



Chemistry Concepts for Biology

How to learn this material:

Because so much of this material can't be seen or touched, many students find learning the vocabulary and concepts of chemistry challenging. Overcoming this is mostly a matter of using your imagination, and working with these new concepts as much as you can. Repetition will help make these new ideas familiar to you.



Try making flash cards with important vocabulary words (in bold on this sheet) and their definitions. Quiz yourself on the bus, waiting in lines, or before you go to bed. Breaking learning up into short sessions will help you learn a few new concepts at every session. Be sure to review this material at least once a day until you've achieved mastery, and then at least one a week until the end of your class.

If you've been away from science for a few years, you may have forgotten what you learned in high school. Firm up your foundation by browsing through a grade 10 science textbook. It will remind you of some of the fundamental concepts you will use in Biology.

THE BASICS

All matter on earth is made up of **elements**. There are 118 elements in the periodic table. For biology, you need to know the names and symbols of the first twenty:

1 H hydrogen					2 He helium		
3 Li lithium	4 Be beryllium	5 B boron	6 C carbon	7 N nitrogen	8 O oxygen	9 F fluorine	10 Ne neon
11 Na sodium	12 Mg magnesium	13 Al aluminum	14 Si silicon	15 P phosphorus	16 S sulphur	17 Cl chlorine	18 Ar argon
19 K potassium	20 Ca calcium						

A sample of any element can be divided into smaller and smaller parts until you reach the **atom**, the smallest piece of matter that has the physical properties of the element.

Atoms are made up of **protons**, **neutrons**, and **electrons**. The **nucleus** is the centre of the atom and contains protons and neutrons. Protons have a positive electrical **charge**. This means they are attracted to or repelled from other particles that have charges. Neutrons have no electrical charge. Electrons form a cloud around the nucleus and



have a negative charge equal to that of protons. An atom typically has the same number of protons and electrons, which means that the overall charge of the atom is **neutral**.

The number of protons in an atom determines the identity of the element. This is its **atomic number**. For example, if an atom has six protons in its nucleus, then its atomic number is 6. From the periodic table, we see that atomic number 6 corresponds to carbon. Therefore, any atom with six protons is carbon.

Unlike protons, the number of neutrons in an atom can vary without changing the identity of the element. Atoms of the same element that don't have the same number of neutrons are **isotopes**. Some isotopes are stable, and others are unstable. Those that are unstable are **radioactive**.



The weight of an atom is determined by adding the number of protons plus the number of neutrons. (The weight of an electron is so small that the electrons aren't included.)

Protons + neutrons = the mass of the atom, in atomic mass units (amu)

For example, an atom with 6 protons and 7 neutrons has a mass of 13 amu.

An **ion** is an atom or molecule that has either gained or lost electrons and thus is no longer neutral; it has a charge. An atom that has gained electrons has a negative charge; it is a negative ion or **anion**. An atom that has lost electrons has a positive charge; it is a positive ion or **cation**. For example, an atom with 6 protons and 8 electrons has a charge of -2 . NH_4^+ (ammonium) and F^- (fluoride) are examples of ions.

A **compound** is a group of elements combined in a fixed ratio. There are two kinds of compounds. **Molecules** and **ionic solids** differ in the type of bond holding the atoms together (you'll learn about these types of bonds later on).



A molecule is two or more atoms bonded to each other with covalent bonds. CH_4 (methane) is an example of a molecule.

An ionic solid is a group of atoms held together by ionic bonds, forming a crystal. NaCl (table salt) is one example of an ionic compound.



CHEMICAL BONDING

Electrons arrange themselves in energy levels around the nucleus of the atom. The innermost shell is filled first. Once an inner shell is full, electrons fill the next shell, moving further away from the nucleus. The electrons in the outermost shell are called **valence** electrons. Valence electrons participate in bonding.

To determine how many valence electrons an element has, count backwards from the element (to the left) until you reach the end of its row. Using this method, we find that oxygen has 6 valence electrons:

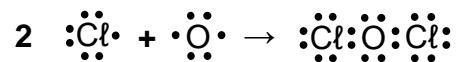
3 Li lithium	4 Be beryllium	5 B boron	6 C carbon	7 N nitrogen	8 O oxygen	9 F fluorine	10 Ne neon
↑6	↑5	↑4	↑3	↑2	↑1		

Atoms can bond to each other in two ways: covalent bonding and ionic bonding.



Covalent bonds are the most common bonds in biology. In a covalent bond, atoms overlap their electron clouds and share two electrons. Covalently bonded atoms arrange themselves so that all the bonding atoms have eight valence electrons. Having a complete **octet** (8 valence electrons) allows the atom to mimic the electron structure of a noble gas (elements in the last column of the periodic table), which is the most stable configuration. Hydrogen is an exception to the **octet rule**, and achieves its noble gas configuration by having two electrons.

Here is an example of covalent bond formation. Valence electrons are represented by dots around the atomic symbol.

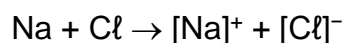


The bonds have formed in such a way that both the chlorine atoms and oxygen atom now have access to eight electrons, and both elements have now achieved the electron structure of a noble gas (8 valence electrons).

In covalent bonds, elements differ in their tendencies to draw the shared (bonding) electrons towards their nuclei. This results in unequally shared electrons in the covalent bond. An element's tendency to draw bonding electrons to its nucleus is its **electronegativity**.

When the electronegativities of two covalently bonded elements differ significantly, the more electronegative atom will pull the bonding electrons towards it. This unequal sharing of electrons is called a **polar covalent bond**.

In other cases, the difference in electronegativity is so great that the atoms do not share the electrons at all, but instead one atom donates one or more electrons to another atom. The resulting ions are held together by electrical attractions between their different charges. This is how an **ionic bond** is formed.



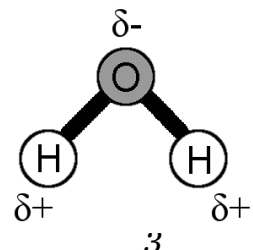
The different types of chemical bonds result from their electromagnetic characteristics:

non-polar no separation of charge	partial separation of charge	complete separation of charge
covalent bonds CH ₄ , O ₂	polar covalent bonds NH ₃ , H ₂ O	ionic bonds NaCl, KF

WATER

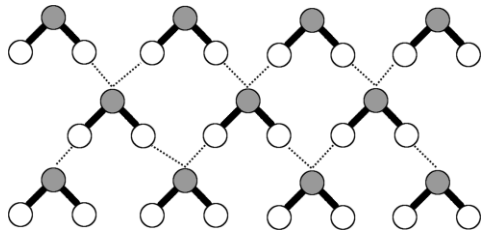
The chemistry of water is very important to biology because so many physiological processes depend on water.

Because oxygen is more electronegative than hydrogen, water's bonds are polar covalent bonds. Because of these polar bonds,



water is a polar molecule.

The Greek letter delta (δ) is used to mark a partial charge on an atom caused by a polar bond.



Water's polarity causes the oxygen of a water molecule to be electrically attracted to the hydrogen end of other water molecules. These attractions result in **hydrogen bonds**. Hydrogen bonds are longer and weaker than the three bond types mentioned before. They occur within or between molecules with strong partial charges involving hydrogen and either oxygen, nitrogen or fluorine. DNA structure is partially due to hydrogen bonds between hydrogen and nitrogen atoms.

The network of hydrogen bonds between water molecules draws the molecules into a rough lattice. These bonds are constantly being formed and broken.

This network of hydrogen bonds gives water some unique characteristics. The most important ones for biology include density, adhesion, cohesion, and hydrolysis/dehydrolysis reactions.

Density

Density is a measure of how much something weighs per unit of volume. Lead is dense; a small amount of lead is fairly heavy. Popcorn is not; even a lot of popcorn doesn't weigh very much, and the shapes of the kernels ensure there's empty space between the pieces to increase the volume even more.

Recall that the molecules in solids vibrate less than those in liquids. Since ice molecules aren't moving around as much as those in liquid water, the network of hydrogen bonds in ice is more stable and rigid. Ice is a crystal — the molecules are evenly spaced and further apart than those in liquid water. This explains why pipes burst when water freezes in them, since the volume the water takes up in solid form is greater than in liquid form.

The increased space between molecules in ice also means that ice is less dense than liquid water. This explains why ice cubes float on top of a drink.

Adhesion

Because water is a polar molecule, it can be electrically attracted to any object with a charge on it. Adhesion is the attraction between molecules such as water molecules and some other material, like wood or glass.

This phenomenon allows water to travel against gravity up narrow capillary tubes in the lab and up the insides of trees, bringing water from the roots to the leaves.



Cohesion

The attraction between water molecules is cohesion. Hydrogen bonding and other intermolecular forces (forces acting between molecules) cause cohesion.

The cohesion of water molecules leads to **surface tension**, water's resistance to an increase in its surface area. Surface tension allows water to hold small objects on its surface, like hairs, leaves, or water-walking bugs.



You can observe cohesion and adhesion working together in a still glass of water. Water pulls up the sides of a glass of water, forming a **meniscus**. Water forms a meniscus because of the attraction between its molecules, and the attraction between water molecules and the glass.

Liquids that don't have strong attractions between their molecules, like oil, don't form a meniscus.

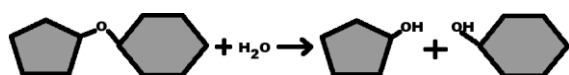
Two Reactions of Water

Hydrolysis

Hydrolysis is a reaction that breaks up a water molecule.

When a molecule joined by covalent bonds dissolves in water, it has reacted with a water molecule in the solvent. A water molecule attaches across the broken bond, putting an H^+ onto one end of the break and an OH^- on the other end.

For example, when sugar dissolves in water, a water molecule attaches across the broken bond.

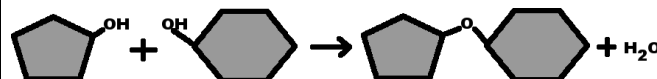


Dehydration

Dehydration is a hydrolysis reaction in reverse: it creates water and a larger molecule from smaller components.

For example, creating a molecule of table sugar from glucose and fructose also creates a water molecule as a product.

Monomers are the two smaller molecules that are brought together in a dehydration reaction. A **polymer** is the long molecule formed by joining monomers together through a series of dehydration reactions.



ACIDS AND BASES

There are several definitions for acids and bases. For biology, an **acid** is usually a chemical that donates H^+ in a reaction and a **base** is a chemical that will accept H^+ in a reaction.

The standard reaction for an acid is: $HA + H_2O \rightarrow A^- + H_3O^+$

The standard reaction for a base is: $B + H_2O \rightarrow BH^+ + OH^-$



From these reactions, we can make the generalization that acids react with water to form H_3O^+ , while bases react with water to form OH^- .

These standard reactions let us predict what a chemical will do when added to water. For example, a common household cleaner is ammonia, which is a base.

Following the standard reactions, we are able to correctly predict its reaction with water without any additional information: $\text{NH}_3 + \text{H}_2\text{O} \rightarrow \text{NH}_4^+ + \text{OH}^-$

The **pH scale** is used to describe how acidic or basic a solution is. pH is the logarithm of the number of H_3O^+ ions in one litre of solution ($\text{pH} = -\log [\text{H}_3\text{O}^+]$). The number of H_3O^+ ions in a litre of solution is also referred to as the **concentration** or **molarity** of the solution.

Use the “log” button on your calculator to take the logarithm. For example a solution that has $1.0 \times 10^{-3} \text{H}_3\text{O}^+$ will have a pH of 3. On your calculator, enter:

+/- **log** **1** **.** **0** **Exp** **+/-** **3** **=**

or:

1 **.** **0** **Exp** **3** **+/-** **=** **log** **+/-** **=**

(The **[Exp]** key may also appear as the **EE** function on your calculator.)

Solutions that are very acidic have a lot of H_3O^+ ions, and their pH is small. Basic solutions have very few H_3O^+ ions, and have a large pH. If you know the pH of a solution, you can determine whether it is an acid or a base:

Acids: pH 1–6 (lemon juice has a pH of about 2)



Neutral: pH 7

Bases: pH 8–14 (baking soda has a pH of about 8)

Buffers are compounds that act both as an acid and a base. They can be either an acceptor or a donor of H_3O^+ ions.

Buffers are important to **homeostasis**, the internal controls that maintain equilibrium within an organism. For example, blood contains buffers that help to keep it at a constant pH.

