Molecular Model Building

Strand Nomenclature, Chemical Formulas, and Reactions

Topic Investigating bonding, nomenclature, and formula writing

Primary SOL CH.3 The student will investigate and understand how conservation of energy and matter is expressed in chemical formulas and balanced equations. Key concepts include
c) writing chemical formulas;
d) bonding types.

Related SOL CH.1 The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include
a) designated laboratory techniques;
b) safe use of chemicals and equipment;
c) proper response to emergency situations.

Background Information

In this activity, students will gain valuable experience working with some hands-on molecular models as they practice drawing Lewis dot structures and predict shapes according to the valence shell electron pair repulsion (VSEPR) theory. The VSEPR rules mainly involve predicting the layout of electron pairs surrounding one or more central atoms in a molecule, which are bonded to two or more other atoms. The geometry of these central atoms in turn determines the geometry of the larger whole.

The number of electron pairs in the valence shell of a central atom is determined by drawing the Lewis structure of the molecule, expanded to show all lone pairs of electrons alongside protruding and projecting bonds. Where two or more resonance structures can depict a molecule, the VSEPR model is applicable to any such structure. For the purposes of VSEPR theory, the multiple electron pairs in a multiple bond are treated as though they were a single "pair."

You will need a classroom set of basic molecular model kits. Number each kit, and sign them out by number; this will greatly reduce the loss of parts from one lab section to the next. If you do not have access to molecular model kits, you can use toothpicks and gumdrops or small Styrofoam balls, but the bond angles will be difficult to achieve.

Students who find the molecules in this lab easy to build can be assigned additional, advanced molecules. Suggested advanced molecules and ions, grouped according to their shapes, are listed in the table at the end of this lesson.

Materials

- Molecular model kits (or toothpicks and small Styrofoam balls or gum drops)

Vocabulary

anion, cation, compound, crystals, evaporation, ionic, lattice points, metallic, particle, pattern, saturated, seed crystal, solution, stereoscope, supersaturated

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

Introduction

1. Review with students the following basic points:
   - The properties of molecules depend not only on their molecular composition and structure, but also on their shape. Molecular shape determines a compound's state of matter, boiling point, freezing point, viscosity, volatility, surface tension, and the nature of its reactions.
   - The geometry of a small molecule can be predicted by examining the central atom and identifying the number of atoms bonded to it and the number of unshared electron pairs surrounding it.
   - The shapes of molecules may be predicted by using the VSEPR rule, which states that electron pairs around a central atom will position themselves to allow for the maximum amount of space between them.
   - Covalent bonds can be classified as either polar covalent or nonpolar covalent. In a polar covalent bond, electrons are more attracted to the atom with the greater electronegativity, resulting in a partial negative charge on that atom. The atom with the smaller electronegativity value acquires a partial positive charge. In a nonpolar covalent bond, the electrons are shared equally, and there is no unequal distribution of charge.
   - Molecules made up of covalently bonded atoms can be classified as either polar or nonpolar. The geometry of the molecule determines whether it is polar or not. For example, if polar bonds are symmetrically arranged around a central atom, their charges may cancel each other out and the molecule is nonpolar. If, on the other hand, the arrangement of the polar bonds is asymmetrical, the electrons will be attracted more to one end of the molecule and a polar molecule or dipole results.
2. Tell students that in this activity, they will construct ball-and-stick models of covalent molecules and name the geometry and the polarity of each molecule.

Procedure

1. Distribute molecular model kits (or toothpicks and small Styrofoam balls or gum drops) to each team of students. Provide each group with enough parts to build several models before having to take them apart to build new ones.
2. Have students build models of assigned molecules by following these steps:
3. Sum all of the molecule's valence electrons.
4. Place the central atom, which is usually the first atom except for H.
5. Arrange the remaining atoms around the central atom.
6. Arrange the electrons around the atoms to obey the octet rule for all elements except H. (C, N, O, and F always obey the octet rule.)
7. Obey the duet rule for H.
8. Form single bonds, if possible. (Form multiple bonds only if absolutely necessary.)
9. Elements in the third row or below on the periodic table can hold extra electrons if they are the central atom. (They have d-orbitals that can hold the extra electrons).
10. Have each student draw Lewis dot diagrams for the following atoms or molecules:

N	Cl2	O_3	ICl_3
S	H2O	SO_4^{2-}	CH_2Cl_2
CH_4	HCN	BrF_3	C_2H_2
H_2	NH_3	XeO_4	C_6H_6
N_2	CO_2	H_2Se	
O2	H_2O_2	CO_3^{2-}	

Assessment

- **Questions**
  - How many lone pairs of electrons are on the sulfur atom in the sulfite ion, SO_3^{2-} ?
- **Journal/Writing Prompts**
  - Identify and explain the polarity of the water molecule.
- **Other**
  - Draw the Lewis diagram for oxygen and for SF_4.
  - Use the VSEPR theory to predict the molecular geometry of each of the following: ICl_3, SO_2, H_2Se, and NH_4^+.

Extensions and Connections (for all students)

- Reinforce the concept of conservation of mass in a chemical reaction by having students build models of the compounds CH_4 and O_2 and then write and balance the equation for the reaction that occurs between CH_4 and O_2. Then, have students build the number of CH_4 and O_2 molecules that are present in the balanced equation. When these models are complete, have students “react” the methane and oxygen models by breaking the bonds in the reactants and reforming the product molecules. They should see that they still have the same number of atoms in the product molecules that they had in the reactants.

Strategies for Differentiation

- Have students take digital photos of the crystal structures formed in each experiment.
- Have students use a draw/paint program to draw the crystal structures seen through a stereoscope.
- Have students use a digital microscope to view the crystals on acomputer monitor and then save the images.
- Have students model ionic model formation, using poker chips to represent the valence electrons and construction paper squares labeled with metal and nonmetal atomic symbols. Have them manipulate the poker chips to show the loss of electrons by the metal atom(s), the gain of electrons by the nonmetal atom(s), and the subsequent electrostatic attraction to form an ionic bond.
- Invite a geologist to bring in samples and describe crystal formation in minerals.

Advanced molecules and ions, grouped according to their shapes

	Tetrahedral arrangement	**Trigonal bipyramidal arrangement**	**Octahedral arrangement**
Linear CO_2 CS_2 OCS BeF_2 NO_2^+ NCF SCN^- OCN^- N_2O	V-shaped (bent) SCl_2 $SeBr_2$ BrO_2^- ClO_2^- OF_2 Trigonal pyramidal NF_3 XeO_3 SO_3^{2-} PO_3^{2-} $SOCl_2$ PCl_3 ClO_3^- IO_3^- Tetrahedral SO_4^{2-} XeO_4 PO_4^{3-} BF_4^- CF_4 BrO_4^- SiF_4 SiO_4^{4-} NF_4^+ $AsCl_4^+$ PF_4^+ $SiCl_4$ ClO_4 CCl_4 NOF_3 SO_2Cl_2	Linear XeF_2 KrF_2 ClF_2^- BrF_2^- IF_2^- T-shaped ClF_3 BrF_3 IF_3 $XeOF_2$ XeF_3^+ See-saw SCl_4 IO_4^{3-} XeO_2F_2 PF_4^- $AsCl_4^-$ Trigonal bipyramidal SbF_5	Square planar IF_4^- BrF_4^- Square pyramidal $XeOF_4$ ClF_5 SeF_5^- TeF_5^- $ClOF_4^-$ IF_5 BrF_5 XeF_5^+ $SbCl_5^{2-}$ Octahedral AlF_6^{3-} SiF_6^{2-} PF_6^- IO_6^{5-} IF_6^+

Structure and Polarity of Molecules Lab
Molecular Geometry Charts

Basic Structures

Total # of e^- pairs	# of bonding pairs	# of lone e^- pairs	Molecular geometry	Bond angles
2	2	0	Linear	180°
3	3	0	Trigonal planar	120°
3	2	1	Bent	<120°
4	4	0	Tetrahedral	109.5°
4	3	1	Trigonal pyramidal	<109.5°
4	2	2	Bent	<109.5°
4	1	3	Linear	180°

More Advanced Structures

Total # of e^- pairs	# of bonding pairs	# of lone e^- pairs	Molecular geometry	Bond angles
5	5	0	Trigonal bipyramidal	90°, 120°
5	4	1	See-saw	180°, 90°, <120°
5	3	2	T-shaped	90°
5	2	3	Linear	180°
6	6	0	Octahedral	90°
6	5	1	Square pyramidal	<90°
6	4	2	Square planar	90°
6	3	3	T-shaped	90°
6	2	4	Linear	180°

For each molecule listed in the box below, use a separate sheet of paper to

- determine the total number of e^- pairs
- draw the Lewis structure
- determine the number of bonding e^- pairs
- determine the number of lone e^- pairs
- state the shape of the molecule
- state whether the molecule is polar or nonpolar.

H_2	C_2H_5OH	CH_3NH_2	IF_3	acetone
N_2	HCN	BCl_3	BH_2^-	isopropyl
CO_2	H_2O_2	$XeOF_4$	$COCl_2$	alcohol
O_2	SO_3	Br_3^-	N_2F_2	acetic
CH_4	$SeBr_2$	SeF_4	C_6H_6	acid
HBr	PCl_3	IF_5	$CH_3CH_2CH_2OCH_2CH_2CH_3$	boric acid
H_2O	CF_4	AsF_5	$CH_3CHCHCH_2CH_2CH_3$	
NH_3	C_2H_2	XeF_4	C_6H_{12}	