This ensures that your phone charges efficiently without overheating.

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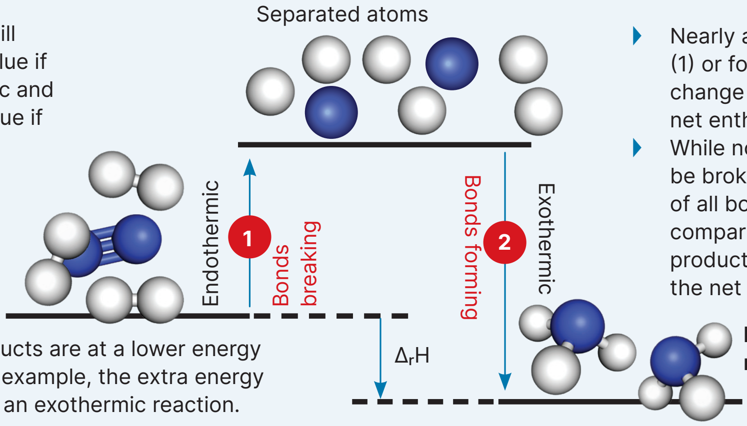
79 Bond Enthalpy

Key Question: How can bond enthalpy be used to calculate the enthalpy change ($\Delta_rH°$) in chemical reactions?

Bond enthalpy to break and form bonds

Bond enthalpy is the change in **enthalpy** when a covalent bond in a gaseous molecule is broken. It is always a positive value because breaking bonds requires an input of energy making it an **endothermic** process. Conversely, forming **bonds** releases energy making it an **exothermic** process. Generally, the more bonds a substance can form, the more stable it will be.

NET $\Delta_rH°$ will have a + value if endothermic and have a - value if exothermic.



As the products are at a lower energy level in this example, the extra energy is released: an exothermic reaction.

- Nearly all reactions involve either breaking bonds (1) or forming new ones (2). The final enthalpy change in a reaction ($\Delta_rH°$) is determined by the net enthalpy change.
- While not every bond in the reactants is likely to be broken, calculating the total **bond enthalpies** of all bonds in the reactant molecules and comparing them with the bond enthalpies in the product molecules allows for the calculation of the net enthalpy change.

Bond enthalpy tables

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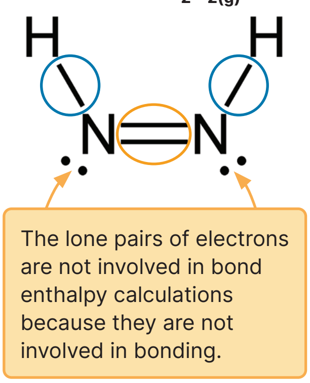
- The strength of a covalent bond depends on the electrostatic attraction between the positive nuclei and the shared electron pair(s). As the atomic radius of an atom increases (recall this trend that occurs down a group in the periodic table), the shared electron pair is further from the positive nucleus. This results in a decrease in electrostatic attraction, leading to a weaker covalent bond and a lower bond enthalpy value.
- Bond enthalpy tables provide the necessary data to calculate $\Delta_rH°$. It is crucial to identify all bond types and their quantities in both the reactants and products, typically using Lewis structures. Additionally, whether a bond is single, double, or triple affects its bond enthalpy value. Enthalpy is measured under standard conditions: 25°C and 1 bar (100 kPa).

Bond enthalpy / kJ/mol at 25°C					
H – H	436	C – H	414	C = C	614
H – O	463	C – Cl	324	C = C	963
H – N	491	C – F	440	C = O	532
H – Cl	431	C – O	352	O = O	498
H – F	568.5	C – C	346	N ≡ N	945
F – F	159	O – O	213	H – S	377
Cl – Cl	242	C ≡ O	1072	N = N	418

Bonds in $N_2H_{2(g)}$



In order to 'break' all bonds in N_2H_2 (cis-diazene) we would need to account for 3 bonds.

2 x H-H bonds (blue) and 1 x N=N bond (orange)

From the table,

H-H = 436 kJ/mol and N=N = 418 kJ/mol

so, total bond enthalpy to break N_2H_2

$\Delta H° = 2 \times 436 + 1 \times 418$

$\Delta H°$ = **1290 kJ/mol** is required to break all bonds in 1 mol of the molecule in gaseous state.

1. Use the bond enthalpy table above to calculate the total enthalpy require to break all the bonds of the following:

   (a) CH_4: ______________________________

   ____

   (b) NH_3: ______________________________

   ____

   (c) $C_2H_4Cl_2$: ______________________________

   ____

   ____

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HOW TO Use bond enthalpy to calculate enthalpy change in a reaction

Calculate the $\Delta_rH°$ for the following reaction: $CO_{(g)} + H_2O_{(g)} \rightarrow H_{2(g)} + CO_{2(g)}$

1. The format below can be used to set out and organize all data to calculate $\Delta_rH°$ Write out the full balanced equation with known information. Some Lewis diagrams may be provided.

where: Δ = change in   r = reaction   H° = enthalpy under standard conditions   ∑ = sum of

2. Reactants: draw Lewis structures to calculate the number and type of bond

3. Multiply the bond energy by the number of bonds

ΔrH°= ∑(energy of bonds broken) - ∑(energy of bonds formed)

$CO_{(g)} + H_2O_{(g)} \rightarrow H_{2(g)} + CO_{2(g)}$ $\Delta_rH°$ = ?

Bonds broken		Bonds formed	
C≡O x 1	995 kJ	C=O x 2	2(743) kJ
H-O x 2	2(463) kJ	H-H x 1	436 kJ
	1921 kJ		**1922 kJ**

$\Delta_rH°$ =1921 kJ/mol - 1922 kJ/mol

$\Delta_rH°$ = -1.0 kJ/mol

5. Products: draw Lewis structures to calculate the number and type of bond

6. Multiply the bond energy by the number of bonds

4. Total the bond energy for reactant molecules

Note that the enthalpy of the reaction is negative, therefore overall the reaction is exothermic

8. Bonds broken (reactants) minus bonds formed (product) = total enthalpy

7. Total the bond energy for product molecules

2. Ethane (C_2H_6) reacts with chlorine (Cl_2) to form chloroethane (C_2H_5Cl) and hydrogen chloride (HCl), as shown in the following equation: **$C_2H_{6(g)} + Cl_{2(g)} \rightarrow C_2H_5Cl_{(g)} + HCl_{(g)}$**
Use the bond enthalpies from the table to calculate the enthalpy change ($\Delta_rH°$) for the reaction. Use the box and table to help you construct your answer.

Bonds broken		Bonds formed	

3. Ethene (C_2H_4) reacts with hydrogen (H_2) in an addition reaction to form ethane (C_2H_6), as shown in the following equation: $C_2H_{4(g)} + H_{2(g)} \rightarrow C_2H_{6(g)}$ Use the bond enthalpies from the table to calculate the enthalpy change ($\Delta_rH°$) for the reaction. You can use blank paper (and attach) to complete your workings.

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107 Indicators

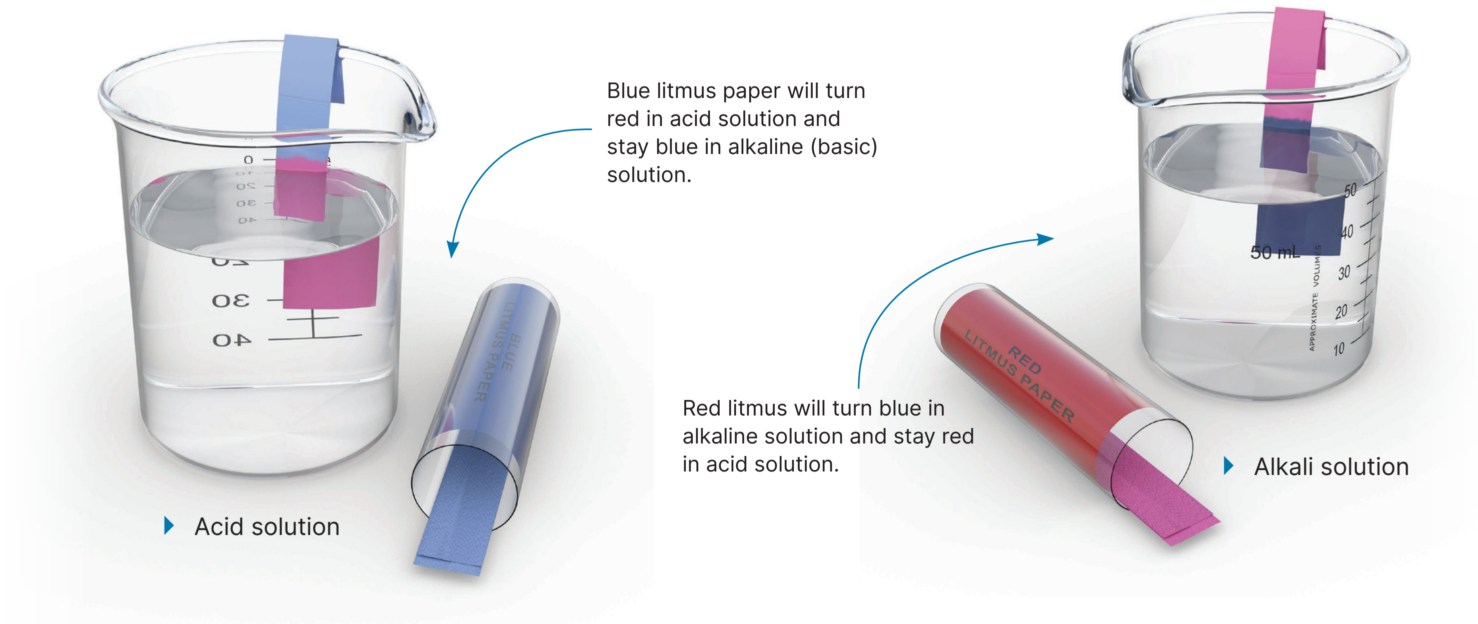
Key Question: How can pH indicators be used to determine the acidity or basicity of a solution?

How can we easily find out the pH of a solution?

- **pH indicators** are substances that change color depending on the acidity or basicity of a **solution**, helping us determine its pH level.
- One of the most common pH indicators is litmus paper. Litmus paper turns red in acidic solutions (pH less than 7) and blue in basic solutions (pH greater than 7). Litmus is a natural pH indicator that comes from certain types of lichens. Lichens are organisms that arise from a close relationship between fungi and photosynthetic bacteria or algae.
- Another widely used indicator is Universal Indicator, a mixture of several indicators that show a range of colors across the entire pH scale. For example, it turns red in strong acids, green in neutral solutions, and purple in strong bases.

An indicator is a large organic molecule that acts like a color dye. It changes color based on the concentration of hydrogen ions (H^+) in a solution. Most indicators are weak acids, which means they only partially **dissociate** in water. This property allows them to react with the solution and show different colors depending on whether the solution is acidic or basic.

Red and blue litmus paper



1. Why would both red and blue litmus be required to indicate neutral (pH 7) solutions?

2. Evaluate some negative and positive aspects of using litmus paper to indicate pH of a solution in the class lab:

3. Research and name some organisms from which other natural pH indicators can be made:

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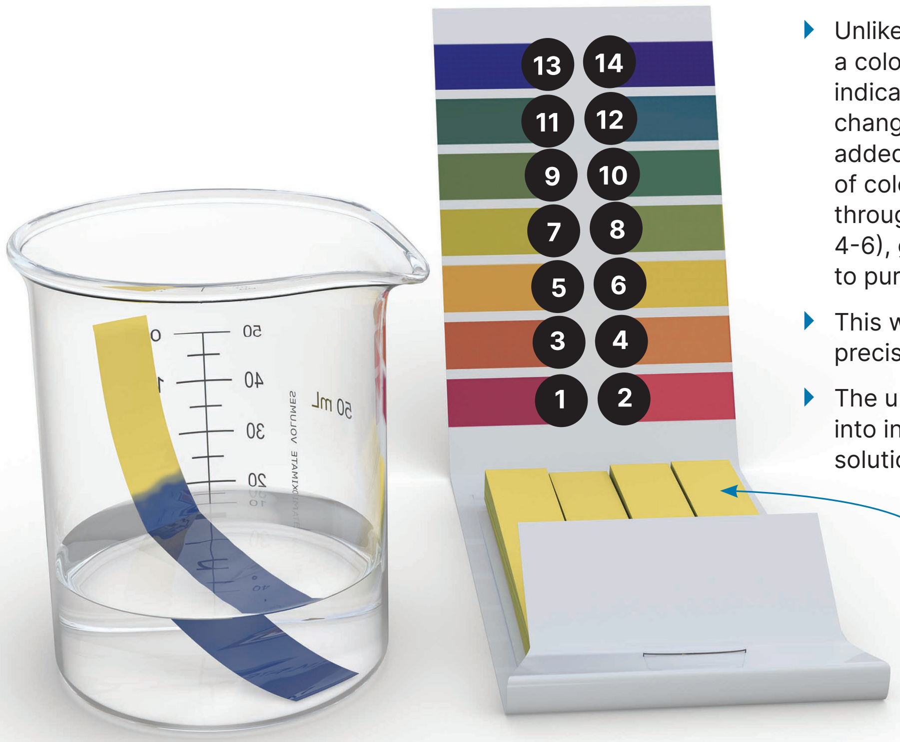
Universal indicator

Approximate colors of universal indicator based on pH range



Universal indicator solution can be soaked into paper. Paper strips are then dipped into the solution to be tested. The color it changes into is then compared against a pH color chart.

- Universal indicator is a special type of pH indicator that shows a range of colors to represent different pH levels, making it easy to determine whether a substance is acidic, neutral, or basic.
- Unlike single pH indicators that only show a color change at a specific pH, a universal indicator is a mixture of several indicators that change color at different pH values. When added to a solution, it can display a variety of colors, from red for strong acids (pH 0-3), through orange and yellow for weaker acids (pH 4-6), green for neutral solutions (pH 7), and blue to purple for bases (pH 8-14).
- This wide range of colors allows for a more precise measurement of the pH of a solution.
- The universal indicator can either be soaked into indicator paper, left, or added directly to a solution as a liquid.

4. What is the advantage of using universal indicator to test a solution's pH compared to red and blue litmus?

____

____

5. Research and list everyday substances and solutions that are approximately at the pH below:

1: ______________________

2: ______________________

3-4: ______________________

5-6: ______________________

7: ______________________

8-9: ______________________

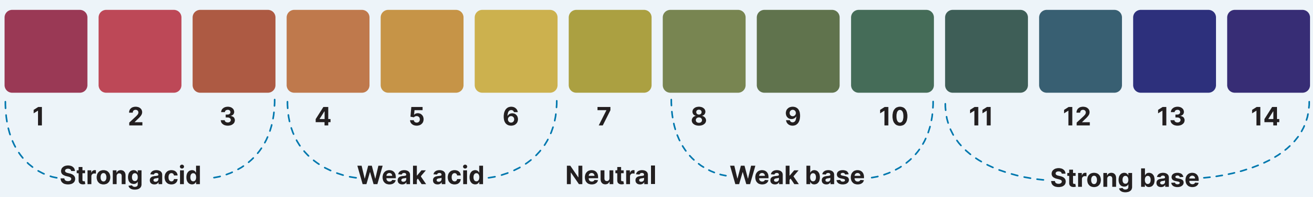
10-11: ______________________

12: ______________________

13: ______________________

14: ______________________

Universal indicator pH scale



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102 Defining Acids and Bases

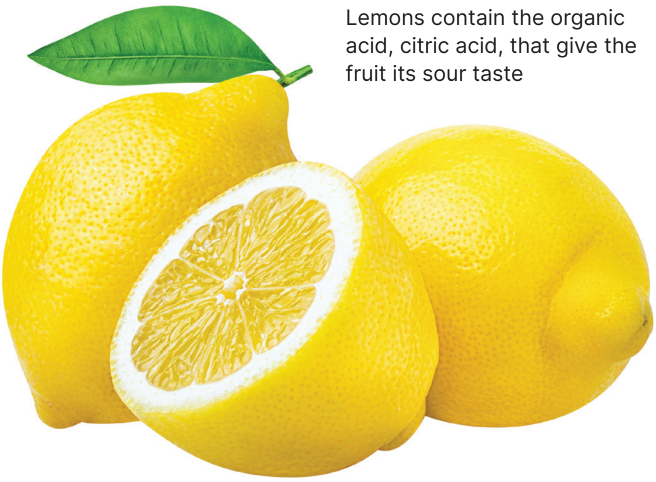
Key Question: What are the properties and definitions of acids and bases, and how do they interact in chemical reactions?

Properties of acids

- Acids are a group of substances that exhibit common acidic characteristics or properties, which are related to their chemical reactions with other substances.
- These properties include a sour taste, the ability to turn blue litmus paper red, and the capacity to react with metals to produce hydrogen gas.
- Acids can be categorized into two main types: organic acids and mineral acids.
  - **Organic acids**, such as citric acid and acetic acid, are found naturally in plants and animals.
  - **Mineral acids**, such as hydrochloric acid and sulfuric acid, are synthesized in laboratories and are commonly used in industrial processes.

Properties of bases

- Bases are a group of chemicals that can **neutralize** acids by removing hydrogen ions (H^+) from a solution.
- They exhibit properties that are opposite to those of acids. Bases typically have a slippery or soapy feel and can turn red litmus paper blue.
- Common household bases include substances such as baking soda, which is used in cooking and cleaning, floor cleaners, and antacid tablets that help relieve indigestion by neutralizing stomach acid.
- Bases are essential in various applications, from cleaning products to medical treatments, due to their ability to counteract acidity.



Lemons contain the organic acid, citric acid, that give the fruit its sour taste

Most household cleaning liquids are bases and feel slippery when touched.

Preserving food in acid: pickles

Before modern refrigeration, pickling was essential for survival in many cultures. It allowed communities to make the most of their harvests and ensured a steady food supply throughout the year. This method of preservation also played a crucial role in trade, as pickled foods could be transported over long distances without spoiling.

Pickling involves immersing food in an acidic solution, typically vinegar (acetic acid) or a naturally fermented brine that produces lactic acid. The high acidity creates an environment that inhibits the growth of harmful bacteria, thus preserving the food.

In many European countries, pickling was a common way to preserve vegetables such as cucumbers, cabbage (to make sauerkraut), and beets. This was especially important during the winter months when fresh produce was scarce.

In Korea, kimchi (fermented cabbage) is a staple food. It is made by fermenting cabbage with a variety of seasonings, including chilli pepper, garlic, and ginger, in a brine that produces lactic acid.

Assorted pickled vegetables

APP SF

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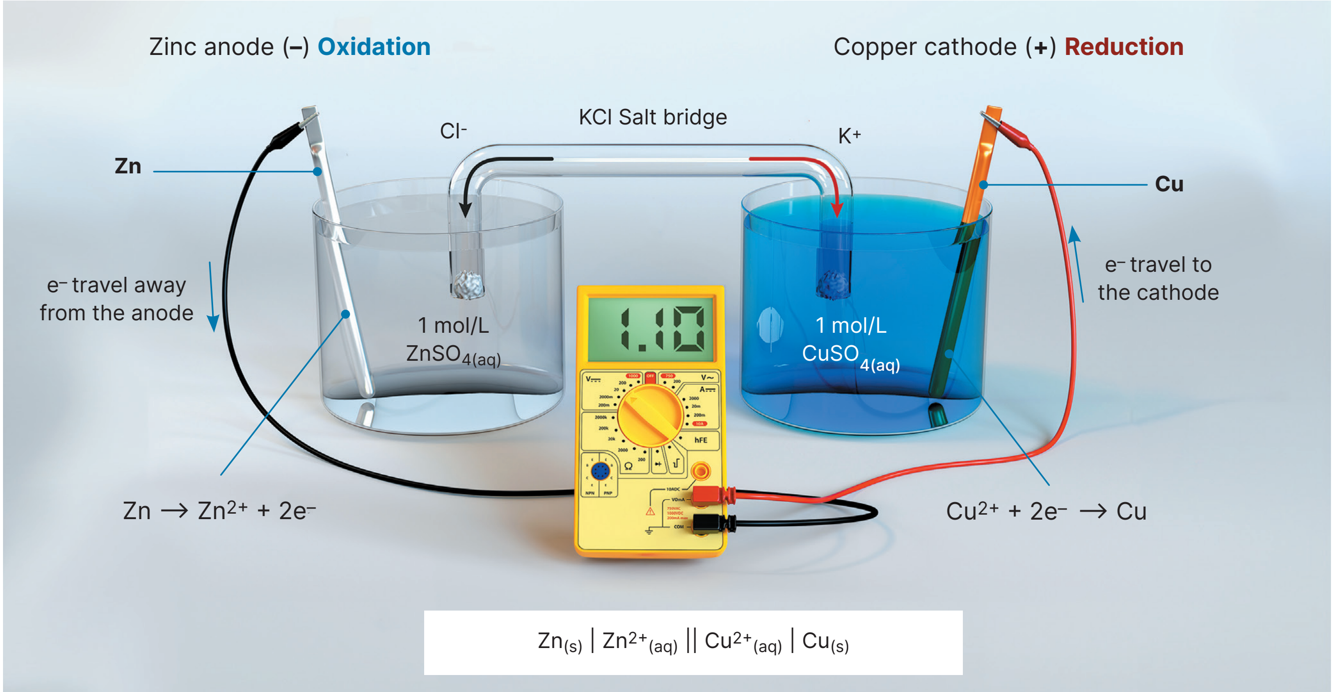
131 Voltaic (galvanic) Cells

Key Question: How can the principles that govern redox reactions be used to build a cell and how can redox reactants be separated to produce a simple battery?

A voltaic cell

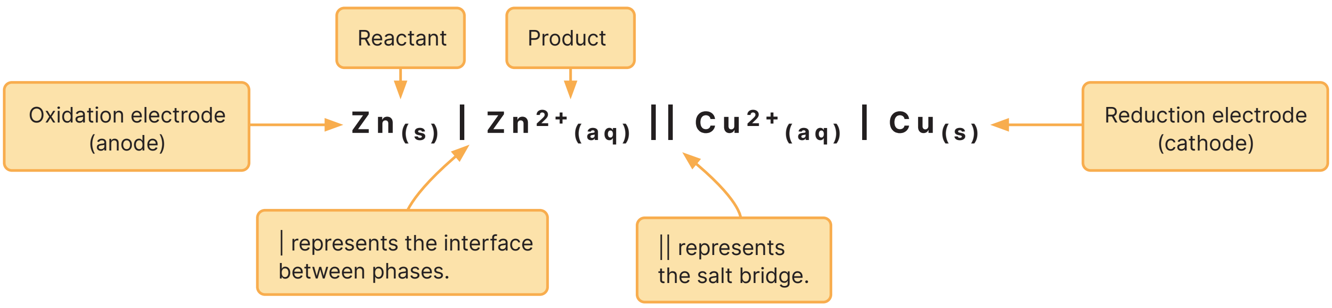
Chemical (voltaic) cells have two **electrodes**, an **anode** and a **cathode**. In a voltaic cell the **anode is the negative electrode** and is the source of electrons for the circuit. It is where **oxidation** takes place. The **cathode is the positive electrode**. Electrons return to the cathode from the circuit. It is the site of **reduction**. The diagram below shows a simple **voltaic cell** using zinc and copper metals. Note that the zinc metal forms the anode and the copper metal forms the cathode.



Cell notation

The voltaic cell consists of two half cells with electrodes. Using the activity series it is possible to deduce which electrode will undergo reduction and which will undergo oxidation. For example, using zinc and copper as electrodes, it can be seen that zinc is more reactive and a better **reducing agent** that silver. It will therefore be oxidized and be the anode.

- The notation for writing a cell diagram is as follows: The electrode at which oxidation occurs (the anode) is on the left. Electrode at which reduction occurs (the cathode) is on the right. Reactants and products are shown as R|P:



Activity series

- Recall the **activity series** from Activity 125. This series can be used to help predict which metal will be the anode and which will be the cathode in the voltaic cell. The more reactive metal (most easily oxidized) will be the anode and the less reactive metal (most easily reduced) will be the cathode.

Most reactive (most easily oxidized) K Na Li Ca Mg Al C* Mn Zn Fe Ni Sn Pb H_2* Cu Ag Au Pt **Least reactive** (most easily reduced)

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132 Applications of Voltaic Cells

Key Question: What different ways can batteries be made?

There is a difference between a cell and a **battery**. The 'batteries' used in torches or television remote controls are in fact single chemical cells. So are the button cells in hearing aids or car alarm remotes. Batteries such as AAA, AA, C, and D are all single cells. In fact the only common 'battery' that is in fact a battery, is the 9V battery commonly used in domestic smoke detectors, made up of six cells. Cells consist of just one electrochemical cell, whereas batteries consist of many cells in series. The 12V car battery is another example, again with six individual cells.

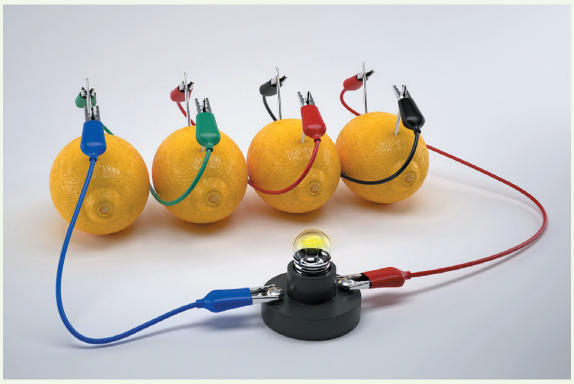
- Building a simple single electrochemical cell is not difficult, and building a battery is also not difficult. Engineering long lasting, easily portable, easy to use, and easy to manufacture cells, however, is.

Investigation 1.4 Building batteries

See appendix for equipment list

Objective: To build two different kinds of battery and measure their voltage output.

Part 1



1. A common battery to build is a lemon battery. The acidic fruit juice in the lemon acts as an electrolyte. Your teacher may get you to do this in groups or as a demonstration.
2. You will need three or four strips of zinc, three or four strips of copper, wires with alligator clips to connect them, three or four lemons, and a red LED. Alternatively you could use copper nails and galvanized nails instead of strips of metal.
3. In each lemon place one copper metal strip in one end of the lemon and one zinc metal strip in the other end. It is important that the metal strips cut into the same segments inside the lemon, so that they are in contact with the same electrolyte. Each lemon is a single cell.
4. To connect the lemons in series, connect the copper strip from one lemon to the zinc strip from a second lemon using the wires and alligator clips. Then connect the copper strip from the second lemon to the zinc strip on the third lemon. When all the lemons are connected you should have a lead from a copper strip and a lead from a zinc strip which can be connected to the LED or bulb and a string of lemons all connected in a line.
5. Connect the LED to the two free wires. If the LED doesn't light up, you might have it connected around the wrong way. It may be dim so a darker area may be needed.
6. Use a voltmeter to measure the voltage of each lemon cell, then all the cells in series. Record your observations below:

___

Part 2

1. A second simple to build battery uses copper, felt or cardboard, and zinc/galvanized washers. You will need 3-4 of each type of washer. The more the better.
2. Start by connecting one copper washer to an alligator lead, or strip a wire and wrap the exposed end around the washer, this helps keep the washers flat. Lay this flat on the bench.
3. Soak the felt or cardboard washers in vinegar (dilute ethanoic acid) or dilute KCl solution. Squeeze it with tongs so that it is damp and not dripping. Place this on top of the copper washer.
4. Place a zinc washer on top of the felt washer.
5. Place a copper washer on top of the zinc washer. Then again place a damp felt washer on top of the copper washer. Then another zinc washer. Repeat this with the remaining washers. Wrap wire or use an alligator clip on the last zinc washer.
6. Connect the LED to the battery. Again if it does not light up it may be around the wrong way.
7. Measure the voltage of your battery (a voltaic pile). Measure the voltage of one cell. Record your observations.

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APP EM

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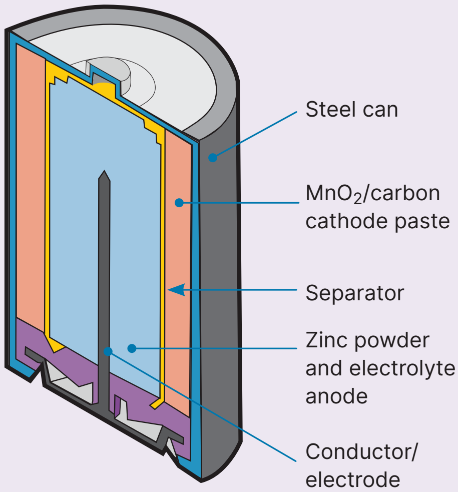
Batteries

The first electrical battery that produced a consistent power supply was the voltaic pile (right), invented by Alessandro Volta. As you built in the investigation on the previous page, the voltaic pile consists of a stack of alternating copper and zinc disks with brine soaked paper or cardboard in between. A voltaic pile is a series of single cells stacked on top of each other. In this configuration the zinc is actually reacting with hydroxide ions in the brine to form zinc hydroxide and hydrogen gas, rather than giving electrons directly to copper.

The wider and bigger the blocks of zinc and copper used, the more current can be produced. Connecting the voltaic piles in parallel also increases the current, enabling more power hungry devices to be connected.

Single cell batteries (e.g AAA and AA) used in domestic devices are called dry cells because they contain no liquid electrolyte. Instead, these types of cells use pastes for the electrolyte and **cathode**. The simplest of these dry cells is the zinc/carbon dry cell. However most cells used today are the alkaline dry cell (shown right). The exact components of the cell vary with manufacturers, but the cathode is often an MnO_2 paste and the **anode** is a Zn based paste.



The half equations for the redox reaction are:

$Zn_{(s)} + 2OH^-_{(aq)} \rightarrow ZnO_{(s)} + H_2O(l) + 2e^-$

$2MnO_{2(s)} + H_2O_{(l)} + 2e^- \rightarrow 2MnO(OH)_{(s)} + 2OH^-_{(aq)}$

1. (a) How could you increase the voltage of a cell? ______________________

   (b) How could you increase the voltage of a battery? ______________________

2. The reactions for the voltaic pile are Zn → Zn + $2e^-$ and $2H^+$ + 2e- → H_2

   Write a cell diagram for the cell: ______________________

3. What role does the juice in the lemon play in the lemon battery? ______________________

4. What was the purpose of soaking the felt washer in the voltaic pile (part 2):

   ____

5. In the space draw a diagram for a single cell of your lemon battery:

6. How does the LED provide evidence for a redox reaction occurring?

   ____

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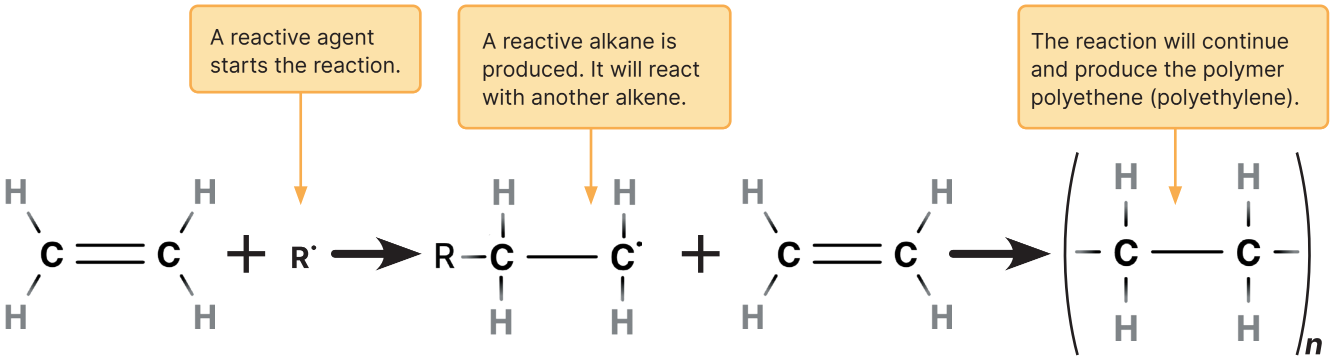
148 Addition Polymerization

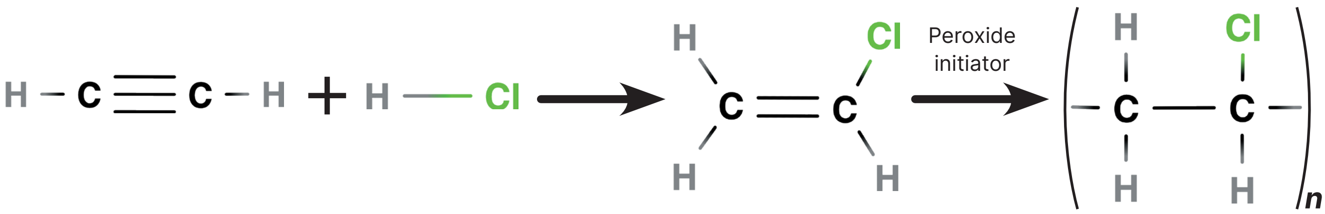
Key Question: What are the steps in a polymerization reaction?

Alkenes and **alkynes** are able to form **polymers** by **addition polymerization**, essentially repeated **addition reactions**:



Alkynes can also be used as a starting unit. The initial reaction forms the alkene monomer which can then be used to produce the polymer.

Ethyne | Hydrogen chloride | Chloroethene (vinyl chloride) | Polyvinyl chloride



CHCH | **HCl** | **CH_2CHCl** | **$(CH_2CHCl)_n$**

Polystyrene is made from monomers of the styrene molecule, an ethene molecule with a benzene side chain. In a foam form it is commonly used in packaging. Its solid form is transparent and can be used as containers, cups, and jewel cases.

Polyethene (polyethylene) is the most commonly used polymer. In its high density formed (HDPE) it can be used for solid but flexible materials, e.g. piping, bottles, and containers. Low density PE is used to make plastic bags.

Polytetrafluoroethylene, PTFE, also known by its brand name Teflon, has one of the lowest friction coefficients of any solid. As a result it is commonly used as a non stick coating for cookware or as a lubricant in machinery.

1. Why is an alkene the usual starting point for an addition polymer? ______________________________

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2. What is the condensed structural formula of the monomer for polytetrafluoroethylene? ______________

3. Describe the formation of polypropene (polyproplylene). Use diagrams if needed:

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