Are All Lewis Structures Created Equal?

Why are we doing this?

The purpose of Lewis structures is to provide a simple way for chemists to represent molecules that allows reasonable predictions to be made about the structure and properties of the actual molecules. However, there may be multiple ways to draw a "correct" Lewis structure following the rules you have generated in Activity 13. So which structure is correct? Are all possible structures correct? In this Activity we will explore some additional factors that will help chemists more closely depict structures that reflect the experimental data.

Your Learning Outcomes

You will be able to:

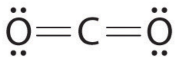
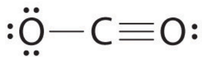
1. Describe the relationship between bond type, bond length, and bond strength.
2. Identify if a molecule has resonance.
3. Describe the structural properties of a molecule that has resonance.

The Plan

1. Assign roles*.
    a. ***Manager*** – This person will keep the team on task and provide direction to the group. This person is responsible for uploading the group's work to Gradescope. Make sure you make a note of everyone in the group. You must add everyone's name when submitting your answers to Gradescope.
    b. ***Spokesperson*** – This person will represent the group be responsible for speaking for the group to the rest of the class.
    c. ***Recorder*** – This person will be responsible for recording the team's answers to the Critical Thinking Questions in an organized and coherent manner.
    d. ***Analyst*** – This person will be responsible for critical analysis of the team's work (i.e., the Devil's Advocate). This person should make sure everyone understands what is happening before the group moves forward.
2. Complete the Critical Thinking Questions as a group.
3. Submit your team's work via Gradescope. Groups may choose to work in a Word document or write out their answers on a separate sheet of paper. All work must be upload to Gradescope as a PDF file.

**Students may choose to complete this activity independently if they are unable to attend discussion due to illness or injury; in which case, the student must perform all roles and complete all aspect of the activity. To receive full credit, documentation as to the need for the absence from discussion must be included with the submission and your TA must be notified of the absence.*

Model 1: Two Possible Lewis Structures for CO_2.

 or 

I II

Critical Thinking Questions

1. How were the numbers of electrons in the possible Lewis structures of CO_2 calculated?
   Four from C and six from each O.

2.
   a. Complete the following for the two possible structures of CO_2 shown in Model 1:

	Structure I	Structure II
Total number of electrons in the Lewis structure	16	16
Number of electrons around the carbon atom	8	8
Number of electrons around the left-hand oxygen atom	8	8
Number of electrons around the right-hand oxygen atom	8	8

   b. Based on your answers above, is each proposed structure in Model 1 a *legitimate* Lewis structure for CO_2? Explain why or why not.
   Yes. There are eight electrons around all atoms.

Information

Consider that **bond length**, the distance between two bonding atoms, is related to the type of bond. For example, the length of a typical C–C single bond is 154 pm. A C=C double bond is 134 pm; and a C≡C triple bond is 120 pm. Additionally, the **bond energy**, the energy required to break a chemical bond, is related to the type of bond. A typical C–C single requires 346 kJ of energy to break one mole of C–C bonds. A C=C bond has a bond energy of 602 kJ/mole; and a C≡C has a bond energy of 835 kJ/mole.

3. Describe the general relationship between bond type and bond length.
   As the bond type increases (single, double, triple), the bond length decreases.

4. Describe the general relationship bond type and bond strength.
   As the bond type increases, the bond strength increases.

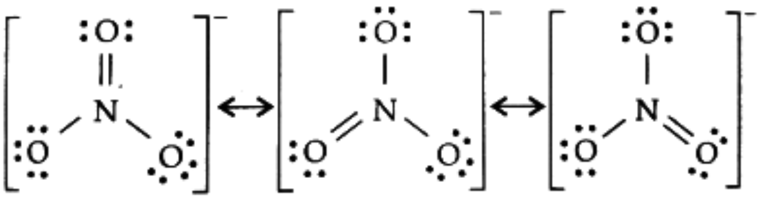
5. Describe the general relationship between bond length and bond strength.
   As the bond length decreases, the bond strength increases.

Information

Experimentally, we find that both C–O bonds in CO_2 are identical. In CO_2, the C–O bond length is 116 pm, and the bond energy is 804 kJ/mole.

6. Based on the experimental results described above, which Lewis structure, I or II, provides a better description of CO_2? Explain your reasoning.
Structure I is better because both bonds are identical, experimentally. In structure II, one C–O bond is a triple bond and one C–O bond is a single bond. If this were true, you would expect that one bond would be shorter and stronger than the other.

Model 2: The Lewis Structure for the Nitrate Ion.



These three structures are called **resonance structures**. A double-headed arrow is used to indicate resonance structures. Each resonance structure is a legitimate Lewis structure. When we draw resonance structures, we leave the atoms in place and change the representation for how the electrons are arranged. **The best description of the structure of the molecule is taken to be the <u>average</u> of the resonance structures, sometimes called a resonance hybrid.**

For the resonance structures of nitrate, above, the N–O bond is somewhere in between a single and a double bond. Experimental measurements show that all three N–O bonds in NO_3^- are identical.

Critical Thinking Questions

7.

a. How many valence electrons does one nitrogen atom have?
5

b. How many valence electrons do three oxygen atoms have?
18

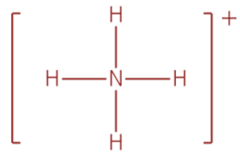
c. How many valence electrons does one NO_3 molecule have?
23

d. How many valence electrons does one NO_3^- ion have?
24

e. How was the number of electrons used for each resonance structure shown in Model 2?
By adding the number of valence electrons for each atom and by adding one electron because of the negative charge on the molecule.

8. Why is a resonance hybrid representation of NO_3^- better than a just a single structure?
   Because all N–O bonds in the molecule are identical.

9. Consider a molecule of ammonium, NH_4^+.
   a. Draw a Lewis structure for ammonium.

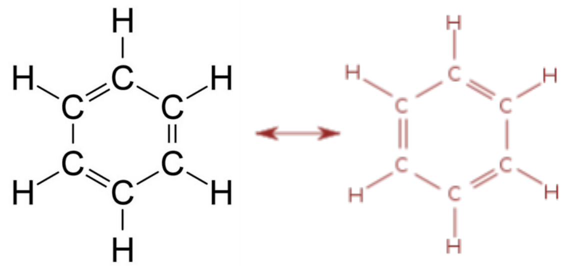


   b. Does ammonium have resonance? Explain your reasoning.
      No. There is no alternative bonding arrangement since hydrogen will only for single bonds.

   c. This molecule contains four N–H bonds. Would you expect the N–H bond lengths to all be the same or different?
      They should all be the same.

   d. Would you expect the N–H bond strengths to all be the same or different?
      They should all be the same.

10. Consider a molecule of benzene, C_6H_6.
   a. Benzene does have resonance. Complete the resonance structure below by drawing the second Lewis structure of benzene. Be sure to include the double headed arrow to indicate that the two structures are resonance structures.



   b. All six C–C bonds are determined to be 139 pm long. Explain this observation.
      Benzene is a resonance structure. The carbon-carbon bonds in the ring would not contain carbon-carbon single (154 pm) or double bonds (134 pm). Instead, the bonds would be somewhere in between (139 pm).

   c. Would you predict the C–C bond strengths to all be the same or different? Explain your reasoning.
      All of the bonds should be identical with the same bond strength. Because all of the carbon-carbon bonds are the same length, we would expect them to have the same bond strength as well.

   d. Why is the Lewis structure an imperfect model to show resonance structures?
      The Lewis structures imply that the bonds are either single, double, or triple bonds. However, they don't show hybrid bond types which is more reflective of the real structure. Often the double headed arrow causes some students to think that resonance structure flip

back and forth between the Lewis structures. This is not true. The real structure for a molecule with resonance is none of the Lewis structures shown, but a hybrid structure.