Reflect

Our world is full of various substances we call **matter**. Matter is anything that takes up space (volume) and has mass. Take a look at the picture on the right. What kinds of matter do you see? The cars are made of solid matter, like the metal frames and glass windows. Cars also need liquid matter to function, like gasoline for fuel and oil for lubrication. The exhaust coming out of the tailpipes is matter in the form of a gas.

matter: anything that has volume and mass; matter occurs as elements, compounds, and mixtures

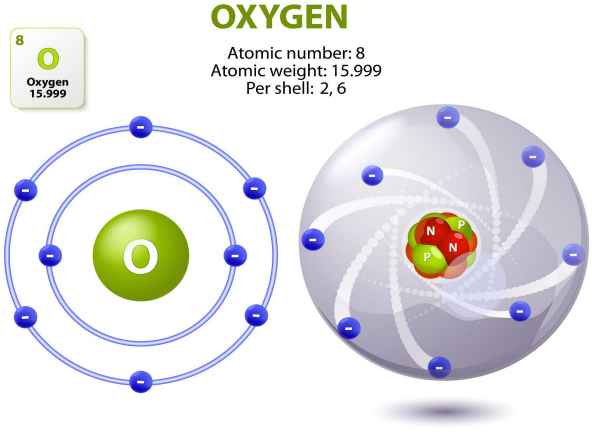
The metal, glass, gasoline, and exhaust are composed of many different types of matter. For example, metal car frames are typically hard steel made from the elements iron and carbon, while the glass is a compound made of silicon and oxygen. The exhaust is a mixture of gases such as carbon dioxide. There are more than 100 different elements, each with its own type of atom. These **atoms** are the tiny particles that serve as building blocks of all **matter.**

A bar of the element gold contains many millions of individual gold atoms. An atom is the smallest particle of an element that cannot be broken down without changing the properties of the element. One atom of gold is very small, too small to be visible. However, a single atom of gold has the same properties as every other gold atom.

atom: the smallest particle of an element, made of electrons, protons, and neutrons

What are atoms made of? Do all atoms have the same structure? All atoms have the same general arrangement of subatomic particles with protons and neutrons in the nucleus or center of the atom surrounded by a cloud of electrons. Scientists refer to this structure as the **electron cloud model** of an atom.

Look Out!



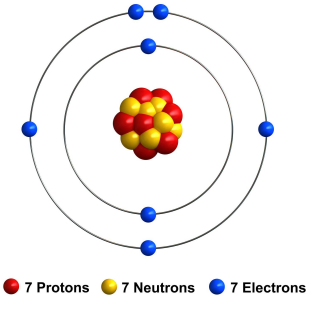
The electron cloud model of an atom is more accurate in its depiction of the electrons than the older atomic model developed by Niels Bohr in 1913. Bohr's model described electrons as orbiting the nucleus in a flat plane like planets in our solar system. In the electron cloud model, the nucleus is surrounded by a negatively charged electron cloud where electrons travel in high-probability areas called orbitals. Both models describe a dense central nucleus composed of positive protons and neutral neutrons.

Reflect

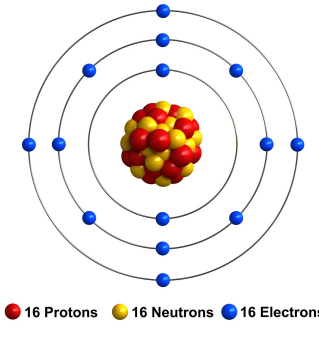
The location and charge of subatomic particles determine structure.
Protons, neutrons, and electrons differ from each other in their locations in an atom and their electrical charges. Electrical attractions and repulsions between charged particles (i.e., atomic nuclei and electrons) in matter explain the structure of atoms:

- **Protons** (shown as red spheres) are positively charged particles found in the nucleus of an atom. Since protons are the only charged particle in the nucleus, an atom's nucleus is always positively charged. Atoms of each element contain a characteristic number of protons. In fact, the number of protons, or **atomic number**, determines the element. For example, all nitrogen atoms have seven protons and, thus, an atomic number of 7. Sulfur atoms have 16 protons, while iron atoms have 26 protons.

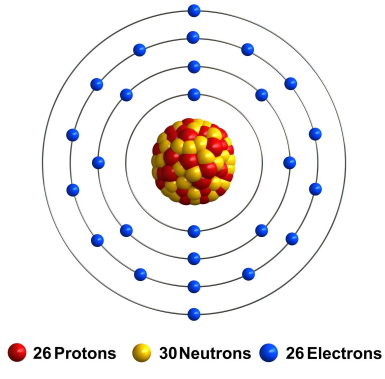
NITROGEN



SULFUR



IRON



- **Neutrons** (shown as yellow spheres) do not have an electrical charge. They are neutral. Neutrons are found in the nucleus of the atom.
- **Electrons** (shown as blue spheres) are negatively charged particles. They travel within the electron cloud surrounding the nucleus. Electrons are constantly moving at nearly the speed of light. The Bohr models above simplify the arrangement of electrons and emphasize the energy levels, which influence how the atom can react with other atoms.

Atomic Mass and Volume

Each proton and neutron has a mass of approximately 1.67×10^{-27} kg. The mass of one electron is negligible at 9.11×10^{-31} kg. Almost all of the atom's mass is located in the nucleus. Atomic mass is the average mass of all of the protons and neutrons in an atom. The average atomic mass, where P = number of protons and N = number of neutrons, is P + N. The unit for atomic mass is the AMU, atomic mass unit. If an atom has three protons and four neutrons, its mass is 7 amu. Electrons are so small that they do not make a significant contribution to the mass of an atom. The nucleus of an atom is very dense, having much more mass than volume. The nucleus only takes up around 1% of the volume of the atom. Almost all of the atom's volume is taken up by the electron cloud.

What Do You Think?

Assumptions for Counting Subatomic Particles

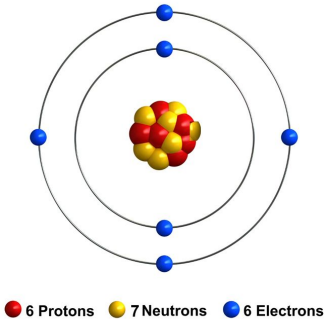
If the number of protons equals the number of electrons, the atom does not have an electrical charge—it is neutral. In other words, the positives and negatives balance out.

If there are more protons than electrons, the atom is positively charged.

If there are more electrons than protons, the atom is negatively charged.

The number of neutrons in an atom does not affect the overall charge of the atom because neutrons have no charge.

Suppose a carbon atom has six protons and seven neutrons and is neutrally charged overall. How many electrons are in this atom of carbon?

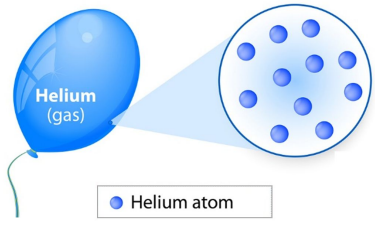


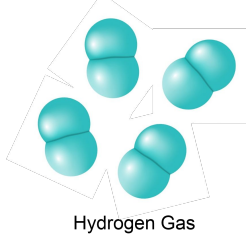
We know that the seven neutrons do not affect the overall charge of the atom. We also know that since the atom is neutral, it must have the same number of protons and electrons. Therefore, we can conclude that this carbon atom has six electrons.

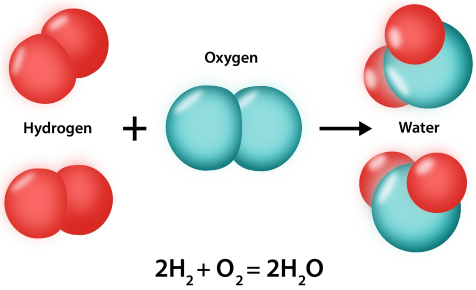
Reflect

Combining Atoms

A pure substance made up of many atoms with the same atomic number is called an **element.** Atoms can exist by themselves (e.g., helium gas) or combine to form a **molecule** with the same type of atom (e.g., hydrogen gas). Atoms can also combine (bond) with different kinds of atoms to form molecules of pure substances called **compounds** (e.g., water). Shorthand equations for describing the reactions that form compounds use chemical letter symbols for each element in a molecular formula. Subscripts indicate how many atoms of each element are in the compound. Coefficients show how many molecules are involved.




Hydrogen Gas



$2H_2 + O_2 = 2H_2O$

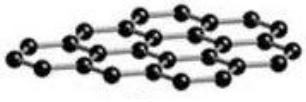
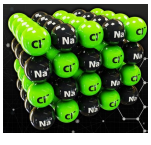
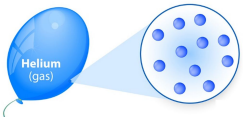
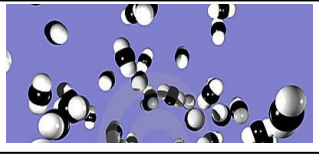
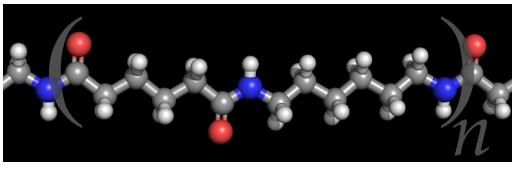
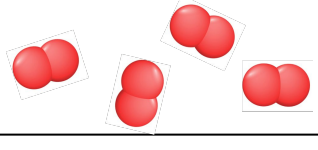
molecule: the simplest unit of a chemical compound that can exist, formed when two or more atoms join together chemically

Look Out!

Names and formulas reveal chemical composition.
Compounds are assigned special chemical names, a common name if the substance is well known, and a formula. This information reveals its chemical composition. For example, the substance commonly known as chalk has a chemical name, calcium carbonate, and a formula, $CaCO_3$. The formula, $CaCO_3$, means every molecule of chalk has one calcium atom (Ca), one carbon atom (C), and three oxygen atoms (O).

Reflect

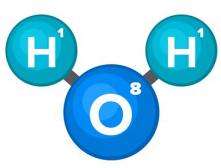
A pure substance is a single substance, either an element or a compound, with a definite composition and set of chemical and physical properties.

Type of Pure Substance	Example with Formula and Molecular Structure
Individual atoms of same type connect to form extended structure	Graphite (carbon) **C** (repeated) 
Solids made up of two atoms of different elements which then connect to form extended crystalline structures	Salt crystal (sodium chloride) **NaCl** 
Individual atoms that are not attracted to each other	Helium **He** 
Molecules of different types of atoms that are not attracted to each other	Carbon dioxide **CO_2** 
Molecules composed of four different types of atoms that are attracted to each other to form extended structures	Nylon **$(C_{12}H_{22}N_2O_2)_n$** 
Diatomic molecules of the same type of atom that are not attracted to each other	Oxygen gas **O_2** 

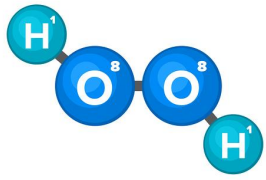
Try Now

A compound is two or more different atoms bonded together. The ratio is important. Just because two compounds have the same elements does not mean they are the same substance. Look at the compounds on the side. The one on the left is water. On the right is hydrogen peroxide, the bubbly stuff you apply to cuts. They both have hydrogen and oxygen, but in different ratios. Water has two hydrogen atoms and one oxygen atom, and hydrogen peroxide has one hydrogen per each oxygen. Different models reveal different structural information. There are many different ways to model a compound.

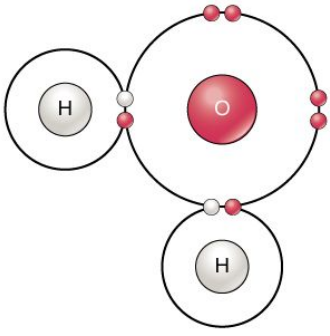
How do these water molecule models compare?

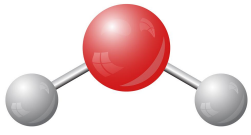


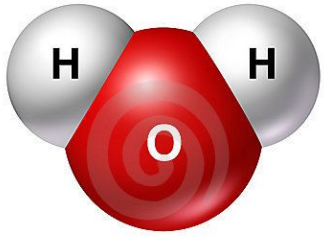
Water

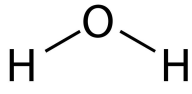


Hydrogen peroxide





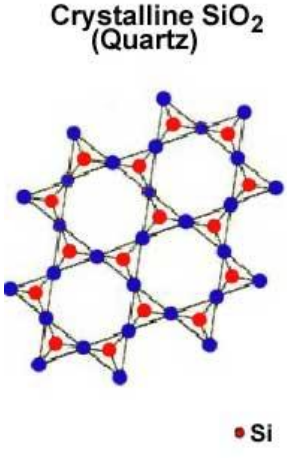


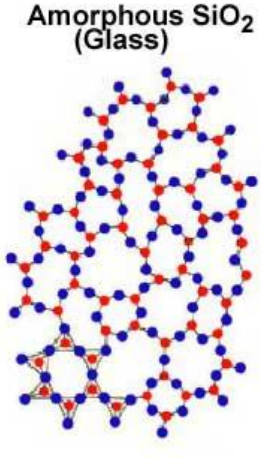


Reflect

Crystal Structure

The structure of solid matter can either be disordered or ordered. In some types of substances, the molecules or atoms arrange themselves into neat, ordered patterns called a crystalline lattice, which is what causes crystals to form. In other instances, there is no order. In the non-ordered solids, there is no pattern; the atoms are disordered, or amorphous.





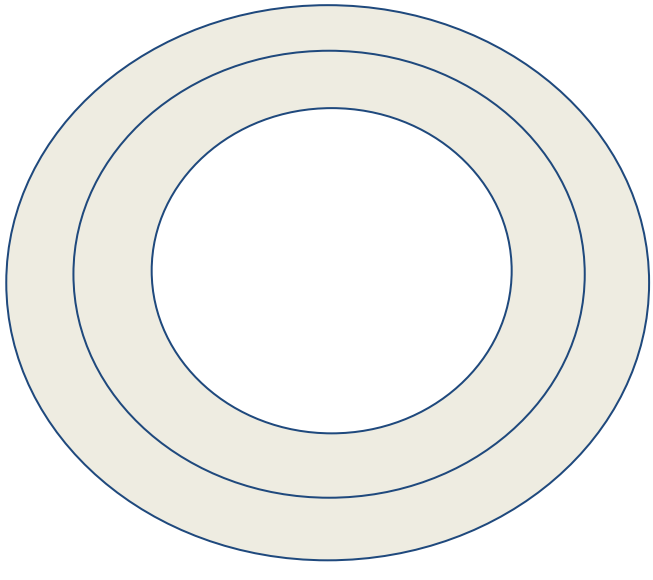
What Do You Think?

Use the table to identify the properties of the subatomic particles.

Subatomic Particles	Location	Mass (amu)	Charge	Function
Proton				
Neutron				
Electron				

Use the steps below to create a model of a typical neutral atom of lithium.

The atomic number is the number of protons.
The atomic mass (rounded to the nearest whole number) minus the atomic number equals the number of neutrons.
This atom is neutral, so the number of electrons must be equal to the number of protons.
Only up to two electrons will fit into the first level and up to eight in the second.



3
Li
6.941