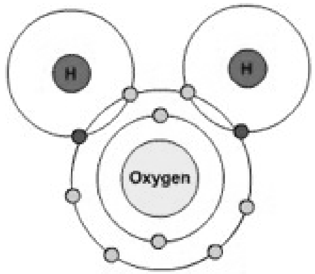
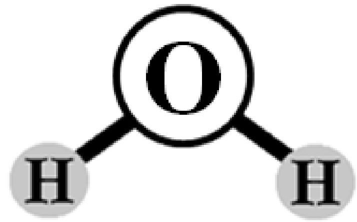
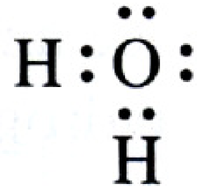


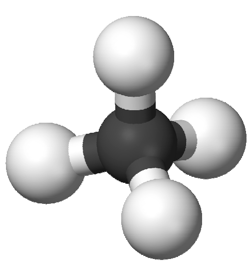


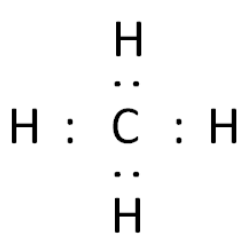


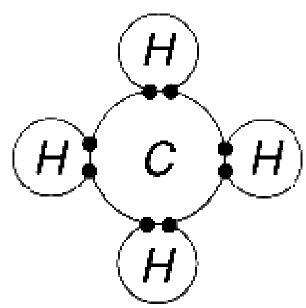
Atoms

and

Molecules







Atoms and Molecules

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THE ATOMIC LAW

Everything is made of atoms – little particles that are always moving around;
they attract each other when they are close to each other,
but they repel each other but if we push them too close together.

In this lesson, we will discuss part of the Atomic Law: "**they attract each other when they are close together.**" Atoms attract each other, but they do not always stay together and form molecules. We will discuss why some atoms come together and form molecules, and why some atoms do not form molecules.

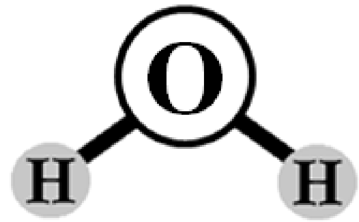
1. How Atoms Change

Sometimes atoms come together and make ***molecules***, but the molecules are very different from the atoms. For example, atoms of sodium (Na) and chlorine (Cl) come together to make NaCl, normal salt. NaCl is everywhere – we put salt in our food, there is salt in ocean water, and there is salt in our blood.

However, sodium and chlorine atoms are very dangerous. Chlorine gas is poison; armies used it to kill people in World War I. Sodium is also dangerous – sodium and water together give an explosion like a bomb. Sodium and chlorine are dangerous atoms, but they are not dangerous when they come together and make NaCl; salt is not a weapon that we use in war, and salt does not explode when we mix it with water. A ***chemical reaction*** can change dangerous and poisonous atoms into normal, everyday salt; it can completely change how atoms act.

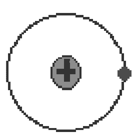
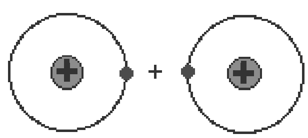
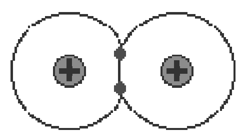
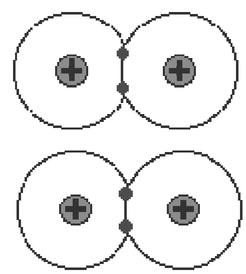
In this lesson, we will discuss two important skills for understanding chemical reactions and molecules: (1) we count the number of ***atoms*** before and after a chemical reaction and (2) we count the number of ***electrons*** each atom has in a molecule. In the next section, we will discuss how to count the number of atoms before and after a chemical reaction; we will also discuss how to balance chemical reactions.

2. Chemical Reactions and Chemical Formulas



We see a water molecule in the picture. The ***chemical formula*** for water is H_2O; this formula tells us that a water molecule has two hydrogen atoms together with an oxygen atom.

Chemical formulas use a special language that we have to understand if we want to understand molecules. Hydrogen (H) will be our example; there are four different kinds of chemical symbols (chemical "words") we will use: H, 2H, H_2, and $2H_2$. The symbol "H" means the hydrogen atom; "2H" means two hydrogen atoms that do not make a molecule: they are just two separate (individual) atoms; "H_2" means the hydrogen molecule (two hydrogen atoms that came together, sharing their electrons); "$2H_2$" means two separate hydrogen molecules.

			
H 1 HYDROGEN ATOM	2H 2 HYDROGEN ATOMS (not together in a molecule)	H_2 1 HYDROGEN MOLECULE	$2H_2$ 2 HYDROGEN MOLECULES

In chemistry, the subscript (for example, the "2" in H_2) tells us that the atoms are already together in a molecule. The number on the left of a symbol (the "2" in 2H or the first "2" in $2H_2$") shows that two atoms or two molecules are near each other, but not bonded together. When we see a more complex symbol, for example $2C_6H_{12}O_6$, we should first read the molecule ($C_6H_{12}O_6$ is a sugar molecule) and then read the "2" so we know that there are two molecules; "$2C_6H_{12}O_6$" is the symbol for two sugar molecules.

When atoms come together to make molecules, atoms cannot be destroyed and they cannot be created – we have to see the same number of each atom at the end of the ***chemical reaction*** as we see at the beginning of the chemical reaction.

For example, an incorrect chemical formula is this: $H + O_2 \rightarrow H_2O$; in this chemical formula, there is one H atom on the left, but a hydrogen molecule with two H atoms on the right; also, there are two oxygen atoms on the left, but only one on the right. This chemical formula is not balanced. The correct formula is this: $2H_2 + O_2 \rightarrow 2H_2O$. The arrow ($\rightarrow$) tells us that we start with the left side (with two hydrogen molecules and one oxygen molecule) and end on the right side (with water); the arrow also tells us that there was a chemical reaction; when something happens to help atoms come together to make molecules, we call it a chemical reaction.

There are 4 hydrogen atoms at the beginning of the chemical reaction (there are 2 hydrogen molecules, and each hydrogen molecule has 2 hydrogen atoms); therefore, there have to be four hydrogen atoms at the end of the chemical reaction. There are two oxygen atoms at the beginning and four oxygen atoms at the end. To count the atoms on each side, we can think of the formula this way:

$2H_2 \quad + \quad O_2 \quad \rightarrow \quad 2H_2O$	or	$H_2 \quad + \quad O_2 \quad \rightarrow \quad H_2O$ $H_2 \qquad\qquad\qquad\qquad H_2O$

If we count each atom before a chemical reaction and then count each atom after a chemical reaction, we can see if a chemical reaction is possible. However, a balanced reaction can be wrong; for example, here is a reaction that is balanced but wrong: $3K_7 + 2He_7 + 7Na \rightarrow 7He_2NaK_3$; we think that this molecule does not exist anywhere in the world. The chemical reaction is balanced, but the final molecule is not real.

We will study the Full-shell Rule in the next section; it is a better way to find real molecules (He_2NaK_3 is not real). In the next activity, we will discuss only how to see if the chemical reaction is balanced.

Activity: How to check for balanced chemical reactions

Work in your group. On the next page is an exercise to help you see if chemical reactions are balanced. The first exercise is this: $H_2 + O_2 \rightarrow H_2O$; on the left, we see H_2 and O_2. This means that the chemical reaction began with 2 hydrogen atoms and two oxygen atoms. On the right, we see H_2O; there is only one oxygen atom, but in the beginning of the chemical reaction, there were two oxygen atoms; one of them disappeared. This is impossible, so the chemical equation in the first exercise is wrong; next to the reaction; when we have a wrong chemical equation, we circle "No" in the table; if the equation is right, we circle the "Yes".

					LEFT SIDE					RIGHT SIDE		
Yes	(No)	1	$H_2 + O_2 \rightarrow H_2O$ hydrogen + oxygen → water	H 2	O 2 ⬅				H 2	O 1 ⬅		
Yes	No	2	$2H_2 + O_2 \rightarrow 2H_2O$	H	O				H	O		
Yes	No	3	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ methane + oxygen → carbon dioxide + water	C	H	O			C	H	O	
Yes	No	4	$CH_4 + 5O_2 \rightarrow CO_2 + 2H_2O + 3O_2$	C	H	O			C	H	O	
Yes	No	5	$2NaCl + 2H_2O \rightarrow 2H_2 + 2Cl_2 + 2NaOH$ salt+ water → hydrogen gas + chlorine gas + sodium hydroxide	Na	Cl	H	O		Na	Cl	H	O
Yes	No	6	$NaCl + 2H_2O \rightarrow 2H_2 + Cl_2 + NaOH$	Na	Cl	H	O		Na	Cl	H	O
Yes	No	7	$2NaCl + 2H_2O \rightarrow H_2 + Cl_2 + 2NaOH$	Na	Cl	H	O		Na	Cl	H	O

Example: Balancing a chemical reaction

Now that we can count atoms to see if chemical reactions are balanced, we can balance some chemical reactions. We will start by looking at this chemical reaction:

$$\_\_\_\_ \text{Al} + \_\_\_\_ O_2 \rightarrow \_\_\_\_ Al_2O_3$$

This reaction is not balanced: there is only one aluminum atom on the left side, but there are 2 aluminum atoms on the right side; also, there are 2 oxygen atoms on the left side, but three on the right.

If we try 2Al + ____ $O_2 \rightarrow Al_2O_3$, then the aluminum is balanced, but the oxygen is not balanced – there are 2 oxygen atoms on the left but three on the right. We will use the "trial and error" method; "trial and error" means that we choose an answer, we test it, and if it doesn't work, we choose another answer. Many times, when we use trial and error two or three times, we find the answer because we learn about the chemical formula when we test our answers.

If we look at the oxygen atoms on both sides of the reaction, we see that on the left, we have O_2, but on the right, we have O_3. When we use trial and error, we think that maybe we need to have **3**O_2 on the left and **2**O_3 on the right; this means that we have six oxygen atoms on each side of the chemical formula: $3O_2$ (on the left) has the same number of oxygen atoms as $2O_3$ (on the right). Therefore, we try: Al + **3**$O_2 \rightarrow$ **2**Al_2O_3; but now the aluminum atoms are not balanced – we have one aluminum atom on the left, but four on the right.

Now we have to balance the aluminum atoms; there are four aluminum atoms on the right, so we try 4 aluminum atoms on the left:

$$\underline{\quad 4 \quad} \text{Al} + \underline{\quad 3 \quad} O_2 \rightarrow \underline{\quad 2 \quad} Al_2O_3.$$

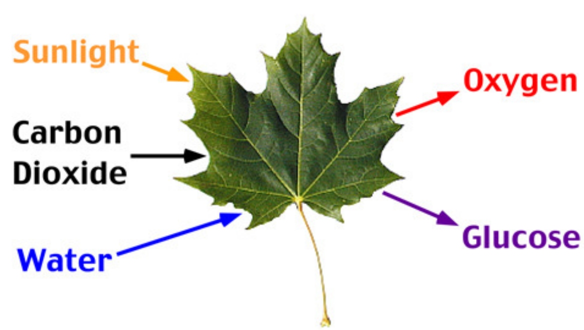
This is the balanced reaction: 4Al has the same number of aluminum atoms as $2Al_2$, and $3O_2$ is the same number of oxygen atoms as $2O_3$.

Activity: Balancing chemical reactions

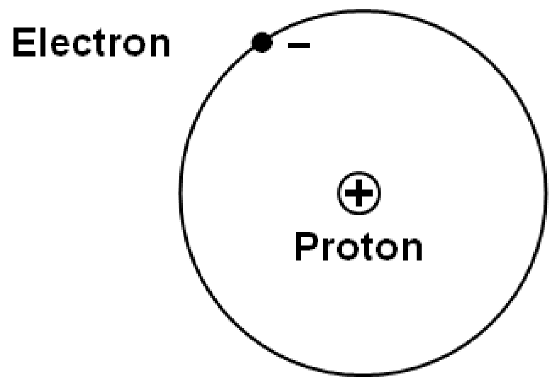
Work in your group. There are some chemical reactions in the table below, but not all of them are balanced. You should find the correct number of molecules for each reaction; draw the number on the underline ("____") symbol. Chemical reaction #1 below is already finished.

1. __4__ Al + __3__ $O_2 \rightarrow$ __2__ Al_2O_3
2. ____ N_2 + ____ $H_2 \rightarrow$ ____ NH_3
3. ____ H_2 + ____ $O_2 \rightarrow$ ____ H_2O
4. ____ H_2O + ____ $SO_3 \rightarrow$ ____ H_2SO_4
5. ____ Fe_3O_4 + ____ CO $\rightarrow$ ____ CO_2 + ____ Fe
6. ____ NaOCl + ____ $NH_3 \rightarrow$ ____ $NaONH_3$ + ____ Cl_2
7. ____ NH_2Cl + ____ $N_2H_4 \rightarrow$ ____ NH_4Cl + ____ N_2
8. ____ $AgNO_3$ + ____ $CaCl_2 \rightarrow$ ____ AgCl + ____ Ca $(NO3)_2$
9. ____ CO_2 + ____ H_2O + sunlight $\rightarrow$ ____ $C_6H_{12}O_6$ + ____ O_2

The last reaction is for photosynthesis; green leaves on trees and other plants need carbon dioxide, water, and sunlight to make sugar (glucose) and oxygen. Sugar molecules give energy to plants and animals. Humans need energy to move our muscles, energy to move blood in our bodies, energy to keep our brains working, and energy to listen and see, and all other activities of our bodies. We get our energy from plants and animals; animals get energy from plants, and plants get energy from the sun.

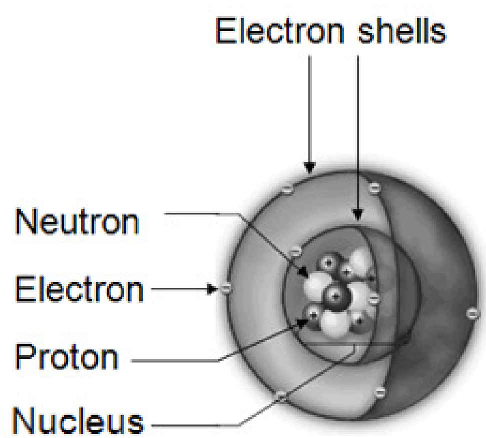


3. Atoms



The smallest atom is the atom of hydrogen, and it has one particle in the middle and another particle going around it. The hydrogen atom reminds us of the Earth and its moon. The Earth is in the middle, and the moon moves around the Earth; the Earth and the moon stay together because of gravity. In the hydrogen atom, the ***proton*** is on the middle, and the ***electron*** moves around the proton.

However, the atom is different from the Earth and moon; in the atom, gravity does not hold the electron in orbit around the proton; there is another force – the ***electrical force***. A scientist from Denmark, Niels Bohr ("bore") developed this picture of the atom, so we call it the Bohr model of the atom.



There are many other atoms bigger than hydrogen; bigger atoms have more protons in the middle and more electrons going around; we can see this in the picture on the right. The picture shows the nitrogen atom with seven electrons and seven protons. We can also see other particles in the nucleus; these are called ***neutrons*** (they do not have the "+" sign inside). Neutrons do not have electrical charge, but they apply a very strong force to help hold the nucleus together. The ***nucleus*** is the name we give to all of the particles that are in the middle of the atom.

When we see the picture, we think about an onion that has many layers; but when we talk about the atom, we do not say "layers" – we say "shells". The electrons move around in ***electron shells***. The first shell of electrons can have a maximum of 2 electrons; if an atom has more than 2 electrons, then the first shell is full, and the other electrons have to go in the next shell.

The second shell of electrons is bigger than the first shell – it can have a maximum of 8 electrons. The picture shows sodium (Na) an atom that has 11 electrons. Sodium has 2 electrons in the first shell (so the first shell is full). It has 8 electrons in the second shell (so the second shell is full). It has only one electron in the third shell.

For the molecules we will be looking at, the shells can hold this many electrons:

1^{st} shell:	2 electrons maximum
2^{nd} shell:	8 electrons maximum
3^{rd} shell:	8 electrons maximum

The sodium atom (Na) has 11 electrons, so its 1^{st} shell has 2 electrons (the maximum number for the 1^{st} shell), the 2^{nd} shell has 8 (also the maximum number of electrons for the 2^{nd} shell); the first two shells have a total of 10 electrons, so the 3^{rd} shell has only one more electron. Before we discuss molecules, we will learn some of the language of molecules.

4. Covalent Bonds

The Atomic Law says that two atoms attract each other when they are close together. Electrons in one atom attract the protons of the other atom; this attraction comes from the electrical force – positive electrical charges (protons) attract negative electrical charges (electrons).

Many times, when atoms come together to form molecules, they share electrons; for example, the hydrogen atom has one electron, but if two hydrogen atoms come together to form a hydrogen molecule, then each hydrogen atom has two electrons. When atoms share electrons, we say that they form covalent bonds. Covalent bonds give each atom the correct number of electrons to make the molecule stable. In chemistry, a “stable” molecule is a molecule that stays together. Many atoms that stay together obey the Full-shell Rule; this rule tells us how we can know the correct number of electrons for each atom.

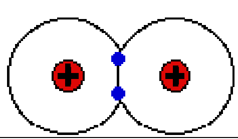
5. The Full-shell Rule

We will now discuss how atoms make molecules when they come together. There is a law for sharing electrons when atoms make molecules, and we can call it the ***Full-shell Rule***.[1]

For a long time, chemists have known that some atoms do not form molecules. For example, helium, neon, and argon did not combine with other atoms; they were given a special name, “noble gases”, to show that they did not like to be around other atoms. In English, “noble” people are people with money or land, (or people in the king’s family), who were so important that they did not want to be with normal people. In a similar way, noble gases are atoms that do not come together to form molecules with other atoms. Atoms of helium, neon, argon, and others each have a full shell of electrons; these atoms are stable – they do not form molecules. In a similar way, in a molecule, if every atom has a full shell of electrons, then the molecule is stable (it does not want any more chemical reactions).

The Full-shell Rule: In a molecule, every atom has a full shell of electrons.

Many times atoms are close together, but they do not form molecules; the Full-shell Rule helps us understand why this happens. Many times when atoms actually make molecules, every atom gets a full shell (some people say that every atom “wants to have” a full shell). For example, when two hydrogen atoms come together, they share their electrons, so each atom has a full shell. The pictures below show us two ways to think about the hydrogen molecule.

	H : H or H – H
H_2 showing the electron orbits	H_2 using the Lewis dot diagram

[1] It is also called the ***Octet Rule;*** the prefix “oct” means “eight”, and many full shells have 8 electrons.

On the left, each hydrogen atom has one electron, and when they share their electrons, each atom has two electrons. The hydrogen electron is in the first shell, and the first shell can hold a maximum of two electrons. So when both hydrogen atoms have two electrons, they each have a full shell. If each atom shares one electron, then they make a ***single bond*** (or a single covalent bond). When a hydrogen atom (H) or a helium (He) atom has two electrons, it has a full shell.

Example: To have a full shell, how many electrons does carbon (C) need? Carbon has 6 electrons.

To do this activity, we have to look at section 3 about atoms; the 1^{st} shell of electrons can have a maximum of 2 electrons; the 2^{nd} shell of electrons can have a maximum of 8 electrons. For carbon:

the 1^{st} shell has 2 electrons
the 2^{nd} shell has 4 electrons

The total number of electrons is 6, so we have counted all of carbon's electrons. We know that the 2^{nd} shell has a maximum of 8 electrons, so carbon needs 4 more electrons to make a full shell.

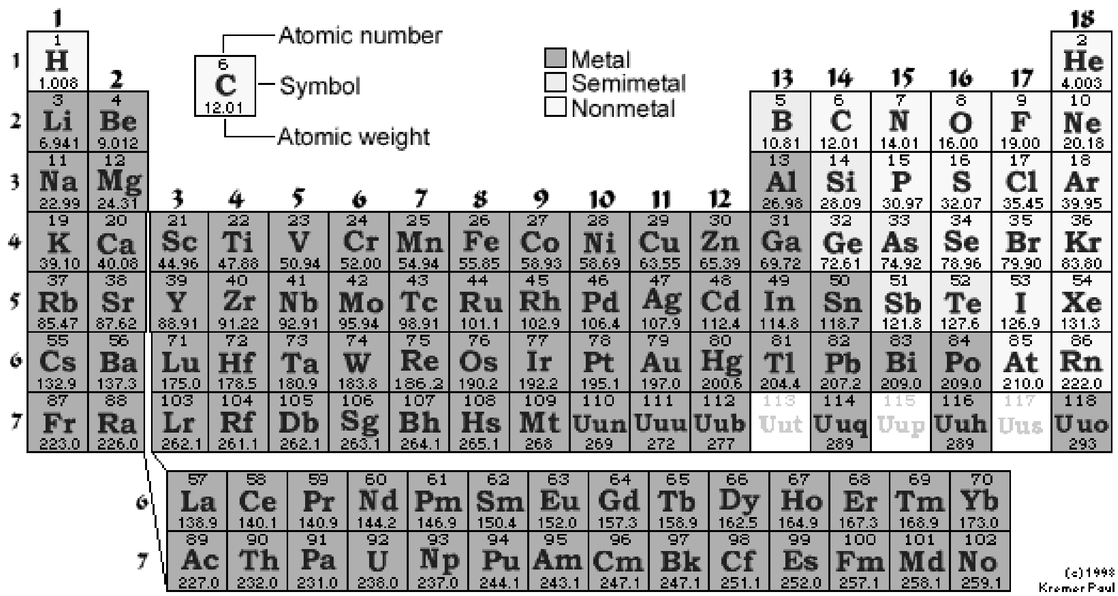
Activity: How to make full shells.
Work in your group.

a. To have a full shell, how many electrons does fluorine (F) need? F has 9 electrons.
b. To have a full shell, how many electrons does chlorine (Cl) need? Cl has 17 electrons.
c. To have a full shell, how many electrons does aluminum (Al) need? Al has 13 electrons.

6. Lewis Dot Diagrams

The Full-shell Rule says that atoms can come together to make molecules when they fill the shells. When each atom in a molecule has a full shell, we say that the molecule satisfies the Full-shell Rule. On the right side of the picture is another way to show the Full-shell Rule with molecules. Each hydrogen atom (H) has only one electron, but when they share electrons, each hydrogen atom has two electrons; for each hydrogen atom, the first shell of electrons is full, so the hydrogen molecule (H**:**H or H**–**H) satisfies the Full-shell Rule. The pictures in the right column of the picture are called ***Lewis dot diagrams***; Lewis is the name of the scientist who worked on this method of drawing molecules.

The Periodic Table of the Elements



1. Use the Periodic Table to find the atomic number – number of electrons in each atom of a molecule.
2. Find the number of electrons in each shell.
3. Circle the number of electrons in the biggest (last) shell; call this number N.
4. Draw the chemical symbol for the atom.
5. Draw N dots around this symbol.

How to Draw a Lewis Dot Diagram for an Atom

If we have to know how many electrons an atom has, we can use the ***Periodic Table*** of the Elements (or the Periodic Table). The Periodic Table below has many small boxes with letters inside; the letters are abbreviations for the names of the atoms. On the top of the letters is a number – the ***atomic number*** – that tells us how many electrons an atom has. For example, in the upper left corner, we can see that H has one electron. In the upper right corner, He has 2 electrons. In the next row, we see that Li has 3 electrons and O has 8 electrons. If we want to draw the Lewis dot diagrams for atoms, we have to know how many electrons they have. Here are the instructions for drawing the Lewis dot diagram for an atom:

When we draw the Lewis dot diagram for salt, NaCl, we have to know the Lewis dot diagram of sodium (Na) and chlorine (Cl). The table below shows how to follow these rules to draw the Lewis dot diagram for Na.

Example: How to draw the Lewis dot diagram for an atom.

In the table below, we use the instructions “How to Draw a Lewis Dot Diagram for an Atom” to draw the Lewis dot diagram for sodium (Na).

1. Use the Periodic Table to find the atomic number – number of electrons in each atom of a molecule.	Na has 11 electrons
2. Find the number of electrons in each shell.	The 1st shell has 2 electrons. The 2nd shell has 8 electrons. The 3rd shell has 1 electron.
3. Circle the number of electrons in the biggest (or last) shell; call this number N.	The 1st shell has 2 electrons. The 2nd shell has 8 electrons. The 3rd shell has 1 electron. N=1
4. Draw the chemical symbol for the atom	Na
5. Draw N dots around the symbol.	Na●

Activity: Lewis dot diagram for F_2

Work in your group. Draw the Lewis dot diagram for the fluorine molecule, F_2; use the Periodic Table and the instructions above.

Activity: Lewis dot diagram for He, Ne, Ar

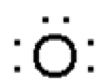
Work in your group. This is a thinking exercise. Find the atoms He, Ne, and Ar in the Periodic Table, and draw their Lewis dot diagrams. These atoms (and other atoms) do not form molecules; can you use the Full-shell Rule to explain why?

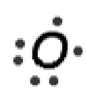
Activity: Lewis dot diagram for HCl

Work in your group. Draw the Lewis dot diagram for hydrochloric acid, HCl; use the Periodic Table and the instructions above.

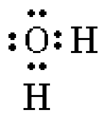
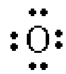
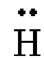
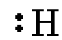
The biggest shell is also called the ***valence shell*** or the ***bonding shell***. For example, water is H_2O, and oxygen has 8 electrons – 2 electrons in the first shell and 6 electrons in the second shell. Therefore, when oxygen and hydrogen come together to make a water molecule, oxygen shares 6 electrons in its bonding shell and each hydrogen shares one electron in its bonding shell.

When the atom has more than one electron, we draw dots all around the atom's symbol; we can draw dots on the left of the symbol, on the right, on top, and on the bottom. For example, the atomic number of oxygen is 8; it has 2 electrons in the first shell and 6 electrons in the second shell. The second shell is the valence shell, so we draw 6 dots around the "O" symbol. Here are two ways to draw the dots:



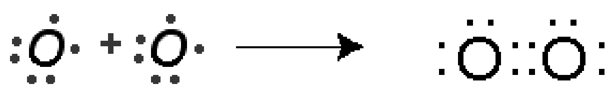


When we draw Lewis dot diagrams for molecules, we can draw the dots in many ways. For example, for water, H_2O, we draw one dot around each hydrogen and then 6 dots around oxygen (as we see in the table below). In the first column of the table is one way to show the H_2O molecule. Each atom in the molecule has a full shell. The hydrogen atom has an electron in only the first shell, and the first shell can have a maximum of 2 electrons, so when H is part of the molecule, it has 2 electrons (so it has a full shell). The oxygen atom has electrons in the second shell, and the second shell can have a maximum of 8 electrons, so oxygen has a full shell in the H_2O molecule.

			
Lewis diagram of the H_2O molecule	In H_2O, O has a full shell – 8 electrons.	In H_2O, H has a full shell – 2 electrons.	And the other H also has a full shell – 2 electrons.

7. Double and Triple Covalent Bonds

When there are two dots between atoms, they are each sharing one electron. However, sometimes atoms have to share two electrons if they form a molecule. For example, oxygen atoms each have to share two electrons to form O_2; the picture below shows the ***double bond*** in the Lewis dot diagram.



There are two oxygen atoms on the left side of the picture; each oxygen atom has 6 valence electrons (they are the little circles around each "O"). The Full-shell Rule says that atoms make molecules with other atoms when every atom gets a full shell, so each oxygen atom needs 8 electrons to fill up the second shell.

The left atom has 8 electrons.

The right atom has 8 electrons.

In the picture, each oxygen atom has 8 electrons around it; the symbol "**::**" shows four electrons. If we try to use a single bond between the oxygen atoms, we cannot satisfy the Full-shell Rule (try using a single bond, and you will see that you cannot do it). When this happens, we can always try a double bond. On the right side of the picture, each oxygen atom has 8 electrons around it; therefore, the O_2 molecule satisfies the Full-shell Rule.

Example: Lewis dot diagram for C_2H_4

To find the Lewis dot diagram for C_2H_4, ethylene[2], we have to first find the Lewis dot diagrams for the atoms. The atomic number of carbon is 6, so it has 2 electrons in the first shell and 4 in the second shell. The valence shell is the second shell (the last one we use), so carbon has four electrons to use when it makes covalent bonds. Hydrogen has on ly one electron, so its valence shell has one electron. Here are the Lewis dot diagrams for every atom in ethylene, C_2H_4:

If we use single bonds, the atoms will not have full shells, but if we use double bonds, we get this diagram; in the Lewis dot diagram, we sometimes draw a songle bond with two dots "**:**"), or we sometimes draw a line (like "|" or "–"); each line means two electrons. We draw a double bond with four dots ("**::**) or two lines ("=").

Ethylene

In ethylene, each hydrogen (H) atom has a full shell; if hydrogen has two electrons, then it has a full shell. Each carbon(C) atom also has a full shell; if carbon has eight electrons, then it has full shell. However, each carbon atom is sharing two electrons; the symbol **C::C (or C=C)** shows that the carbon-carbon bond has four electrons – two electrons from the carbon atom on the left and two electrons from the carbon atom on the right. If two atoms share four electrons, then the atoms form a double bond.

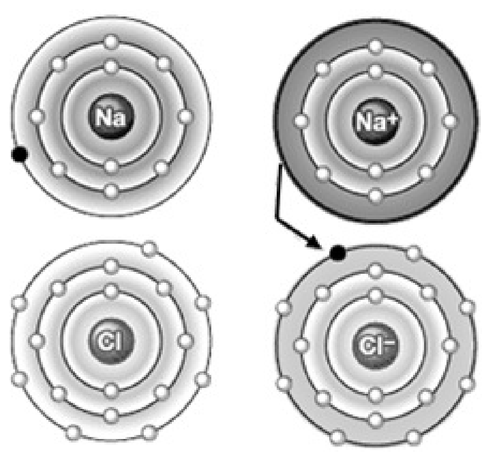
[2] We say, "ETH-uh-leen".

Atoms can also form molecules when they share three electrons; this bond is called a ***triple bond***; in the nitrogen molecule, N_2, the atoms make a triple bond. In the activity at the end of this chapter we will see some examples of triple bonds.

8. Ionic Bonds

When atoms share electrons, we say that they form a covalent bond. However, sometimes an atom does more than share an electron – it gives its electron to another atom. This kind of bond is called an ***ionic bond***. (We can think of an ionic bond as a special kind of covalent bond – the atom shares by giving its electron to another atom.)

An ***ion*** is an atom or molecule that has a positive or negative charge. The Na atom has 11 positive charges in the ***nucleus*** and 11electrons going around the nucleus; if we count the electrical charges as positive and negative numbers, then the nucleus has an electrical charge of +10 and the electrons have an electrical charge of –10; if we add 10 and –10, the sum is zero, so Na is a neutral atom (it has a total electrical charge of zero). If Na loses one electron, it has 11 positive charges, (+11), and only 10 negative charges (–10), so its total charge is +1 (11– 10 = +1).

Before sodium forms an ionic bond, it has 11 electrons. Before chlorine forms an ionic bond, it has 17 electrons.	 Before After	After sodium gives an electron to chlorine, sodium has 10 electrons. Sodium has 8 valence electrons – a full shell. After chlorine takes an electron from sodium, chlorine has 18 electrons. chlorine has 8 valence electrons – a full shell.

Na has 11 electrons: 2 in the 1^{st} shell, 8 in the 2^{nd} shell, and 1 in the 3^{rd} shell;

Cl has 17 electrons: 2 in the 1^{st} shell, 8 in the 2^{nd} shell, and 7 in the 3^{rd} shell.

To make NaCl, Na gives its 3rd-shell electron to Cl, so Na has a full 2nd shell; Cl gets another electron, so it has a full shell of 8 electrons.

Na and Cl atoms are on the left side of the picture below. Na has one electron in its biggest shell, and Cl has 7 electrons in its biggest shell, so we might expect both atoms to share electrons so that there are 8 electrons in the biggest shell of the molecule. However, during the chemical reaction, Na gives its electron to Cl. Cl has an extra electron, so it has a negative electrical charge (that is what the negative sign means in the symbol "Cl^-"), and Na lost an electron, so it has more positive charges than negative charges (the plus sign in "Na+" means that the atom has one more positive charges than negative charges). When NaCl is a solid, it looks like "+" and "–" charges bonded together, as the picture shows.

Activity: Ionic bonding, Lewis dot diagram for KCl

Work in your group. Draw the Lewis diagram for KCl; use the Periodic Table to find the number of electrons for K and for Cl, and then follow the instructions on page 4. In the molecule, how many electrons does K have in its full shell; how many electrons does Cl has in its full shell? Do you think KCL forms an ionic bond?

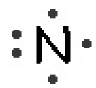
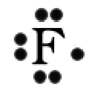
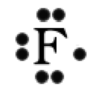
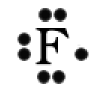
9. Lewis Dot Diagrams for Bigger Molecules

When we draw the Lewis dot diagrams, we can put an atom next to another atom, above it, or below it. NF_3, nitrogen trifluoride is a good example. To find the Lewis dot diagram for nitrogen trifluoride, NF_3, we have to find the number of valence electrons for nitrogen (N) and fluorine (F):

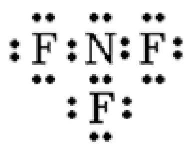
From the Periodic Table, we know that the atomic number of **nitrogen** is 7:
2 electrons in the 1st shell
5 electrons in the 2nd shell.
N = 5 for nitrogen

From the Periodic Table, we know that the atomic number of **fluorine** is 9:
2 electrons in the 1st shell
7 electrons in the 2nd shell.
N = 7 for fluorine

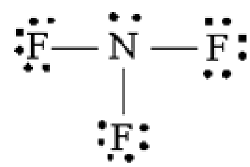
The table below shows the Lewis dot diagrams for each atom in NF_3.

The "N" has five dots around it because it has 5 bonding electrons; each "F" has seven dots around it because fluorine has seven bonding electrons. When we put the atoms together, we have nitrogen trifluoride (in English, "tri" often means "3").



or



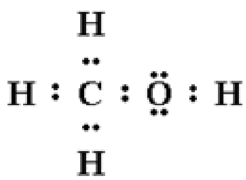
The two pictures show the same thing, but sometimes, chemists use a straight line (——) instead of two dots (**:**) to show that the atoms are each sharing one electron. (We could put the F atom on the top, not the bottom; it does not matter.) The Lewis dot diagram for NF_3 molecule gives us a good idea for making Lewis dot diagrams. In the NF_3 molecule, we see three F atoms, but only (one) single N atom; therefore, we put the one N in the middle, and then put the F atoms around the N. The rule is this: put a single atom in the middle, and put repeated atoms around the middle one.

Now we have four special tools or skills to help us make Lewis dot diagrams for molecules. The table below shows four special "tools" that can help us draw Lewis dot diagrams.

Tool #1: Use ionic bonding so an atom can give away an electron. Tool #2: Use double and triple bonds. Tool #3: Put dots on all four sides (top, bottom, left, right) of another atom. Tool #4: Put single atoms in the middle; put repeated atoms around the middle atom.
Four special rules to help us for draw Lewis diagrams for molecules

Remember that you do not have to use these tools all the time, but sometimes when you cannot find the right Lewis dot diagram, you should try these tools.

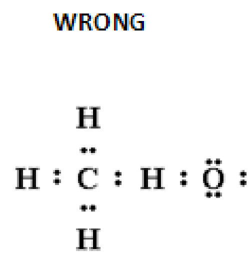
Activity-1: CH_4O



Work in your group. The picture on the left shows the molecule CH_4O (methanol). Show that the dots in the picture are correct; draw the Lewis dot diagram for each atom (H, C, and O), and then show that when you put them together, you can get this picture. Does the molecule satisfy the Full-shell Rule?

Activity-2 CH_4O

Work in your group. The picture on the right is wrong. Count the electrons for each atom, and then explain why the diagram is wrong.



A reminder about trial and error: Sometimes scientists have to try again and again to find an answer. We call this activity "trial and error" – we try ("make a trial") and make a mistake (an error), and then try again. When we make mistakes, we become smarter because we learn from our mistakes.

Activity: Lewis dot diagrams for a table of molecules

Work in your group. Draw the Lewis dot diagrams for the molecules in the table. Follow the instructions on page 13 and the example on page 14.

1. hydrogen molecule	H_2	
2. chlorine molecule	Cl_2	
3. sodium chloride: (table salt)	NaCl	
4. potassium chloride	KCl	
5. fluorine molecule	F_2	
6. hydrochloric acid	HCl	
7. chloroform	$CHCl_3$	
8. carbon tetrafluoride	CF_4	
9. ammonia	NH_3	
10. water	H_2O	
11. ethane	C_2H_6	

12. sulfuric acid	H_2SO_4	
13. methyl chloride	CH_3Cl	
14. methane	CH_4	
15. magnesium chloride	$MgCl_2$	
16. borane	BH_3	
17. oxygen molecule	O_2	
18. nitrogen molecule	N_2	
19. carbon dioxide	CO_2	
20. carbon monoxide	CO	
21. ethyne	C_2H_2	

10. Chemistry Vocabulary – New Words

Atom: An atom is one of the smallest systems of particles that we find in chemical reactions; atoms have positive electrical charge in the middle and negative electrical charge around the outside.

Atomic Law: "Everything is made of atoms – little particles that always move around; they attract each other when they are close together, but repel each other if we push them too close together."

Atomic number: The atomic number is the number of electrons an atom has in its normal condition with a total electrical charge of zero; the atomic number is also the number of protons in the nucleus.

Bohr model of the atom: The "Bohr atom" is similar to the earth and the moon. The Earth is in the middle, and the moon moves around the Earth; the gravitational force holds the moon and the Earth together. In the Bohr atom, the nucleus is in the middle, and electrons (but there is only one electron in the hydrogen atom) move around the nucleus; the electrical force holds the electrons and the nucleus together.

Bonding shell: When atoms share electrons to make molecular bonds, they use electrons from the valence shell of electrons – an atom's largest unfilled electron shell.

Chemical formula: The symbol that shows information about a molecule – which atoms it has and how many of each atom; the chemical formula for water is H_2O; the chemical formula for methane is CH_4.

Chemical reaction: Atoms come together to form molecules; sometimes atoms and molecules come together to form new molecules. A chemical reaction tells us the old atoms and molecules and the new atoms and molecules. A chemical reaction for water is $2H_2 + O_2 \rightarrow 2H_2O$. In the beginning, we have the old molecules (two hydrogen molecules and one oxygen molecule), then we have a chemical reaction, and then, at the end, we have the new molecules (two water molecules).

Covalent bond: When atoms come together and form molecules, they form molecular bonds. If they share one or more electrons, they form a covalent bond.

Double bond: When atoms come together and form molecules, and each atom shares two electrons, they form a double bond. "Double bond" also means "double covalent bond".

Electrical force: Positive electrical charges attract negative electrical charges, but positive electrical charges repel other positive charges; negative charges attract positive negative charges, but they repel other negative charges. We say that like charges repel each other ("+" repels "+"; and "–" repels "–"), and opposite charges attract each other ("+" attracts "–").

Electron: An electron is a particle that has an electrical charge of –1; electrons move around the nuclei of atoms.

Electron shells: If we think of an atom as an onion, then the layers of an onion are like the electron shells. The nucleus is the middle of the onion, and then each later is farther and farther away from the middle. The valence shell of an atom is the biggest shell that has at least one electron in it.

Full-shell Rule: When atoms come together to form molecules, each atom has a full valence shell of electrons at the end; this is the Full-shell Rule. The Full-shell Rule is not correct all the time, but it is a simple way to predict how atoms will come together to form molecules.

Ion: If an atom has, for example, five positive charges (+5) and four negative charges (–4), it is an ion; it is a positive ion because if we add the electrical charges (+5 – 4 = +1), we get a positive number. An atom or molecule that does not have the same number of positive charges as it has negative charges, is an ion. The symbol for a sodium ion with a +1 electrical charge is Na^+; the symbol for a chlorine ion with a – 1 electrical charge is Cl^-.

Ionic bond: When atoms come together and form molecules, they form molecular bonds. If one atom gives one or more electrons to another atom, they form an ionic bond.

Lewis dot diagrams: Lewis dot diagrams show how atoms share electrons when they come together to form molecules; each dot in a Lewis dot diagram is one valence electron. The Full-shell Rule helps us understand Lewis dot diagrams because each atom has a full shell of dots around it. The Lewis dot diagram for the hydrogen molecule is H**:**H; each "H" has two dots next to it, and each hydrogen atom has two electrons (because of their covalent bond).

Nuclei: ("new-clee-eye") This word is the plural of "nucleus: one nucleus, two nuclei.

Nucleus: ("new-clee-us") Atoms have electrons that move around the nucleus; the nucleus (or "atomic nucleus") is the middle part of the atom. The nucleus of a hydrogen atom is just one proton (a positive charge); the nucleus of every other atom has protons and neutrons.

Periodic Table: The Periodic Table (or "Periodic Table of the Elements") is a picture that shows the symbol for each atom, how heavy each atom is, and how many electrons it normally has in nature.

Proton: The nucleus of every atom has at least one proton; a proton is a particle that has a positive electrical charge of +1. (An electron has a negative electrical charge of –1.)

Single bond: When atoms come together and form molecules, and each atom shares only one electron, they form a single bond. "Single bond" also means "single covalent bond".

Double bond: When atoms come together and form molecules, and each atom shares only two electrons, they form a double bond. "Double bond" also means "double covalent bond".

Triple bond: When atoms come together and form molecules, and each atom shares three electrons, they form a triple bond. "Triple bond" also means "triple covalent bond".

Valence shell: The valence shell of an atom is the biggest electron shell that has at least one electron in it. For example, the valence shell of magnesium (Mg) is the 3^{rd} shell. Mg has 12 electrons: the 1^{st} shell has two electrons, the second shell has eight electrons, and the 3^{rd} shell has two electrons. The 1^{st} electron shell is full (because the 1^{st} shell can have a maximum of 2 electrons); the 2^{nd} electron shell is full (because the 2^{nd} shell can have a maximum of 8 electrons); the 3^{rd} shell is not full (because the 3^{rd} shell can have a maximum of 8 electrons, but the 3^{rd} shell of Mg has only 2 electrons). Therefore, the 3^{rd} shell is the valence shell for Mg.