4.3: Lewis Structures and Multiple Bonding

The Basics

Let's go over some of the main things you need to consider if you want to draw Lewis structures. Lewis structures will be the principal way you communicate ideas about molecules in this course, so it is best to get some practice with them as soon as possible.

Here's what you need to do:

a. count up the valence electrons in the atoms that will be bonded together.
b. place the atoms beside each other on paper.
c. arrange the given electrons around the atoms so that each atom has an octet.
d. these electrons can be shared between the atoms (these are called bonding pairs) or held by one atom or the other (these are called nonbonding pairs or "lone pairs")

Occasionally, you will need to share more than one pair of electrons between two atoms so that all atoms can obtain an octet. That's what happens in the structure of carbon monoxide, CO.

Figure 4.3.1: Carbon monoxide: both atoms have octets.

Carbon has 4 valence electrons and oxygen has 6, for a total of 10 electrons. That's 5 pairs. If carbon and oxygen share a pair of electrons, there will be four pairs left. You could put three pairs on the oxygen and one pair on the carbon. The oxygen has four pairs, including the lone pair and the shared pairs. Carbon only has two pairs. That isn't an octet, and if possible the molecule will avoid that situation.

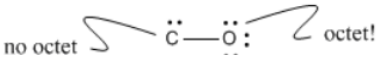


Figure 4.3.2: Carbon monoxide: not all the atoms have octets.

A carbon and oxygen atom with a single bond. Carbon has one lone pair while oxygen has three. Carbon does not have an octet, while oxygen does.

There could be one bond, and two lone pairs on each atom. That isn't much better. Now neither atom has an octet.

Figure 4.3.3: Carbon monoxide: neither atoms have octets.

Figure 4.3.4: Carbon monoxide: neither atoms have octets.

That means we can only have three bonds between the carbon and oxygen -- a total of six electrons. The other four electrons could become lone pairs -- one on carbon and one on oxygen. Now both atoms have an octet.

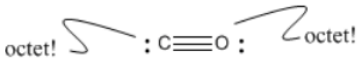


Figure 4.3.5: Carbon monoxide: both atoms have octets.

A carbon and oxygen atom with three bonds. Both have a single lone pair of electrons and a complete octet.

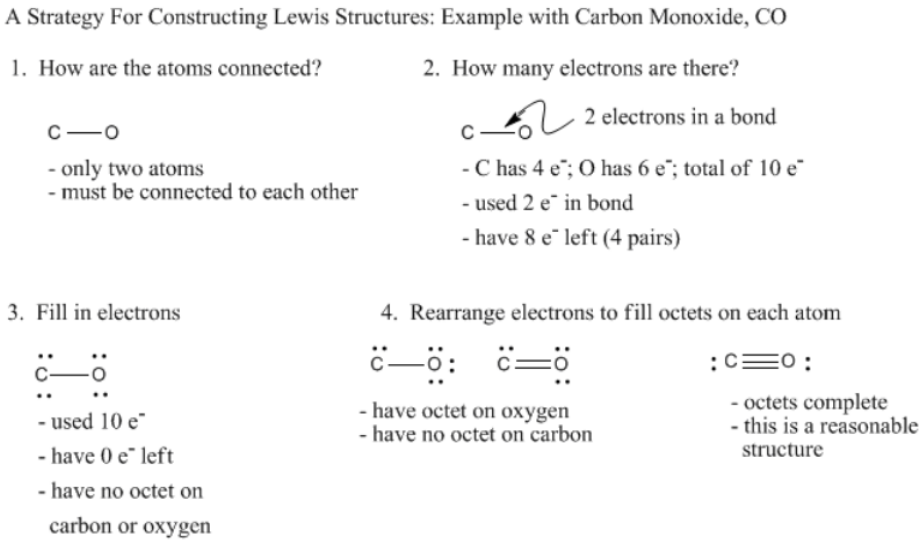


Figure 4.3.6: A *beginning* set of instructions for completing a Lewis structure.

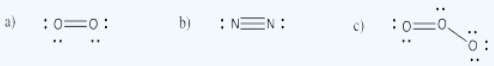
Steps for constructing lewis structures. Step one: connect the atoms together. Step two: calculate how many valence electrons are present. Step 3: fill in electrons. Step 4: rearrange electrons to fill octets on each atom.

? Exercise 4.3.1

Try drawing Lewis structures for the following molecules:

a) O_2 b) N_2 c) O_3

Answer



Consequences of multiple bonding: bond distances

Are there really three bonds between the carbon and oxygen in carbon monoxide? How could we tell?

Multiple bonds have important consequences. A bond is a pair of electrons shared by two atoms. Since both atoms need the pair of electrons to complete an octet, the atoms must stay close to the electron pair and close to each other in order to be stable. Hence, a bond is also an attractive force between atoms. That idea means additional bonds between two atoms leads to additional attraction between the atoms. Two atoms with multiple bonds should be more tightly bound to each other than two atoms with fewer bonds.

- a double bond between two atoms is shorter than a single bond between the same two atoms
- a triple bond between two atoms is shorter than a double bond between the same two atoms
- a quadruple bond between two atoms is shorter than a triple bond between the same two atoms

Experimental data suggests that this is true. Microwave spectroscopy is a technique that can be used to measure bond distances (the distance from one atom to the next) in molecules in the gas phase. The data on carbon monoxide indicates that the C-O distance is about 1.13 A (1 A = 10^{-10} m). In carbon dioxide, CO_2, the distance is 1.16 A. The shorter distance in carbon monoxide suggests the carbon and oxygen are held a little more tightly together than they are in carbon dioxide, in which the Lewis structure shows only a double bond.

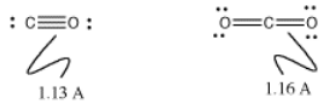


Figure 4.3.7: A comparison of experimentally determined bond distances.

Comparison of bond length between carbon monoxide (1.13 Ångstroms) and carbon dioxide (1.16 Ångstroms).

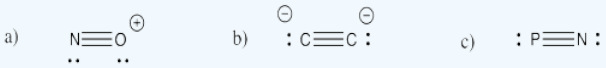
The additional bond between a pair of atoms is often called a pi bond (pronounce "pie" bond). The first bond between a pair of atoms is sometimes called a sigma bond. Carbon monoxide has one sigma bond and two pi bonds.

Exercise 4.3.2

Draw structures for the following molecules and ions.

a) NO^+ b) C_2^{2-} c) PN

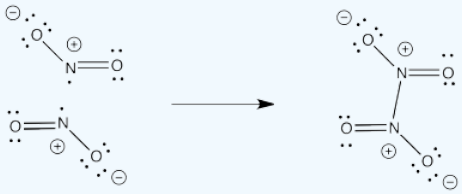
Answer



Exercise 4.3.3

NO_2 is a brown gas (connectevity O-N-O) that comes from car exhausts. It is partly responsible for smog in large cities. NO_2 dimerizes at low temperature to form N_2O_4, a colorless gas. Dimerization refers to two molecules coming together to form one, bigger structure. Show why this phenomenon happens with NO_2, with the help of structures.

Answer



Exercise 4.3.4

Do you expect the NO_2^- anion to dimerize? Explain.
