VSEPR Theory

Unit: Covalent Bonding & Molecular Geometry

MA Curriculum Frameworks (2016): HS-PS1-2

Mastery Objective(s): (Students will be able to…)

- Identify the VSEPR shapes and bond angles for simple molecules (one central atom).

Success Criteria:

- VSEPR shapes show the correct number of lone pairs in the correct locations.
- VSEPR shapes have the correct bond angles.

Tier 2 Vocabulary: bond, cloud

Language Objectives:

- Explain how repulsion between electron clouds results in VSEPR shapes.

Notes:

Valence Shell Electron Pair Repulsion (VSEPR*) theory: a theory that the shape of a molecule is determined by the repulsion between electrons in the bonds and unshared pairs of the atoms.

The Lewis structure of a molecule represents the structure in 2 dimensions. The VSEPR shape is the 3-dimensional equivalent.

The VSEPR shapes are determined by the following constraints:

Electrons are all negatively charged, so they repel each other. Valence electrons exist in electron clouds, which can be either:

- unshared electrons (in pairs), attached to only one atom
- as part of a covalent bond (shared pair of electrons) between two atoms

The VSEPR shape of the molecule is the shape that occurs when all of these "clouds" of electrons are as far apart as possible.

* VSEPR is pronounced as if it were written "vesper".

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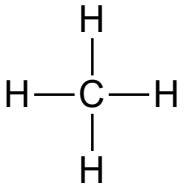
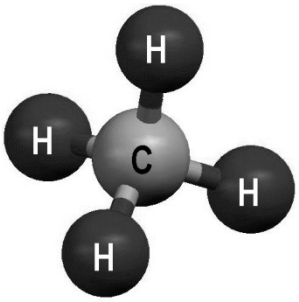
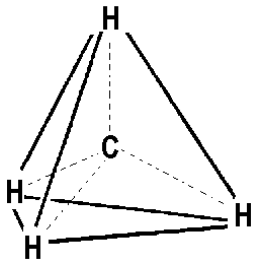
For example, in CH_4, the electron clouds around carbon are the four bonds to the hydrogen atoms. These electrons repel, which means they get as far apart as possible. In the Lewis structure, we draw the bonds at 90° angles, which is as far apart as possible in a 2-dimensional drawing:



However, the molecule is really 3-dimensional. This means the bonds are actually equally spaced around a *sphere*. This would result in a 3-dimensional molecule, with the hydrogens at 109.5° angles around the carbon atom:



If we described this molecule as a geometric shape, it would be a regular (all edges and angles equal) tetrahedron, with the carbon atom in the center and hydrogen atoms at the vertices:



This means that, according to VSEPR theory, CH_4 is a "tetrahedral" molecule.

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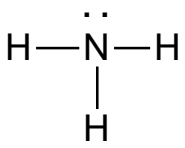
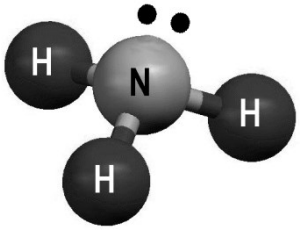
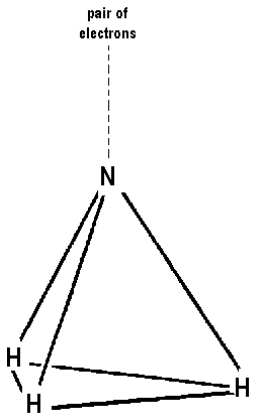
Now, consider the NH_3 molecule. The Lewis structure looks like this:



The "lone pair" of electrons (above the N atom) and the three bonds all repel each other.



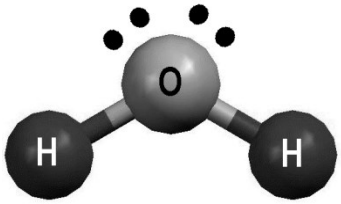
This gives *four* electron clouds, just like CH_4. However, because the lone pair is closer to the nucleus, it repels the other electrons more strongly than bond electrons. This compresses the bond angles slightly, to about 107.5°.



This time, the shape of the molecule is a triangular pyramid, but not a regular tetrahedron. This means the VSEPR shape of NH_3 is "trigonal pyramidal". The shape at right shows the pyramid (from the N atom downward), plus the "invisible" lone pair of electrons above.

H_2O has two bonds to hydrogen atoms, and two lone pairs of electrons.

The VSEPR shape of the H_2O molecule is therefore "bent". Because the lone pairs are closer to the nucleus, they repel a little more strongly than bond electrons, and the bond angle compresses to 104.5°.



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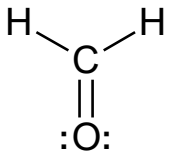
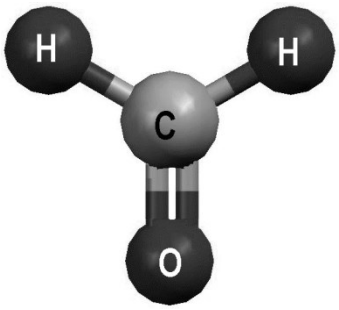
Now, suppose we have a molecule with a double bond, such as CH_2O. The Lewis structure is:

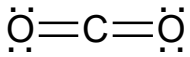


The electrons around the carbon atom are in <u>three</u> clouds, two smaller clouds for the C-H single bonds, and one larger cloud for the C=O double bond.

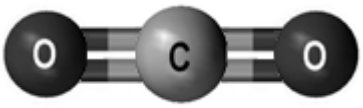


If these bonds got as far apart as possible in 3-dimensional space, they would be the points of a triangle, all in the same plane. This means that CH_2O is a "trigonal planar" molecule:

Finally, the CO_2 molecule has the following Lewis structure:



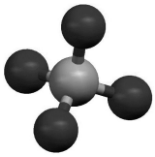
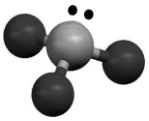
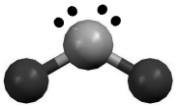
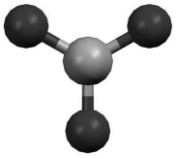
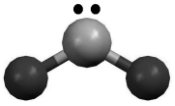
It has two large electron clouds for the C=O double bonds. The farthest these clouds can be from each other is 180° apart. This means the molecule forms a straight line, and its VSEPR shape is "linear":



The VSEPR shapes in this document are summarized in the table on the following page.

Use this space for summary and/or additional notes:

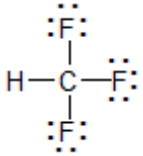
Table of VSEPR Shapes

Electron Clouds	Bond Atoms	Lone Pairs	Hybridization	Bond Angle	Picture	VSEPR Shape
4	4	0	sp^3	109.5°		tetrahedral
4	3	1	sp^3	107.5°		trigonal pyramidal
4	2	2	sp^3	104.5°		bent
3	3	0	sp^2	120°		trigonal planar
3	2	1	sp^2	118°		bent
2	2	0	sp	180°		linear

Use this space for summary and/or additional notes:

Homework Problems

For each of the following molecules, draw the Lewis structure. Then build a model of the molecule, and use your model to determine the shape of the electron clouds, and the shape of the molecule.

Formula	Lewis Structure	# of Electron Clouds around Central Atom	VSEPR shape
CHF_3		4	tetrahedral
NI_3			
H_2S			
CO_2			
AsH_3			
$COCl_2$			
PCl_3			

Use this space for summary and/or additional notes: