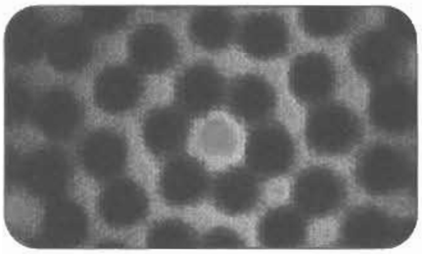
What Makes Up Matter?



▲ **Figure 1** This image of silicon atoms was made by a scanning tunneling microscope.

READ TO UNDERSTAND

- Describe the three kinds of subatomic particles.
- Why is an element's atomic number important?
- How is the periodic table organized?
- What are three ways that atoms can form bonds with one another?

VOCABULARY

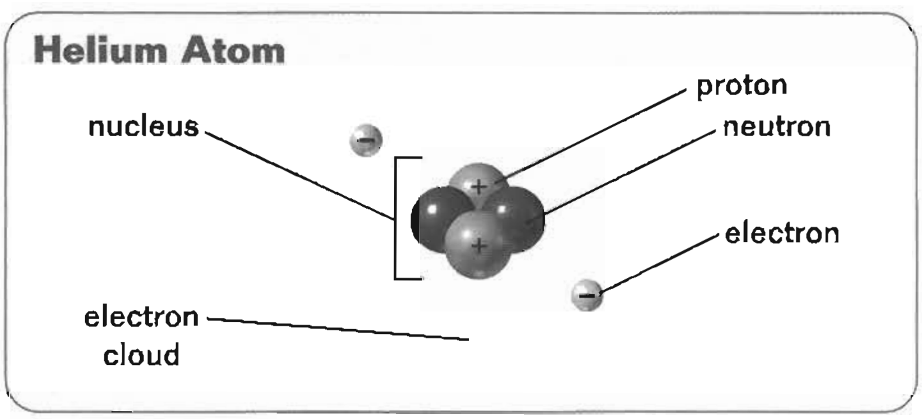
matter	nonmetal
atom	metalloid
nucleus	compound
subatomic	chemical formula
proton	chemical bond
neutron	ion
electron	ionic bond
atomic number	metallic bond
mass number	covalent bond
isotope	molecule
valence electron	polar molecule
element	organic compounds
periodic table	hydrocarbon
noble gas	isomer
metal	

Atoms

Everything around us—water, air, land, and even living things—is made of matter. **Matter** is anything that has mass and takes up space. All matter is made of tiny building blocks called **atoms.** Atoms are so small that we cannot see them, except with powerful microscopes (Figure 1). Scientists have gathered evidence about the structure of atoms by experimenting with how substances behave.

Scientists have found that most of an atom's mass is located in its center, called the **nucleus.** An atom's nucleus is made of smaller, **subatomic** particles called protons and neutrons (Figure 2). A **proton** is a subatomic particle with a positive (+) electric charge. Every atom has at least one proton in its nucleus. The nuclei of most atoms also contain neutrons. **Neutrons** are subatomic particles with no electric charge. They are neutral. A proton and a neutron have about the same mass.

The size of an atom's nucleus is very tiny compared to the size of the whole atom. Most of the area around the nucleus is empty space. An atom's electrons move around in this space. **Electrons** are a third kind of subatomic particle. An electron has a negative (–) electric charge. Imagine that the nucleus of an atom is the size of the period at the end of this sentence. The closest electrons would be moving around it about 50 meters (about 164 feet) away. Electrons have very little mass. An electron is 1,836 times lighter than a proton.



▲ **Figure 2** A helium atom contains two protons, two neutrons, and two electrons. In the model shown, the electron cloud is the region where the electrons are most likely to be located.

When the number of electrons in an atom is equal to the number of protons, the atom as a whole is neutral. The electric charges of the subatomic particles are balanced.

Scientists used to think that electrons revolved around the nucleus in predictable paths, like planets revolving around the Sun. Now we know that this is not true. Instead, electrons move quickly throughout all the space around the nucleus. Scientists show this using a model called the electron cloud model. We cannot know exactly where the electrons are at any given time, but the cloud represents the area where electrons are most likely to be found.

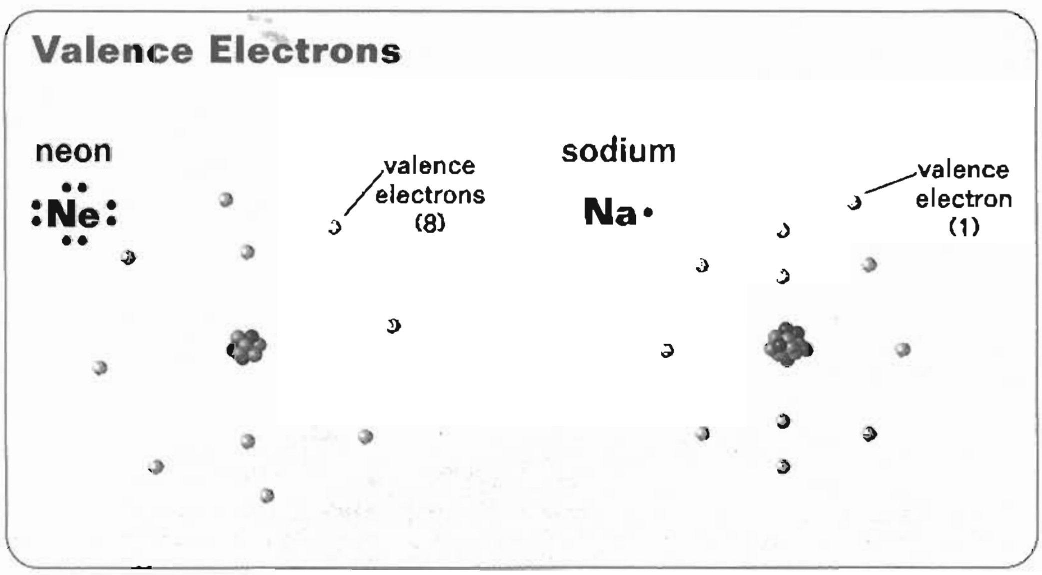
An atom can be identified by the number of protons in its nucleus. This number is called the atom's **atomic number.** For example, a hydrogen (H) atom has one proton in its nucleus, so hydrogen's atomic number is 1. Any atom with only one proton is a hydrogen atom. Helium (He) has two protons, so its atomic number is 2. Lithium (Li) has three protons, so its atomic number is 3, and so on.

The atomic **mass number** of an atom is equal to the number of protons *plus* the number of neutrons in its nucleus. The number of electrons is not included in the mass number because the mass of an electron is so small.

Most oxygen (O) atoms have eight protons and eight neutrons, giving them a mass number of 16. However, not all oxygen atoms have eight neutrons. Atoms of the same type that have different numbers of neutrons are called **isotopes.** Oxygen in the air is a mixture of three different oxygen isotopes.

Recall that electrons are always moving around the nucleus. Their distance from the nucleus depends on how much energy they have. The various positions that electrons can occupy in an atom are called *shells* or *energy levels*. Electrons in the energy levels that are closest to the nucleus have low energy. Electrons in the energy levels that are farther away from the nucleus have higher energy. Each energy level can hold only a certain number of electrons. The electrons in the outermost energy level are called **valence electrons** (Figure 3). The number of valence electrons that an atom has is an important property. It determines the way the atom will join with other atoms.

An atom will gain, lose, or share electrons with other atoms in order to fill its outermost energy level. Most atoms need eight valence electrons to fill their outer level. Hydrogen and helium are two exceptions. They need only two valence electrons to fill their outer level.



◄ **Figure 3**
Dot diagrams show the number of valence electrons in an atom. A neon atom has eight valence electrons. To show this, eight dots are positioned, two per side, around neon's chemical symbol, Ne. A sodium atom has only one valence electron. Which kind of atom, neon or sodium, is more likely to join with other atoms in order to have a full outermost energy level?

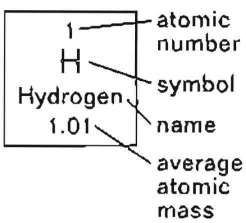
Elements

An **element** is a substance that cannot be broken down chemically into any other substance. An element is made up of only one kind of atom. More than 100 different kinds of elements are known. Recall that the number of protons in an atom's nucleus determines its identity. The simplest element is hydrogen. It has one proton. The most complex element found in nature is uranium (U). It has 92 protons. Elements with greater than 92 protons have been created artificially in a laboratory.

Scientists have organized the elements in a chart called the **periodic table** (Figure 4). Each box in the table represents an element. The elements are arranged according to their atomic number. The element's atomic number, chemical symbol, name, and average atomic mass are displayed from top to bottom in each box.

The rows of the periodic table are called *periods*. The atomic numbers increase from left to right across a row. All the elements in the same row or period have the same number of energy levels. For example, every element in the fourth period has four energy levels for its electrons. All the elements in the fifth period have five energy levels for their electrons.

The columns of the periodic table are called *groups* or *families*. Elements in the same group have similar properties and the same number of valence electrons. Every element in the first group has one valence electron. This group of elements is very reactive. This means they join easily with other elements. Every element in



Classification

Metal

Metalloid

Nonmetal

State

Ag Solid

Hg Liquid

H Gas

PERIOD	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
1	1 H Hydrogen 1.01							
2	3 Li Lithium 6.94	4 Be Beryllium 9.01						
3	11 Na Sodium 22.99	12 Mg Magnesium 24.31						
4	19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85
5	37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium [98]	44 Ru Ruthenium 101.07
6	55 Cs Cesium 132.91	56 Ba Barium 137.33		72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23
7	87 Fr Francium [223]	88 Ra Radium [226]		104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [277]

57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium [145]
89 Ac Actinium [227]	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium [237]

State refers to state of matter at room temperature. Atomic masses in brackets are those of the most common or stable isotope.

Periodic Table of Elements

▲ **Figure 4** The periodic table displays data about each element and groups similar elements together.

Group 17 has seven valence electrons. These elements are also very reactive.

The elements that make up Group 18 are known as **noble gases.** The atoms of all noble gases have full outer energy levels. So all noble gases have eight valence electrons, except helium, which is full with two valence electrons. Because the atoms of noble gases have full outer energy levels, they do not readily bond with other atoms. We say they are stable, or unreactive.

Most elements are **metals.** Copper (Cu), iron (Fe), and aluminum (Al) are common metals. Most metals are solids at room temperature (about 22°C or 72°F). An exception is mercury (Hg), which is a liquid at room temperature. Metals have many properties that make them useful. Metals can be hammered, stretched, or molded into different shapes. Heat and electricity move easily through metals. The wire inside an electrical cord usually contains the metal copper. Many metals, such as gold (Au), are shiny.

Other elements have properties that differ from those of metals. **Nonmetals** are elements that are not shiny and cannot be stretched into wires. Heat and electricity do not move easily through nonmetals. Most nonmetals are gases or solids at room temperature. Oxygen and nitrogen (N) are two common nonmetal gases in the air we breathe.

Some elements have properties in between those of metals and nonmetals. These elements are called **metalloids.** For example, silicon (Si) is a metalloid. It conducts electricity better than a nonmetal does, but not as well as a metal.

Group 9	Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16	Group 17	Group 18
									2 He Helium 4.00
				5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
				13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.41	31 Ga Gallium 69.72	32 Ge Germanium 72.64	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80
45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29
77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.20	83 Bi Bismuth 208.98	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]
109 Mt Meitnerium [268]	110 Ds Darmstadtium [271]	111 Rg Roentgenium [272]	112 Uub Ununbium	113 Uut Ununtrium	114 Uuq Ununquadium	115 Uup Ununpentium	116 Uuh Ununhexium		

62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
94 Pu Plutonium [244]	95 Am Americium [243]	96 Cm Curium [247]	97 Bk Berkelium [247]	98 Cf Californium [251]	99 Es Einsteinium [252]	100 Fm Fermium [257]	101 Md Mendelevium [258]	102 No Nobelium [259]	103 Lr Lawrencium [262]

Elements 112–116 were reported recently and have temporary names and symbols.