Atoms

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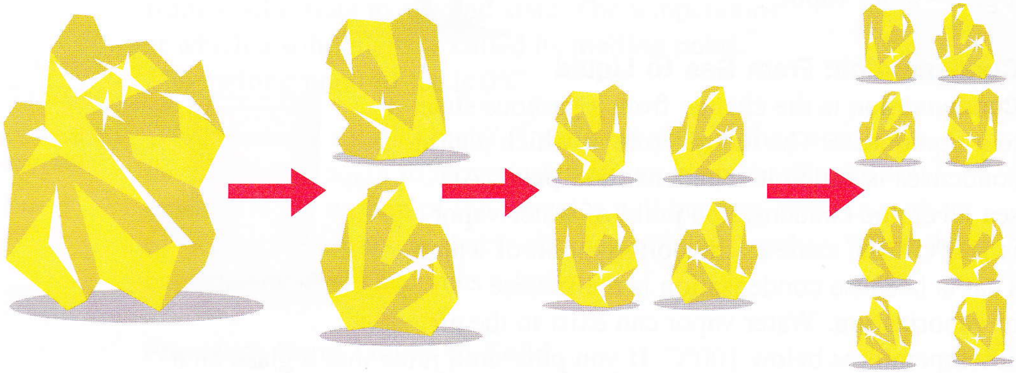
Imagine finding a gold nugget while panning for gold in Colorado. You decide to share your prize with family and friends by having it cut into smaller pieces. Using a special tool, you cut the nugget in half, then in half again, over and over. Eventually you end up with a piece of gold that is too small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

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

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.

Word Watch!

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

Atomic Structure

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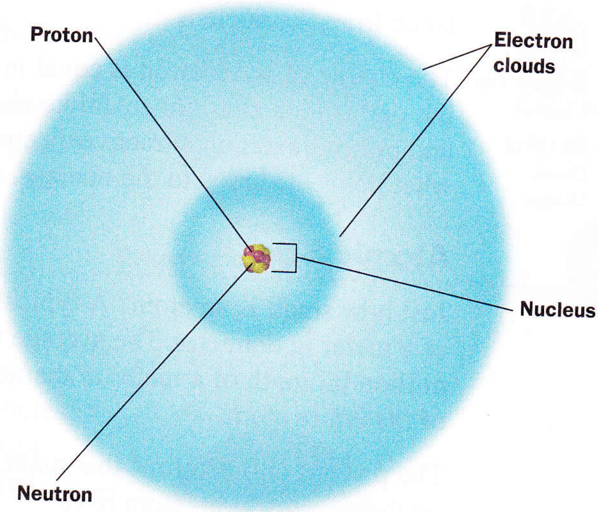
Atoms are made up of even smaller particles called protons, neutrons, and electrons. Protons and neutrons stick together to form an atom's **nucleus,** which is at the center of the atom. Electrons are found in regions surrounding the nucleus.

Current model of the atom



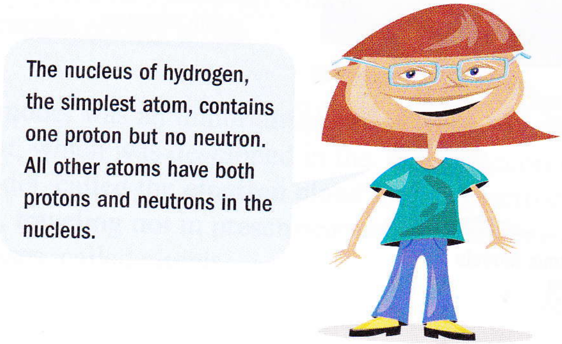
Protons are the positively charged particles located in the nucleus of an atom. All protons are identical. An atom is identified by the number of protons in its nucleus. For example, an atom with one proton is called hydrogen; an atom with eight protons is called oxygen. All atoms of the same element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



MORE

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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.

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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.

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.

SEE ALSO
250 Matter

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!

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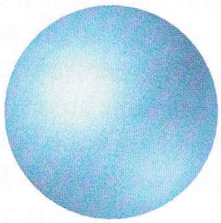
The Evolution of Atomic Theory

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.



Dalton's model of the atom

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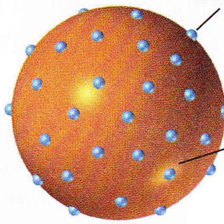
440 History of Science Time Line

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.

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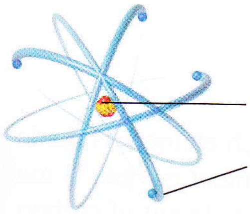
450 Famous Scientists



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
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Elements, Molecules, and Compounds

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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.

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Elements

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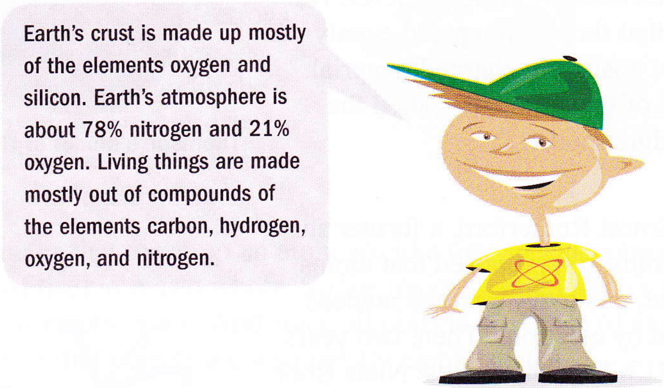
177 Structure of Earth

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.



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.

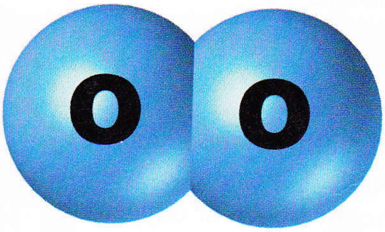
Molecules

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.

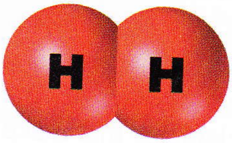
SEE ALSO
255 Atoms

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



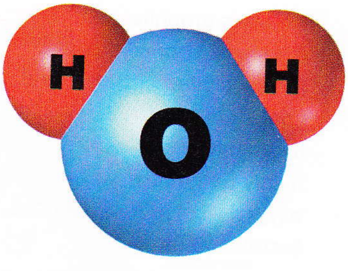
Oxygen molecule (O_2)



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)

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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.

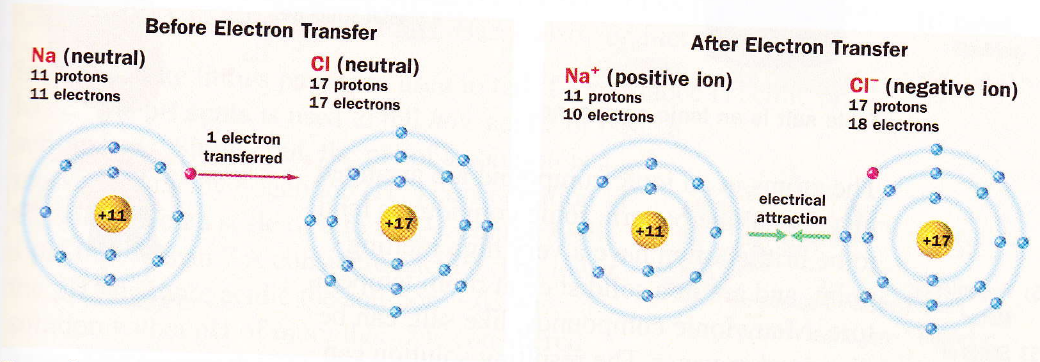
Compound Name and Formula	Contains These Elements	Properties of Each Element	Properties of Compound
Table salt: sodium chloride ($NaCl$)	**sodium**, Na **chlorine**, Cl	**sodium**—a soft, extremely malleable metal; silver-white in color; reacts explosively with water **chlorine**—a poisonous, highly 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

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.

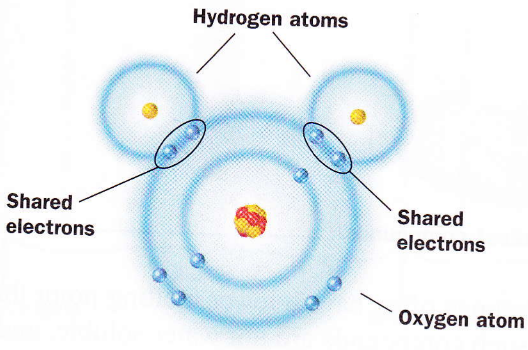
SEE ALSO
264 Families of Chemical Compounds
315 The Law of Electric Charges



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.

Families of Chemical Compounds

There are millions of chemical compounds in the world. Scientists classify compounds by the similarities in their properties.

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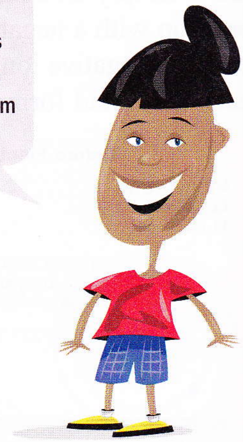
261 Molecules

Ionic and Covalent Compounds

One way to classify compounds is by the type of bond they contain. **Ionic compounds** are compounds formed with ionic bonds. Ordinary table salt (sodium chloride, NaCl) is an example of an ionic compound.

Table salt is an ionic compound.



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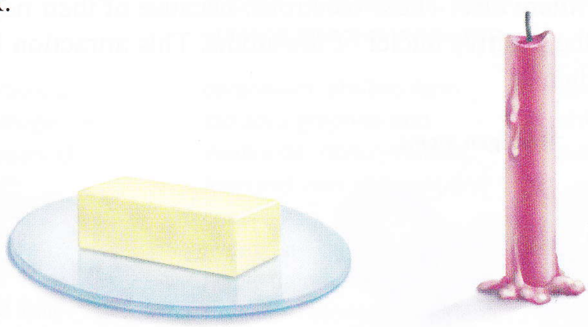
253 States of Matter
272 Parts of a Solution
317 Current Electricity

The atoms in an ionic compound are arranged in a crystalline pattern. Ionic compounds tend to be brittle, often have a very high melting point, and are in a solid state at room temperature. Many ionic compounds, like salt, can be dissolved in water. The resulting solution can conduct electric current.

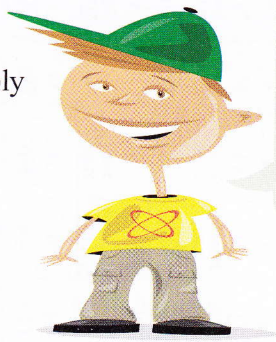
Covalent compounds are compounds formed with covalent bonds. Water (H_2O) is an example of a covalent compound. So are butter and wax.



Butter and wax are both covalent compounds.

In general, covalent compounds often have a lower melting point than ionic compounds. Many such compounds are not water soluble, and those that are, such as sugar, usually do not conduct electricity.

Acids and Bases



An **acid** is any compound that produces hydrogen ions (H^+) in water. (An **ion** is simply an atom that has gained or lost electrons and therefore has a positive or negative charge.) The greater the concentration of hydrogen ions produced, the stronger the acid. Acids taste sour, change blue litmus paper red, and react with metals to produce hydrogen gas. Acidic solutions also conduct electricity.

Litmus paper is an **indicator**, a substance that changes color when it comes in contact with an acid or a base.

SEE ALSO
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269 Chemical Reactions
317 Current Electricity

A **base** is any compound that produces hydroxide ions (OH^-) in water. The greater the concentration of hydroxide ions produced, the stronger the base. Bases taste bitter, change red litmus paper blue, feel slippery, and dissolve oils and fats. Bases also conduct electricity.

Indicators like litmus paper are used to tell if a substance is acidic or basic. The **pH scale** is used to tell *how* acidic or basic a substance is. Simply put, the pH of a solution is a measure of the hydrogen ion (H^+) concentration in the solution on a scale of 0 to 14. A solution with a pH of less than 7 is considered acidic. The lower the pH, the more acidic the solution. Likewise, a solution with a pH of more than 7 is considered basic. The greater the pH, the more basic the solution. A solution with a pH of 7 is considered neutral—neither acidic nor basic.

Word Watch!

pH comes from the French "**pouvoir hydrogène**," meaning "hydrogen power."

pH Scale with Values of Some Common Substances