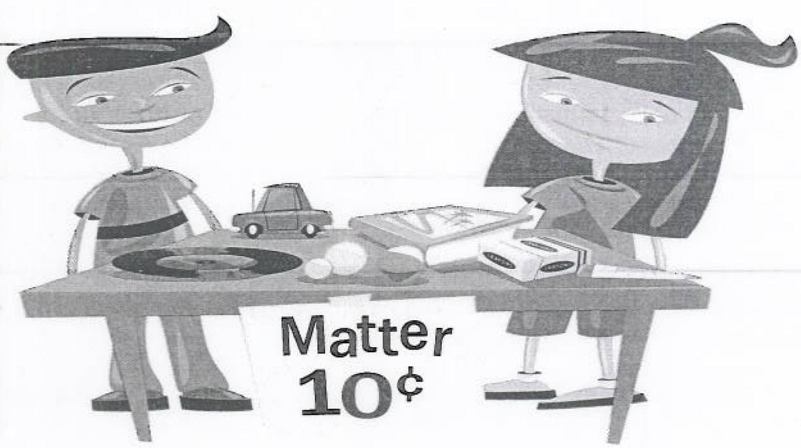
250

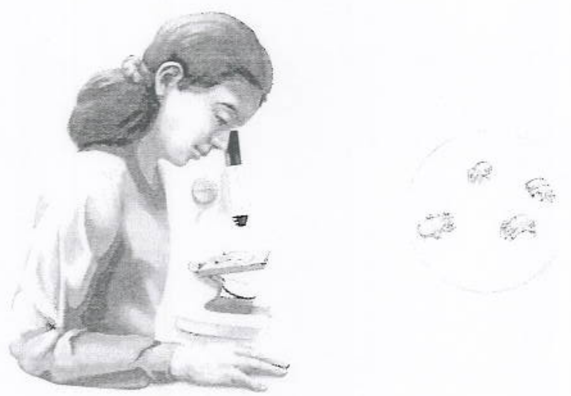
Matter

Matter is the "stuff" that all objects and substances in the universe are made of. Because all matter takes up space (has **volume**) and contains a certain amount of material (has **mass**), all matter can be detected and measured.



You can observe some types of matter easily with your senses. For example, you can see or feel things like rocks, trees, bicycles, and different kinds of animals. And you can see and smell things like smoke from a fire.

Other types of matter are a little more difficult to observe. The dust mites that live in your upholstered furniture and rugs are an example of matter that is too small to see with the naked eye. They can be observed only with special instruments, like a microscope.



Another example of matter that's hard to detect is air, the invisible gas that surrounds you. How do you know it's there? You can't see it or smell it, but you know it exists because you can feel it when the wind blows and see it bend the branches of trees.

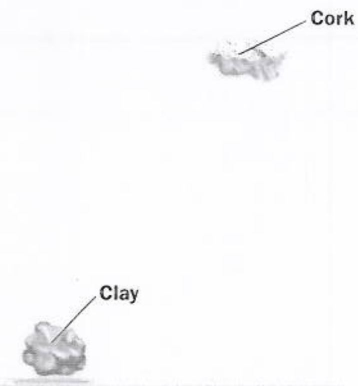
Word Watch!

The word *matter* comes from the Latin word *materia*, meaning "material" or "stuff."

Properties of Matter

251

You know that a piece of cork is different from a piece of clay. Cork will break if you squeeze it hard, but clay will flatten or bend into a new shape. If you had a scale handy, you would find that a piece of cork weighs less than a piece of clay the same size. If you dropped both objects in water, you would see that the cork floats but the clay sinks. Characteristics like these, that help us identify or classify matter, are called **properties.**



Tendency to float or sink is a physical property of matter.

All matter has both physical properties and chemical properties. **Physical properties** are those that can be observed without changing the make-up, or identity, of the matter. For example, clay is malleable, which means it will bend or flatten when squeezed. Squeezing changes the shape of the clay but does not change what the clay is made of. Malleability is an example of a physical property. The chart below lists some common physical properties of matter.

Physical Property	What It Means
Density	The amount of matter in a given volume (mass per unit volume)
Ductility	The ability to be pulled into a thin strand, like a wire
Malleability	The ability to be pressed or pounded into a thin sheet
Boiling point	The temperature at which a substance changes from a liquid to a gas
Melting point	The temperature at which a substance changes from a solid to a liquid
Electrical conductivity	How well a substance allows electricity to flow through it
Solubility	The ability to dissolve in another substance

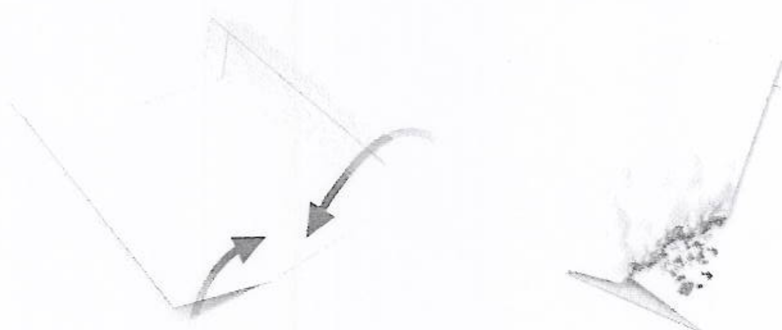
Chemical properties describe matter based on its ability to change into a new kind of matter with different properties. For example, paper is flammable: it is capable of burning in the presence of oxygen. Flammability is a chemical property of paper. A chemical property of iron is its tendency to rust. Rusting occurs when iron reacts with oxygen to produce iron oxide. Reactivity to acid and to water are two more examples of chemical properties.

SEE ALSO
265 Periodic Table
269 Chemical Reactions

Physical and Chemical Changes

252

If you fold a sheet of paper into thirds, you're left with a piece of paper one-third the size of the original. But the newly folded paper is still paper. Two physical properties of the paper—its size and shape—have changed, but not its chemical properties. Such a change is called a **physical change.**



If you hold a lit match to the paper, the paper will burn. What you're left with—ash, gases, and smoke—is no longer paper. The chemical properties of the paper have changed, producing new substances. This kind of change is called a **chemical change.**

SEE ALSO
269 Chemical Reactions

Many physical changes can be reversed. For example, you can unfold the piece of paper to return it to its original size and shape. Most chemical changes, on the other hand, cannot easily be undone. For example, you can't "unburn" a charred piece of paper.

253 States of Matter

Think about the differences between, for example, a rock, milk, and air. The shape of a rock does not change unless you cut or smash it. Milk takes on the shape of its container, and if you pour it on the floor it will spread out to form a puddle. Air spreads out even more than milk does. And it keeps spreading out in all directions.

Rocks, milk, and air represent different physical forms in which a substance can exist: a rock is a **solid,** milk is a **liquid,** and air is a **gas.** Solids, liquids, and gases are three **states of matter.** The chart below lists the defining features of each state.

Word Watch!

The three **states of matter** are also known as the **phases of matter.**

SEE ALSO
254 Changing States of Matter

State of Matter	Defining Features
Solid	• keeps its shape and volume
Liquid	• takes on the shape of its container • keeps the same volume, in a container or not • can flow
Gas	• takes on the shape and volume of its container • can flow (through a room, for example)

Did You Know?

A fourth state of matter is called a plasma. Like a gas, a plasma does not have a definite shape or volume. Plasmas only exist at very high temperatures. Stars, including the sun, are made of matter in a plasma state.

SEE ALSO
255 Atoms
259 Elements, Molecules, and Compounds

But why are solids solid, liquids liquidy, and gases gassy? To answer this question, you first need to understand three things:

- All matter is made up of tiny particles called atoms and molecules.
- These particles attract each other; the greater the attraction, the closer the particles get.
- These particles are constantly in motion and bumping into each other. The temperature of a substance is related to the speed at which its particles move.

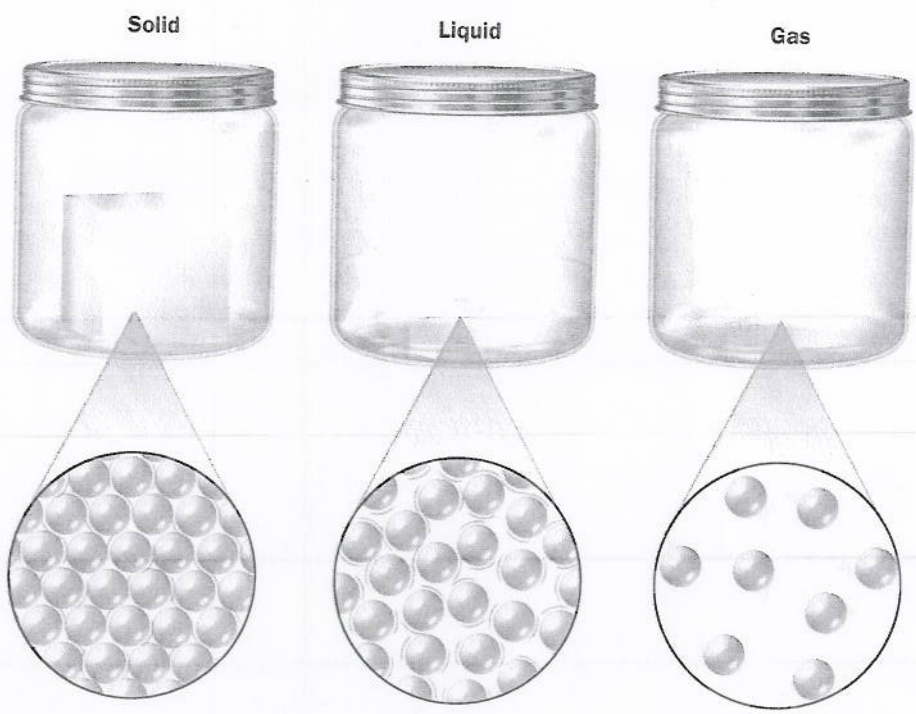
The state of a substance depends on how fast its particles move and how strong the attraction is between the particles.

Solid The particles of a substance in its solid state vibrate in place, but the vibration isn't great enough to overcome the attraction between the particles and cause them to separate. As a result, the forces between the particles cause them to lock together.

Liquid The particles of a substance move even faster when the substance is in a liquid state. As a result, the particles in a liquid can overcome some of the attraction between them. So, unlike the particles in a solid, which are locked together, the particles in a liquid can flow around and over each other. If you spill a glass of water on the floor, for example, the water molecules stick together enough to make a puddle, but not enough to keep the shape the water had when it was in the glass.

Gas The particles of a substance move fastest when the substance is in a gaseous state—so fast that they are able to overcome the attraction between them and separate from each other entirely. That's why a gas will spread out in all directions, filling up a balloon, a room, or the atmosphere.

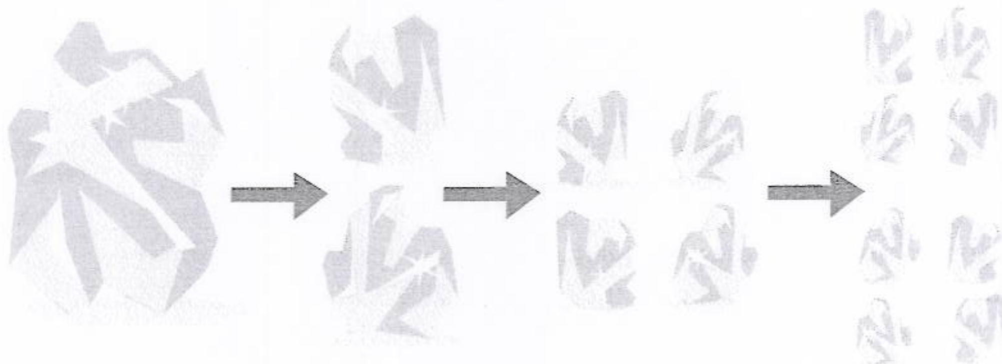
SEE ALSO
213 Earth's Atmosphere



255

Atoms

Imagine finding a gold nugget while panning for gold in Colorado. You decide to share your prize with family and friends by having it cut into smaller pieces. Using a special tool, you cut the nugget in half, then in half again, over and over. Eventually you end up with a piece of gold that is too small to cut with your tool!



But you've got a lot of family and friends, so suppose you were able to keep cutting the gold into smaller and smaller pieces. Would you be able to keep cutting forever? The answer is no! At some point you would end up with a piece that could not be divided. That smallest piece would be an atom.

An **atom** is the smallest particle into which an element (such as gold) can be divided and still maintain the properties of that element. Because all matter is made up of elements, and all elements are made up of atoms, atoms are considered the building blocks of matter.

SEE ALSO
259 Elements, Molecules, and Compounds
265 Periodic Table

Word Watch!

The word *atom* comes from the Greek word *atomos*, which means "indivisible."

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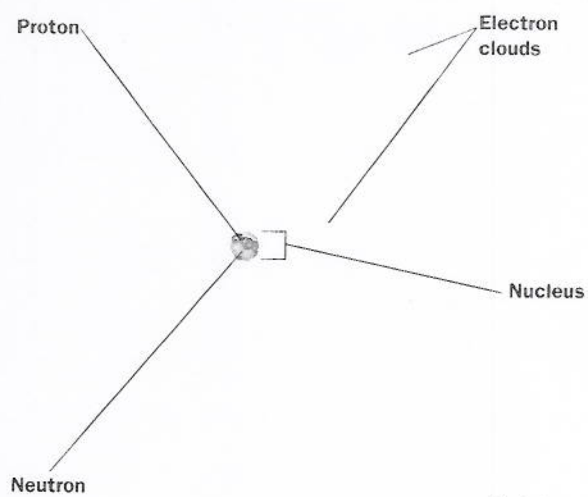
Atomic Structure

Atoms are made up of even smaller particles called protons, neutrons, and electrons. Protons and neutrons stick together to form an atom's **nucleus,** which is at the center of the atom. Electrons are found in regions surrounding the nucleus.

Current model of the atom



Protons are the positively charged particles located in the nucleus of an atom. All protons are identical. An atom is identified by the number of protons in its nucleus. For example, an atom with one proton is called hydrogen; an atom with eight protons is called oxygen. All atoms of the same element have the same number of protons.

SEE ALSO
265 Periodic Table

Neutrons are also located in the nucleus. As their name suggests, neutrons are electrically neutral. That is, they have no electric charge. All neutrons are identical. Sometimes, atoms of the same element can have different numbers of neutrons. Because neutrons have no charge, the overall charge of the atom is not changed by the extra neutrons. **Isotopes** are atoms of the same element that have different numbers of neutrons.

Electrons are the negatively charged particles found outside the nucleus of an atom. All electrons are identical. The number and arrangement of the electrons in an atom determine its chemical properties.

SEE ALSO
251 Properties of Matter
268 Electron-Dot Diagrams
258 The Evolution of Atomic Theory

The nucleus of hydrogen, the simplest atom, contains one proton but no neutron. All other atoms have both protons and neutrons in the nucleus.

MORE

SEE ALSO
240 Planets

Scientists used to think that electrons orbited the nucleus in fixed paths, the way the planets orbit the sun. Now they theorize that electrons travel in random paths in areas around the nucleus called **electron clouds**. An electron's **energy level** determines its average distance from the nucleus.

SEE ALSO
315 The Law of Electric Charges

The charge of an electron is equal in size to the charge of a proton, but opposite in sign. Since unlike charges attract each other, electrons and protons exert an attractive electrical force on each other. That's what holds electrons to the nucleus.

257

Atomic Size

Just how small is an atom? A typical atom is about one ten-billionth of a meter in diameter. The average nucleus of an atom is about one million billionth of a meter in diameter—a tiny fraction of the size of the entire atom.

SEE ALSO
250 Matter

The protons and neutrons that make up the nucleus of an atom have about the same mass. Electrons have a much smaller mass—about one two-thousandth the mass of protons or neutrons. That means most of the mass of an atom is in the nucleus.

Word Watch!

Mass is a measure of the amount of "stuff" in an object.

The particles that make up an atom are like tiny specks compared to the size of the atom as a whole. So the majority of an atom's volume consists of empty space. And since all objects are made of atoms, you could argue that objects are also mostly empty space!

There are more than a million million billion atoms in a single drop of water!

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The Evolution of Atomic Theory

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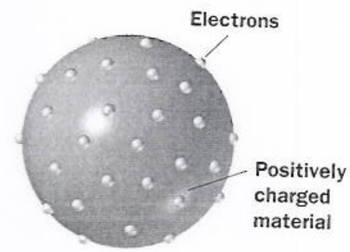
Atomic theory has changed quite a bit since the Greek philosopher Democritus proposed the existence of atoms in 440 B.C. By the early 1800s, British chemist John Dalton had come up with a theory that he based on observations from experiments. Dalton proposed that all substances were made of atoms—small, hard, dense spheres that could not be created, destroyed, or altered.

SEE ALSO
440 History of Science Time Line

Dalton's model of the atom

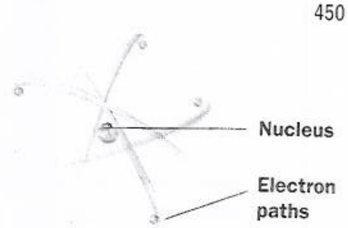
Then, in 1898, British scientist J. J. Thomson proposed that atoms themselves were made up of smaller particles. He discovered that atoms contain negatively charged particles, but he did not know the location of these particles. He theorized that they were spread evenly throughout positively charged material. His model of the atom was called the plum-pudding model.



Thomson's model of the atom

In 1911, Ernest Rutherford, a former student of Thomson's, proposed that atoms had a dense, positively charged nucleus surrounded by electrons. Then, two years later, in 1913, Danish scientist Niels Bohr modified this model even further. He said that electrons revolved around the nucleus in circular paths, called orbits, and that electrons could only exist in certain orbits and at certain energy levels.

SEE ALSO
450 Famous Scientists



Bohr's model of the atom

Bohr's model was an important stepping stone to today's model of the atom, which was developed in the 1920s. According to the current model, called the **electron cloud model,** electrons surround the nucleus, traveling not in prescribed paths but in regions of various thicknesses, called clouds.

SEE ALSO
256 Atomic Structure

Elements, Molecules, and Compounds

259

SEE ALSO
255 Atoms

All matter is made up of atoms. But think about all the different kinds of matter there are in the universe. What makes one kind of matter different from another? Different kinds of atoms! Different kinds of atoms are called **elements.** Two or more elements that have combined are called a **compound.** Elements and compounds of elements make up all the different kinds of matter in the universe.

260

Elements

SEE ALSO
265 Periodic Table
177 Structure of Earth

An **element** is considered the simplest form of matter. It cannot be broken down into simpler substances under normal laboratory conditions. There are about 110 known elements in the universe. Ninety-two of these are found naturally on Earth or in the atmosphere. The rest are synthetic, or made in the laboratory.

Earth's crust is made up mostly of the elements oxygen and silicon. Earth's atmosphere is about 78% nitrogen and 21% oxygen. Living things are made mostly out of compounds of the elements carbon, hydrogen, oxygen, and nitrogen.

Each element is made of atoms of the same type. For example, the element oxygen is made out of oxygen atoms. The element carbon is made out of carbon atoms. Each element is considered a pure substance because it contains only one kind of atom.

SEE ALSO
251 Properties of Matter

Each element has a unique set of physical and chemical properties that distinguish it from all other elements. These properties can be used to identify different elements. They can also be used to separate combinations of elements into pure substances.

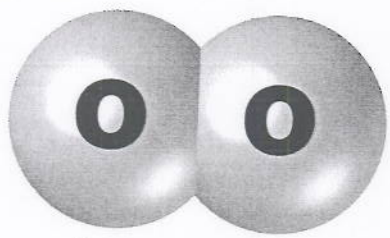
Molecules

When two or more atoms combine, they form a **molecule.** Just as an atom is the smallest particle of an element with the same properties of that element, a molecule is the smallest particle of a substance with the same properties of that substance.

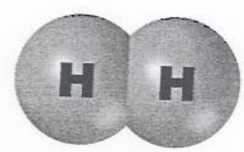
SEE ALSO 255 Atoms

The simplest molecules contain only two atoms. These are called **diatomic molecules** (the prefix *di-* means "two"). For example, an oxygen molecule (O_2) is a diatomic molecule. It is made up of two oxygen atoms (O) that have joined together. A hydrogen molecule (H_2) is also diatomic: it consists of two hydrogen atoms (H).

SEE ALSO 265 Periodic Table



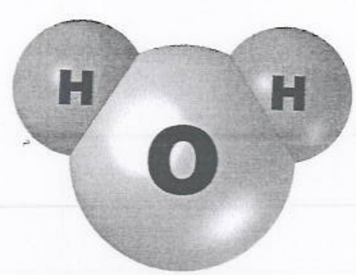
Oxygen molecule (O_2)



Hydrogen molecule (H_2)

Most molecules are made out of two or more atoms of different kinds (different elements). For example, a water molecule (H_2O) is made of two hydrogen atoms (H) and one oxygen atom (O). Each molecule of water behaves like water. If the molecules are divided into separate hydrogen and oxygen atoms, however, the particles no longer behave like water.

SEE ALSO 267 Chemical Formulas



Water molecule (H_2O)

262

Compounds

Most elements are found in combination with other elements—that is, in chemical **compounds.** The elements in any given compound have a fixed ratio. For example, the compound water (H_2O) always has two parts of the element hydrogen to one part of the element oxygen.

SEE ALSO
261 Molecules

Science Alert!

What's the difference between a compound and a molecule? The term *compound* is used to describe the chemical substance in general, while the term *molecule* refers to the smallest particle of the substance that has the same properties of the substance.

The properties of compounds are different from the properties of elements that make up the compounds. For example, water has properties that are different from either hydrogen or oxygen, the elements that make up water.

Compound Name and Formula	Contains These Elements	Properties of Each Element	Properties of Compound
Table salt: sodium chloride (NaCl)	**sodium,** Na **chlorine,** Cl	**sodium**—a soft, extremely malleable metal; silver-white in color; reacts explosively with water **chlorine**—a poisonous, highly irritating greenish-yellow gas	colorless crystals are cubic; many crystals together look white; salty taste
Table sugar: sucrose ($C_{12}H_{22}O_{11}$)	**carbon,** C **hydrogen,** H **oxygen,** O	**carbon**—crystalline form includes graphite and diamonds; noncrystalline form includes charcoal and coal **hydrogen**—colorless, highly flammable gas **oxygen**—colorless, odorless, tasteless gas	clear crystals or white powder; sweet taste
Baking soda: sodium bicarbonate ($NaHCO_3$)	**sodium,** Na **hydrogen,** H **carbon,** C **oxygen,** O	see properties of each element above	white crystalline powder or lumps

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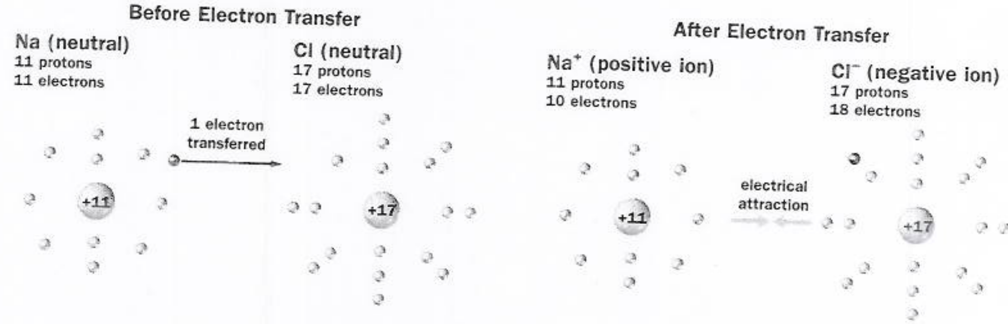
Chemical Bonds

The atoms in a molecule are held together by chemical bonds. A **chemical bond** is the force of attraction between atoms. Chemical bonds occur when atoms either transfer or share electrons.

An **ionic bond** is a type of bond in which one or more electrons from one atom are transferred to another atom. The atom that loses electrons ends up with a positive charge (remember, electrons have a negative charge). An atom with a positive charge is called a positive ion. (An **ion** is simply an atom with a charge.) The atom that gains electrons ends up with a negative charge. An atom with a negative charge is called a negative ion. These two ions, having unlike charges, attract each other and form a bond.

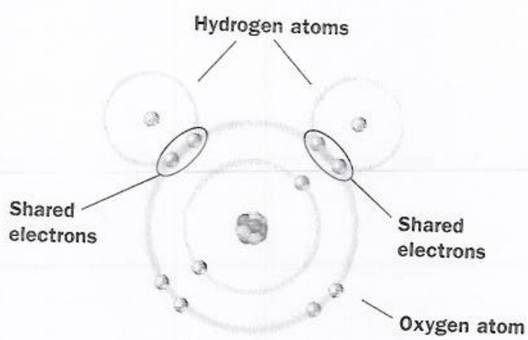
SEE ALSO
264 Families of Chemical Compounds
315 The Law of Electric Charges



Example of ionic bonding (salt, NaCl)

A **covalent bond** is a type of bond in which atoms share one or more electrons. The shared electrons spend more time between the two atoms than anywhere else. These electrons, because of their negative charge, attract the positive nuclei of the atoms. This attraction holds the atoms together.

SEE ALSO
261 Molecules



Example of covalent bonding (water, H_2O)

Word Watch!

Ionic bonds get their name from the ions that form as the bond is created. Covalent bonds get their name from the root *co-*, meaning "together" or "jointly," and the word *valence*, which refers to the capacity of an atom to join with other atoms.