TEACHER'S MANUAL

ATOMS AND MOLECULES

Atoms and Molecules

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An outline of this lesson

How Atoms Change

Molecular bonds hold atoms together in molecules; they can completely change the way atoms act. Chemical reactions change individual atoms into molecules.

Chemical Reactions and Chemical Formulas

We can count each kind of atom before a chemical reaction and then after the chemical reaction; if the numbers are not the same, then the reaction is not correct. However, if we want to predict correct molecules, we need more information about atoms.

Atoms

Atoms have positive electrical charges on the inside and negative electrical charges – electrons – moving around on the outside; atoms use their electrons when they come together to form molecules.

The Full-shell Rule

Atoms come together to form molecules by sharing their electrons; the Full-shell Rule helps us predict correct chemical reactions.

Lewis Dot Diagrams

We use Lewis dot diagrams to draw valence electrons in chemical formulas; the diagrams help us show that molecules obey the Full-shell Rule.

Double and Triple Covalent Bonds

Some atoms in a molecule share two or three electrons; if they each share only one electron, they cannot obey the Full-shell Rule.

Ionic Bonds

Sometimes an atom cannot obey the Full-shell Rule if it shares electrons; it has to give an electron to another atom.

Lewis Dot Diagrams for Bigger Molecules

Big molecules also obey the Full-shell Rule; for big molecules, we draw more complex Lewis dot diagrams.

1. How Atoms Change

There are no activities for this section.

2. Chemical Reactions and Chemical Formulas

Answers for the worksheet of chemical formulas

				LEFT SIDE					RIGHT SIDE			
Yes	[✓ No]	1	$H_2 + O_2 \rightarrow H_2O$ hydrogen + oxygen → water		O 2 ⬅				H 2	O 1 ⬅		
[✓ Yes]	No	2	$2H_2 + O_2 \rightarrow 2H_2O$	H 4	O 2				H 4	O 2		
[✓ Yes]	No	3	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ methane + oxygen →carbon dioxide + water	C 1	H 4	O 4			C 1	H 4	O 4	
Yes	[✓ No]	4	$CH_4 + 5O_2 \rightarrow CO_2 + 2H_2O + 3O_2$	C 1	H 4	O 10			C 1	H 4	O 8	
Yes	[✓ No]	5	$2NaCl + 2H_2O \rightarrow 2H_2 + 2Cl_2 + 2NaOH$ sodium chloride (salt) + water → hydrogen gas + chlorine gas + sodium hydroxide	Na 2	Cl 2	H 4	O 2		Na 2	Cl 4	H 5	O 2
Yes	[✓ No]	6	$NaCl + 2H_2O \rightarrow 2H_2 + Cl_2 + NaOH$	Na 1	Cl 1	H 4	O 2		Na 1	Cl 2	H 5	O 1
[✓ Yes]	No	7	$2NaCl + 2H_2O \rightarrow H_2 + Cl_2 + 2NaOH$	Na 2	Cl 2	H 4	O 2		Na 2	Cl 2	H 4	O 2

How to balance chemical reactions using mathematics

We can balance chemical reactions using algebra, but we can also use trial and error. Students can try an answer, and if it doesn't work, try another one. You do not need to use mathematics – sometimes students discover a method for balancing chemical reactions. However, here is some mathematics; $H_2 + O_2 \rightarrow H_2O$. This does not balance because there are 2 oxygen atoms on the left and only one oxygen atom on the right. We write this reaction:

$k\ H_2 + m\ O_2 \rightarrow n\ H_2O$

All of the numbers k, m, and n must be counting numbers (1, 2, 3 , …) because we are counting atoms and molecules (we will not use fractions like $^1/_2$ or $^2/_3$). We do not know k, m, or n, but we know that there are *2k* hydrogen atoms and *2m* oxygen atoms on the left; there are *2n* hydrogen atoms and *n* oxygen atoms on the right. To balance the chemical reaction, we must have the same number of hydrogen atoms and the same number of oxygen atoms on each side; therefore

(a) $2k = 2n$ (the same number of hydrogen atoms on each side)
(b) $2m = n$ (the same number of oxygen atoms on each side)

In (a), we see that $2k = 2n$, or $k=n$. First we try $k=1$; if $k=1$, then $n=1$. Then we look at (b) and see that $2m = n$. But if $2m = 1$, then $m= {}^1/_2$, so we have to change n.

Next we try **k=2**; if k=2, then **n=2**. If n=2, then 2m=2, or **m=1**. Now we can see if the answer works; we copy the chemical reaction above:

$k\ H_2 + m\ O_2 \rightarrow n\ H_2O$
$2H_2 + (1)O_2 \rightarrow 2H_2O$

There are four oxygen atoms on the left side and four oxygen atoms on the right side.; there are two oxygen atoms on the left side and two oxygen atoms on the right side. Therefore, the right answer is: $2H_2 + O_2 \rightarrow 2H_2O$.

Remember that we do not need to use this mathematics. Sometimes students find the right answer without mathematics; they learn how to think about chemical reactions after they do a few problems.

Answers to balancing chemical reactions

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

   During photosynthesis, plants put together carbon dioxide, water, and sunlight to get glucose (sugar) and oxygen.

3. Atoms

There are no activities for this section.

4: Covalent Bonds.

There are no activities here; see the worksheet at the end of the lesson.

5. The Full-shell Rule

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 aluminum (Al) need?

Al has 13 electrons.

c. To have a full shell, how many electrons does chlorine (Cl) need?

Cl has 17 electrons.

Answer to How to make full shells.

a. F has 9 electrons: 2 electrons in the 1st shell and 7 electrons in the 2nd shell. The 2nd shell can have a maximum of 8 electrons, so fluorine needs <u>one more electron</u> to fill its 2nd shell.

b. Al has 13 electrons: 2 electrons in the 1st shell, 8 electrons in the 2nd shell, and 3 electrons in the 3rd shell. The 3rd shell can have a maximum of 8 electrons, so Al needs <u>5 more electrons</u> to fill its 3rd shell.

c. Cl has 17 electrons: 2 electrons in the 1st shell, 8 electrons in the 2nd shell, and 7 electrons in the 3rd shell. The 3rd shell can have a maximum of 8 electrons, so Al needs <u>one more electron</u> to fill its 3rd shell.

6. Lewis Dot Diagrams

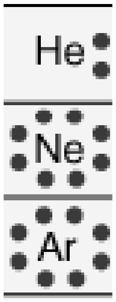
Answer to F_2 exercise

Exercise: work in your group. Draw the Lewis dot diagram for the fluorine molecule, F_2; use the Periodic Table and the four steps of the instructions above.

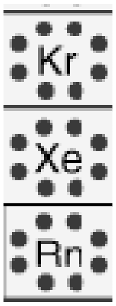
F has 9 electrons: 1st shell has 2, 2nd shell has 7, so we have these two atoms:

Answer to the He, Ne, Ar question

Exercise: 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?



The atoms in the last column of the Periodic Table have full shells; you can see them on the left side of the page. According to the Full-shell Rule, atoms bond so they can <u>get</u> a full shell, but these atoms already <u>have</u> full shells; therefore, they would not have any need to form molecules.



Answer to the HCl activity.

Exercise: work in your group. Draw the Lewis dot diagram for hydrochloric acid, HCl; use the Periodic Table and the four steps of the instructions above.

Hydrogen has one electron, and chlorine has 17: 1st shell 2 electrons, 2nd shell 8 electrons, 3rd shell: 7 electrons. So we have:

7. Double and Triple Bonds.

There are no activities here; see the worksheet at the end of the lesson.

8. Ionic Bonds

Answer to the KCl activity.

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?

K has 19 electrons: 2 electrons in the 1st shell
8 electrons in the 2nd shell
8 electrons in the 3rd shell
1 electron in the 4th shell
N = 1 for K

Cl has 17 electrons: 2 electrons in the 1st shell
8 electrons in the 2nd shell
7 electrons in the 3rd shell
N=7 for Cl

The Lewis dot diagram for K is K●; the Lewis dot diagram for Cl is 

Therefore, the Lewis dot diagram for KCl is this: 

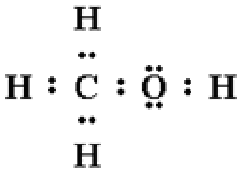
This diagram has a dot (●) and some x's; this diagram shows another way of writing the Lewis dot diagram. It is very easy to see that one electron comes from K and 7 electrons come from Cl. Sometimes the Lewis dot diagrams are easier to draw if we draw a special symbol for each atom's electrons.

But we must remember that K does not have two electrons; it gave its valence electron to Cl, so K is a positive ion (19 protons and 18 electrons; +19 –18 = +1); Cl is a negative ion because it has 18 electrons and 17 protons. The 3rd shell of K had 8 electrons, and the 4th shell had 1 electron; if K gave its valence electron to Cl, then K's 3rd shell was full.

If Cl takes one electron from K, then the 3rd electron shell of Cl is also full. For ionic bonding, an atom does not share an electron to make a full shell; the atom gives its electron to another atom.

9. Lewis Dot Diagrams for Bigger Molecules

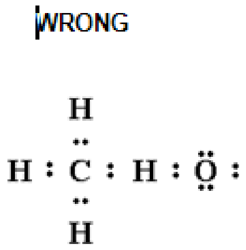
Answer to Activity-1: CH_4O



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?

We know that H needs 2 electrons to have a full shell; every H in the Lewis dot diagram has only 2 electrons, so their shells are full. We see that the carbon atom (C) and oxygen atom (O) have 8 electrons. This molecule satisfies the Full-shell Rule.

Answer to Activity-2: CH_4O



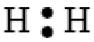
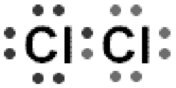
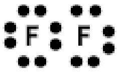
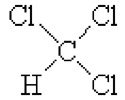
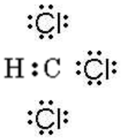
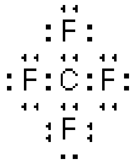
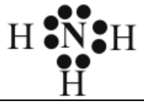
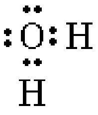
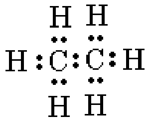
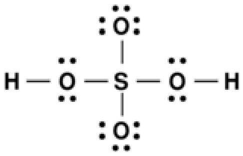
Work in your group. The picture on the right is wrong. Count the electrons for each atom, and then explain why the diagram is wrong.

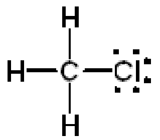
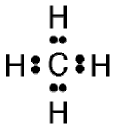
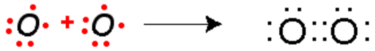
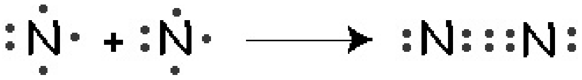
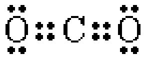
The C atom has 8 electrons (dots), so the electron shell is full.
The O atom has 8 electrons (dots), so the shell is full.

However, the H atom on the right looks like this **: H :**, so the hydrogen atom has four electrons; this hydrogen atom has too many electrons because the hydrogen electron needs only 2 electrons.

<u>This diagram is wrong</u> because the hydrogen has too many electrons.

Answers to the Lewis dot diagram worksheet

1. hydrogen molecule	H_2	 H(1) 1st shell: 1
2. chlorine molecule	Cl_2	 Cl(17): 1st shell: 2 2nd shell: 8 3rd shell: 7
3. sodium chloride: (table salt)	NaCl	 Na(11) 1st shell: 2 2nd shell: 8 3rd shell: 1
4. potassium chloride	KCl	 K(19): 1st shell: 2 2nd shell: 8 3rd shell: 8 4th shell: 1
5. fluorine molecule	F_2	 F(9): 1st shell 2 2nd shell 7
6. hydrochloric acid	HCl	
7. chloroform	$CHCl_3$	 
8. carbon tetrafluoride	CF_4	
9. ammonia	NH_3	
10. water	H_2O	 O(8): 1st shell 2 2nd shell 6
11. ethane	C_2H_6	 C(6) 1st shell 2 2nd shell
12. Sulfuric acid	H_2SO_4	 Remember, | and – mean 2 electrons.

13. methyl chloride	CH_3Cl	
14. methane	CH_4	
15. magnesium chloride	$MgCl_2$	
16. borane	BH_3	
17. oxygen molecule[1]	O_2	
18. nitrogen molecule	N_2	
19. carbon dioxide	CO_2	
20. carbon monoxide	CO	: C : : : O :
21. ethyne	C_2H_2	**H:C:::C:H**

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[1] Some atoms have to share two or three electrons to satisfy the Full Shell Rule (or the Octet Rule). All of these exercises have real molecules, so students will have to try sharing one electron, and if that doesn't work, try sharing two and then three electrons. Each O atom in #17 has 8 electrons around it. Likewise, in #18, each N atom is surrounded by 8 electrons.

Extra information: Lewis dot diagrams of some atoms

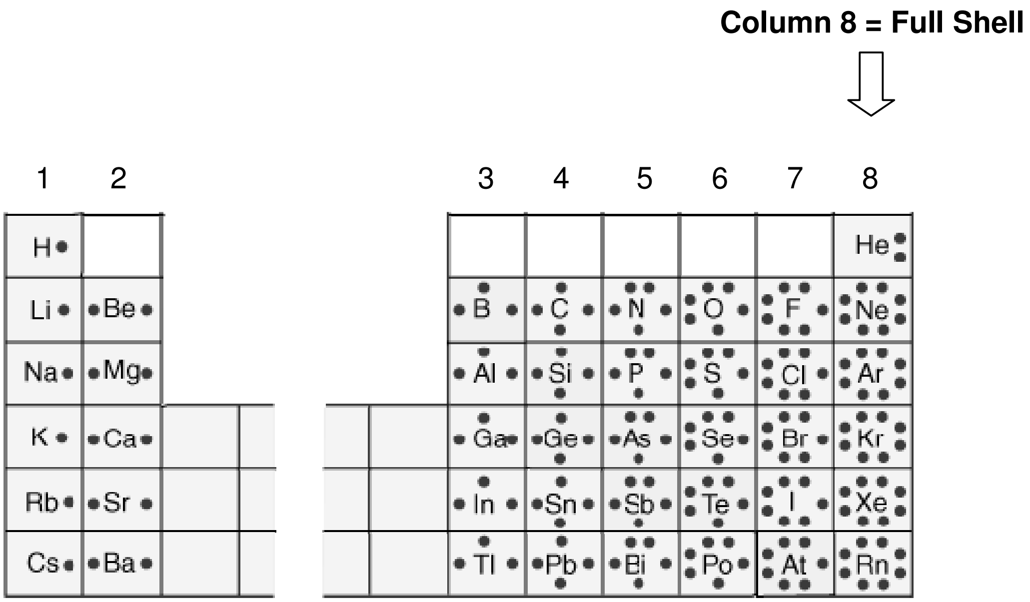
Rows of the periodic table:

If you look at the table, you see that every row, you see that the number of valence electrons (the number of dots around the chemical symbol) goes up one by one. For example, in the second row, Li has 1 valence electron, Be has 2 valence electrons, B has 3 valence electrons, C has 4 valence electrons, and so on.

Columns of the periodic table: If you look down the columns, you see the same number of valence electrons. For example, in column 1, all of the atoms have 1 valence electron; in column 2, all atoms have two valence electrons, and so on. In the last column, helium (He) is different because helium has only two electrons, its shell is full.

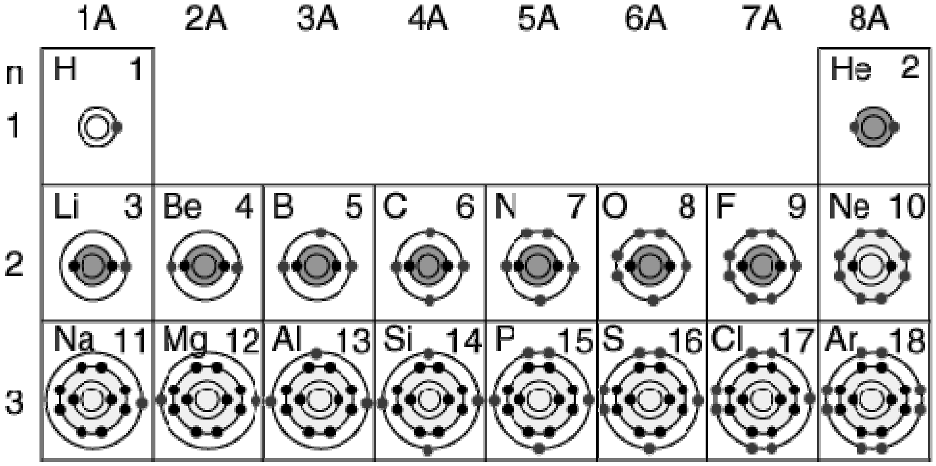
In English, “periodic” means that something comes back to the same place over and over again; for example, the moon moves around the earth in a 28-day period. The Periodic Table of the Elements has the same number of valence electrons over and over again:

Row 1: 1,2
Row 2: 1,2,3,4,5,6,7,8
Row 3: 1,2,3,4,5,6,7,8
Row 4: 1,2,3,4,5,6,7,8 …



Extra information: Electron diagrams for 3 rows of the Periodic Table

The table shows all of the electrons in each atom. For example, carbon (C) has 6 electrons: 2 electrons in the 1st shell and 4 electrons in the 2nd shell. In the picture, there are 2 dots on the smaller circle and 4 dots on the big circle. The Lewis dot diagram for carbon has 4 dots because the Lewis dot diagrams show only the valence electrons.

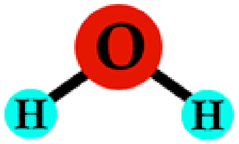


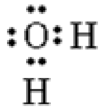
These diagrams of the atoms look similar to the Lewis dot diagrams in the picture above. However, the two pictures are different; this picture shows all electrons, not just valence electrons. Lewis dot diagrams show only valence electrons because when atoms come together to form molecules, they share valence electrons.

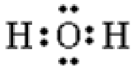
Extra information: Lewis dot diagrams are not enough

The Lewis dot diagrams are very useful for predicting the atoms that can come together to make molecules. However, the Lewis diagrams do not tell us everything. For example:

1. The Lewis diagrams do not tells us the **shape** of the molecule; below we see the water molecule (H_2O) and two Lewis dot diagrams. The middle diagram shows that H_2O is not straight, but it does not tell us how big the angle is.







(2) Also, the Lewis diagram does not tell us that H_2O has a "+" electrical charge on the oxygen end and a "–" electrical charge on the hydrogen end; H_2O is a **polar** molecule – it is electrical neutral, but the electrons prefer oxygen because it has so many positive charges in the nucleus.

(3) The Lewis diagrams do not tell us why two elements with similar diagrams can have **different chemical activity**. For example, Li, Na, and K have the same kind of Lewis diagram: Li●, Na●, K● (they all have one valence electron), but K has stronger reactions than Na does, and Na has stronger reactions than Li does. K has bigger electron shells, so the electrons are farther away from the nucleus than the electrons in Na or Li. Electrical force gets smaller when you the distance between

the electrical charges is bigger; therefore, the valence electrons of K do not need as much energy to move away from K and form molecules.

(4) The Lewis diagrams also do not tell about the many kinds of **special bonds** that molecules can make. The electron shells are more complex than this lesson described; however, even with a simple idea about electron shells, we can develop a lot of good information about how atoms form molecules.

(5) The Lewis dot diagram does **not** predict all possible molecules; there is a molecule for boron: B_2. If we try to use the Full-shell Rule and the Lewis dot diagrams, we cannot get B_2. The Full-shell Rule is very good, but nature is much more complex than one or two simple rules. An molecule of noble gases, HeNe has been found[2]; according to the Full-shell Rule, noble gases cannot form molecules. Therefore, the Full-shell Rule is very helpful, but nature is always much more creative than we think.

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[22] *"Infrared spectroscopy for the identification of modes of vibration in a temporary HeNe molecule."* Cristian Bahrim et al 2006 J. Phys. B: At. Mol. Opt. Phys. 39 4683-4700.

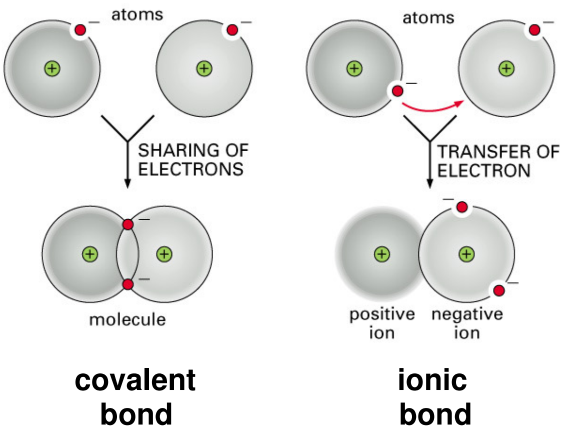
Extra information: Atoms alphabetized by symbol (Ar, As, …)

Ar	Argon	**Fe**	Iron	**Nd**	Neodymium	**Si**	Silicon
As	Arsenic	**Fm**	Fermium	**Ne**	Neon	**Sm**	Samarium
At	Astatine	**Fr**	Francium	**Ni**	Nickel	**Sn**	Tin
Au	Gold	**Ga**	Gallium	**No**	Nobelium	**Sr**	Strontium
B	Boron	**Gd**	Gadolinium	**Np**	Neptunium	**Ta**	Tantalum
Ba	Barium	**Ge**	Germanium	**O**	Oxygen	**Tb**	Terbium
Be	Beryllium	**H**	Hydrogen	**Os**	Osmium	**Tc**	Technetium
Bh	Bohrium	**He**	Helium	**P**	Phosphorus	**Te**	Tellurium
Bi	Bismuth	**Hf**	Hafnium	**Pa**	Protactinium	**Th**	Thorium
Bk	Berkelium	**Hg**	Mercury	**Pb**	Lead	**Ti**	Titanium
Br	Bromine	**Ho**	Holmium	**Pd**	Palladium	**Tl**	Thallium
C	Carbon	**Hs**	Hassium	**Pm**	Promethium	**Tm**	Thulium
Ca	Calcium	**I**	Iodine	**Po**	Polonium	**U**	Uranium
Cd	Cadmium	**In**	Indium	**Pr**	Praseodymium	**Uub**	Ununbium
Ce	Cerium	**Ir**	Iridium	**Pt**	Platinum	**Uuh**	Ununhexium
Cf	Californium	**K**	Potassium	**Pu**	Plutonium	**Uun**	Ununnilium
Cl	Chlorine	**Kr**	Krypton	**Ra**	Radium	**Uuo**	Ununoctium
Cm	Curium	**La**	Lanthanum	**Rb**	Rubidium	**Uup**	Ununpentium
Co	Cobalt	**Li**	Lithium	**Re**	Rhenium	**Uuq**	Ununquadium
Cr	Chromium	**Lr**	Lawrencium	**Rf**	Rutherfordium	**Uus**	Ununseptium
Cs	Cesium	**Lu**	Lutetium	**Rg**	Roentgenium	**Uut**	Ununtrium
Cu	Copper	**Md**	Mendelevium	**Rh**	Rhodium	**Uuu**	Unununium
Db	Dubnium	**Mg**	Magnesium	**Rn**	Radon	**V**	Vanadium
Ds	Darmstadtium	**Mn**	Manganese	**Ru**	Ruthenium	**W**	Tungsten
Dy	Dysprosium	**Mo**	Molybdenum	**S**	Sulfur	**Xe**	Xenon
Er	Erbium	**Mt**	Meitnerium	**Sb**	Antimony	**Y**	Yttrium
Es	Einsteinium	**N**	Nitrogen	**Sc**	Scandium	**Yb**	Ytterbium
Eu	Europium	**Na**	Sodium	**Se**	Selenium	**Zn**	Zinc
F	Fluorine	**Nb**	Niobium	**Sg**	Seaborgium	**Zr**	Zirconium

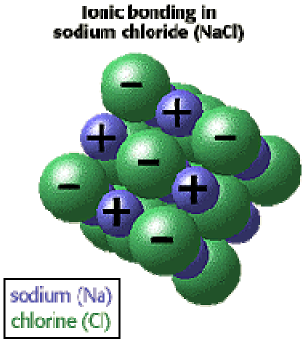
Extra information: Atoms alphabetized by name (Antimony, Argon, …)

Antimony	Sb
Argon	Ar
Arsenic	As
Astatine	At
Barium	Ba
Berkelium	Bk
Beryllium	Be
Bismuth	Bi
Bohrium	Bh
Boron	B
Bromine	Br
Cadmium	Cd
Calcium	Ca
Californium	Cf
Carbon	C
Cerium	Ce
Cesium	Cs
Chlorine	Cl
Chromium	Cr
Cobalt	Co
Copper	Cu
Curium	Cm
Darmstadtium	Ds
Dubnium	Db
Dysprosium	Dy
Einsteinium	Es
Erbium	Er
Europium	Eu
Fermium	Fm
Fluorine	F
Francium	Fr
Gadolinium	Gd
Gallium	Ga
Germanium	Ge
Gold	Au
Hafnium	Hf
Hassium	Hs
Helium	He
Holmium	Ho
Hydrogen	H
Indium	In
Iodine	I
Iridium	Ir
Iron	Fe
Krypton	Kr
Lanthanum	La
Lawrencium	Lr
Lead	Pb
Lithium	Li
Lutetium	Lu
Magnesium	Mg
Manganese	Mn
Meitnerium	Mt
Mendelevium	Md
Mercury	Hg
Molybdenum	Mo
Neodymium	Nd
Neon	Ne
Neptunium	Np
Nickel	Ni
Niobium	Nb
Nitrogen	N
Nobelium	No
Osmium	Os
Oxygen	O
Palladium	Pd
Phosphorus	P
Platinum	Pt
Plutonium	Pu
Polonium	Po
Potassium	K
Praseodymium	Pr
Promethium	Pm
Protactinium	Pa
Radium	Ra
Radon	Rn
Rhenium	Re
Rhodium	Rh
Roentgenium	Rg
Rubidium	Rb
Ruthenium	Ru
Rutherfordium	Rf
Samarium	Sm
Scandium	Sc
Seaborgium	Sg
Selenium	Se
Silicon	Si
Sodium	Na
Strontium	Sr
Sulfur	S
Tantalum	Ta
Technetium	Tc
Tellurium	Te
Terbium	Tb
Thallium	Tl
Thorium	Th
Thulium	Tm
Tin	Sn
Titanium	Ti
Tungsten	W
Ununbium	Uub
Ununhexium	Uuh
Ununnilium	Uun
Ununoctium	Uuo
Ununpentium	Uup
Ununquadium	Uuq
Ununseptium	Uus
Ununtrium	Uut
Unununium	Uuu
Uranium	U
Vanadium	V
Xenon	Xe
Ytterbium	Yb
Yttrium	Y
Zinc	Zn
Zirconium	Zr

Extra information: Two pictures about ionic bonding



This is another picture of molecular bonding. On the left side of the picture, two atoms come together and share their electrons with each other. But on the right side of the picture, one atom gives its electron to the other.



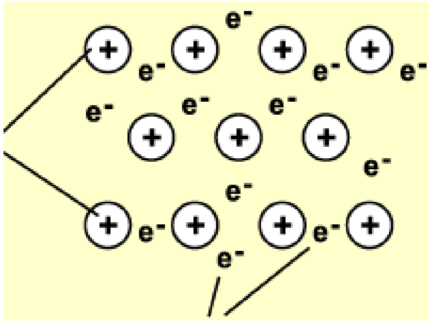
In this picture, we see that table salt (NaCl – sodium chloride) forms ionic bonds as a solid; the atoms do not share electrons, but Na gives the valence electron in its 3rd shell to Cl. Chlorine now has a full third shell and sodium has a full 2nd shell.

Extra information: Metallic Bonding

Metallic bonding shows how metals (for example, aluminum, copper, nickel, zinc) come together. We can discuss metallic bonding in a lesson about solids, but we discuss it here because metallic bonding is about **sharing electrons**. When we discussed covalent bonds, we said that atoms share electrons with other atoms in the molecule. But the molecules we discussed were small. In metals, every atoms shares an electron with all of the other atoms – millions and billions of atoms, and more.[3]

In metallic bonding, we see "+" and "–" charges as we did for ionic-bonded solids (like NaCl); however, in metals, the atoms do not give electrons to other atoms but to the whole (large) solid. The electrons in the "sea of electrons" can move all around the solid. For example, in electrical wire, the electrons flow through the wire, but they also "hit" the "+" charges and make them vibrate. This vibration is heat; therefore, when we use electrical wire, the wire becomes hotter.

These circles are the atoms and their inner-shell electrons (not the valence electrons). They have a positive electrical charge because they lost electrons and therefore the number of positive charges is bigger than the number of negative charges. The positive charges normally repel each other, but they are also attracted to the electrons, so they stay together.



These electrons come from the metal atoms; in a metal, atoms share their outer-shell (valence) electrons with every other atom; the "**sea of electrons**" can move all around the metal (like water in the ocean moves around everywhere).

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[3] One million = 1 000 000; one billion = 1 000 000 000.