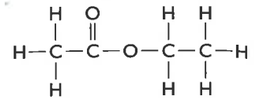
LESSON

3 HONC if You Like Molecules

Bonding Tendencies

Think About It



In order to understand the chemistry of smell, it is necessary to understand how molecules are put together. If you examine the structural formulas of molecules, you can see patterns in the way the atoms are connected. For example, hydrogen atoms are always arranged around the outside of the molecule. Plus, hydrogen atoms are always connected to other atoms with only one line, while carbon atoms are always connected to other atoms with more than one line.

What are the rules for drawing structural formulas?

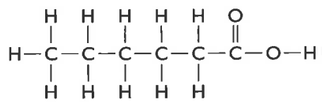
To answer this question, you will explore

1. The HONC 1234 Rule
2. Drawing Structural Formulas

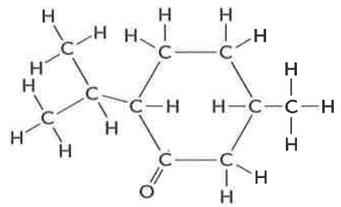
Exploring the Topic

1 The HONC 1234 Rule

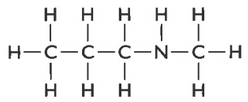
The structural formulas for three molecules are shown here. Take a moment to count the number of times each type of atom—hydrogen, oxygen, nitrogen, and carbon—is connected to other atoms.



$C_6H_{12}O_2$



$C_{10}H_{18}O$



$C_4H_{11}N$

- Every **H**ydrogen atom has **one** line connecting it to other atoms.
- Every **O**xygen atom has **two** lines connecting it to other atoms.
- Every **N**itrogen atom has **three** lines connecting it to other atoms.
- Every **C**arbon atom has **four** lines connecting it to other atoms.

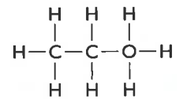
This information is sometimes referred to as the **HONC 1234 rule.** Within most molecules, hydrogen makes one bond, oxygen makes two bonds, nitrogen makes three bonds, and carbon makes four bonds. The bonds in a structural formula are represented by lines. One line connecting two atoms is called a *single bond.* A pair of lines connecting the same two atoms, as in C=O, is called a *double bond.*

The HONC 1234 rule tells you how four of the most common nonmetal atoms will bond. You will learn about the bonding of other nonmetal atoms like sulfur, S, and chlorine, Cl, in later lessons.

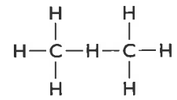
Example 1

HONC 1234

Are the following molecules correct according to the HONC 1234 rule? If not, what is wrong with them?



Molecule 1



Molecule 2

Solution

Both molecules are incorrect according to the HONC 1234 rule. In molecule 1, there is an oxygen atom with four bonds. It should have only two bonds. In molecule 2, there is a hydrogen atom with two bonds. It should have only one. The hydrogen atom cannot go in the middle of the molecule, between two carbon atoms.

ASTRONOMY CONNECTION

At room temperature, ethane, C_2H_6, is a flammable gas. On Earth, ethane is one of the components of natural gas. It has also been detected in the atmospheres of Jupiter, Saturn, Uranus, and Neptune.

2 Drawing Structural Formulas

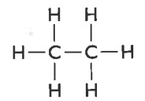
The HONC 1234 rule is all you need in order to draw the structural formulas for thousands of different molecules correctly. Some examples are given here and on top of the next page.

Structural Formula for C_2H_6

Consider a molecule with two carbon atoms and six hydrogen atoms. Its molecular formula is C_2H_6. What structural formula would this molecule have? Start by connecting the two carbon atoms with a single bond. The "carbon backbone" is generally a good place to start when drawing molecules.

Step 1: Connect the carbon atoms: C—C

Step 2: Add hydrogen atoms. Make sure each hydrogen atom has just one bond and each carbon atom has a total of four bonds.



The structural formula shown above is consistent with the HONC 1234 rule. This is the only structure you can make out of this molecular formula. It represents a substance called *ethane.*

Structural Formula for C_2H_6O

Consider a molecule with two carbon atoms, six hydrogen atoms, and one oxygen atom. Its molecular formula is C_2H_6O. What structural formula could this molecule have?

CONSUMER CONNECTION

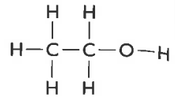
Ethanol, C_2H_6O, can be made from plants such as sugarcane, corn, and switchgrass, and can be used as an alternative fuel for automobiles. It can be used alone or blended with gasoline. However, it currently takes about a liter of fuel to produce one liter of ethanol, which may offset its environmental benefit.

Start by connecting the carbon atoms. Then add the oxygen atom.

Step 1: Connect the carbon atoms:

Step 2: Add the oxygen atom to the carbon chain:

Step 3: Add hydrogen atoms last:



Make sure your structural formula follows the HONC 1234 rule. Notice that hydrogen atoms are generally the last atoms you add when creating a structural formula.

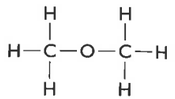
This molecule is called *ethanol* or *ethyl alcohol.*

A Second Structure—An Isomer

Ethanol is not the only possible structure for this particular molecular formula. The atoms in C_2H_6O can also be arranged a different way, to form a completely different molecule. This new structure is created by placing the oxygen atom between the two carbon atoms.

Step 1: Connect the carbon and oxygen atoms:

Step 2: Add hydrogen atoms:



This structure *also* follows the HONC 1234 rule and is a correct structural formula for C_2H_6O. This molecule is called *dimethyl ether.* Ethanol and dimethyl ether are isomers. They have the same molecular formula but different structural formulas. Dimethyl ether has different properties from ethanol, including smell.

Not all structural formulas are simple to figure out. As the number and type of atoms increase, there are more possible ways to connect the atoms.

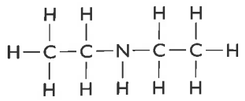
Example 2

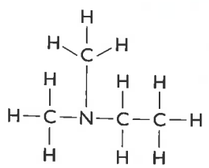
Structural Formula for $C_4H_{11}N$

Draw a structural formula for the molecular formula $C_4H_{11}N$.

Solution

Start by making a chain of the carbon atoms. Place the nitrogen atom anywhere in the chain. Finish by adding hydrogen atoms so that every carbon atom has four bonds and the nitrogen atom has three bonds. Two possible solutions are shown here, but many more are possible.





Key Term

HONC 1234 rule

Lesson Summary

What are the rules for drawing structural formulas?

The individual atoms in molecules are not connected randomly. Each atom in a molecule has a tendency to bond a specific number of times. The HONC 1234 rule describes the bonding patterns of hydrogen, oxygen, nitrogen, and carbon atoms. The HONC 1234 rule can be a valuable tool for creating structural formulas from molecular formulas.

EXERCISES

Reading Questions

1. What is the HONC 1234 rule?
2. Explain why one molecular formula can represent more than one structural formula.

3 + 4

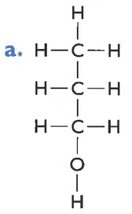
Reason and Apply

3. Use the HONC 1234 rule to create possible structural formulas for molecules with these molecular formulas. Remember that it is easiest to start with the carbon atoms.

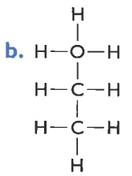
   a. $C_3H_8O_2$ **b.** $C_4H_{11}N$ **c.** C_4H_{10} **d.** $C_5H_{12}O$

4. Is each structural formula correct according to the HONC 1234 rule? For any molecules that don't follow the HONC 1234 rule, repair the incorrect structural formula. (*Note:* There may be more than one correct way to repair a formula.)

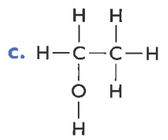
a.



b.



c.



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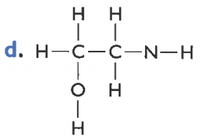
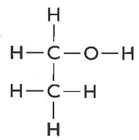


e.



5. Think about how molecules might interact with your nose. Why do you think molecules with different structural formulas have different smells?

LESSON

4 Connect the Dots

Lewis Dot Symbols

Think About It

The HONC 1234 rule is a great trick to help you figure out the structures of molecules. But why does it work? Why does carbon connect with four atoms, while hydrogen can connect with only one atom? To answer these questions, let's take a closer look at bonds.

How does one atom bond to another in a molecule?

To answer this question, you will explore

1. The Covalent Bond
2. Lewis Dot Symbols and Structures
3. Bonded Pairs and Lone Pairs

Exploring the Topic

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Topic: Chemical Bonding
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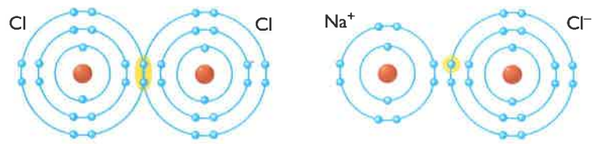
1 The Covalent Bond

All of the smelly compounds we have studied so far have been molecules. In fact, most of the substances that smell are made up of molecules, not ionic, metallic, or network covalent compounds.

The bonds that are found in molecules are called covalent bonds. Covalent bonds are formed between the atoms of nonmetallic elements. There are only about 15 nonmetallic elements in the periodic table. That is not many compared to the number of metallic elements.

The atoms involved in a covalent bond *share* a pair of valence electrons between them. The drawing below shows the difference between covalent bonds and ionic bonds.



Covalent bonding: electron sharing — Ionic bonding: electron transfer

In covalent bonds, the nonmetal atoms are *sharing* electrons. As a result, the nonmetal atoms are tightly bound together but the atoms do not become ions with charges.

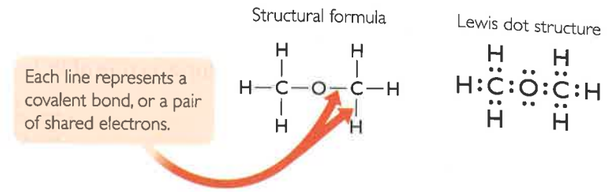
BIG IDEA A covalent bond is one in which nonmetal atoms *share* one or more pairs of electrons with one another. An ionic bond is one in which a metal atom *gives up* electrons to a nonmetal atom.

HISTORY CONNECTION

The Lewis dot symbol is named after a chemist who was a professor at the University of California at Berkeley. Gilbert Newton Lewis first introduced the idea of shared electrons and covalent bonds in 1916. He was the first scientist to use a system of dots to represent valence electrons in atoms.

2 Lewis Dot Symbols and Structures

Structural formulas are one way to show the structure of a molecule on paper. Each line in a structural formula can be replaced with a pair of dots to represent the electrons that are being shared.



A drawing of a molecule that uses dots to represent the valence electrons is called a **Lewis dot structure.** Above is a molecule of dimethyl ether, C_2H_6O. Both the structural formula and the Lewis dot structure represent the same molecule.

Lewis dot structures keep track of every valence electron in every atom of a molecule. If you break the molecule apart into its individual atoms, you can see where each valence electron came from.

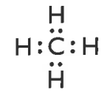
A **Lewis dot symbol** is the symbol of an element with dots to show the number of valence electrons that a single atom of that element has. Examine these Lewis dot symbols for hydrogen, oxygen, nitrogen, and carbon. Notice that some electrons are not paired up. These electrons are referred to as *unpaired electrons* and they are available for bonding. The unpaired electrons form covalent bonds with other atoms. These symbols can help to explain the HONC 1234 rule and the bonding of nonmetal atoms.

1 valence electron	6 valence electrons	5 valence electrons	4 valence electrons
H·	·Ö:	·N·	·Ċ·
1 electron available for sharing	2 electrons available for sharing	3 electrons available for sharing	4 electrons available for sharing

Recall that you can determine the number of valence electrons in an atom by locating its element on the periodic table. Hydrogen is in Group 1A and has one valence electron. Carbon is in Group 4A and has four valence electrons. Once you know the number of valence electrons an atom has, it is easy to draw a Lewis dot symbol for it.

3 Bonded Pairs and Lone Pairs

Lewis dot symbols can be used to draw Lewis dot structures and structural formulas for molecules. Imagine bringing together the Lewis dot symbols for hydrogen and carbon to form methane, CH_4.



Because carbon bonds four times, it will bond with four hydrogen atoms. Once they are bonded, every valence electron in all of the atoms is paired up. The pairs of electrons between atoms are called **bonded pairs.** There are four bonded pairs in the methane molecule shown at right.

CONSUMER CONNECTION

The smell of ammonia is powerful and irritating. Ammonia is toxic and can damage the interior of your nose and lungs. However, solutions with dissolved ammonia make good household cleansers. And small amounts of ammonia are used in smelling salts to revive a person who has fainted.

A pair of electrons in a molecule that are not shared between atoms is called a **lone pair** of electrons. In a molecule of ammonia, the nitrogen atom has one lone pair of electrons.

Example

Lewis Dot Structure of PCl_3

Examine the Lewis dot structure of PCl_3, phosphorus trichloride.

a. Draw the Lewis dot symbols for phosphorus and chlorine.

b. How many bonds does a phosphorus atom make? How many does each chlorine atom make?

c. How many bonded pairs does this molecule have? How many lone pairs?

d. How many covalent bonds does this molecule have?

Solution

a. The periodic table can help you figure out how many valence electrons phosphorus and chlorine have. Phosphorus is in Group 5A and chlorine is in Group 7A, so they have five and seven valence electrons, respectively.

b. Phosphorous has three unpaired electrons, so it makes three bonds. Chlorine has only one unpaired electron, so it makes one bond.

The three bonded pairs of electrons are circled.
All of the other pairs of electrons are lone pairs.

c. The molecule has three bonded pairs and ten lone pairs.

d. Each bonded pair represents one covalent bond. There are three covalent bonds in the molecule.

Key Terms

Lewis dot symbol
Lewis dot structure
bonded pair
lone pair

Lesson Summary

How does one atom bond to another in a molecule?

Molecules are made of nonmetal atoms that are covalently bonded. A covalent bond is a bond in which a pair of electrons is shared by two atoms. Lewis dot symbols keep track of the number of valence electrons in each atom. They can help you to predict covalent bonding between atoms. A Lewis dot structure shows how the atoms in an entire molecule are bonded together. The valence electrons that are involved in bonding are called a bonded pair. The valence electrons that are paired up in a molecule, but do not take part in bonding, are called lone pairs.

EXERCISES

Reading Questions

1. How are an ionic bond and a covalent bond different? Similar?
2. What is a Lewis dot structure? Explain how you would create one.

Reason and Apply

3. Draw the Lewis dot symbols for these elements:

   Te I K Bi In Pb

   a. Arrange them in order of their group numbers on the periodic table.

   b. Determine how many covalent bonds each element would make.

4. Germanium, antimony, selenium, and bromine each bond to a different number of hydrogen atoms.

   GeH_4 SbH_3 H_2Se HBr

   a. Draw Lewis dot symbols for Ge, Sb, Se, and Br.

   b. Draw a Lewis dot structure for each molecule.

   c. Explain the pattern in the number of hydrogen atoms.

5. Draw Lewis dot structures for the molecules listed here.

   a. $TeCl_2$ **b.** HI **c.** $AsBr_3$ **d.** SiF_4 **e.** F_2

6. How many lone pairs does each of the molecules in Exercise 5 have?
7. In your own words, explain why the HONC 1234 rule works.
8. Draw Lewis dot puzzle pieces for Si, P, S, and Cl. What rule would you make for Si, P, S, and Cl? What would be the name of this bonding rule?

2 & 5

LESSON

5 Eight Is Enough

Octet Rule

Think About It

When atoms bond covalently to form molecules, they share electrons to obtain an electron arrangement similar to a noble gas atom. Lewis dot structures can help you to discover how atoms share electrons to form molecules.

How do atoms bond to form molecules?

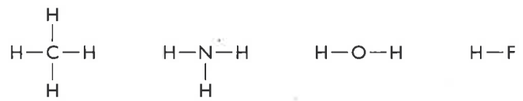
To answer this question, you will explore

1. The Octet Rule
2. Double and Triple Bonds

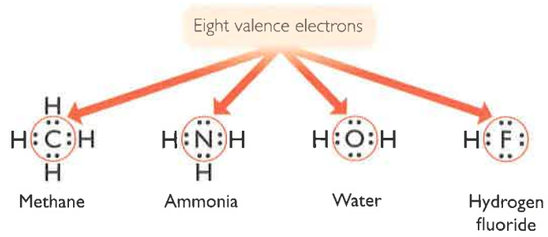
Exploring the Topic

1 The Octet Rule

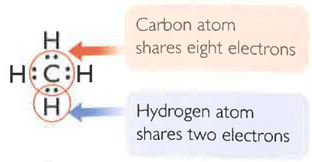
When carbon, nitrogen, oxygen, and fluorine combine with hydrogen, they form these molecules:



All of the above compounds are extraordinarily different. However, their Lewis dot structures reveal a striking similarity. Once carbon, nitrogen, oxygen, and fluorine are bonded, they are each surrounded by eight valence electrons.



This tendency to bond until eight valence electrons surround an atom is called the **octet rule.** (The word *octet* comes from *octo,* which is Latin for "eight.") After these atoms are bonded, they all resemble a noble gas in their electron arrangements. Recall that the electron arrangements of the noble gases are very stable.



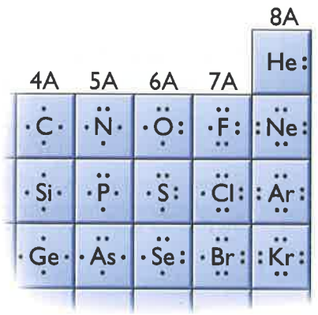
CONSUMER CONNECTION

Saturated fats are called "saturated" because the carbon atoms are bonded with as many hydrogen atoms as possible. Saturated fats are found in meat, dairy products, and tropical oils such as palm oil and coconut oil and are usually solid at room temperature. In contrast, vegetable oils are usually monounsaturated or polyunsaturated, meaning that they have one or more double bonds between carbon atoms and are therefore bonded with fewer hydrogen atoms. They are usually liquid at room temperature.

Note that hydrogen is an exception to the octet rule. Each hydrogen atom shares two electrons, not eight. A covalently bonded hydrogen atom resembles the noble gas helium, He, which has only two valence electrons.

Periodic Trends

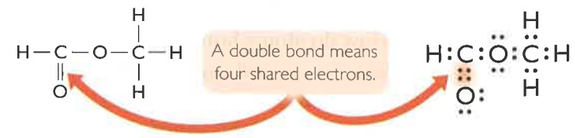
The periodic table can be used to predict covalent bonding in molecules. In the illustration, Lewis dot symbols are shown for nonmetal elements in the second, third, and fourth rows. Notice that the elements in the same group have similar Lewis dot symbols and bond in a similar way. For example, selenium, Se, which is below oxygen, O, has two unpaired electrons and forms two bonds, just like oxygen.



Elements in the same group have the same number of valence electrons and therefore have similar Lewis dot symbols. Helium is an exception.

2 Double and Triple Bonds

There is more than one way to satisfy the octet rule through bonding. Quite a few of the structural formulas you have examined so far have a bond with two lines. This type of bond is called a **double bond.** In a Lewis dot structure, a double bond is represented by four dots instead of the usual two. A double bond contains four electrons that are being shared between atoms. Methyl methanoate, $C_2H_4O_2$, is an example of a molecule that contains a double bond. Its structural formula and Lewis dot structure are shown here.



The carbon and oxygen atoms with double bonds are surrounded by a total of eight valence electrons each, just like the atoms with single bonds.

Example

Carbon Dioxide

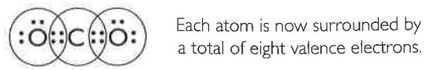
Draw the Lewis dot structure and structural formula for carbon dioxide, CO_2.

Solution

Step 1: Start with the Lewis dot symbols. Bring the atoms together.

Step 2: Check to see if the octet rule is satisfied. This Lewis dot structure isn't correct. Move the remaining unpaired electrons to create double bonds.

Step 3: Check your molecule again to see that each atom in it satisfies the octet rule and still has the right number of valence electrons.



Step 4: To make the structural formula, replace each pair of dots with a line.

O=C=O

If two atoms can share four electrons, can they share six electrons, or even more? The answer is yes.

Nitrogen gas, N_2, has a **triple bond** between the two nitrogen atoms, so each nitrogen atom has six shared valence electrons. Notice that there are also two lone pairs in this molecule. Oxygen gas, O_2, has a double bond between the oxygen atoms. The four lone pairs in the oxygen molecule have been adjusted slightly in this Lewis dot structure, to space the electrons more evenly around the atoms. Quadruple bonds are also possible, but quite rare.

N≡N	O=O	H–H
:N:::N:	:O::O:	H:H
Triple bond	Double bond	Single bond

ENVIRONMENTAL CONNECTION

Some of the most common substances in the world around you are molecules with double and triple bonds. The air you breathe is composed of a mixture of nitrogen gas, oxygen gas, and a sprinkling of carbon dioxide and other gases. In fact, the air is 78% nitrogen gas.

Key Terms

octet rule
double bond
triple bond

Lesson Summary

How do atoms bond to form molecules?

When nonmetal atoms bond, they share electrons to obtain the same electron arrangement as a noble gas atom. Nonmetal atoms will share electrons with other atoms so that both atoms end up sharing a total of eight valence electrons each. This is called the octet rule. Hydrogen still fits the sharing pattern, but it ends up with only two valence electrons, like the noble gas helium. Atoms can also satisfy the octet rule by forming double and triple bonds in which they share four or six valence electrons.

EXERCISES

Reading Questions

1. Explain why nitrogen bonds with hydrogen to form NH_3, but not NH_2 or NH_4. Use Lewis dot structures to support your argument.
2. What is the octet rule, and how can you use it to create a molecular structure?

Reason and Apply

3. List three nonmetal elements that combine with only one fluorine atom to satisfy the octet rule.
4. List two nonmetal elements that combine with three hydrogen atoms to satisfy the octet rule.
5. Draw Lewis dot structures for these molecules. Notice that in part d and part f, the formulas are written in a way that emphasizes the structure of the molecule.
   a. CF_4 b. CH_3Cl c. $SiCl_2H_2$
   d. CH_3OH e. HOCl f. CH_3NH_2
6. Use the octet rule to draw Lewis dot structures for all the stable molecules with the molecular formula C_3H_8O. (*Hint:* There are three total molecules.)
7. Consider the molecules C_2H_2, N_2H_2, and H_2O_2.
   a. Draw a Lewis dot structure for each one. What pattern do you notice?
   b. What can you do to check that your Lewis dot structures are correct? Name at least two ways.
8. Consider the molecules C_2H_4 and N_2H_4. Draw a Lewis dot structure for each of the molecules.
9. Which is more likely to exist in nature, a molecule of CH_3 or a molecule of CH_4? Explain your reasoning.