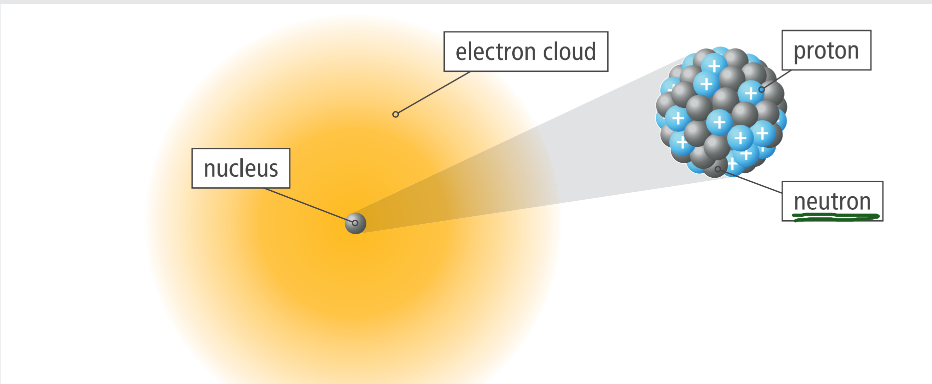
Atoms, Elements, and Compounds

Living systems require complex interactions, some of which you can observe on a large, or macroscopic, scale every day. To understand these interactions on a deeper level, we need to take a closer look and explore the composition of living things at a molecular level. All organisms depend on different chemicals and chemical reactions. The study of living things relies on a basic understanding of chemistry.

Atoms and Elements

Every physical thing you can think of, living or not, is made of incredibly small particles called atoms. An atom is the smallest basic unit of matter. Trillions of atoms could fit in a space the size of the period at the end of this sentence. Although there is a huge variety of matter on Earth, all atoms share the same basic structure.

FIGURE 2: Atoms consist of three types of particles. Protons have a positive charge, electrons have a negative charge, and neutrons have no charge.



An element is a substance made up of one type of atom and cannot be broken into simpler substances by ordinary chemical means. All the atoms of a given element have a specific number of protons. This number never varies. Atoms of different elements have different numbers of protons. For example, all hydrogen (H) atoms have one proton, and all carbon (C) atoms have six protons. Because the proton number never varies, we often identify an element by the number of protons in its nucleus. Scientists refer to the number of protons in the atoms of any given element as that element's atomic number. The elements are organized in a table called the periodic table.

Engineering

Some elements occur naturally and are abundant on Earth. Other elements are very rare or synthesized in laboratories. Research the processes scientists and engineers use to synthesize or isolate rare elements. What types of elements have only been found in a laboratory? Why don't we see these elements in nature? Create an infographic detailing your findings.

Chemical Bonds

The electrons of an atom orbit the nucleus, occupying different energy levels. An atom is most stable when its outer energy levels are filled with electrons. The atoms of some of the elements, such as neon (Ne) and helium (He), have full outer energy levels and are rather unreactive. These elements rarely form bonds because they are already stable. The atoms of most other elements become more stable by bonding with other atoms, which is why atoms rarely exist alone in nature. For example, sodium (Na) and chlorine (Cl) atoms can bond to form sodium chloride (NaCl), also known as table salt.

FIGURE 3: Table salt is formed by a chemical bond.

$Cl_2 \rightarrow$ gas

FIGURE 4: Sodium chloride is an example of ionic bonding.

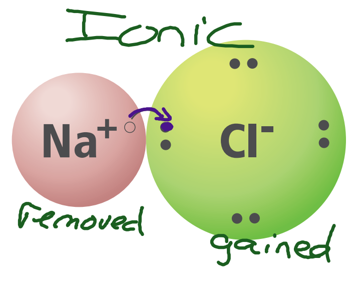
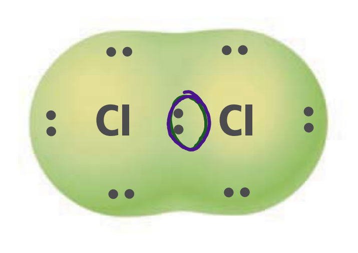


FIGURE 5: Two chlorine atoms form a covalent bond.



$Cl_2 \rightarrow$ gas

Ionic Bonds

One way that some atoms become more stable is by gaining or losing electrons. Atoms that have gained or lost electrons are known as ions. Atoms that gain electrons become negatively charged ions. Atoms that lose electrons become positively charged ions. Positive and negative ions are attracted to one another. Ionic bonds form through this attraction. Ionic bonds are a very strong type of chemical bond.

Sodium chloride (NaCl), or table salt, is an example of an ionic bond. A sodium atom (Na) transfers one electron to a chlorine atom (Cl). When it loses its one outer electron, the sodium atom becomes a positively charged sodium ion (Na^+). When it gains an electron the chlorine atom becomes a negatively charged chloride ion (Cl^-). The attraction between the Na^+ and Cl^- ions forms NaCl, shown in Figure 4.

Covalent Bonds

Not all chemical bonds form by the transfer of electrons. Some atoms become more stable by sharing one or more pairs of electrons with other atoms, known as covalent bonding. Covalent bonds are generally weaker than ionic bonds but are still very strong. Depending on the number of electrons an atom has, two atoms may form several covalent bonds, or share several pairs of electrons.

A molecule is two or more atoms held together by covalent bonds. A chlorine molecule (Cl_2), shown in Figure 5, shares a pair of electrons in a covalent bond. Covalent bonding is what makes it possible for atoms to form very large molecules, often with very complex shapes. Many substances in living things are composed of large, complex molecules.

Analyze Create a Venn diagram to compare and contrast ionic and covalent bonds in terms of electrons and stability.

Compounds

Compounds are substances composed of atoms of two or more different elements bonded together in specific ratios. Common compounds in living things include water (H_2O) and carbon dioxide (CO_2).

Model The chemical formula for carbon dioxide is CO_2. According to the model of this molecule in Figure 6, what does the 2 represent?

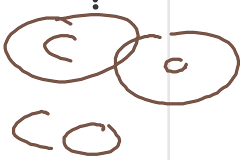
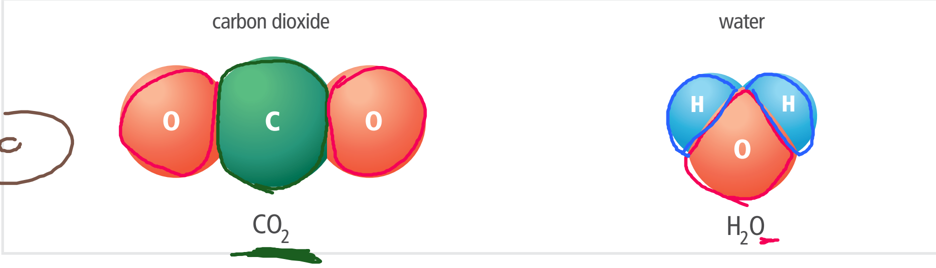


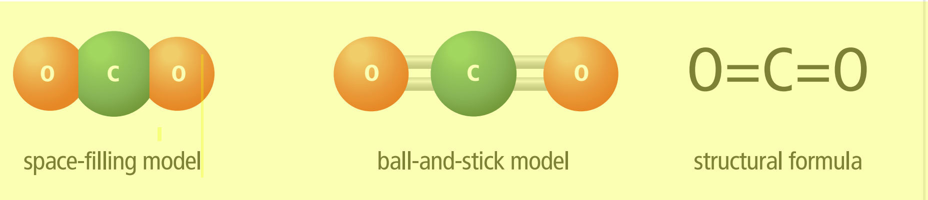
FIGURE 6: Carbon dioxide is made of two oxygen atoms each bonded to a carbon atom. Water is made of two hydrogen atoms each bonded to an oxygen atom.



The diagrams of the CO_2 and H_2O molecules use one type of model, known as a space-filling model, to represent molecules. Space-filling models are three-dimensional diagrams that show atoms as spheres attached to one another. Atoms of different elements are usually represented by different colors.

A space-filling model is only one type of model scientists use to conceptualize molecules. Another type of model, called a ball-and-stick model, also uses spheres but uses sticks to represent the bonds between the atoms. A third, much simpler model, is a structural formula. This model uses letters to represent atoms and lines to represent bonds. Figure 7 shows carbon dioxide using three different molecular models.

FIGURE 7: Types of Molecular Models



Analyze Although different kinds of models are useful for understanding phenomena, all models have limitations. Describe one strength and one limitation for each of these types of models.

The properties of a compound are often very different from the properties of the elements that make up the compound. For example, at 25 °C (77 °F), hydrogen and oxygen are extremely flammable gases. Tanks containing either gas often bear warning symbols to prevent accidental explosions. When bonded together, however, these flammable elements form water. At room temperature, water is a liquid, not a gas, and—far from being flammable—it is often used to put out fires caused when other compounds react with oxygen!

FIGURE 8: The flammable gases oxygen and hydrogen combine to make a nonflammable liquid essential to life on Earth—water.

O_2 gas

H_2 gas

water liquid

When examining the chemical formulas for compounds, look closely at the ratios of the atoms of the elements in the compound. For example, water (H_2O) has two hydrogen atoms for each oxygen atom. If the ratio of oxygen to hydrogen changes, a new compound with new properties results. Hydrogen peroxide (H_2O_2), for example, has two hydrogen atoms and two oxygen atoms. The same elements are present but in a different ratio, so this compound has different properties than water.

Explain Think back to the hamburger that was placed in the acid. Answer these questions about the matter in the hamburger:

1. How can matter be arranged? Draw a diagram to illustrate the difference between atoms, elements, and compounds.
2. How are atoms held together? Explain the differences between the two main types of bonding.
3. How do you think the arrangement of matter, such as the matter in the hamburger, changes in chemical reactions?

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