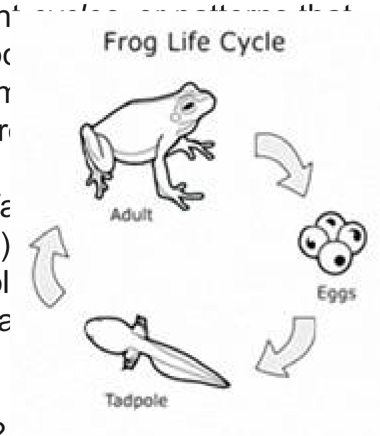
Electron Patterns and Properties of Elements

Reflect

In your study of science, you have probably learned about many differen
repeat over time. All organisms have life cycles, for example. A frog is bo
a tadpole, and finally becomes an adult frog capable of reproducing by m
pattern repeats itself throughout each generation of frogs. The life of a fr



Another term that means *cyclical* is *periodic*. You are probably already fa
your study of chemical elements, which are arranged into rows (*periods*)
the periodic table. This arrangement is periodic because each row or col
with similar properties, and these properties follow predictable patterns a
table.

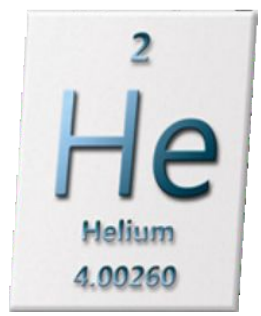
What are some properties of elements you have already learned about?
trends, or patterns involving these properties? (You can review the periodic table at the top of the next page.)

The Periodic Table

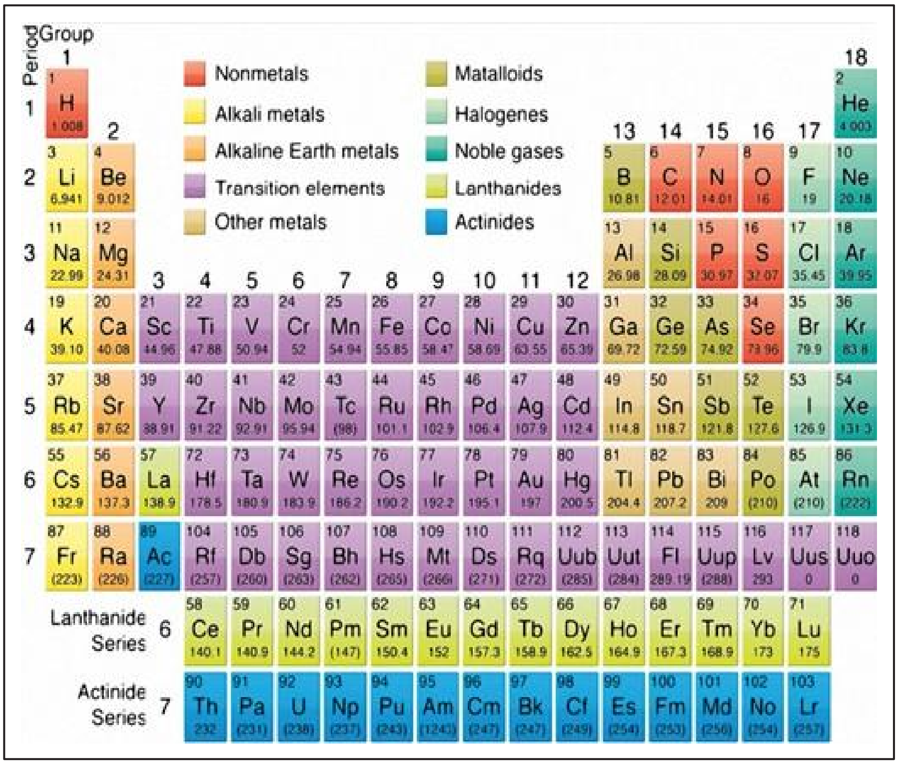
To date, scientists have confirmed the discovery of at least 114 chemical elements. (The discoveries of several more elements are awaiting confirmation.) Based on an element's location on the periodic table, you can draw several conclusions and make several predictions about the element.

Some versions of the periodic table contain more information than others. However, nearly all versions provide three basic pieces of information about each element:

- **Chemical symbol**: Each element is given a unique one- or
- two-letter abbreviation. The chemical symbol for hydrogen is H, while the chemical symbol for helium is He.
- **Atomic number**: This whole number reveals the number of protons in an atom of the element. Each element is identified by its unique atomic number.
- **Atomic mass**: An atom's mass is roughly equivalent to the sum of its protons and neutrons. (Electrons are extremely small, so their masses are negligible.)



An atom of helium (He) has two protons and an atomic mass of approximately 4.



As you can see, the atomic number of elements increases as you move from left to right across each period (or row) of the periodic table. Periods and groups also provide information about the number of electrons that fill an element's energy levels. As a general rule, elements in the same period have the same number of energy levels.

Elements in the same group have the same number of electrons in their **valence shells**, which means they tend to behave similarly during chemical reactions.

Trends in Atomic Size

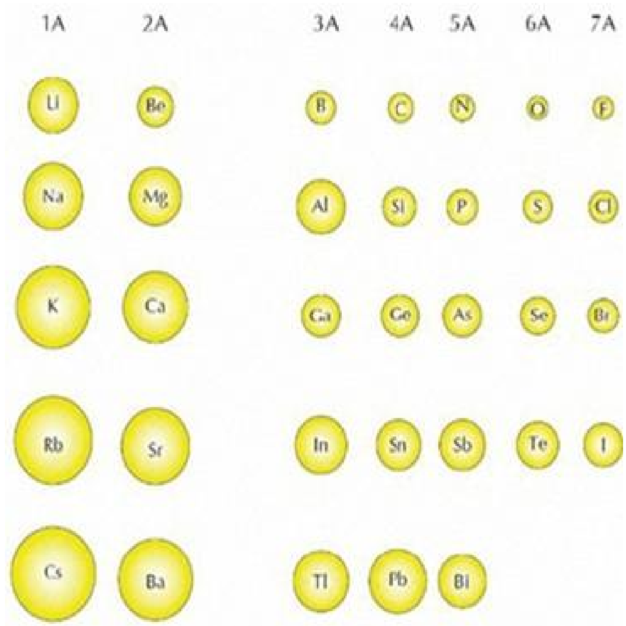
We can describe additional trends based on an element's location in the periodic table. The size of an atom determines its *atomic radius*, or one-half the distance between atoms in a **covalent bond**. Two factors determine the size of an atomic radius: the number of energy levels in an atom and the number of protons in an atom's nucleus.

- **Energy levels:** Atoms farther down in a group have a higher energy level than atoms farther up in the same group. Because each energy level increases an atom's atomic radius, atoms at the top of a group have smaller radii than atoms at the bottom of the group. You can see this trend in the figure on the next page.

valence shell: an atom's outermost energy level

covalent bond: the connection between two atoms that share electrons

- **Number of protons:** Protons have positive charges, electrons have negative charges, and opposite charges attract. Therefore, the nucleus of an atom with more protons exerts a greater attractive force on the atom's valence electrons, pulling the electrons closer to the nucleus. Atoms farther to the right in a period have more protons than atoms farther to the left in the same period. Therefore, atomic radii decrease when moving from left to right across the periodic table. You can see this trend in the figure at right.



In general, atomic radii decrease from left to right across the periodic table and increase from top to bottom.

Trends in Ionic Size

An *ion* is an atom that has acquired an electric charge by gaining or losing electrons. The size of an ion depends on the ion's charge. A positively charged *cation* is always smaller in size than its parent atom. This is because a cation forms when an atom loses electrons. The resulting cation has more protons than electrons and therefore a net positive charge. This increase in positive charge pulls the cation's valence electrons toward its nucleus. As a result, the ionic radius is smaller than the radius of the parent atom. The greater the positive charge, the greater the pull on the valence electrons and the smaller the ionic radius.

In contrast, an *anion*—a negatively charged ion—is larger in size than its parent atom. An anion has more electrons than protons. Because like charges repel, the stronger negative charge pushes the electrons away from each other, giving an anion a larger ionic radius than its parent atom's radius. Anions with greater negative charges have larger ionic radii.

Finally, ions toward the bottom of a group have greater ionic radii than ions toward the top of the same group. This is because ions farther down in a group have additional electron shells.

What Do You Think?

The following diagram outlines the top six periods of the periodic table. Based only on their locations on the periodic table, atoms of which element have the largest atomic radii: A, B, or C?

Trends in Electronegativity

Some elements are able to attract electrons more easily than others. These elements have greater *electronegativities*. An American scientist named Linus Pauling established an electronegativity scale for each element, as shown below. Atoms with larger numbers according to Pauling's scale have greater electronegativities and more easily attract electrons.

Electronegativities

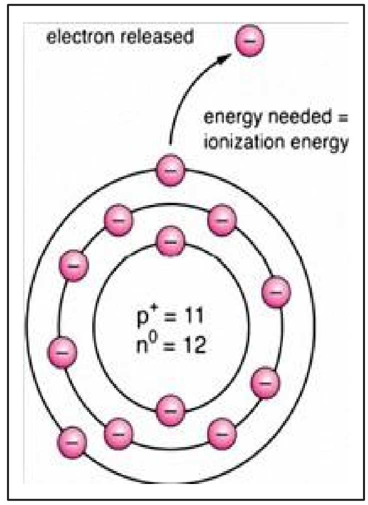
Period	1A	2A	3B	4B	5B	6B	7B	← 8B	8B	8B →	1B	2B	3A	4A	5A	6A	7A	8A
1	H 2.1																	
2	Li 1.0	Be 1.5											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	
3	Na 0.9	Mg 1.2											Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	
4	K 0.8	Ca 1.0	Sc 1.3	Ti 1.5	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.7	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	
5	Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	
6	Cs 0.7	Ba 0.9	La* 1.1	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.0	At 2.2	
7	Fr 0.7	Ra 0.9	Ac† 1.1															

*Lanthanide series 1.1-1.3
†Actinide series 1.3-1.5

These values suggest two trends. First, the electronegativity of atoms typically decreases as you move down a group. Second, the electronegativity of atoms increases as you move left to right across a period.

Trends in Ionization Energy

Energy is needed to remove an electron from the outer electron shell of a neutral atom. This energy is the atom's *ionization energy* because a neutral atom that loses an electron becomes an ion. The first electron removed from a neutral atom is referred to as the *first ionization energy*. For example, here is the chemical equation representing the first ionization of a sodium atom:



Ionization energy is the energy necessary to remove a valence electron from an atom.

[Ionization Energy] + Na → Na^+ + e^-

The ionization energy converts the sodium atom (Na) into a sodium cation (Na^+) by removing an electron (e^-). Protons in an atom's nucleus keep electrons in orbit around the nucleus. Moving down a group on the periodic table, an atom's valence shell gets farther from the atom's nucleus. As a result, less energy is necessary to remove a valence electron from atoms farther down in a group. In other words, as you move down a group on the periodic table, the first ionization energy typically decreases. Ionization energy typically increases, however, as you move from left to right across a period. This is because atoms farther to the right on the periodic table have more protons. As a result, their larger nuclei exert greater attractive forces on their electrons.

Look Out!

First ionization energy refers to the removal of only the first electron from a neutral atom. Trends relating to ionization energy are slightly different for ions.

For example, a neutral sodium atom (Na) has only one electron in its valenc electron is removed, the resulting sodium cation (Na^+) has eight electrons in shown in the diagram. According to the *octet rule*, atoms with eight valence likely to gain or lose more electrons. As a result, much more energy is nece electron from Na^+ than from Na.

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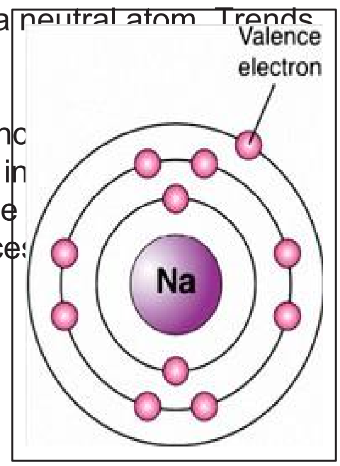


A neutral sodium atom (Na) has 11 electrons distributed among three energy levels

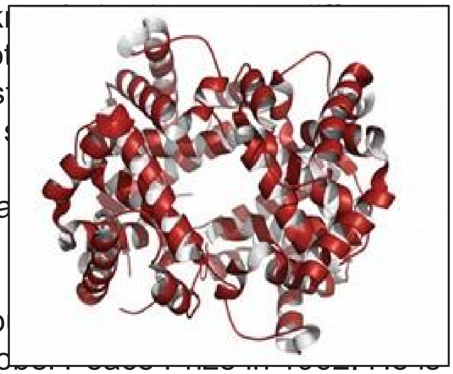
Scientists in the Spotlight: Linus Pauling

American chemist Linus Pauling (1901–1994) won the 1954 Nobel Prize in chemistry for his work on chemical bonds. Pauling challenged the contemporary view of how elements are connected. Pauling used an interdisciplinary approach to describe his concept of electronegativity. For example, he borrowed from the study of physics to describe the structure of atoms and molecules, including the angles at which chemical bonds form and the distances between atoms in compounds.

In addition to his work on chemical bonds, Pauling expanded his k
areas of science. He used x-ray crystallography to understand prot
proteins often contain two different types of folds: regions that twis
helixes) and regions that fan out like folded paper (known as beta s

Pauling also studied medicine and health, developing our understa
anemia, and the importance of vitamin C in the human diet.

Linus Pauling used his popularity as a Nobel-winning scientist to p
nuclear testing and proliferation. For this work, Pauling won the Nobel Peace Prize in 1962. He is the only person to have individually won two Nobel prizes.

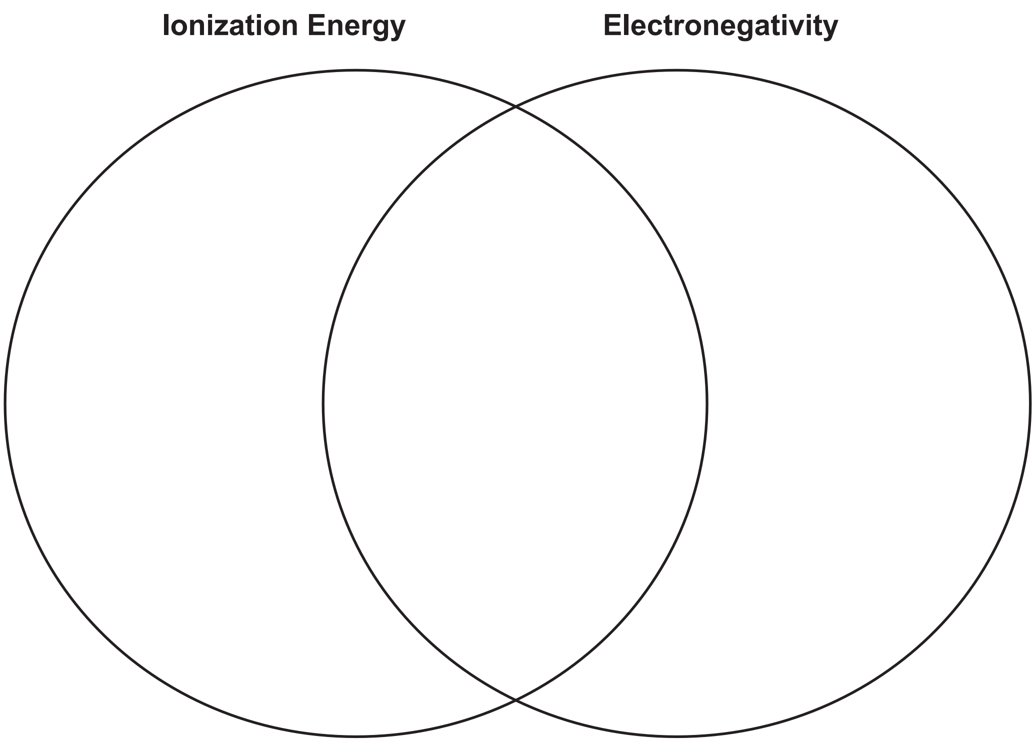


Pauling discovered the structure of hemoglobin, a protein in the blood, is made of many alpha helices.

Try Now

What do you know?
Compare ionization energy with electronegativity. Read the list of terms in the box below. Write each term in the correct place on the Venn diagram on the next page.

Ionization Energy vs. Electronegativity	
• Decreases going down a column	• Is described by this equation:
• Is the energy needed to remove an electron	$X \rightarrow X^{+} + e^{-}$
• Increases going across a row	• Is the greatest for the element fluorine
• Is a value determined from an atom's	• Is the greatest for the element helium
ability to attract an electron	• Is the smallest for the element cesium
• Was identified by Linus Pauling	



Connecting With Your Child

Modeling Periodic Trends
Your child can learn more about trends in the periodic table by creating a three- dimensional model of one of the four trends discussed in this companion: atomic radius, ionic radius, ionization energy, and electronegativity. First, you will need to locate a copy of the periodic table that describes the trend you wish to model. (You can find a copy online.) Your child may use pipe cleaners, sticks, or straws of various sizes to illustrate the magnitude of each property and represent it in three dimensions.

For example, here are the atomic radii, measured in picometers (pm), of the elements in Group 1 (sometimes labeled 1A), from top to bottom:

- Lithium (Li): 157 pm
- Sodium (Na): 186 pm
- Potassium (K): 231 pm
- Rubidium (Rb): 244 pm
- Cesium (Cs): 262 pm

Your child may represent each 100 picometers with 1 inch of pipe cleaner. In this case, the pipe cleaner for Li would measure approximately 1.6 inches. Once your child has measured the appropriate lengths for each element, your child may compare them to see the relative size of each element, as measured by atomic radius.

Here are some questions to discuss with your child:

1. How can models help you to better understand periodic trends? Explain.
2. Could you use your three-dimensional model to identify other trends in the periodic table? Explain.
3. Based on your model, what are the trends going down a group or across a period for the property you chose? Does this trend hold for each group and/or period? Explain.