



15.2 Electrons and Chemical Bonds

The discovery of energy levels in the atom solved a 2,000-year-old mystery. The mystery was why elements combined with other elements only in particular ratios (or not at all). For example, why do two hydrogen atoms bond with one oxygen atom to make water? Why isn't there a molecule with three (H_3O) or even four (H_4O) hydrogen atoms? Why does sodium chloride have a precise ratio of one sodium ion to one chloride ion? Why don't helium, neon, and argon form compounds with any other element? The answer has to do with energy levels and electrons.

Valence electrons

What are valence electrons?

Chemical bonds are formed only between the electrons in the highest unfilled energy level. These electrons are called **valence electrons**. You can think of valence electrons as the outer "skin" of an atom. Electrons in the inner (filled) energy levels do not "see" other atoms because they are shielded by the valence electrons. For example, chlorine has 7 valence electrons. The first 10 of chlorine's 17 electrons are in the inner (filled) energy levels (Figure 15.9).

Most elements bond to reach 8 valence electrons

It turns out that *8 is a magic number for chemical bonding*. All the elements heavier than boron form chemical bonds to try and get to a configuration with eight valence electrons (Figure 15.10). Eight is a preferred number because 8 electrons are a complete (filled) energy level. The noble gases already have a magic number of 8 valence electrons. They don't form chemical bonds because they don't need to!

Light elements bond to reach 2 valence electrons

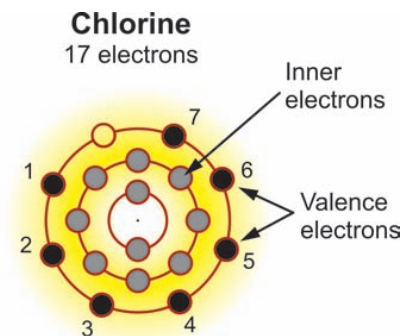
For elements with atomic number 5 (boron) or less, the magic number is 2 instead of 8. For these light elements, 2 valence electrons completely fills the *first* energy level. The elements H, He, Li, Be, and B form bonds to reach the magic number of 2 valence electrons.

Hydrogen is special

Because of its single electron, hydrogen can also have 0 valence electrons! Zero is a magic number for hydrogen, as well as 2. This flexibility makes hydrogen a very "friendly" element; hydrogen can bond with almost any other element.

VOCABULARY

valence electrons - electrons in the highest unfilled energy level of an atom. These electrons participate in chemical bonds.



Chlorine has 7 valence electrons

Figure 15.9: Chlorine has 7 valence electrons. The other 10 electrons are in filled (inner) energy levels.

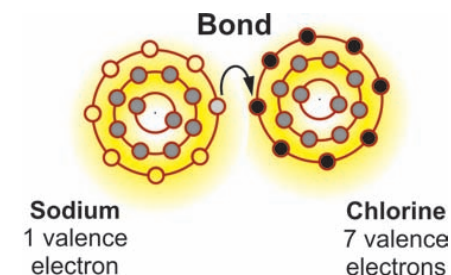
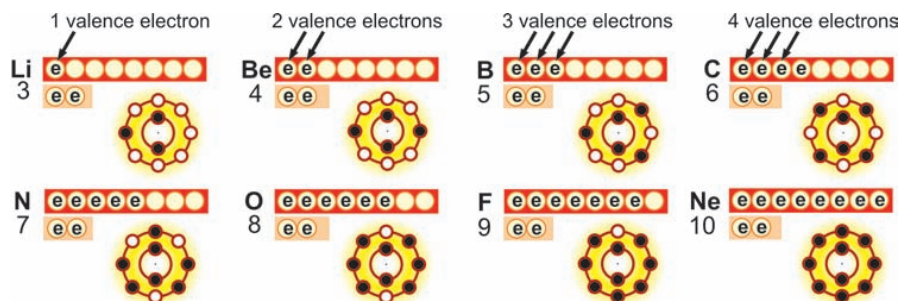


Figure 15.10: Chlorine and sodium bond so each can reach a configuration with 8 valence electrons.

Valence electrons and the periodic table

Period 2 elements The illustration below shows how the electrons in the elements in the second period (lithium to neon) fill the energy levels. Two of lithium's three electrons go in the first energy level. Lithium has one valence electron because its third electron is the only one in the second energy level.

Each successive element has one more valence electron Going from left to right across a period, each successive element has one more valence electron. Beryllium has two valence electrons, boron has three, and carbon has four. Each element in the second period adds one more electron until all 8 spots in the second energy level are full at atomic number 10, which is neon, a noble gas. Neon has 8 valence electrons



Bonding Oxygen has 6 valence electrons. To get to the magic number of 8, oxygen needs to add two electrons. *Oxygen forms chemical bonds that provide these two extra electrons.* For example, a single oxygen atom combines with two hydrogen atoms because each hydrogen can supply only one electron. Oxygen combines with one beryllium atom because beryllium can supply two valence electrons to give oxygen its preferred number of 8 (Figure 15.11).

Double bonds share 2 electrons Carbon has four valence electrons. That means two oxygen atoms can bond with a single carbon atom, each oxygen sharing two of carbon's four valence electrons. The bonds in carbon dioxide (CO_2) are double bonds because each bond involves 2 electrons (Figure 15.12).

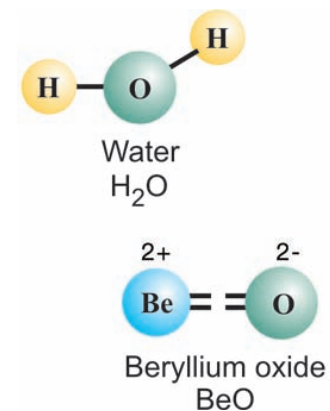


Figure 15.11: Water (H_2O) and beryllium oxide (BeO).

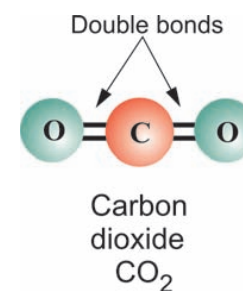


Figure 15.12: Carbon forms two double bonds with oxygen to make carbon dioxide.



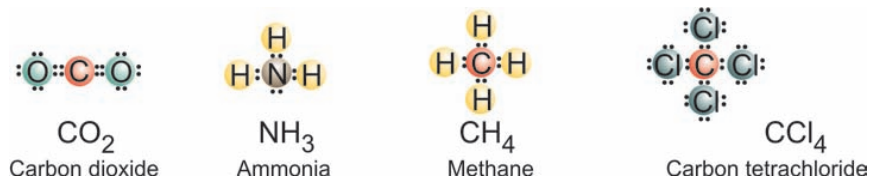
Lewis dot diagrams

Dot diagrams of the elements

A clever way to keep track of valence electrons is to draw Lewis dot diagrams. A dot diagram shows the element symbol surrounded by one to eight dots representing the valence electrons. Each dot represents one electron. Lithium has one dot, beryllium has two, boron has three, etc. Figure 15.13 shows the dot diagrams for the first 10 elements.

Dot diagrams of molecules

Each element forms bonds to reach one of the magic numbers of valence electrons: 2 or 8. In dot diagrams of a complete molecule, each element symbol has either 2 or 8 dots around it. Both configurations correspond to completely filled (or empty) energy levels.



Example dot diagrams

Carbon has four dots and hydrogen has one. One carbon atom bonds with four hydrogen atoms because this allows the carbon atom to have eight valence electrons (8 dots)—four of its own and four shared from the hydrogen atoms. The picture above shows dot diagrams for carbon dioxide (CO_2), ammonia (NH_3), methane (CH_4), and carbon tetrachloride (CCl_4), a flammable solvent.



Dot diagrams

Draw the dot diagram for nitric acid, HNO_3 .

1. Looking for: Dot diagram
2. Given: Chemical formula HNO_3
3. Relationships: add diagram answer
4. Solution:

Lewis dot diagrams

Neon

8 valence electrons



Fluorine

7 valence electrons



Oxygen

6 valence electrons



Nitrogen

5 valence electrons



Carbon

4 valence electrons



Boron

3 valence electrons



Beryllium

2 valence electrons



Lithium

1 valence electron



Hydrogen

1 valence electron

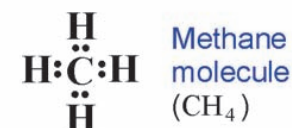


Figure 15.13: Lewis dot diagrams show valence electrons as dots around the element symbol. Atoms form bonds to get eight valence electrons by sharing with other atoms.

Oxidation numbers

Oxidation numbers A sodium atom always ionizes to become Na^+ (a charge of +1) when it combines with other atoms to make a compound. Therefore, we say that sodium has an **oxidation number** of 1+. An oxidation number indicates the charge on the remaining atom (ion) when electrons are lost, gained, or shared in chemical bonds. Table 15.1 shows the oxidation numbers for some elements. Notice that the convention for writing oxidation numbers is the opposite of the convention for writing the charge. When writing the oxidation number, the positive (or negative) symbol is written after the number, not before it.

Oxidation numbers and the periodic table Oxidation numbers correspond closely to an element's group on the periodic table. All of the alkali metals have oxidation numbers of 1+ since these elements all prefer to lose one electron in chemical bonds. All of the halogens have an oxidation number of 1- because these elements prefer to gain an electron in chemical bonds. The diagram below shows the trend in oxidation numbers across the periodic table. Most transition metals have complicated oxidation numbers because they have many more electrons.

1+	2+	Most common oxidation number										3+	4+	3-	2-	1-		
↓	↓											↓	↓	↓	↓	↓		He 2
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10	
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18	
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36	
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54	

NOTE: Many elements have more than one possible oxidation number.

VOCABULARY

oxidation number - indicates the charge of an atom when an electron is lost, gained, or shared in a chemical bond. An oxidation number of +1 means an electron is lost, -1 means an electron is gained.

Table 15.1: Some oxidation numbers

atom	electrons gained or lost	oxidation number
K	loses 1	1+
Mg	loses 2	2+
Al	loses 3	3+
P	gains 3	3-
Se	gains 2	2-
Br	gains 1	1-
Ar	loses 0	0

SOLVE IT!

What is fluorine's (F) oxidation number? If you think it is 1-, you are right. Like the other halogens, fluorine gains one electron, one negative charge, when it bonds with other atoms.



Predicting a chemical formula

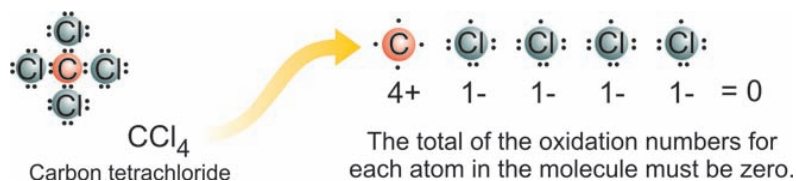
Oxidation numbers in a compound add up to zero

When elements combine in molecules and ionic compounds, the total electric charge is always zero. This is because any electron donated by one atom is accepted by another. The rule of zero charge is easiest to apply using oxidation numbers. The total of all the oxidation numbers for all the atoms in a compound must be zero. This important rule allows you to predict many chemical formulas.

The oxidation numbers for all the atoms in a compound must add up to zero.

Example, carbon tetrachloride

To see how this works, consider the compound carbon tetrachloride (CCl_4). Carbon has an oxidation number of $4+$. Chlorine has an oxidation number of $1-$. It takes four chlorine atoms to cancel with carbon's $4+$ oxidation number.



STUDY SKILLS

Multiple oxidation numbers

Many periodic tables list multiple oxidation numbers for most elements. This is because more complex bonding is possible. This course gives you the fundamental ideas but there is much more!

When multiple oxidation numbers are shown, the most common one is usually in bold type. For example, nitrogen has possible oxidation numbers of $5+$, $4+$, $3+$, $2+$ and $3-$ even though $3-$ is the most common.

$5+$, $4+$, $3+$ $2+$, $3-$
N 7 nitrogen



Predict a chemical formula

Iron and oxygen combine to form a compound. Iron (Fe) has an oxidation number of $3+$. Oxygen (O) has an oxidation number of $2-$. Predict the chemical formula of this compound.

- Looking for: Chemical formula
- Given: Oxidation numbers Fe $3+$ and O $2-$
- Relationships: The oxidation numbers for all the atoms in a compound must add up to zero.
- Solution: Three oxygen atoms contribute the total oxidation number of $6-$. It takes only two iron atoms to get a total oxidation number of $6+$. Therefore, the chemical formula is Fe_2O_3 .

Your turn...

- Predict the chemical formula of the compound containing beryllium ($2+$) and fluorine ($1-$). **Answer:** BeF_2

Ionic and covalent bonds

Why bonds are ionic or covalent Whether or not a compound is ionic or covalently bonded depends on how much each element “needs” an electron to get to a magic number (2 or 8). Elements that are very close to the noble gases tend to give or take electrons rather than share them. These elements often form ionic bonds rather than covalent bonds.

Sodium chloride is ionic As an example, sodium has one electron more than the noble gas neon. Sodium has a very strong tendency to give up that electron and become a positive ion. Chlorine has one electron less than argon. Therefore, chlorine has a very strong tendency to accept an electron and become a negative ion. Sodium chloride is an ionic compound because sodium has a strong tendency to give up an electron and chlorine has a strong tendency to accept an electron.

Widely separated elements form ionic compounds On the periodic table, strong electron donors are the left side (alkali metals). Strong electron acceptors are on the right side (halogens). The farther separated two elements are on the periodic table, the more likely they are to form an ionic compound.

Nearby elements form covalent compounds Covalent compounds form when elements have roughly equal tendency to accept electrons. Elements that are nonmetals and therefore close together on the periodic table tend to form covalent compounds with each other because they have approximately equal tendency to accept electrons. Compounds involving carbon, silicon, nitrogen, and oxygen are often covalent.

Alkali metals												Halogens					He 2
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54

← **Strong electron donors** **Strong electron acceptors** →



Predicting ionic or covalent bonds

Potassium (K) combines with bromine (Br) to make the salt, potassium bromide (KBr). Is this likely to be an ionic or covalently bonded compound?

- Looking for: Ionic or covalent bond
- Given: K and Br
- Relationships: K is a strong electron donor. Br is a strong electron acceptor.
- Solution: KBr is an ionic compound because K and Br are from opposite sides of the periodic table.

Your turn...

- Is silica (SiO₂) likely to be an ionic or covalently bonded compound?
Answer: covalent
- Is calcium fluoride (CaF₂) likely to be an ionic or covalently bonded compound?
Answer: ionic



15.2 Section Review

- Atoms form chemical bonds using:
 - electrons in the innermost energy level
 - electrons in the outermost energy level
 - protons and electrons
- Which of the diagrams in Figure 15.14 shows an element with three valence electrons? What is the name of this element?
- Which of the following elements will form a double bond with oxygen making a molecule with one atom of the element and one atom of oxygen.
 - lithium
 - boron
 - beryllium
 - nitrogen
- Name two elements that have the Lewis dot diagram shown in Figure 15.15.
- The oxidation number is:
 - the number of oxygen atoms an element bonds with
 - the positive or negative charge acquired by an atom in a chemical bond
 - the number of electrons involved in a chemical bond
- Name three elements that have an oxidation number of 3+.
- What is the oxidation number for the elements shown in Figure 15.16?
- When elements form a molecule, what is TRUE about the oxidation numbers of the atoms in the molecule?
 - The sum of the oxidation numbers must equal zero.
 - All oxidation numbers from the same molecule must be positive.
 - All oxidation numbers from the same molecule must be negative

Which of these diagrams shows 3 valence electrons?

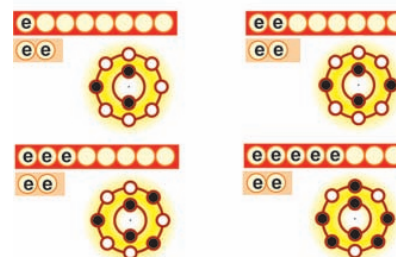


Figure 15.14: Question 2.

Name two elements that have this Lewis dot diagram.



Figure 15.15: Question 4.

What is the oxidation number for these elements?

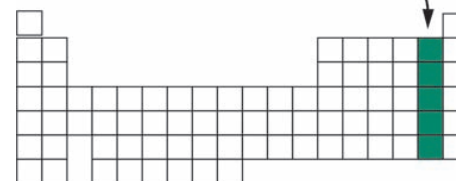


Figure 15.16: Question 7