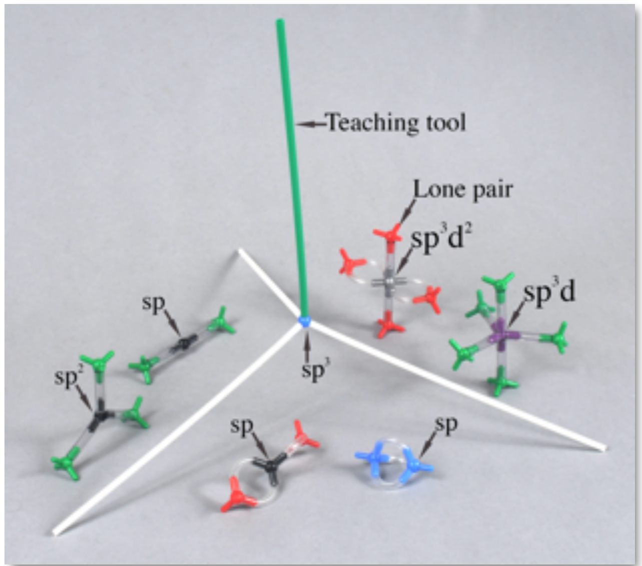
Super Models by Ryler Enterprises, Inc.



THE ORIGINAL, ULTIMATE, COMPREHENSIVE, HEURISTIC (OUCH!) MODELING KIT©

THE ONE KIT THAT COVERS 15 GENERAL CHEMISTRY TOPICS

TEACHER DEMONSTRATION &
CLASSROOM SET FOR STUDENT HANDS-ON ACTIVITIES

A Complete Teaching and Learning Kit for Modeling:

- Covalent Bonding
- VSEPR Theory
- Balancing Equations
- Enthalpy Change
- Equilibrium
- Acid-Base Reactions
- Reaction Mechanisms
- Dispersion Forces
- Hydrogen Bonding
- Water and Ice
- Solvation
- σ and π Bonds
- Functional Groups
- Isomers
- Reaction Quotients

Kit Contents:

90 1-peg Hydrogen (white)	90 4-peg Halogens (green)	90 4.0 cm Clear Bonds
16 6-peg Metal, Sulfur (silver)	30 4-peg Carbon (black)	14 0.87´´ Clear Bonds
16 5-peg Phosphorus (purple)	15 2-peg Beryllium (black)	14 0.87´´ White Bonds
30 4-peg Nitrogen (blue)	15 3-peg Boron (black)	6 0.87´´ Black Bonds
60 4-peg Oxygen (red)	17 21 cm Straws	6 2.12´´ White Bonds
15 4-peg Sulfur (yellow)	92 1.25´´ Clear Bonds	30 Magnets

Phone: 806-438-6865 E-mail: etishler@rylerenterprises.com Website: www.rylerenterprises.com

⚠ **Caution:** Atom centers and vinyl tubing are a choking hazard. Do not eat or chew model parts.

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Labs 5-9 General Chemistry Topics Using Stop-Motion-Video

How to Use the Flexible Bonds in this Kit

There are seven kinds of flexible bonds in your kit. The following table relates the type of bond to its function. Also, see Figs. 1 and 2.

BONDING TUBES AND THEIR USES-1	
Length/Color	**Use**
1.25´´/Clear	Single Bonds
1.25´´/Black	Solvation Bonds on Sodium Ion w/magnets
4 cm/Clear	Double or Triple Bonds
2.125´´/White	Pi Bonds
0.87´´/Clear	Single Bonds w/ magnets
0.87´´/White	Single Bonds w/ magnets
0.75´´/Clear	Sigma Bond

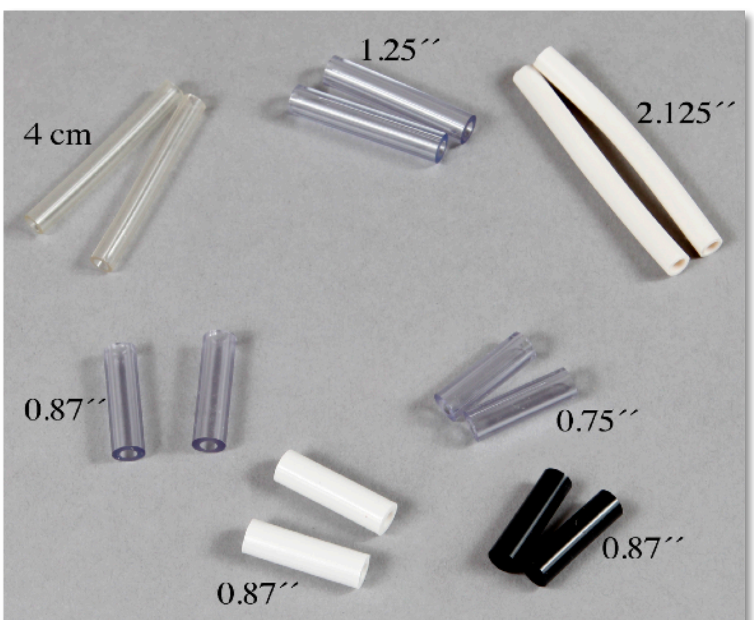


Fig. 1 The seven kinds of bonding tubes in this kit.

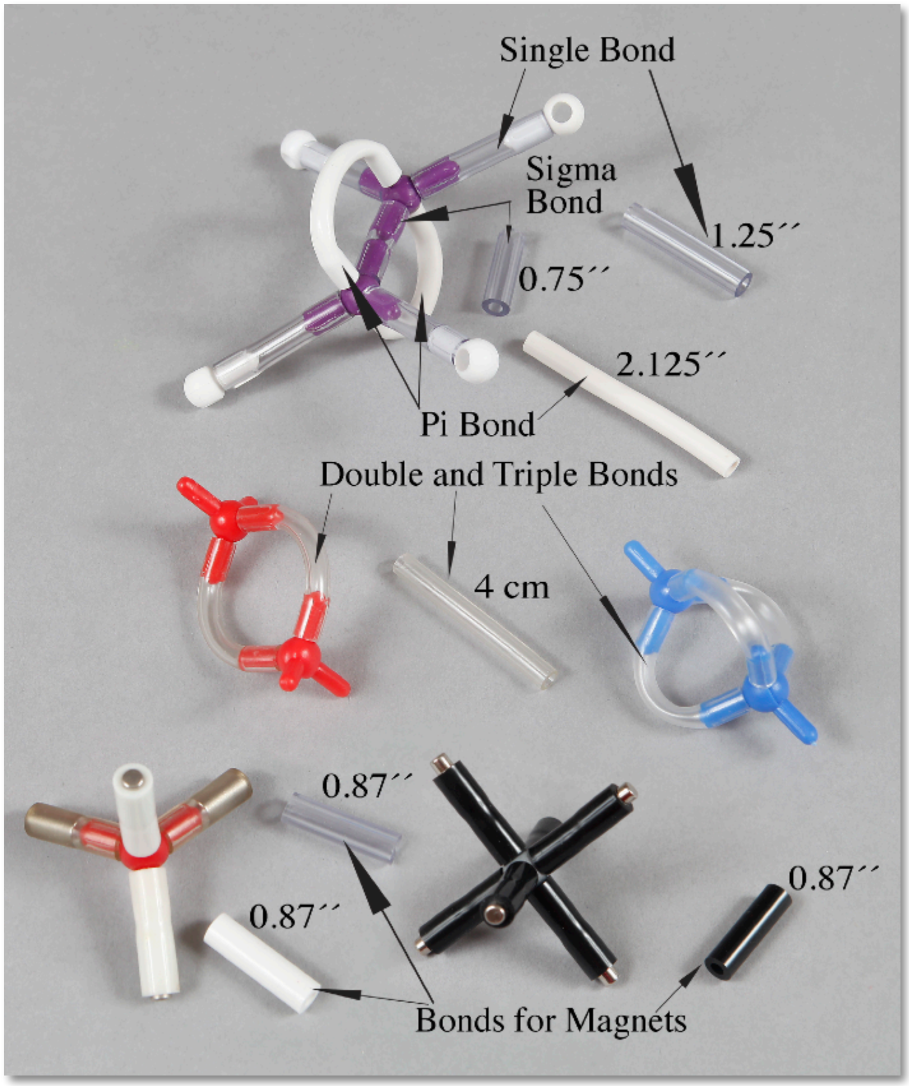


Fig. 2 How to use the flexible bonds in the OUCH! kit.

DEMONSTRATION 1: MOLECULAR GEOMETRY (VSEPR THEORY)

Using 21 cm long straws, a trigonal planar, a tetrahedral, a trigonal bipyramidal, and an octahedral atom center, the instructor will be able to prepare students for the VSEPR portion of the labs. During these demonstrations, students can be made aware of the difference between steric number (SN), also called electron domains (ED), and coordination number (CN). SN, or ED, is the number of lone pairs of electrons and atoms surrounding a central atom, while CN is only the number of other atoms surrounding an atom of interest.

In Fig. 1, a teacher holds a trigonal planar, black atom with three attached green straws. The SN is three, and the shape is trigonal planar. All bonds are 120^{o} apart. An example of a molecule with this shape is boron trifluoride (BF_3).

Fig. 1 A trigonal planar molecular shape.

In Fig. 2, a teacher holds a tetrahedral, black atom with four attached green straws. The SN is four, and the shape is tetrahedral. All bonds are 109.5^{o} apart. An example of a molecule with this shape is methane (CH_4).

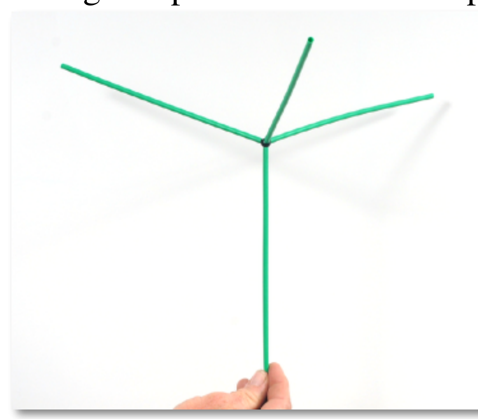


Fig. 2 A tetrahedral molecular shape.

In Fig. 3, a teacher holds a tetrahedral black atom with four attached green straws. The ends of two straws are pinched together to form a double bond. The SN is three (the four electrons in the double bond are counted as one group), and the shape is trigonal planar. The three SN groups are 120^{o} apart. An example of a molecule with this shape is formaldehyde (H_2CO).

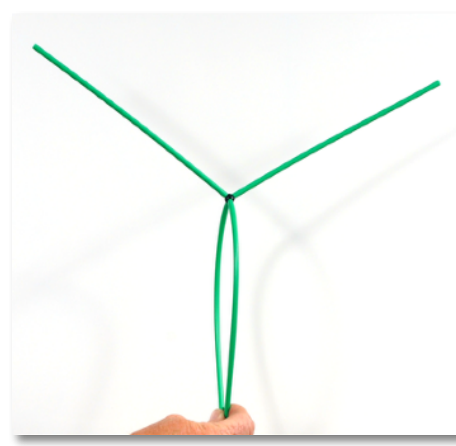


Fig. 3 A trigonal planar molecular shape.

In Fig. 4, a teacher holds a tetrahedral black atom with four attached green straws. The ends of two straws are pinched together to form a double bond. This is repeated with the other two straws. The SN is two (the four electrons in each double bond are counted as one group), and the shape is linear. The two double bonds are 180° apart. An example of a molecule with this shape is carbon dioxide (CO_2).

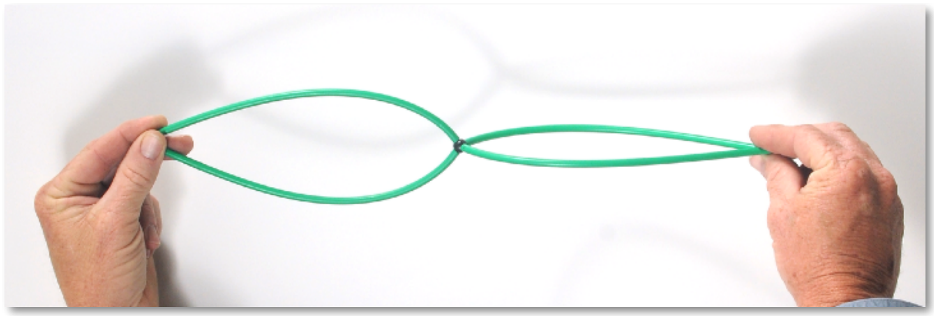


Fig. 4 A linear molecular shape.

In Fig. 5, the teacher continues to use a tetrahedral black atom, but now with three attached green straws. The SN is four (three bonding electron pairs and one lone, unused, pair), and the shape is trigonal pyramidal. The three bonding electron pairs are 107.3° apart. An example of a molecule with this shape is ammonia (NH_3).

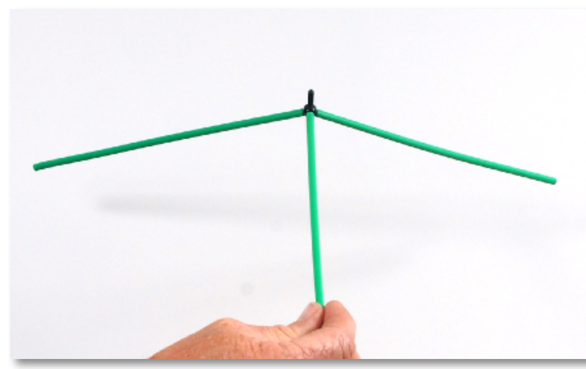


Fig. 5 A trigonal pyramidal molecular shape.

In Fig. 6, the teacher uses a black tetrahedral atom with three attached green straws. Two of the straws are pinched together on their free ends. The SN is three (a double bond, a single bond, and one lone pair), and the shape is bent with an angle of 116°. An example of a molecule with this shape is ozone (O_3).

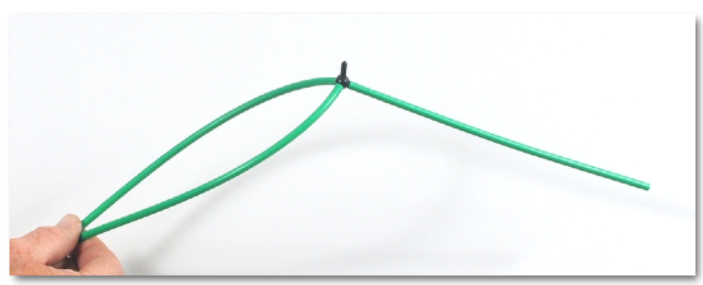


Fig. 6 A bent molecular shape.

In Fig. 7, the teacher holds a black tetrahedral atom, with two attached green straws. The SN is four (two single bonds, and two lone pairs), and the shape is bent. The bonding angle is 104.5^{o}. An example of a molecule with this shape is water (H_2O).

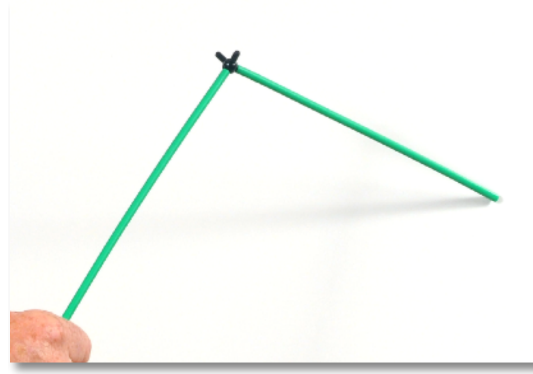


Fig. 7 A bent molecular shape.

In Fig. 8, the teacher uses a purple, trigonal bipyramidal atom with five attached red straws. The SN is five, and the shape is trigonal bipyramidal. The angles between the equatorial and axial bonds are all 90^{o}. The angle between the two axial bonds is 180^{o}, and the three equatorial bonds are 120^{o} apart. An example of a molecule with this shape is phosphorus pentachloride (PCl_5).

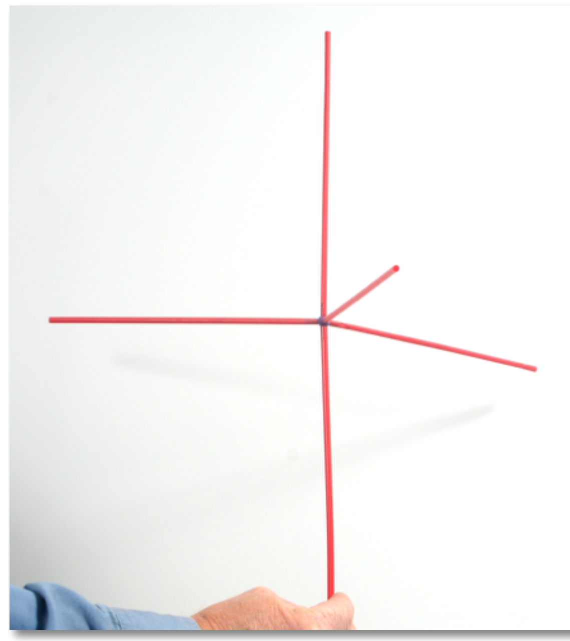


Fig. 8 A trigonal bipyramidal shape.

In Fig. 9, the teacher holds a purple, trigonal bipyramidal atom with four attached red straws. An equatorial straw is omitted. The SN is five (four bonding electron pairs and one lone, unused, pair), and the shape is "see-saw". Lone pairs of electrons are most stable in an equatorial position due to the greater angle with the other equatorial bonded electrons. The two equatorial electrons are 102^{o} apart, and the two axial bonds are 173^{o} apart. An example of a molecule with this shape is sulfur tetrafluoride (SF_4).

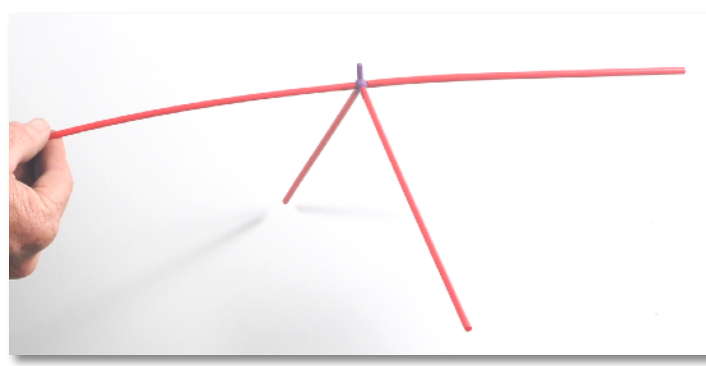


Fig. 9 A see-saw shape.

In Fig. 10, a purple, trigonal bipyramidal atom with three attached red straws is demonstrated. Two equatorial straws are omitted. The SN is five (three bonding electron pairs and two lone, unused, pairs), and the shape is a “T”. The angle between the two bonds at the top of the T is 175°. An example of a molecule with this shape is chlorine trifluoride (ClF_3).

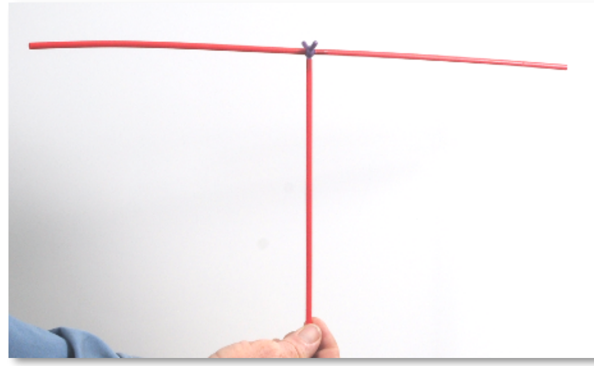


Fig. 10 A T-shape.

In Fig. 11, the teacher uses a silver, octahedral atom with six attached green straws. The SN is six, and the shape is octahedral. There are 90° between any two bonds. An example of a molecule with this shape is sulfur hexafluoride (SF_6).

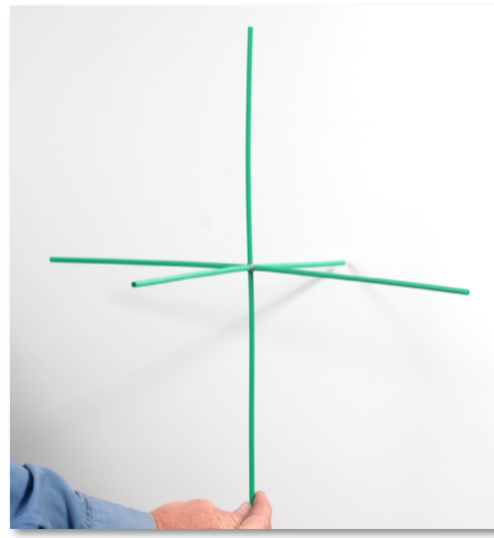


Fig. 11 An octahedral shape.

In Fig. 12, the teacher displays a silver, octahedral atom with five attached green straws (five bonding electron pairs and one lone, unused, pair). The SN is six, and the shape is square pyramidal. There are 90° between any two bonds. An example of a molecule with this shape is sulfur hexafluoride (SF_5).

Fig. 12 A square pyramidal shape.

In Fig. 13, the teacher is holding a silver, octahedral atom with four attached green straws (four bonding electron pairs and two lone, unused, pairs). The SN is six, and the shape is square planar. There are 90° between any two bonds. An example of a molecule with this shape is xenon tetrafluoride (XeF_4).

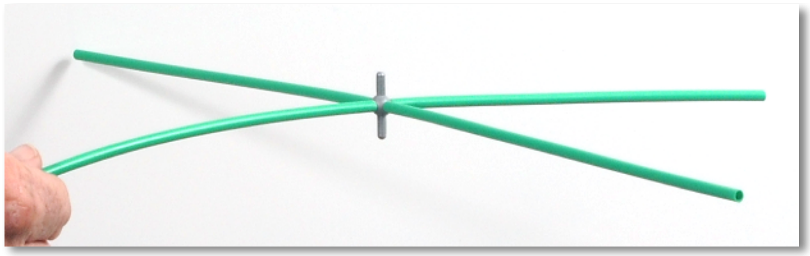


Fig. 13 A square planar shape.

DEMONSTRATION 2: BALANCING EQUATIONS

Materials Needed: OUCH! Kit

Write this equation on the board: $H_2 + O_2 \rightarrow H_2O$. Make six hydrogen molecules, three oxygen molecules, and six water molecules using the white, 1-peg atom centers (hydrogen), red, 4-peg atom centers (oxygen), clear, 1.25´´ tubes (single bonds), and clear, 4 cm tubes (used for double bonds). Fig. 1 shows two hydrogen molecules, one oxygen molecule, and two water molecules.

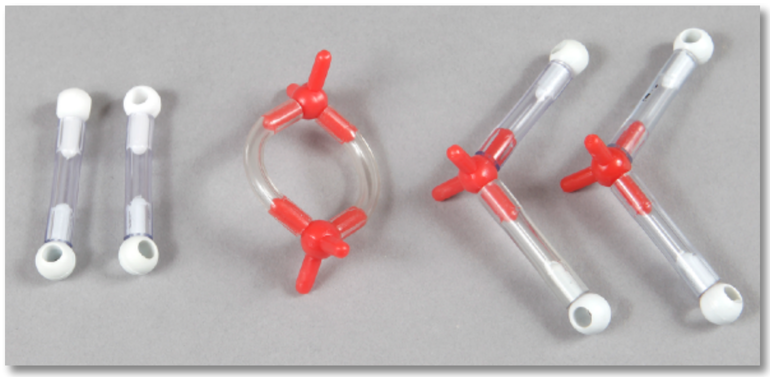


Fig. 1 Set-up for making two water molecules.

Show the students a model of a hydrogen molecule and an oxygen molecule, and explain the diatomic nature of these elements. Show the students the model of a water molecule. Ask the students to balance the equation: $H_2 + O_2 \rightarrow H_2O$.

Then ask the students to arrange the model molecules to match the balanced equation.

Add another model oxygen molecule, two hydrogen model molecules and two water model molecules to the arrangement. Ask the students to write a balanced equation to represent the new number of models.

If they write, $4H_2 + 2O_2 \rightarrow 4H_2O$, say “Incorrect,” and explain that the balanced equation written on the board, $2H_2 + O_2 \rightarrow 2H_2O$, the lowest-whole-number ratio of reactants and products, is used to represent an infinite number of possible multiples which can all be reduced or increased proportionally to fit the representative equation. This concept will have importance later when Avogadro’s number and moles are introduced.

Add another model oxygen molecule, two hydrogen model molecules and two water model molecules to the arrangement in order to emphasize, again, that it is the lowest ratio of coefficients that defines the ultimate ratios in a balanced equation.

DEMONSTRATION 3: ORBITAL HYBRIDIZATION, SIGMA AND PI BONDS

Materials Needed: OUCH! Kit

For a detailed explanation of orbital hybridization and sigma and pi bonds, please consult the Ryler Enterprises kit instruction manual, “General Chemistry,” available on the Ryler Enterprises website: www.rylerenterprises.com. Click on “Instructions and Quizzes,” locate the **General Chemistry** section, then click on General Chemistry (GEN-1). Pages six through 12 cover hybridization, and pages 15 through 17 cover sigma (σ) and pi (π) bonds.

Fig. 1 illustrates how to make a model showing sp^2 hybridization with one pi bond and five sigma bonds.

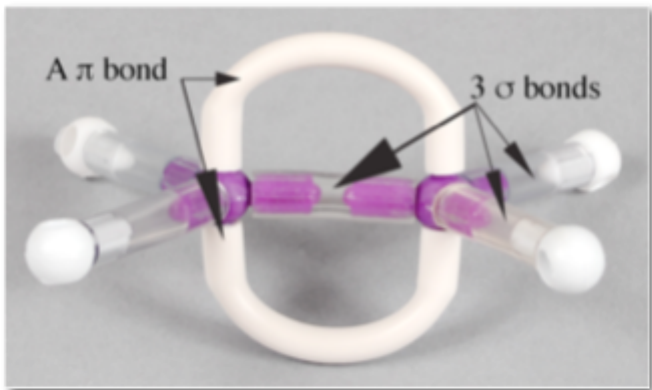


Fig. 1 An sp^2 model with 5 sigma and 1 pi bonds.

Fig. 2 illustrates how to make a model showing sp hybridization with two pi bonds and three sigma bonds.

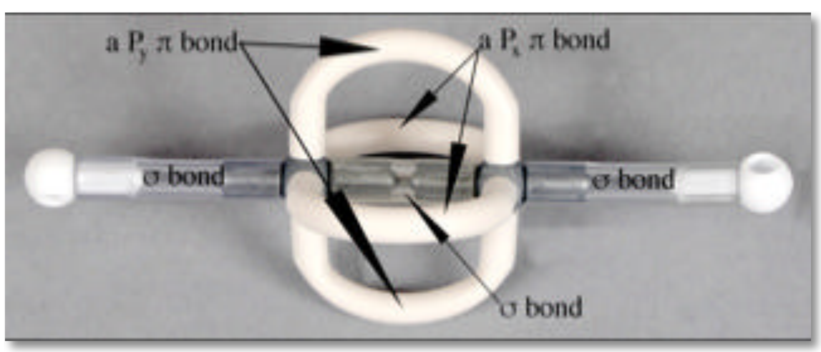


Fig. 2 An sp model with 3 sigma and 2 pi bonds.

The models help students visualize and understand that a single pi bond has two parts (lobes) with a “side to side” and/or “top to bottom” overlap of p orbitals, and a sigma bond has an “end to end" overlap of hybridized orbitals. The models also help demonstrate that a double bond is made up of one sigma bond and one pi bond, and a triple bond is made up of one sigma bond and two pi bonds.

ACTIVITY 1: HYDROGEN BONDING

Materials Needed: OUCH! Kit, 8 student volunteers

Teaching suggestions: Prepare the 0.875´´ white and clear tubes as follows. Push a cylindrical magnet into each white tube. See caution below.

CAUTION: PLEASE MAKE SURE THAT ALL THE MAGNETS HAVE THE SAME N/S ORIENTATION. ONCE IN A TUBE, A MAGNET IS VERY DIFFICULT TO REMOVE WITHOUT DESTROYING THE TUBE.

Next, push a cylindrical magnet into each clear tube. See caution below.

CAUTION: PLEASE MAKE SURE THAT THE MAGNETS HAVE A N/S ORIENTATION OPPOSITE TO THE MAGNETS IN THE WHITE TUBES.

You might want to test the polarity of each magnet by seeing that it is attracted to a magnet in a white tube, before inserting it completely into a clear tube.

Before class begins, build two of each the following molecules using the atom centers from the OUCH! Kit: H_2O, NH_3, HF, CH_3OH, using the bonds containing the magnets to represent hydrogen bonding sites (the white bonds represent hydrogens which are capable of hydrogen bonding, and the clear ones represent lone pairs of electrons). Note that the methyl group of CH_3OH has four 1.25´´ tubes without magnets and three, one peg, white atoms for the hydrogens.

Direct all students to draw Lewis structures in their notes (using dashes for bonds, and including dots for lone pairs) for H_2O, NH_3, HF, and CH_3OH. See Fig. 1.

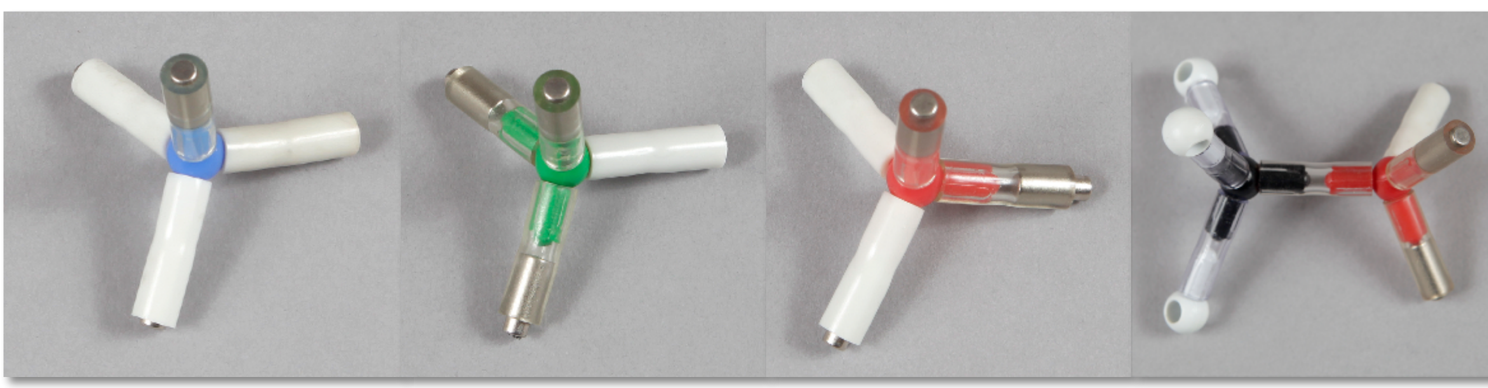


Fig. 1 From left to right, NH_3, HF, H_2O, and CH_3OH.

Ask two students to stand up in front of the class. Give each student an H_2O molecule model. Direct the students to demonstrate hydrogen bonding with their models. Direct all observing students to draw the hydrogen bonding arrangement in their notes. See Fig. 2, and refer to **Activity 2: Water (Ice) and Solvation,** as well.

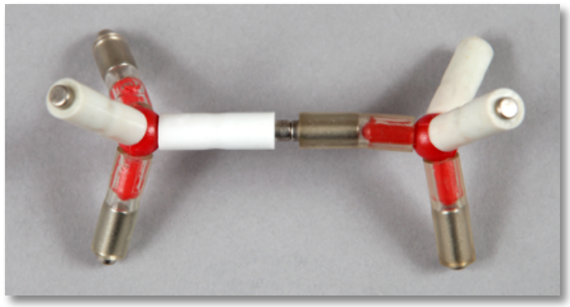


Fig. 2 Two water molecules hydrogen bonded.

Ask two more students to stand up in front of the class. Give each student an NH_3 molecule.

Ask the students to demonstrate hydrogen bonding with their models. Direct all observing students to draw the hydrogen bonding arrangements in their notes. See Fig 3.

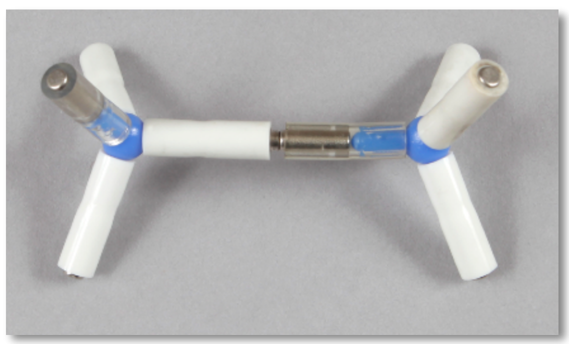


Fig. 3 Hydrogen bonding between two ammonia molecules.

Ask two more students to stand up in front of the class. Give each student an HF molecule. Have the students demonstrate hydrogen bonding with their models. Direct

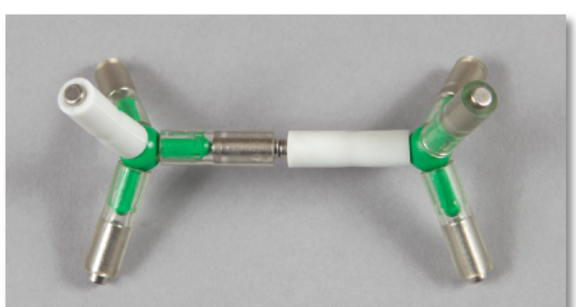


Fig. 4 Hydrogen bonding between two hydrogen fluoride molecules.

all observing students to draw the hydrogen bonding arrangement in their notes. See Fig. 4.

Have another two students to stand up in front of the class. Give each student a CH_3OH molecule. Direct the students to demonstrate hydrogen bonding with their models. Using the methanol (CH_3OH) molecular models demonstrates that not all hydrogens in a molecule form hydrogen bonds. Ask students to look for differences in hydrogens bonded to oxygen and hydrogens bonded to carbon. Direct all observing students to draw the hydrogen bonding arrangement in their notes. See Fig. 5.

Fig. 5 Hydrogen bonding between two methanol molecules.

To expand the concept, hydrogen bonding have the students find someone with a molecule different from their own and demonstrate hydrogen bonding between dissimilar molecules. Repeat until all arrangements of the four molecules are demonstrated. As before, direct all observing students to draw the hydrogen bonding arrangements in their notes.

ACTIVITY 2: WATER (ICE) AND SOLVATION

Materials Needed: OUCH! Kit

For more detailed background information consult the Ryler Enterprises “Chemistry of Water” kit available on the Ryler Enterprises website: www.rylerenterprises.com. Click on “Instructions and Quizzes,” locate the **General Chemistry** section, then click on Chemistry of Water (WAT-1).

Teaching suggestions: Before class begins, build six water molecules (see instructions for preparing the tubes with magnets in **Activity 1: Hydrogen Bonding**).

Put black, 0.87´´ tubes on the six pegs of a silver atom to make a sodium ion, and insert a magnet in each tube. See caution below.

CAUTION: PLEASE MAKE SURE THAT THE MAGNETS HAVE A N/S ORIENTATION EXACTLY THE SAME AS THE MAGNETS IN THE WHITE TUBES. SEE FIG. 2 BELOW.

Put clear, 0.87´´ tubes on the six pegs of a green atom to make a chloride ion, and insert a magnet in each tube. See caution below.

CAUTION: PLEASE MAKE SURE THAT THE MAGNETS HAVE A N/S ORIENTATION EXACTLY THE SAME AS THE MAGNETS IN THE OTHER CLEAR TUBES. SEE FIG. 3 BELOW.

The white bonds represent hydrogens which are capable of hydrogen bonding, and the clear ones represent lone pairs of electrons. See the caution about the black bonds above.

Ask two students to stand up in front of the class. Give each student an H_2O molecular model. Direct the students to demonstrate hydrogen bonding with their models. Ask the students to demonstrate different hydrogen bonding configurations (ways of forming bonds). Direct all observing students to draw the hydrogen bonding arrangements in their notes. Fig. 1 shows five different arrangements of hydrogen bonding between two water molecules.

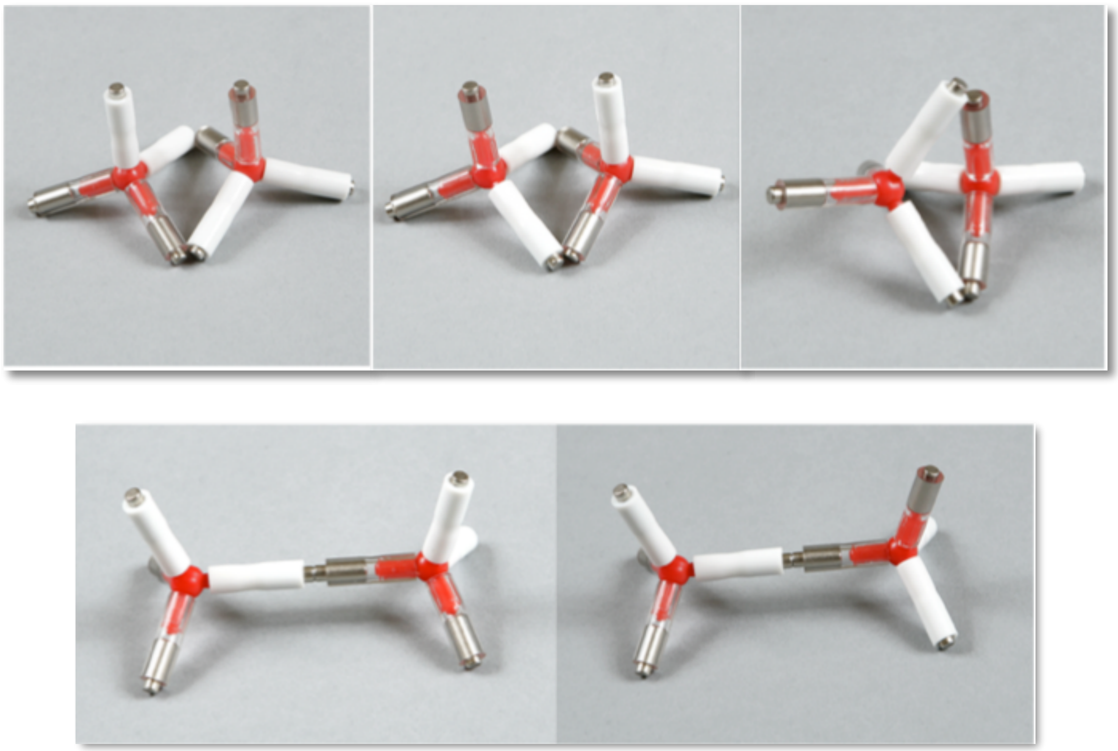


Fig. 1 Five possible ways of hydrogen bonding between two water molecules.

Make a sodium chloride model by attaching the sodium ion to the chloride ion. Hand the model to a student and ask the him/her to stand up in front of the class. Give six students one H_2O molecule model each. Have the students with the water molecules demonstrate how the water molecules are attracted to the sodium ion to form a ion-dipole interaction (Fig. 2). Now repeat the process with the chloride ion (Fig 3). Direct all observing students to draw the arrangements in their notes.

Fig. 2 Silver sodium ion, with black tubes, surrounded by six water molecules.

Fig. 3 Green chloride ion surrounded by six water molecules.

Separating and isolating the sodium and chloride ions with water molecules demonstrates solvation. When the topic of heat of solvation is studied, the demonstration could be used again.

Take six water molecules and arrange them into a hexagon to represent an hexagonal ice crystal. Because the oxygen atoms in the water molecules are sp^3 hybridized, they are tetrahedral, and the structure will tend to form a chair or boat conformation. If you twist oxygen number “1” up and number “4” down, you will get the more stable chair conformer. You might also try the boat conformer by twisting “1” up and “4” up as well. See Fig. 4.

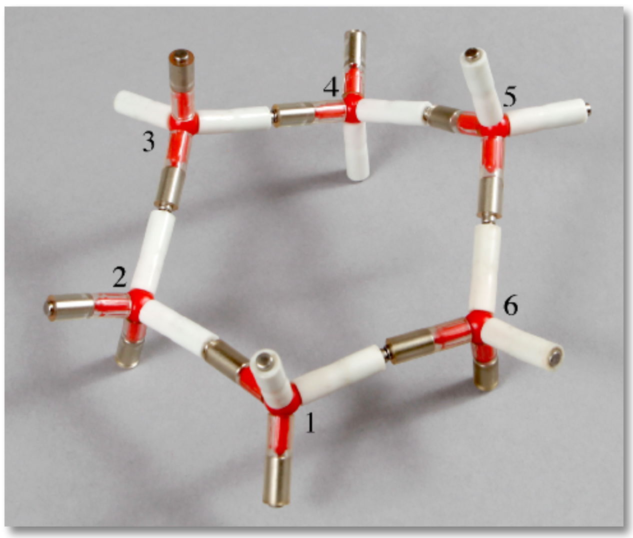


Fig. 4 A chair conformation of six water molecules in an ice crystal.

Ask students why water freezes from the top down rather than in the other direction. The answer lies in the structure of the ice crystal expanding and becoming less dense and therefore being able to float on liquid water. You might also relate this property to plant and animal life being protected by this phenomenon.

Labs 1-4 Principles of VSEPR

Introduction

Labs 1 through 4 cover the following topics related to VSEPR theory: 1) valence electrons and electron lone pairs; 2) the octet rule and exceptions; 3) bond angles and molecular geometry; 4) steric number (SN), electron density (ED), and coordination number (CN); 5) Lewis structures; 6) formal charges; 7) resonance; 8) orbital hybridization; 9) bond polarity; and 10) molecular polarity.

Below, you will find supplementary material covering theses topics which you may want to copy and hand out to your students.

1) Valence Electrons: Bonding, and Lone Pair Electrons

Electrons which are used for bonding are called valence electrons, and the shell (highest energy level) that contains them is called the valence shell. Frequently, some atoms have valence electrons which are not used for bonding. They usually occur in pairs, and they are called non-bonding, or lone pair electrons. When diagraming atoms with lone pairs, the electrons are simply shown as paired dots around the atom's symbol. Some atoms use electrons from the next lower energy level for bonding.

2) The Octet Rule and Exceptions

Atoms of the main group elements (groups 1,2 and 13-18, or in the older numbering system, IA, IIA and IIIA through VIIIA) will become most stable (resist change) when they have a total of eight electrons in their outer shell s and p subshells. This is known as the octet rule.

Note that there are three categories of exceptions to the octet rule:

1) Electron deficiency: For example, hydrogen and helium are most stable with two electrons in their valence shell (the duet rule). Additionally, some elements of groups 2 and 3 are able to form stable compounds with two or three valence electrons (e.g. $BeCl_2$, BCl_3, and $AlCl_3$).

2) Odd numbers of electrons: For example, nitrogen atoms in some molecules have seven valence electrons (e.g. NO_2, NO).

3) An expanded octet: The elements beyond period two may participate in bonding using more than eight electrons (forming an expanded octet). Some examples are sulfur in H_2SO_4 and phosphorus in H_3PO_4, and the transition metals in groups 3 through 12 (IB through VIIIB). These exceptions are due to *d* orbitals becoming available for bonding.

3) and 4) Bond Angles and Molecular Geometry

These topics were covered in **DEMONSTRATION 1: MOLECULAR GEOMETRY (VSEPR THEORY)** above.

Steric Number, Electron Density, Coordination Number, and Bond Number

These topics were covered in **DEMONSTRATION 1: MOLECULAR GEOMETRY (VSEPR THEORY)** above.

5), 6), and 7) Lewis Structures, Formal Charges, and Resonance

Drawing Lewis Structures

Step 1.

From the molecular formula of the molecule, write the symbols of the atoms with dashed lines between them. The least electronegative should be used as the central atom. Hydrogen atoms will always be terminal (on an end), since those atoms usually have one bond. The same is true for the halogens, except in some molecules which are composed of halogens exclusively. Fluorine, the most electronegative element will always be terminal. When the chemical formula of a compound is written, very often the order in the formula is the same as the order of the atoms in the Lewis structure.

Step 2.

Using a periodic table, find the number of valence electrons of all the participating atoms. The group number in the older "A, B" system will be the number of valence electrons. If you use the new numbering system, subtract ten from group numbers 13 through 18 to get the valence number. Subtract two for each dash put between the atoms (each dash represents a pair of shared electrons). Subtract one for each positive charge if you are dealing with a positively charged ion. Add one for each negative charge if you are drawing the Lewis structure of a negatively charged ion.

Step 3.

Next, using the total from Step 2, place the valence electrons, in pairs, around the atoms starting with the most electronegative elements first until each atom has an octet. Be aware that some elements will have less than an octet: H, Be, Be, Al, and sometimes N. Some might have more than eight electrons: transition metals and elements in the p block beyond row two of the periodic table. If there are left over electrons, put them on the central atom.

Step 4.

If some atoms have less than an octet, move lone pairs from the terminal atoms into a bond with the central another atom to form an octet.

Step 5.

Check the structure for formal charges. If the structure is a neutral molecule, formal charges on each atom will be zero, but if some atoms have charges, they should be as low as possible, and the charge should fit with the electronegativity of the atom. That is, usually negative charges will reside on highly electronegative atoms.

Step 6. Formal Charges

Formal charges of atoms in a compound presume that electrons between atoms are being equally shared. An atom, will therefore, "own" its nonbonding electrons and one half of all its bonding electrons. Use the following formula to find formal charges. Formal charge = Valence Electrons – Nonbonding Electrons – ½ Bonding Electrons.

When calculating formal charges, the following situations will indicate that the structure you have drawn may be incorrect.

1) Atoms with large charges; charges greater than +2 or – 2.

2) Positive charges on highly electronegative elements, or negative charges on elements which are not very electronegative.

There is one more molecular strategy that can overcome the problem of formal charges. It is the chemical equivalent of a mule, and it is called resonance.

Step 7.

Make resonance hybrids, if needed.

Resonance will be illustrated using NO_3^-, the nitrate ion (Fig. 1).

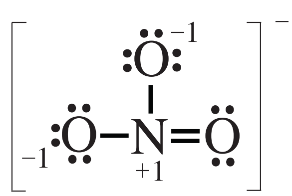


Fig. 1 The nitrate ion.

Each atom has an octet, and one of the negative charges matches the ionic charge, while the other negative charge cancels the positive charge on the N atom. There is not a way to get rid of the positive charge and one of the negative charges. If the negative charge can be shared among the three oxygen atoms, the energy expense of holding the charge can be lowered. The sharing is called resonance, and the Lewis structures in Fig. 2 give an imaginary picture of how it takes place. (Chemists use the double pointed arrows for resonance only. These are not ordinary chemical reactions).

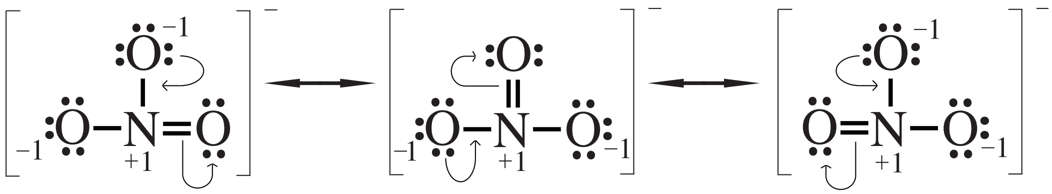


Fig. 2 Changing electron pair positions in a nitrate ion.

These are not actual changes. The three forms of the nitrate ion do not switch back and forth with each other, but it is difficult to make drawings that reflect the true situation. In reality, the three forms blend together to form one structure, a hybrid.

Consider a similar blending of characteristics in the biological world. The mating of a horse with a donkey produces a hybrid we call a mule. A mule is not a horse at one moment in time and a donkey at another. A mule has characteristics of both parents at all times.

Resonance hybrids present a similar situation chemically. How do chemists know that resonance hybrids exist as one blended structure? Measurements of the lengths of the bonds between the O atoms and the central N atom indicate that each bond is shorter than a single bond but longer than a double bond, and each bond is exactly like the other two. Below, in Fig. 3, is the best Lewis structure that can be made for a hybrid molecule or ion. The dotted lines are partial bonds, and the three negative charges of (–2/3) + (–2/3) + (–2/3) add up to –2. The +1 charge on N cancels –1, leaving a charge of –1 on the ion.

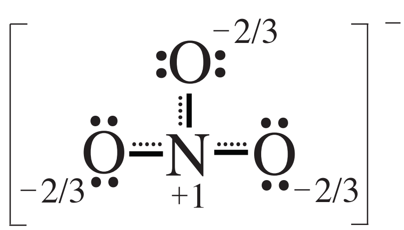


Fig. 3 The nitrate ion resonance hybrid.

8) Orbital Hybridization

This topic was discussed in **DEMONSTRATION 3: ORBITAL HYBRIDIZATION** above.

9) Bond Polarity

A bond between atoms of two different elements with different electronegativities will be polar (having oppositely charged ends). In general, a bond between atoms of any two elements will be polar, some bonds being more polar than others.

10) Molecular Polarity

A molecule with polar bonds and lacking symmetry will be polar (having oppositely charged ends). A molecule with polar bonds and having symmetry will be nonpolar (not having oppositely charged ends). Usually, a molecule with non polar bonds will not be polar. One notable exception to this generality is ozone (O_3), a bent molecule with a central atom which has a positive charge and two peripheral oxygen atoms which are slightly negative.

LAB 1: Building Models of Molecules and Polyatomic Ions and Identifying Geometries.

Teacher's Guide

1. The first 10 molecules and ions are based on the octet rule. These would be appropriate for introducing or refreshing the rules of VSEPR theory. See **Labs 1-4 Principles of VSEPR-Introduction** above.
2. The second set of 10 molecules and ions is based on expanded octets.
3. Choose any or all of the examples for your students to work on.
4. Student will put their responses on their own papers.
5. Each group of students will need the following parts which you might want to put in baggies before the lab. There are enough parts in the kit for 15 groups.

ATOM CENTERS-LAB 1		
Qty	Element	Color/ Pegs
3	Oxygen	Red/4
1	Nitrogen	Blue/4
6	Halogen	Green/4
1	Sulfur	Yellow/4
1	Sulfur	Yellow/6
1	Carbon	Black/4
4	Hydrogen	White/1
1	Xenon	Silver/6
1	Phosphorus/ Iodine	Purple/5

BONDING TUBES-LAB 1		
Qty	Length	Color
6	1.25´´	Colorless
4	4 cm	Colorless

6. For an explanation of the placement of the least electronegative element in an equatorial position in a trigonal bipyramidal molecule, do a Google search for Bent's Rule.

Key:

1. F_2: Linear 3. H_2S: Bent 5. SO_3: Trigonal Planar 7. PH_4^{1+} :Tetrahedral 9. OCl_2: Bent

2. N_2O: Bent 4. PF_3: Trigonal Pyramidal 6. SO_2: Bent 8. CO_3^{2-} : Trigonal Planar 10. CH_4: Tetrahedral

11. SF_6: Octahedral 13. XeO_2F_2: See Saw 15. XeF_4: Square Planar 17. SCl_4 : See Saw 19. ICl_4^{1-}: Square Planar

12. ClF_3: T-shaped 14. PCl_5: Trigonal Bipyramidal 16. BrF_5: Square pyramidal 18. Cl_2^{1-} : Linear 20. I_3^{1-}: Linear

LAB 1: Building Models of Molecules and Polyatomic Ions and Identifying Geometries.

Student Procedure

Your teacher will assign molecules to you from the following list. Draw their Lewis structures, build their models, and name their geometries. Show your models and your written answers to your instructor. Note that a peg without another atom center attached to it usually represents a lone pair of electrons. Can you think of an exception to this generality?

Octet-Rule Molecules and Ions

1. F_2	3. H_2S	5. SO_3	7. PH_4^{1+}	9. OCl_2
2. N_2O	4. PF_3	6. SO_2	8. CO_3^{2-}	10. CH_4

Expanded-Octet Rule Molecules and Ions

11. SF_6	13. XeO_2F_2*	15. XeF_4	17. SCl_4	19. ICl_4^{1-}
12. ClF_3	14. PCl_5	16. BrF_5	18. ICl_2^{1-}	20. I_3^{1-} †

*The least electronegative element should be in an equatorial position.

† Use a trigonal bipyramidal atom center for the central iodine atom.

LAB 2: Molecules Containing Atoms with an Incomplete Octet.

Teacher's Guide

1. Provide each group of students with the following atom centers and tubes. Two green atoms will represent chlorine, and the additional three green atoms will represent fluorine. The blue and red atoms are provided in order to make a molecule of nitric oxide (NO) which has a double bond. Usually, a peg without a bond on it would represent a lone pair of electrons, but for NO the single unused peg on nitrogen will represent a single electron. You may want to package each set in a baggy beforehand to save time. There are enough parts in the kit for 15 groups.

ATOM CENTERS-LAB 2		
Qty	Element	Color/Pegs
1	Beryllium	Black/2
1	Boron	Black/3
5	Chlorine/ Fluorine	Green/4
1	Nitrogen	Blue/4
1	Oxygen	Red/4

BONDING TUBES-LAB 2		
Qty	Length	Color
5	1.25´´	Clear
2	4 cm	Clear

2. Before doing the lab, please read the student instructions. Each student will be asked to complete the lab table and turn it in, but only one student table per group is checked by you during the lab. Staple the papers from each group together to make sure that all students complete the work.

3. Read the instructions with students to make sure they understand the procedure. You may want to review (or teach) Lewis structures and VSEPR shapes, and clarify the difference between SN, CN and Bond Number count. FOR ANSWERS IN COLUMN 6, YOU WILL HAVE TO DECIDE WHAT YOU WANT THE STUDENTS TO REPORT: SN (THE COORDINATION NUMBER, PLUS THE NUMBER LONE PAIRS); OR CN (THE NUMBER OF ATOMS BONDED TO THE CENTRAL ATOM, IGNORING THE ACTUAL NUMBER OF BONDS); OR THE ACTUAL NUMBER OF BONDS.

4. Pegs without bonds are usually lone pairs of electrons. Sometimes an exception to this generalization might be an atom with an odd number of electron, such as nitrogen in NO. The nitrogen will not obey the octet rule. See Labs 1-4 Principles of VSEPR-Introduction.

5. The lab table, with blanks to be filled in, is supplied with the student instructions.

LAB 2: Molecules Containing Atoms with an Incomplete Octet.

Student Procedure

1. Your teacher will provide your group with atoms and bonds for this activity.

2. Make one copy in your group the Master Copy, and have your teacher check that sheet. Each student must fill out a lab report, but only the Master Copy will be used for the final grade for each member of the group.

3. Use a pencil to fill in all blank boxes except the Model Checked (COLUMN 9) which your teacher will initial. You will fill in each horizontal row and then show the model and the Master Copy to the instructor for verification.

Doing the lab

1. Draw the Lewis structure in COLUMN 2, and then use it to determine molecular structure. Rules for making Lewis structures will be supplied by your teacher.

2. In COLUMN 3, labeled Molecular Shape, and in COLUMN 4, labeled Bond Angles °, write the shape name such as linear, bent, etc., and the angle between the central atom and the peripheral atoms. The shape is determined by the position of the atoms, not the electrons.

3. In your molecule, look for pegs without bonds. They represent lone pairs of electrons. Enter that number in COLUMN 5, #Lone Pairs.
4. In COLUMN 6 (SN/CN/# Bonds), your teacher will tell you how to report the appropriate answer.
5. In COLUMN 7 (Bonds, Polar/Non), write either Polar or Non-polar in the blank to describe individual bonds in the molecule.
6. In COLUMN 8 (Molecule, Polar/Non), write either Polar or Non-polar in the blank to describe the whole molecule.

1	2	3	4	5	6	7	8	9
Molecular Formula	Lewis Structure	Shape	Bond Angle	# of Lone Pairs	# of Bonds	Bonds Polar?	Molecule Polar?	Model Checked
$BeCl_2$								
BF_3								
NO								

LAB 3: Molecules and Polyatomic Ions Containing Atoms that Follow the Octet Rule

Teacher's Guide

1. The following parts are needed by each group for this lab. You may want to package each set in a baggy beforehand to save time. There are enough parts in the kit for 15 groups.

ATOM CENTERS-LAB 3		
Qty	Element	Color/Pegs
4	Hydrogen	White/1
1	Carbon	Black/4
2	Chlorine	Green/4
3	Oxygen	Red/4
2	Nitrogen	Blue/4
1	Sulfur	Yellow/4

BONDING TUBES-LAB 3		
Qty	Length	Color
8	1.25´´	Clear
8	4 cm	Clear

2. Before doing the lab, please read the student instructions. Each student will be asked to complete the lab table and turn it in, but only one student table per group is checked by you during the lab. Staple the papers from each group together.

3. Read the instructions with students to make sure they understand the procedure. You may want to review (or teach) the following topics: Lewis structures and VSEPR shapes, and clarify the difference between CN and SN, using the demonstrations with straws shown above. Pegs without bonds are lone pairs of electrons. Additional topics are resonance, bond polarity, and molecular polarity. See **Labs 1-4 Principles of VSEPR-Introduction** above.

4. FOR ANSWERS IN COLUMN 6, YOU WILL HAVE TO DECIDE WHAT YOU WANT THE STUDENTS TO REPORT: SN (THE COORDINATION NUMBER, PLUS THE NUMBER LONE PAIRS); OR CN (THE NUMBER OF ATOMS BONDED TO THE CENTRAL ATOM, IGNORING THE ACTUAL NUMBER OF BONDS); OR THE ACTUAL NUMBER OF BONDS.

5. The lab table, with blanks to be filled in, is supplied with the student instructions.

6. The answer key is on the next page.

Molecular Formula	Lewis Structure	Shape	Bond Angle	# of Lone pairs	# of Bonds	Resonance?	Bonds Polar?	Molecule Polar?	Model
H_2	H:H	linear	180	0	1	No	No	No	
Cl_2	:Cl:Cl:	linear	180	6	1	No	No	No	
H_2O	H:O:H	bent	105	2	2	No	Yes	Yes	
HCl	H:Cl:	linear	180	3	1	No	Yes	Yes	
O_2	:O::O:	linear	180	4	1	No	No	No	
CO_2	O::C::O	linear	180	4	2	No	Yes	No	
NH_3	H:N:H H	trigonal pyramidal	107	1	3	No	Yes	Yes	
NH_4^+	H H:N:H H	tetrahedral	109.5	0	4	No	Yes	No	
O_3	:O::O:O:	bent	117	6	2	Yes	No	Yes	
CH_4	H H:C:H H	tetrahedral	109.5	0	4	No	Yes	No	
NO_2^{1-}	:O:N::O:	bent	117	6	2	Yes	Yes	Yes	
NO_3^{1-}	:O:N::O: :O:	trigonal planar	120	8	3	Yes	Yes	No	
N_2	:N:::N:	linear	180	2	1	No	No	No	
SO_2	:O:S::O:	bent	117	6	2	Yes	Yes	Yes	
SO_3	:O:S::O: :O:	trigonal planar	120	8	3	Yes	Yes	No	

LAB 3: Molecules and Polyatomic Ions Containing Atoms that Follow the Octet Rule

Student Procedure

1. Your teacher will provide your group with atoms and bonds for this activity.

2. Make one copy of the lab the Master copy and have the teacher check that one sheet. Each student should fill out a sheet, but only the Master copy will be used for the final grade.

3. Use a pencil to fill in all blank boxes except the Model Checked (COLUMN 10). This is where your instructor initials that the models are correct. You will fill in the entire first horizontal row and bring the model to the instructor for verification.

Doing the lab

1. Draw the Lewis structure in COLUMN 2, and then use it to determine molecular structure. Rules for making Lewis structures will be supplied by your teacher.

2. In COLUMN 3, labeled Shape, and in COLUMN 4, labeled Bond Angles °, write the shape name such as linear, bent, etc., and the angles between all atoms. The shape is determined by the position of the atoms, not the electrons.

3. In your molecule, look for pegs without bonds. They represent lone pairs of electrons. Enter that number in COLUMN 5, #Lone pairs.

4. In COLUMN 6, SN/CN/# Bonds, your teacher will tell you how to report the appropriate answer.

5. In COLUMN 7, Resonance, insert a yes or no. Your teacher will explain the meaning of the term.

6. In COLUMN 8, Bonds, Polar/Non, write either yes or no in the blank to describe individual bonds in the molecule. Your teacher will explain the meaning of the term, polar, as it applies to a bond.

7. In COLUMN 9, Molecule Polar/Non?, write either yes or no in the blank to describe the whole molecule. Your teacher will explain the meaning of the term, polar, as it applies to a molecule.

1	2	3	4	5	6	7	8	9	10
Molecular Formula	Lewis Structure	Shape	Bond Angle	# of Lone pairs	# of Bonds	Resonance?	Bonds Polar?	Molecule Polar?	Model Checked
H_2									
Cl_2									
H_2O									
HCl									
O_2									
CO_2									
NH_3									
NH_4^+									
O_3									
CH_4									
NO_2^{1-}									
NO_3^{1-}									
N_2									
SO_2									
SO_3									

LAB 4: Molecules and Polyatomic Ions Containing Atoms with an Expanded Octet

Teacher's Guide

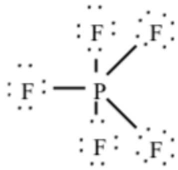
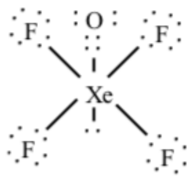
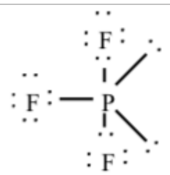
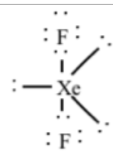
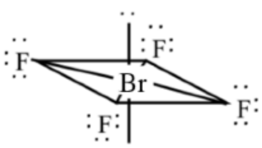
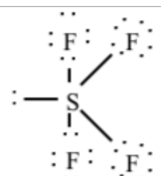
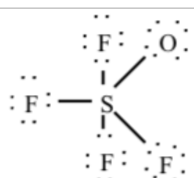
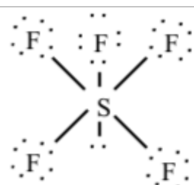
1. The following parts are needed by each group for this lab. You may want to package each set in a baggy beforehand to save time. There are enough parts in the kit for 15 groups.

ATOM CENTERS-LAB 4		
Qty	Element	Color/Pegs
4	Oxygen	Red/4
6	Halogen	Green/4
1	Phosphorus/ Selenium/Xenon/ Sulfur/Iodine/ Chlorine	Purple/5
1	Sulfur/Xenon/ Iodine/Bromine	Silver/6
1	Sulfur/Phosphorus	Yellow/4

BONDING TUBES-LAB 4		
Qty	Length	Color
12	1.25´´	Clear
12	4 cm	Clear

2. Before doing the lab, please read the student instructions. Each student will be asked to complete the lab table and turn it in, but only one student table per group is checked by you during the lab. Staple the papers from each group together.
3. Read the instructions with students to make sure they understand the procedure. You may want to review (or teach) the following topics: Lewis structures and VSEPR shapes, and clarify the difference between CN and SN, using the demonstrations with straws shown above. Pegs without bonds are lone pairs of electrons. See **Labs 1-4 Principles of VSEPR-Introduction** above.
4. FOR ANSWERS IN COLUMN 7, YOU WILL HAVE TO DECIDE WHAT YOU WANT THE STUDENTS TO REPORT: SN (THE COORDINATION NUMBER, PLUS THE NUMBER LONE PAIRS; OR CN (THE NUMBER OF ATOMS BONDED TO THE CENTRAL ATOM, IGNORING THE ACTUAL NUMBER OF BONDS); OR THE ACTUAL NUMBER OF BONDS.
5. The lab table, with blanks to be filled in, is supplied with the student instructions.

The answer key is on the following page.

Molecular Formula	Lewis Structure	Shape Angle(s)	Formal Charges	# of bonds on the central atom	# of lone pairs on the central atom	Hybridization of the central atom	Model
PF_5		trigonal bipyramidal 120/90	P: 0 F:0	5	0	sp^3d	
TeF_4		see-saw 90/170	Te: 0 F: 0	4	2	sp^3d	
XeF_4O*		square pyramid 90	Xe: 0 F: 0 O: 0	5	1	sp^3d^2	
PF_3^{2-}		T shaped 90/180	P: -2 F:0	3	2	sp^3d	
XeF_2		linear 90	Xe: 0 F: 0	2	3	sp^3d	
BrF_4^{1-}		square planar 90	Br: -1 F: 0	4	2	sp^3d	
SF_4		see-saw 90/170	S: 0 F: 0	4	1	sp^3d	
SOF_4		trigonal bipyramidal 120/90	S: +1 O: -1 F: 0	5	0	sp^3d	
SF_5^{1-}		square pyramid 90	S: -1 F: 0	5	1	sp^3d^2	
PF_4^{1-}		see-saw 90/170	P: -1 F: 0	4	1	sp^3d	
* Oxygen is not in the same plane as the 4 fluorine atoms							

LAB 4: Molecules and Polyatomic Ions Containing Atoms with an Expanded Octet

Student Procedure

1. Your teacher will provide your group with atoms and bonds for this activity.

2. Make one copy of the lab the Master Copy and have the teacher check that one sheet. Each student should fill out a sheet, but only the Master Copy will be used for the final grade.

3. Use a pencil to fill in all blank boxes except the Model Checked (COLUMN 10). This is where your instructor stamps or initials that the models are correct. You will fill in an entire horizontal row and then bring the model to the instructor for verification.

Doing the lab

1. Draw the Lewis Structure in COLUMN 2, and then use it to determine molecular structure. Rules for making Lewis structures will be supplied by your teacher.

2. In COLUMN 3, Shape Angles °, the shape name should go on top (such as linear, bent, etc.), and the angle in degrees goes on the bottom. The shape is determined by the position of the atoms, not the bonds.

3. In COLUMN 4, Formal Charge , write the formal charge of the each atom in the structure.

4. In COLUMN 5, SN/CN/# Bonds, your teacher will tell you how to report the appropriate answer.

5. In COLUMN 6, # of lone pairs, write the number of pairs of nonbonding electrons. This is determined by the number of unused pegs (one peg being equal to one pair of electrons).

6. In COLUMN 7, write the hybrid orbitals of the central atom, (e.g. sp^3, sp^2, sp^3d, etc.)

7. In COLUMN 8, Model, your teacher will initial or stamp to verify if you made the correct model.

1	2	3	4	5	6	7	8
Molecular Formula	Lewis Structure	Shape Angle(s)	Formal Charge of each element	# of bonds on the central atom	# of lone pairs on the central atom	Hybridization of the central atom	Model Checked
PF_5			P: F:				
TeF_4			Te: F:				
XeF_4O*			Xe: F: O:				
PF_3^{2-}			P: F:				
XeF_2			Xe: F:				
BrF_4^{1}			Br: F:				
SF_4			S: F:				
SOF_4			S: O: F:				
SF_5^{1-}			S: F:				
PF_4^{1-}			P: F:				
* Oxygen is not in the same plane as the 4 fluorine atoms							

Labs 5-9: General Chemistry Topics Using Stop-Motion-Video

Introduction

Labs 5-9 are designed to bring a three dimensional aspect to the visualization of topics that are usually learned by a paper and pencil modality only. This novel pedagogic methodology brings into play several brain areas facilitating student understanding and memorization of topics that may be difficult for some to learn. The procedures have been used successfully with high school students in chemistry labs.

Lab 5 Balancing Equations is a starting point for doing labs 6-9.

In each lab procedure, one student in each group will use an iPhone, iPad, or android phone with an app for Stop-Motion-Video. Apple devices can download the free app "Stop Motion Studio," and there are a wide variety of apps, some for a small fee and some free, available for android phones. The following URL has a listing of android apps.

https://play.google.com/store/apps/collection/similar_apps_jal.clickstudio.mainpack?clp=qgEgCh4KGGphbC5jbGlja3N0dWRpby5tYWlucGFjaxABGAM%3D:S:ANO1ljKQR50

For each of the 5-9 labs, each group will attach a Stop-Motion-Video recording device with the downloaded app to a ring stand with a test tube clamp or ring clamp about 10-15 cm above the top of the table. Placing rubber bands on the ring clamps provides a secure platform for the phone. Refer to Figs. 1 and 2 below.

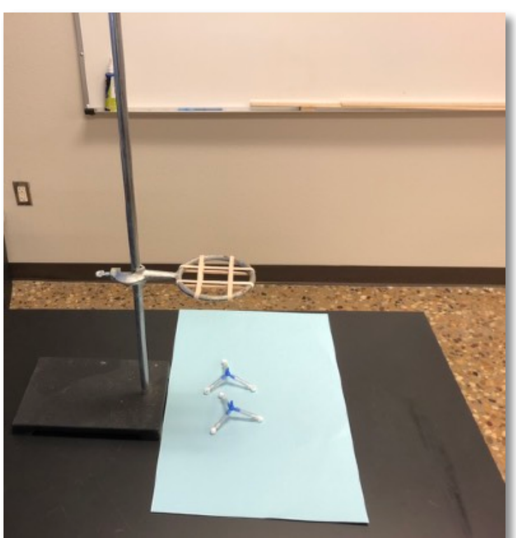


Fig. 1 Setting up a ring clamp with rubber bands.

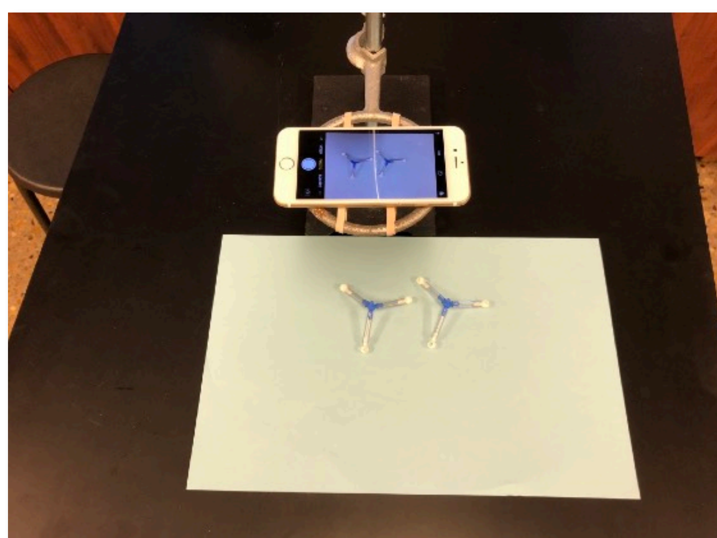


Fig. 2 A cell phone resting on a ring clamp.

If an iPad is used, two ring clamps provide a more stable platform (Figs. 3 and 4).

Fig. 3 A support set up for an iPad.

Fig. 4 An iPad resting on two ring clamps.

Students may choose to add audio and additional slides to their movies to make them more interesting and personal.

Lab 5: Balancing Equations Using Stop-Motion-Video

Teacher's Guide

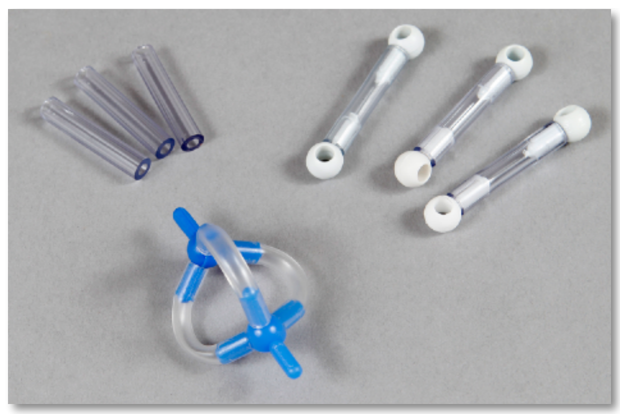
1. Each student should prepare his/her own paper to be turned in after completing the lab. There are enough parts in the kit for 15 groups.

2. You may wish to review, **Demonstration 2: Balancing Equations**, listed above.

3. You might want to tie in how the next lab, **Lab 6: Modeling Enthalpy Changes Using Stop-Motion-Video**, depends on a knowledge of how to balance equations.

4. Each student writes the skeleton and the balanced equation for the reaction: $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$. Optional: have them show their work to you.

5. The group then attaches the iPhone, android phone, or iPad with the Stop-Motion-Video app to a ring stand as shown in the introduction to Stop-Motion-Video section above.



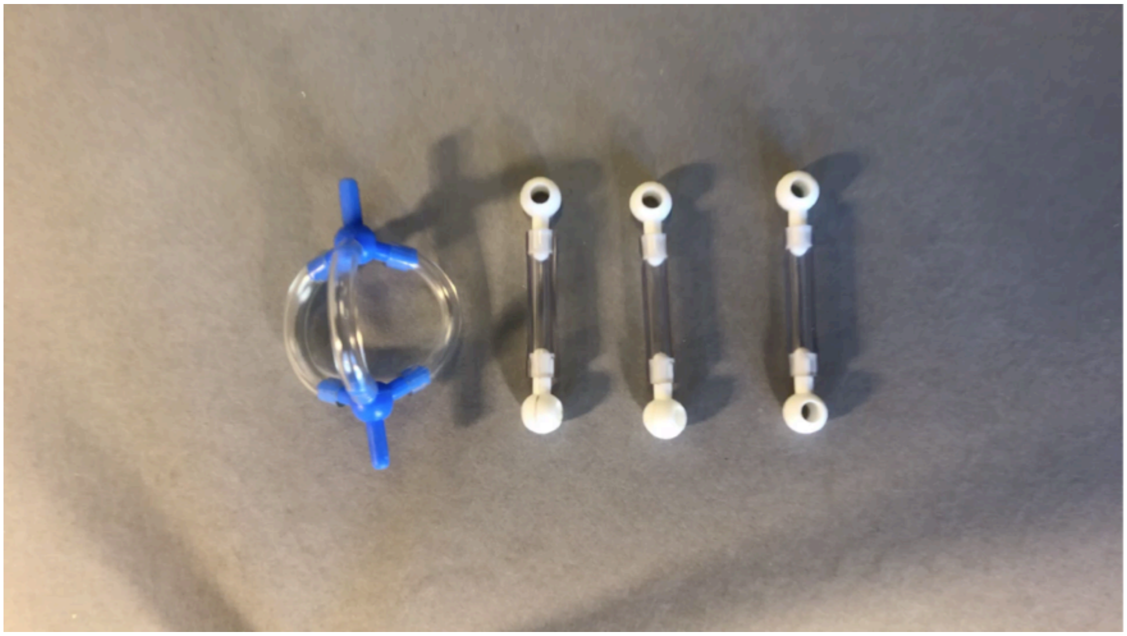
6. Have students set up one nitrogen molecule (two blue, 4-peg atoms and three clear, 4 cm tubes) and three hydrogen molecules (six white, 1-peg atoms and three clear, 1.25´´ tubes) as pictured to the right. Three additional clear, 1.25´´ tubes must also be supplied.

7. Students will then make a stop action video of the original bonds breaking, the rearrangements of atoms, and the making of new bonds. The original 4 cm tubes can be set aside while all six of the 1.25´´ bonds will be used. You can decide how the students will separate the atoms and original bonds, or you can tell them to try to create their own method of bond changes.

8. Have the students turn in their papers with the completed balanced equation for the reaction and the answers to the five questions. Explain how students will share their videos with you. For instance they can email the stop motion video to you or if there is enough time you can check their videos as they complete them.

9. Below, you will find a sample Stop-Motion-Video for this procedure.

Example Stop-Motion-Video:



Key:

1. What is a skeleton equation? An equation that has the correct subscripts on all molecules and formula units but may not have the correct coefficients (it may be unbalanced).

2. How are the subscripts determined when writing chemical formulas? Either the charges on the ions that make up the compound have to be balanced, or the molecule's proper formula based on covalent bonding and the name of the molecule is used.

3. How are coefficients determined when writing a balanced equation? By counting the number of atoms of each element on each side of the equation and finding a common multiple to balance the atoms on each side of the equation.

4. What changes take place in a chemical reaction? A rearrangement (separation and recombination) of atoms.

5. What is wrong with this equation, $Na + Cl_2 \rightarrow NaCl_2$? The formula should be $NaCl$ not $NaCl_2$ and there should be a coefficient of 2 in front of Na on the left and a 2 in front of NaCl on the right.

LAB 5: Balancing Equations Using Stop-Motion-Video

Student Procedure

Objective: To model and visualize the process and stoichiometry of a chemical reaction.

Materials: Ryler Enterprises model kit parts: 6 white (hydrogen) atom centers, 2 blue (nitrogen) atom centers, 6 clear, 1.25´´ tubes (single bonds), 3 clear, 4 cm tubes (double/ triple bonds), Stop-Motion-Video app, ring stand, ring clamp(s), rubber bands.

1. Write the skeleton equation for the reaction of a molecule of nitrogen gas with three molecules of hydrogen gas to form two molecules of ammonia.
2. Balance the equation. Each student will show the balanced equation to the teacher.
3. Your teacher will demonstrate how to attach one or two rings to one or more ring stands with rubber bands on the rings. Place an iPhone, android phone, or iPad on the ring(s) about 10 cm above the lab table. Next open a Stop Motion app to create a stop motion video detailing the breaking and making of bonds to form a new product. The video should show the rearrangements of the atoms to form the products. Adjust the speed of the movie so that the process details are clearly observable.
4. Each student will turn in a copy of the skeleton equation and balanced equation for the reaction, and the answers to the questions below. Each lab group will share its video with the instructor.

Questions:

1. What is a skeleton equation?

2. How are the subscripts determined when writing chemical formulas?

3. How are coefficients determined when writing a balanced equation?

4. What changes take place in a chemical reaction?

5. What is wrong with this equation, $Na + Cl_2 \rightarrow NaCl_2$?

Lab 6: Modeling Enthalpy Changes Using Stop-Motion-Video

Teacher's Guide

1. Make sure that your classes understand the concept of enthalpy and its relationship to chemical reactions.

2. Assign each group one reaction from the following list (**a-d**) and provide each group with the necessary parts. There are enough parts in the kit for 16 groups.

a. Hydrogen gas reacting with oxygen gas to form water.

	Atom Centers			Bonding Tubes	
Qty	Element	Color/Pegs	Qty	Length	Color
4	Hydrogen	White/1	4	1.25´´	Colorless
2	Oxygen	Red/4	2	4 cm	Colorless

b. Carbon (graphite) reacting with oxygen gas to form carbon monoxide.

Atom Centers			Bonding Tubes		
Qty	Element	Color/Pegs	Qty	Length	Color
2	Carbon	Black/4	6	4 cm	Colorless
2	Oxygen	Red/4			

c. Nitrogen gas reacting with hydrogen gas to form ammonia.

Atom Centers			Bonding Tubes		
Qty	Element	Color/Pegs	Qty	Length	Color
6	Hydrogen	White/1	6	1.25´´	Colorless
2	Nitrogen	Blue/4	3	4 cm	Colorless

d. Hydrogen peroxide decomposing into water and oxygen gas.

Atom Centers			Bonding Tubes		
Qty	Element	Color/Pegs	Qty	Length	Color
4	Hydrogen	White/1	6	1.25´´	Colorless
4	Oxygen	Red/4	2	4 cm	Colorless

3. Each group will place an iPhone, android phone, or iPad, with the Stop-Motion-Video app, on a ring stand as shown in the introduction above.

4. The data from the following table are to be used to make enthalpy change determinations.

Average Bond Energies (kJ/mol)

Bond	Energy	Bond	Energy	Bond	Energy	Bond	Energy
Single Bonds							
H—H	432	N—H	391	Si—H	323	S—H	347
H—F	565	N—N	160	Si—Si	226	S—S	266
H—Cl	427	N—P	209	Si—O	368	S—F	327
H—Br	363	N—O	201	Si—S	226	S—Cl	271
H—I	295	N—F	272	Si—F	565	S—Br	218
		N—Cl	200	Si—Cl	381	S—I	~170
C—H	413	N—Br	243	Si—Br	310		
C—C	347	N—I	159	Si—I	234	F—F	159
C—Si	301					F—Cl	193
C—N	305	O—H	467	P—H	320	F—Br	212
C—O	358	O—P	351	P—Si	213	F—I	263
C—P	264	O—O	204	P—P	200	Cl—Cl	243
C—S	259	O—S	265	P—F	490	Cl—Br	215
C—F	453	O—F	190	P—Cl	331	Cl—I	208
C—Cl	339	O—Cl	203	P—Br	272	Br—Br	193
C—Br	276	O—Br	234	P—I	184	Br—I	175
C—I	216	O—I	234			I—I	151
Multiple Bonds							
C=C	614	N=N	418	C≡C	839	N≡N	945
C=N	615	N=O	607	C≡N	891		
C=O	745 (799 in CO_2)	O_2	498	C≡O	1070		

Key:

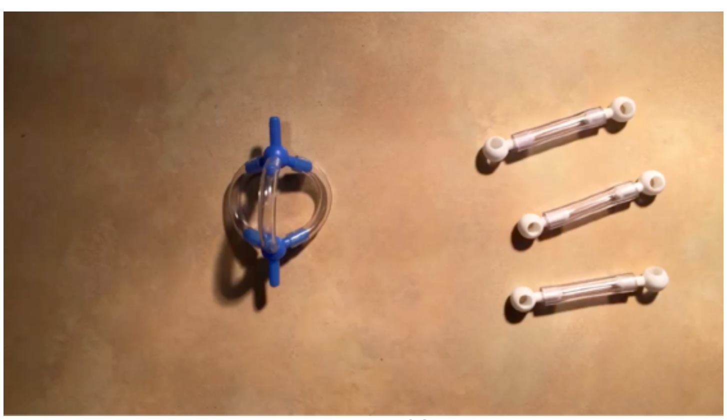
a. $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$ $\Delta H = (432 \times 2 + 498) - (467 \times 4) = 1362 - 1868 = -506$ kJ

b. $2C_{(s)} + O_{2(g)} \rightarrow 2CO_{(g)}$ $\Delta H = (498) - (1070 \times 2) = 498 - 2140 = -1642$ kJ

c. $N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$ $\Delta H = (945 + 432 \times 3) - (391 \times 6) = 2241 - 2346 = -105$ kJ

d. $2H_2O_{2(l)} \rightarrow 2H_2O_{(l)} + O_{2(g)}$ $\Delta H = (467 \times 2 + 204) - (467 \times 4 + 498) = -1228$ kJ

Example Stop-Motion-Video:



LAB 6: Modeling Enthalpy Changes Using Stop-Motion-Video

Student Procedure

Objective: To model the process of bond breaking and bond formation, and to calculate the change in enthalpy for a chemical reaction.

Materials: Ryler Enterprises model kit parts, Stop-Motion-Video app, ring stand, test tube clamp or ring clamp(s), rubber bands, sticky notes, Sharpie pen.

1. Write the skeleton equation for the reaction assigned to you.

2. Balance the equation. Write the balanced equation.

3. Determine and draw the Lewis structures for the reactants and products in the reaction assigned to you.

4. Clamp (or support on rings) an iPhone, android phone, or iPad onto the ring stand about 10 cm above the lab table.
5. Open a Stop-Motion app to create a stop motion video detailing the collision of molecules, bond breaking (with energy in kJ), bond forming (with energy in kJ) and ΔH (in kJ) for the reaction. Adjust the speed of the movie so that the energy values and the reaction process are legible. The video should show the rearrangements of the atoms to form the products. Write the bond breaking and bond forming enthalpies (in kJ) on sticky notes with a Sharpie pen and include them in your video.
6. Each lab group should share the video with the instructor by the method given to you by your teacher. Put ΔH (in kJ) for the reaction here:_______________

Questions:

1. When a chemical bond is broken, is energy absorbed or released?

2. When a chemical bond is formed, is energy absorbed or released?

3. What are the two ways to calculate change in enthalpy for a chemical reaction?

Lab 7: Modeling Equilibrium Using Stop-Motion-Video

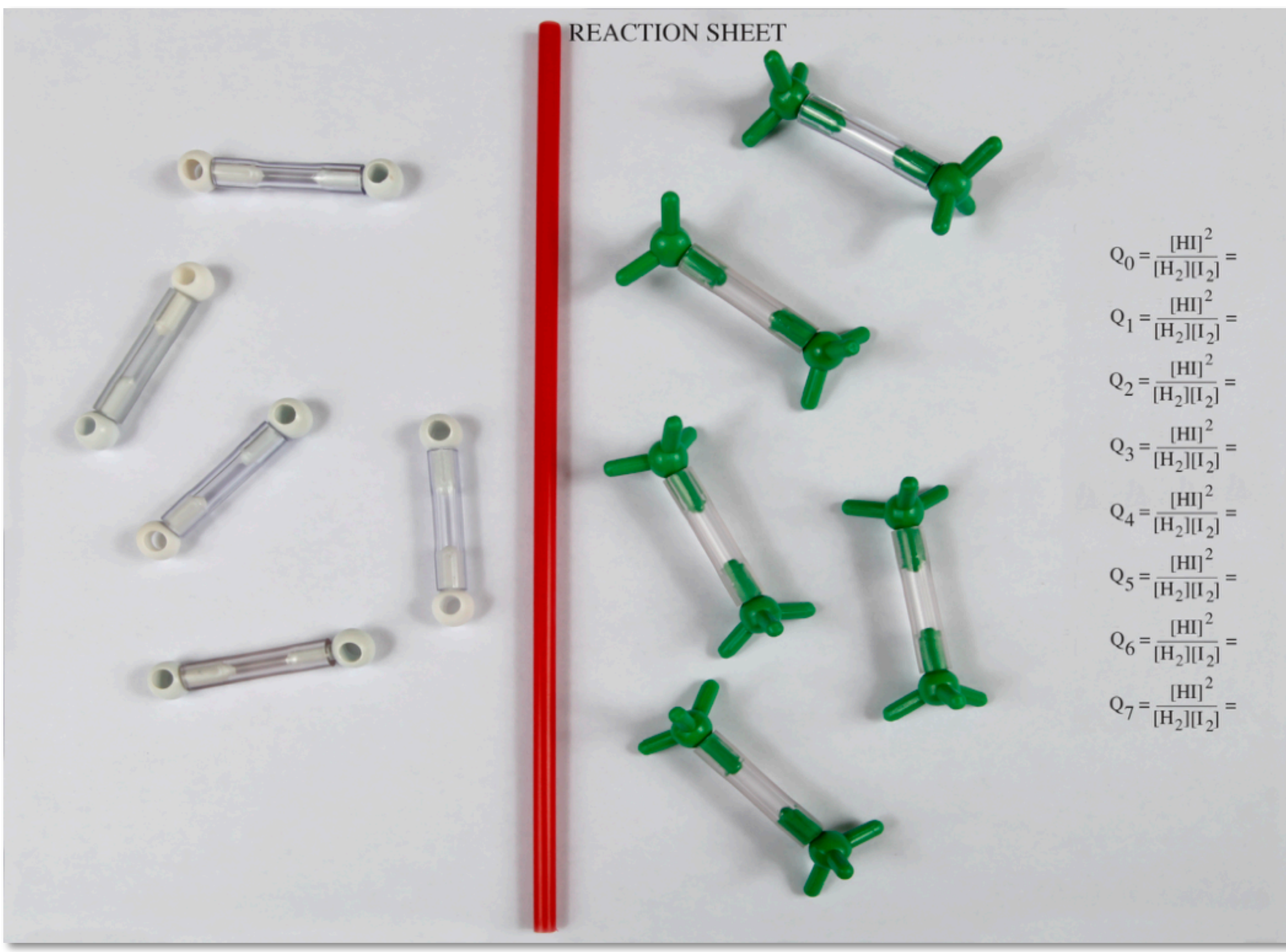
Teacher's Guide

Provide each group with the proper model parts. There are enough parts in the kit for 9 groups.

Atom Centers			Bonding Tubes/Straws		
Qty	Element	Color/Pegs	Qty	Length	Color
10	Hydrogen	White/1	10	1.25´´	Colorless
10	Iodine	Green/4	1	21 cm	Red

Supply the necessary kit parts to each group along with a REACTION SHEET and two 3 x 5 index cards.

Make a copy of the photo below, and show it to your students. It will be the beginning position of the models used for the equilibrium Stop-Motion-Video.



Students will fill in the Q values, in pencil, on the right side as the procedure progresses following the guidelines below.

1. At the start of the reaction, immediately after the straw is removed, $Q_0 = 0$. This value is entered on the right side of the REACTION SHEET.

2. After 1 H_2 and 1 I_2 react, the Q_0 value is covered with an index card, and $Q_1 = (2)^2 / (4)(4) = 0.25$ is calculated and entered on the right side of the REACTION SHEET.

3. After 2 H_2 and 2 I_2 react, all previous Q values are covered with an index card, and $Q_2 = (4)^2 / (3)(3) = 1.78$ is calculated and entered on the right side of the REACTION SHEET.

4. After 3 H_2 and 3 I_2 react, all previous Q values are covered with an index card, and $Q_3 = (6)^2 / (2)(2) = 9.0$ is calculated and entered on the right side of the REACTION SHEET.

5. In order to show that the [HI] has become high enough for the reverse reaction to occur, have students use 2 HI molecules to remake 1 I_2 and 1 H_2 molecules. All previous Q values are covered with an index card, and $Q_4 = (4)^2 / (3)(3) = 1.78$ is calculated and entered on the right side of the REACTION SHEET.

6. After 3 H_2 and 3 I_2 react again, all previous Q values are covered with an index card, and $Q_5 = (6)^2 / (2)(2) = 9.0$ is calculated and entered on the right side of the REACTION SHEET.

After 4 H_2 and 4 I_2 react, all previous Q values are covered with an index card, $Q_6 = (8)^2 / (1)(1) = 64$ is calculated and entered on the right side of the REACTION SHEET.

In this exercise K = 64, so the video is now complete.

The above can be altered to suit your own teaching style.

Answers to questions:

1. Write the equilibrium constant expression for the reaction: $H_{2(g)} + I_{2(g)} \leftrightharpoons 2HI_{(g)}$

   $K = [HI]^2/[H_2][I_2]$

2. What would happen if ten molecules react to form products (calculate Q and explain)? Q would be undefined (infinity) and the system would not be at equilibrium. Q > K and so there would be a shift back towards the reactants to re-establish equilibrium.

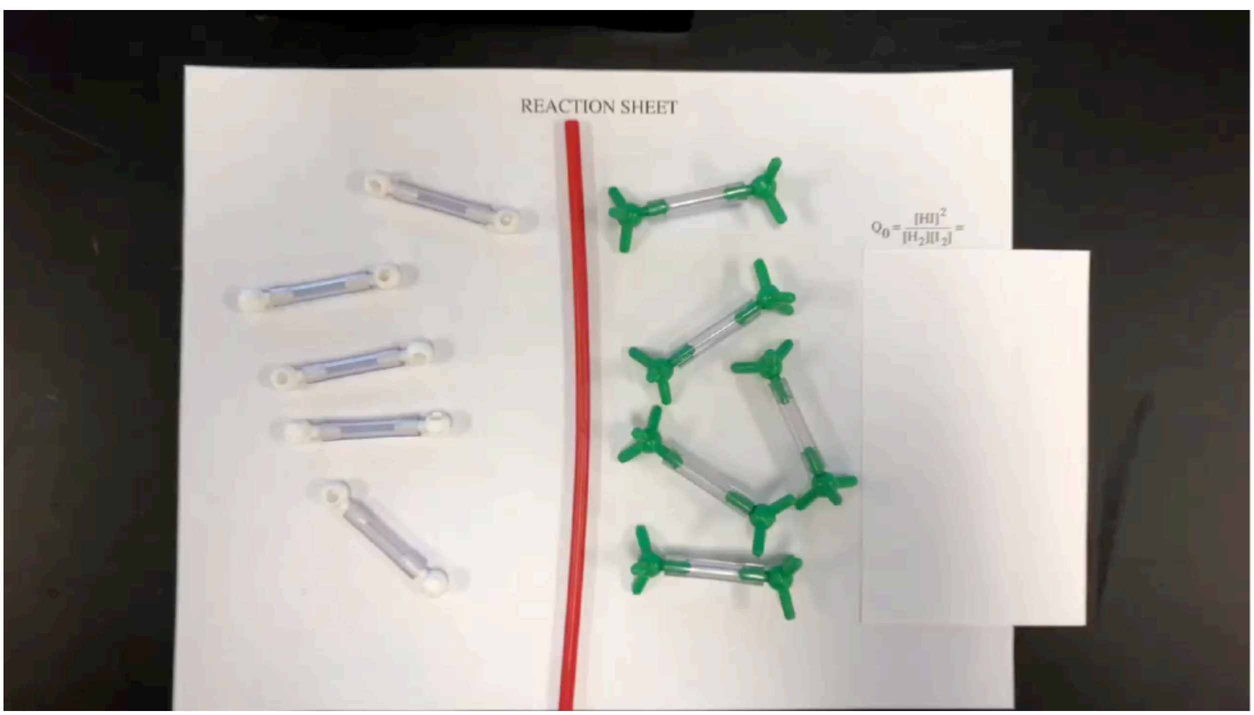
3. Explain what would happen in the following circumstances for a reaction:

   a. Q < K   Not at equilibrium: There would be shift towards the products to establish equilibrium.

   b. Q > K   Not at equilibrium: There would be shift towards the reactants to establish equilibrium.

   c. Q = K At Equilibrium: There would be changes taking place in both directions but the ratio of products to reactants would remain the same.

Sample Video:



LAB 7: Stop Motion Equilibrium Lab

Student Procedure

Objective: To model equilibrium and change which could take place in a reversible chemical reaction $H_{2(g)} + I_{2(g)} \leftrightharpoons 2HI_{(g)}$; K = 64 (at an unspecified temperature) as it moves towards and reaches equilibrium. Assume each molecule model represents a mole of molecules and the volume of the reaction = 1 liter.

Materials: Ryler Enterprises model parts:10 white (hydrogen) atom centers, 10 green (iodine) atom centers, 10 1.25´´ single bond tubes, one 21 cm, red straw, smart phone or iPad, Stop-Motion-Video app, Reaction Sheet, two 3 x 5 index cards, ring stand, test tube ring(s), rubber bands.

1. Assemble 5 hydrogen (H_2) molecules and 5 Iodine (I_2) molecules. Place the 5 hydrogen molecules on the left of a straw and the 5 iodine molecules on the right of the straw on the REACTION SHEET. The left and right sides of the straw represent chambers in a one liter container (the paper).
2. Clamp or set the iPhone, android phone, or iPad onto the ring clamp about 10 cm above the lab table. Then open a Stop-Motion app to create a stop motion video detailing the changes that occur during the reversible reaction of hydrogen with iodine.
3. Removing the straw allows the molecules to mix freely.
4. The video should show collision of molecules, bond breaking, and bond forming. Adjust the speed of the movie to 1 frame per second so that the Q value and the reaction are legible.
5. Show each step in the reaction progress, calculate the new reaction quotient, Q, and, using a pencil, write the new Q value in the space provided.
6. Continue until Q = K.
7. Share the video with your instructor.
8. Calculations (show your work):

At the start of the reaction, Q_0 =

After 1 H_2 and 1 I_2 react, Q_1 =

After 2 H_2 and 2 I_2 react, Q_2 =

After 3 H_2 and 3 I_2 react, Q_3 =

After the reverse reaction, Q_4 =

After 3 H_2 and 3 I_2 react, Q_5 =

After 4 H_2 and 4 I_2 react, Q_6 =

Questions:

1. Write the equilibrium constant expression for the reaction: $H_{2(g)} + I_{2(g)} \leftrightharpoons 2HI_{(g)}$

2. What would happen if ten molecules react to form products (Calculate Q and explain)?

3. Explain what would happen in the following circumstances for a reaction:

    a. $Q < K$

    b. $Q > K$

    c. $Q = K$

REACTION SHEET

$$Q_0 = \frac{[HI]^2}{[H_2][I_2]} =$$

$$Q_1 = \frac{[HI]^2}{[H_2][I_2]} =$$

$$Q_2 = \frac{[HI]^2}{[H_2][I_2]} =$$

$$Q_3 = \frac{[HI]^2}{[H_2][I_2]} =$$

$$Q_4 = \frac{[HI]^2}{[H_2][I_2]} =$$

$$Q_5 = \frac{[HI]^2}{[H_2][I_2]} =$$

$$Q_6 = \frac{[HI]^2}{[H_2][I_2]} =$$

$$Q_7 = \frac{[HI]^2}{[H_2][I_2]} =$$

Lab 8: Brønsted Lowry Acid/Base Reactions Using Stop-Motion Video

Teacher's Guide

1. Provide each group the following model parts. There are enough parts in the kit for 15 groups.

Atom Centers				Bonding Tubes		
Qty	Element	Color/Pegs		Qty	Length	Color
2	Oxygen	Red/4		5	1.25´´	Colorless
1	Fluorine	Green/4				
5	Hydrogen	White/1				
1	Nitrogen	Blue/4				

2. Each student should prepare his/her own paper to be turned in after completing the lab.

3. Each student should write the balanced equations for three reactions:

   a. Water and ammonia form an ammonium ion and a hydroxide ion:

   $$H_2O + NH_3 \rightleftharpoons OH^- + NH_4^+$$

   d. Water and hydrogen fluoride form a hydronium ion and a fluoride ion:

   $$H_2O + HF \rightleftharpoons H_3O^+ + F^-$$

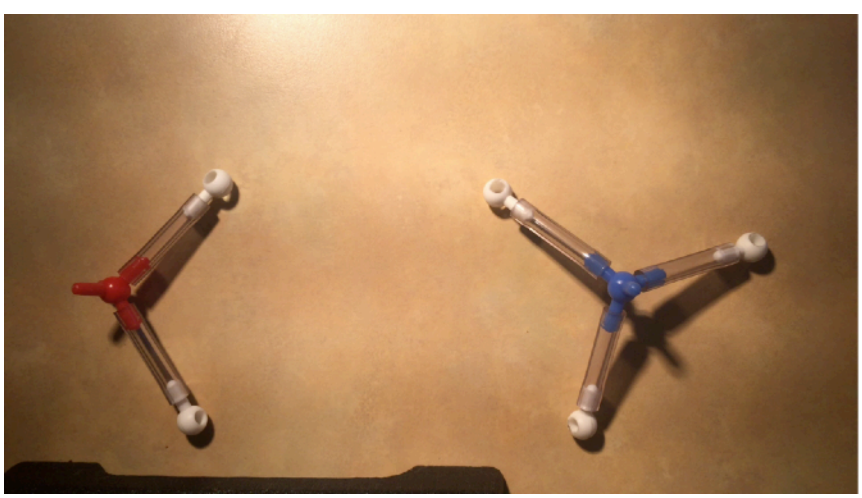
   e. Ammonia and hydrogen fluoride form a fluoride ion and an ammonium ion:

   $$NH_3 + HF \rightleftharpoons F^- + NH_4^+$$

6. Have one student in each group download the free app "Stop Motion Studio," into an iPhone or iPad. An app is also available for android phones.

7. The group then attaches the iPhone, android phone, or iPad with a test tube clamp or ring clamp(s) to a ring stand about 10-15 cm above the top of the table.

Example Stop Motion Video:



LAB 8: Brønsted-Lowry Acid/Base Reactions Using Stop-Motion Video

Student Procedure

Objective: To model the process of Brønsted Lowry Acid/Base reactions.

Materials: Ryler Enterprises model kit parts, Stop Motion Studio app (free), ring stand, test tube clamp or ring clamp(s), rubber bands, sticky notes, Sharpie pen, paper.

1. Write the equations for the reversible reactions between water and ammonia, water and hydrogen fluoride, and ammonia and hydrogen fluoride.
2. Balance the equations. Show the balanced equations to the teacher.
3. Assemble models of water, ammonia, and hydrogen fluoride.
4. Make three stop motion videos of the reactions you wrote in step 2 (both forward and reverse reactions) using the Stop Motion Studio app. Write the word "acid" on one sticky note and the word "base" on another sticky note with a Sharpie and include them in your video.
5. The video should show the transfer of the hydrogen ion (proton). Adjust the speed of the movie so that the reaction process is clearly legible. Share the videos with your instructor.

Questions:

1. What is the definition of a Brønsted Lowry Acid?
2. What is the definition of a Brønsted Lowry Base?
3. Define the term amphoteric.
4. What are the conjugate acids of H_2O, NH_3, and F^-?
5. What are the conjugate bases of H_2O, NH_3, and HF?

LAB 9: Reaction Mechanisms Using Stop-Motion Video

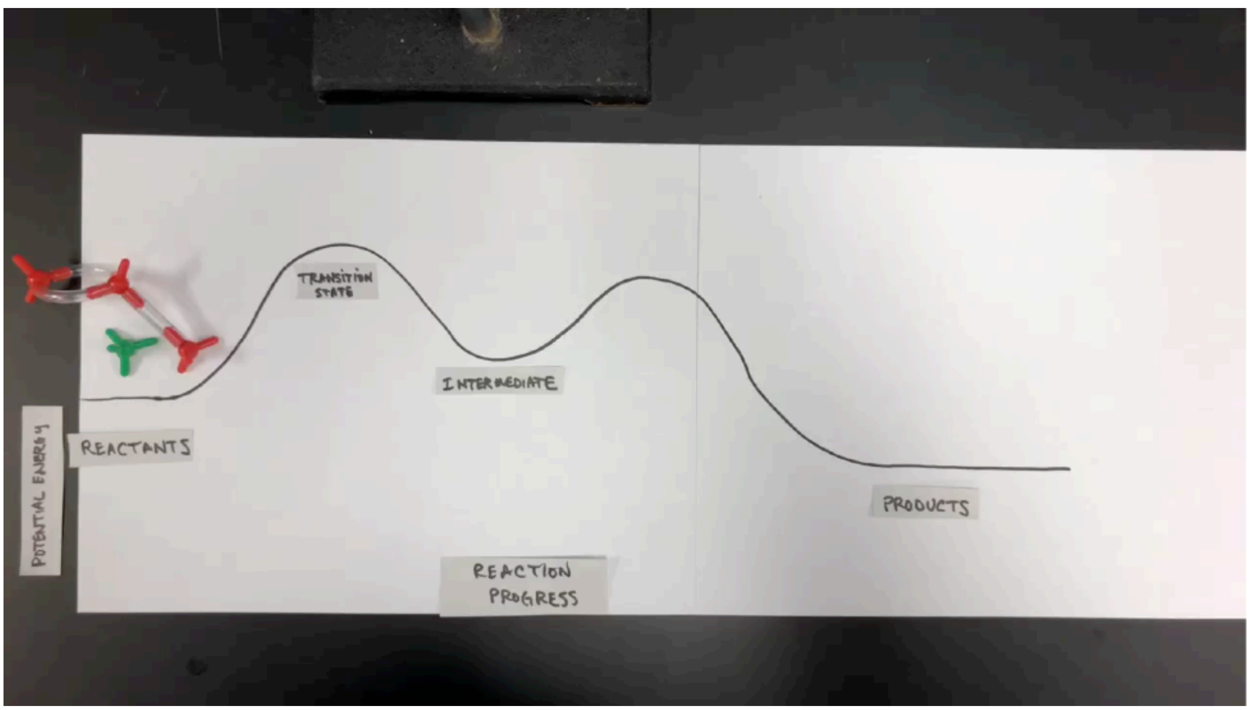
Teacher's Guide

Provide each group with the proper model parts. There are enough parts in the kit for 10 groups.

Atom Centers				Bonding Tubes		
Qty	Element	Color/Pegs		Qty	Length	Color
6	Oxygen	Red/4		4	1.25´´	Colorless
1	Chlorine	Green/4		6	4 cm	Colorless

On two blank sheets of paper taped end to end, the students should use a pencil to draw a labeled (on sticky notes) energy diagram similar to the one shown in the sample video. Check student diagrams for accuracy before they make their videos.

Example Stop Motion Video:



Answers to Questions:

1. An intermediate is a temporary product in a reaction mechanism. It is recognized by the fact that it is the product of one step and the reactant of another step.
2. A catalyst is a substance that can increase the rate of a chemical reaction and is the same at the end as it was at the start of the reaction. In a reaction mechanism a catalyst is a reactant of one step and the product of another step.
3. The uncatalyzed energy diagram would have a higher activation energy,
4. Another name for a transition state is an activated complex.

LAB 9: Visualizing A Reaction Mechanism Using Stop-Motion Video

Student Procedure

Objective: To model the mechanism of a chemical reaction ($2O_3 \rightarrow 3O_2$) with a catalyst (Cl) and an intermediate (ClO) and to model the concept of an activated complex.

Materials: Ryler Enterprises OUCH! model kit, Stop Motion Studio app (free), ring stand, test tube clamp or ring clamp, sticky notes, marker, two sheets of blank paper.

1. Assemble two models of ozone, O_3.
2. Using clear tape, tape two blank sheets of paper together, end to end. Using a pencil, draw a potential energy diagram with the following attributes: two steps, exothermic. Label six sticky notes with the following: Potential Energy, Reaction Progress, Reactants, Products, Transition State, Intermediate. Place the sticky notes on the diagram in the proper locations. Have the instructor verify the diagram before making the video.
3. Make a stop motion video of the reaction process where ozone decomposes into oxygen with a chlorine atom catalyst utilizing this proposed mechanism:
   a. Step 1: $Cl + O_3 \rightarrow ClO + O_2$
   b. Step 2: $ClO + O_3 \rightarrow Cl + 2O_2$
4. ClO_3 is the transition state for step 1 and ClO_4 is the transition state for step 2. Place the models on the potential energy diagram in the proper locations.
5. The video should show the steps in the reaction. Adjust the speed of the movie so that the reaction process is clearly legible. Share the video with your instructor.

Questions:

1. What is an intermediate? How do you recognize an intermediate in a reaction mechanism?
2. What is a catalyst? How do you recognize a catalyst in a reaction mechanism?
3. Describe the uncatalyzed energy diagram for this reaction.
4. What is another name for a transition state?

LAB 10: Intermolecular Forces

Teacher's Guide

This lab can be done with wireless temperature probes or analog thermometers. If wireless probes are used, the software that accompanies the probes can be used to graph the results in real time. If analog thermometers are used, the students will need to record data in a table and create their own graphs.

1. Have some students assemble one model of each compound, and use the models to discuss intermolecular forces, and then relate those forces to predict evaporation rates.

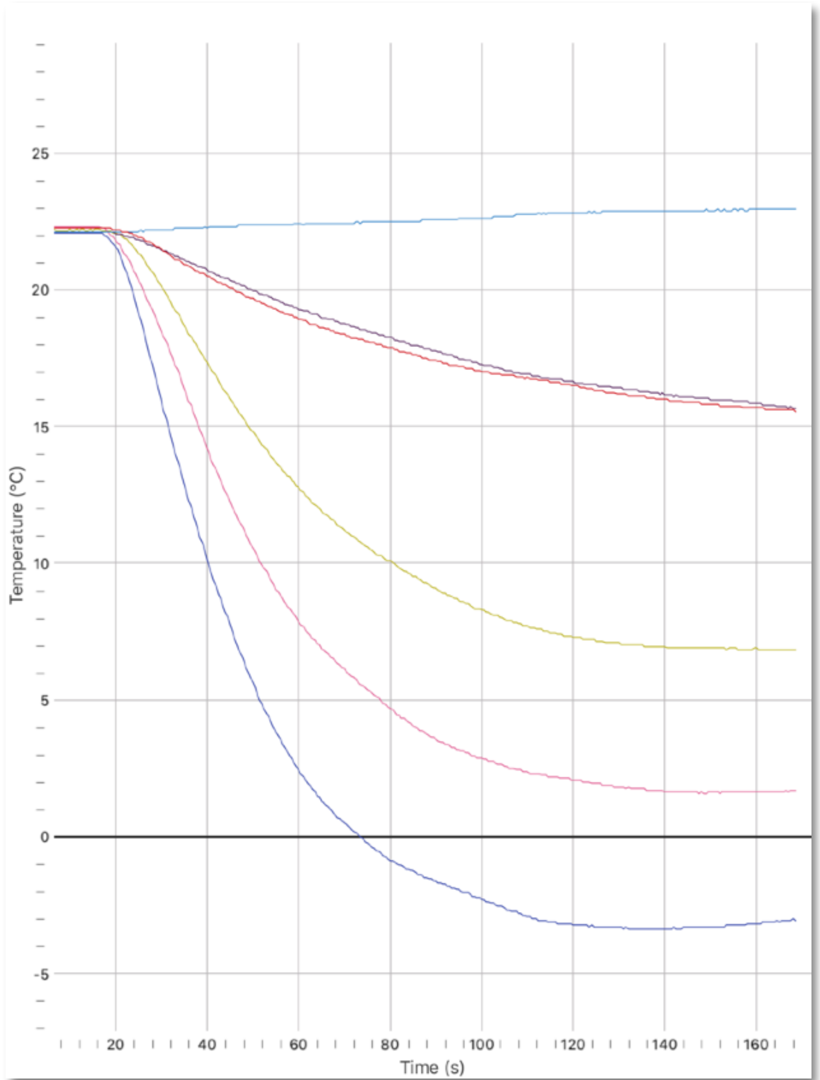
2. Make sure the Vernier Graphical Analysis app is downloaded to the iPad or iPhone that the students will use for the experiment.

3. Intermolecular forces present in each molecule:

Liquid	London Dispersion Forces	Dipole-Dipole Interactions	Hydrogen Bonds
1-propanol	X	X	X
water	X	X	X
glycerin	X	X	X
cyclohexane	X		
acetone	X	X	
methanol	X	X	X

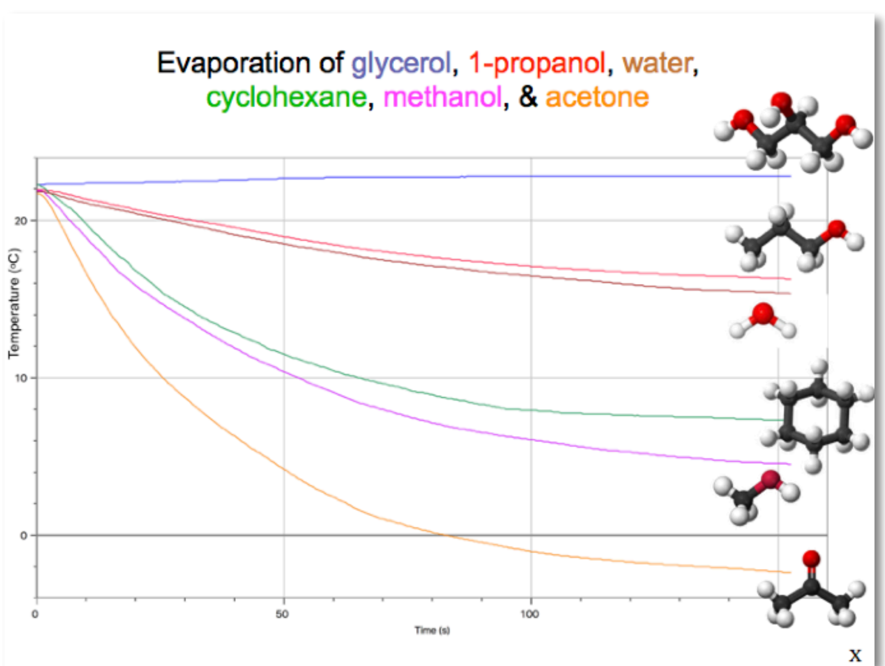
4. The ranking from greatest to least intermolecular attraction is: glycerin (glycerol), 1-propanol, water, cyclohexane, methanol, acetone

5. The graph should resemble Figure 1 or Figure 2:



Temperature (°C)
Time (s)

Fig. 1



Evaporation of glycerol, 1-propanol, water,
cyclohexane, methanol, & acetone
Temperature (°C)
Time (s)
x

Fig. 2

6. Describe the graph and explain: Evaporation of the liquid requires heat absorption from the surroundings (the probe). Heat is absorbed faster by the molecules with the weaker intermolecular forces causing a faster drop in temperature. Heat is absorbed more slowly by the molecules with stronger intermolecular forces.

a. The probe in the glycerin did not record a drop in temperature (it stayed constant). Glycerin has the largest electron cloud (50) of the liquids in the lab which results in stronger dispersion forces and it has three hydrogens that can hydrogen bond.

b. 1-Propanol dropped about $5^{o}C$. It has a electron cloud of medium size (34), is polar, and has one hydrogen that can hydrogen bond.

c. Water dropped about $6^{o}C$. It has a small electron cloud (10), is polar, and has two hydrogens that can hydrogen bond.

d. Cyclohexane dropped about $15^{o}C$. It has a relatively large electron cloud (48), is nonpolar, and can not hydrogen bond.

e. Methanol dropped about $20^{o}C$. It has a relatively small electron cloud (18), is polar, has one hydrogen that can hydrogen bond.

f. Acetone dropped about $25^{o}C$. It has a relatively small electron cloud (32), is polar, and can not hydrogen bond.

g. Conclusion: To determine the effect of intermolecular forces on physical properties, three factors should be considered: the size of the electron cloud (dispersion forces), dipole moment (polarity), and hydrogen bonding.

LAB 10: Intermolecular Forces (Wireless Probes)

Student Procedure

Objective: To observe the rate of temperature change due to evaporation of six different liquids and then use intermolecular forces to explain the differences in evaporation rates.

Materials: iPad, Vernier Graphical Analysis App, 6 Vernier wireless temperature probes, paper towel, rubber bands, 6 small test tubes (10 ml), test tube rack, 1-propanol, cyclohexane, propanone (acetone), glycerol (glycerin), methanol, water.

1. Make a model of 1-propanol, cyclohexane, acetone, methanol, water, and glycerin. Use the web for reference. Examine the model for each compound and predict the type and strength of intermolecular forces present in each.
2. Cut a paper towel into a piece about 2 cm by 6 cm, wrap each temperature probe, and secure with a small rubber band (see Figs. 1 and 2).

Fig. 1 Probe, paper towel and rubber band.

Fig. 2 Paper towel attached to probe.

3. Open the app: Graphical Analysis. Now connect the six temperature probes. Set these aside for a moment.
4. Add about 3 ml of each liquid to six different small test tubes and place them in a test tube rack.
5. Insert each temperature probe into a test tube containing the liquids (Fig. 3).

Fig. 3 Probes with towels attached placed in test tubes.

6. Click the “Collect” button. Simultaneously remove all six temperature probes, invert them and hold them so that they do not touch each other or the table (or anything else). Observe the graph displayed on the computer. Allow the data to collect for about 150 seconds, then click the “Stop” button.
7. Dispose of the 1-propanol, acetone, methanol, water, and glycerin into the sink and rinse with tap water. The cyclohexane should be place in a waste container (not in the sink).
8. Print or sketch the graph displayed on the iPad and answer the following questions:

a. Use the graph to rank the six liquids from most intermolecular forces to least intermolecular forces.

b. Which intermolecular forces are present in each of the liquids:

c. Explain the results of the experiment. Include the intermolecular forces at work in each substance.

LAB 10: Intermolecular Forces (Analog Thermometers)

Student Procedure

Objective: To observe the rate of temperature change due to evaporation of six different liquids and then use intermolecular forces to explain the differences in evaporation rates.

Materials: 3 thermometers, paper towel, 3 rubber bands, 3 medium sized test tubes (30 ml), test tube rack, 1-propanol, cyclohexane, propanone (acetone), glycerol (glycerin), methanol, water.

1. Make a model of 1-propanol, cyclohexane, acetone, methanol, water, and glycerin. Use the web for reference. Examine the model for each compound and predict the type and strength of intermolecular forces present in each.
2. Cut a paper towel into a piece about 2 cm by 6 cm, wrap each thermometer, and secure with a small rubber band. See Figs. 1 and 2.

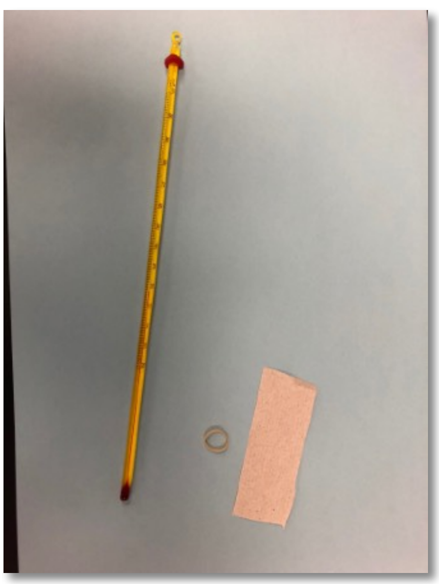


Fig. 1 Thermometer, paper towel and rubber band.

Fig. 2 Paper towel attached to thermometer.

3. Add about 5 ml of each liquid to six different small test tubes and place them in a test tube rack.
4. Insert the three thermometers into three different test tube containing the liquids. Record the temperature of the liquids. See Fig. 3.

Fig. 3 Thermometers with towels attached placed in test tubes.

5. Simultaneously remove three thermometers, invert them and hold them so that they do not touch each other or the table (or anything else). Read and record the temperature on each thermometer every 10 seconds for 2 minutes.
6. Repeat the experiment with the other liquids.
7. Dispose of the 1-propanol, acetone, methanol, water, and glycerin into the sink and rinse with tap water. The cyclohexane should be place in a waste container (not in the sink).
8. Create a graph of temperature vs time for each liquid.

d. Use the graph to rank the six liquids from most intermolecular forces to least intermolecular forces .

e. Which intermolecular forces are present in each of the liquids:

Liquid	London Dispersion Forces	Dipole-Dipole Interactions	Hydrogen Bonds
1-propanol			
water			
glycerin			
cyclohexane			
acetone			
methanol			

f. Explain the results of the experiment. Include the intermolecular forces at work in each substance.

Labs 11-13 Organic Chemistry

Introduction

Labs 11-13 introduce students to the chemistry of carbon compounds. Lab 11 covers naming and drawing structural diagrams of some hydrocarbons. Lab 12 expands on naming and drawing of carbon compounds to include several common functional groups
which have significance in biology as well as chemistry. Lab 13 includes the use of a dichotomous key, applying logic, decision making, and evaluation techniques to learn about isomerism.

LAB 11: Hydrocarbons

Teacher's Guide

For more detailed background information consult the Ryler Enterprises Kit "Organic Chemistry" kit available on the Ryler Enterprises website: www.rylerenterprises.com. Click on "Instructions and Quizzes," locate the **Organic Chemistry** section, then click on Organic Chemistry (ORG-1).

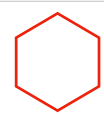
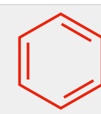
Provide each group with the proper model parts. There are enough parts in the kit for 5 groups.

ATOM CENTERS-LAB 8		
Qty	Element	Color/Pegs
12	Hydrogen	White/1
6	Carbon	Black/4

BONDING TUBES-LAB 8		
Qty	Length	Color
16	1.25´´	Colorless
6	4 cm	Colorless

The students should fill in the empty slots on the lab sheet and build the model. You check the model and verify it with your initials or stamp in the "Model" column on the lab sheet.

The key is on the next page.

	1	2	3	4	5
	Name	Chemical Formula	Type of Compound	Structural Formula (use dashes)	Model
1	methane	CH_4	alkane	H H-C-H H	
2	ethane	C_2H_6	alkane	H H H-C-C-H H H	
3	butane	C_4H_{10}	alkane	H H H H H-C-C-C-C-H H H H H	
4	pentane	C_5H_{12}	alkane	H H H H H H-C-C-C-C-C-H H H H H H	
5	methylbutane	C_5H_{12}	alkane	H CH_3 H H H-C-C-C-C-H H H H H	
6	dimethylpropane	C_5H_{12}	alkane	H CH_3 H H-C-C-C-H H CH_3 H	
7	cyclohexane	C_6H_{12}	cyclic alkane		
8	benzene	C_6H_6	aromatic		
9	ethene	C_2H_4	alkene	H H C=C H H	
10	trans-2-butene	C_5H_{10}	alkene	H_3C H C=C H CH_3	
11	cis-2-butene	C_5H_{10}	alkene	H H C=C H_3C CH_3	
12	ethyne	C_2H_2	alkyne	H-C≡C-H	

LAB 11: Hydrocarbons

Student Procedure

Objective: To model and visualize the structure of hydrocarbons.

Materials: Ryler model kit parts: 6 black (carbon), 12 white (hydrogen) atom centers, 16 clear, 1.25´´ tubes (single bonds), 6 clear, 4 cm tubes (double/ triple bonds).

1. Make one copy of the table the "Master" copy and have the instructor check only that one sheet. Each student should fill out a sheet, but only the Master copy will be used for the final grade.
2. Use a pencil to fill in all blank boxes, except the "Model" column. This is where your instructor stamps or initials when your model is correct.
3. Students should be prepared to answer questions about the models. Students may use scratch paper to draw Lewis structures to help determine structural formulas.

	Name	Chemical Formula	Type of Compound	Structural Formula (use dashes)	Model
1	methane		alkane		
2	ethane				
3	butane				
4		C_5H_{12}			
5		C_5H_{12}			
6		C_5H_{12}			
7	cyclohexane				
8	benzene				
9	ethene				
10	trans-2-pentene				
11	cis-2-pentene				
12	propyne				

LAB 12: Functional Groups

Teacher's Guide

For more detailed background information consult the Ryler Enterprises Kit “Organic Chemistry” kit available on the Ryler Enterprises website: www.rylerenterprises.com. Click on “Instructions and Quizzes,” locate the **Organic Chemistry** section, then click on Organic Chemistry (ORG-1).

There are enough parts in the kit for 4 groups.

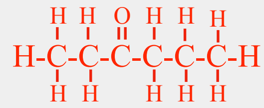
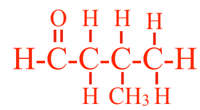
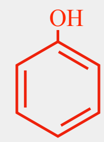
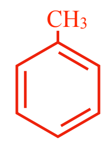
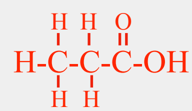
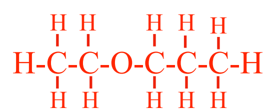
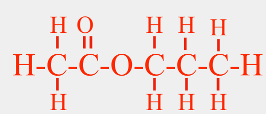
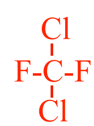
ATOM CENTERS-LAB 9		
Qty	Element	Color/Pegs
12	Hydrogen	White/1
7	Carbon	Black/4

BONDING TUBES-LAB 9		
Qty	Length	Color
16	1.25´´	Colorless
6	4 cm	Colorless

The students should fill in the empty slots on the lab sheet and build the model. You check the model and verify it with your initials or stamp in the “Model” column on the lab sheet.

Key:

	Name	Chemical Formula	Type of Funcional Group	Structural Formula (use dashes)	Model
1	methanol	CH_3OH	alcohol	OH H-C-H H	
2	2-butanol	C_4H_9OH	alcohol	H OH H H H-C-C-C-C-H H H H H	
3	1,2-ethandiol	$C_2H_6(OH)_2$	alcohol	OH H H-C-C-H H OH	
4	propanone	C_3H_6O	ketone	H O H H-C-C-C-H H H	

5	3-hexanone	$C_6H_{12}O$	ketone		
6	3-methylbutanal	$C_5H_{10}O$	aldehyde		
7	phenol	C_6H_5OH	aromatic w/ alcohol		
8	methylbenzene	C_7H_8	aromatic w/ alkyl		
9	propanoic acid	$C_3H_6O_2$	carboxylic acid		
10	ethylpropyl ether	$C_5H_{12}O$	ether		
11	propylethanoate	$C_5H_{10}O_2$	ester		
12	dichlorodifluoro methane	CCl_2F_2	halocarbon		

LAB 12: Functional Groups

Student Procedure

Objective: To model and visualize the structure of organic functional groups.

Materials: Ryler Enterprises model kit parts: 7 black (carbon) atom centers, 12 white (hydrogen) atom centers, 2 red (oxygen) atom centers, 4 green (halogen) atom centers, 16 clear, 1.25´´ tubes (single bonds), 3 clear, 4 cm tubes (double/ triple bonds).

1. Make one copy of the table the "Master" copy and have the instructor stamp only that one sheet. Each student should fill out a sheet, but only the Master copy will be used for the final grade.

2. Use a pencil to fill in all blank boxes, except the "Model" column. This is where your instructor stamps or initials when your model is correct.

3. Students should be prepared to answer questions about the models. Students may use scratch paper to draw Lewis structures to help determine structural formulas.

	Name	Chemical Formula	Type of Functional Group	Structural Formula (use dashes)	Model
1	methanol		alcohol		
2	2-butanol				
3	1,2-ethandiol				
4	propanone				
5	3-hexanone				
6	3-methylbutanal				
7	phenol				
8	methylbenzene				
9	propanoic acid				
10	ethylpropyl ether				
11	propylethanoate				
12	dichlorodifluoro methane				

LAB 13: Isomers

Teacher's Guide

The reactions and structures of isomers are studied in organic chemistry, inorganic chemistry, biology, medicine, and physics. Since an undertaking of a full exploration of isomerism in introductory chemistry would be be too time consuming, we present lab procedures which utilize a dichotomous key to be used, along with some models to study organic isomers only. No matter which of the five methods of running the lab you choose (or one you design yourself), please make sure that the pairs of models are labeled 1 through 7, so student responses can be checked.

For more detailed background information consult the Ryler Enterprises "Organic Stereochem-Large Set" kit available on the Ryler Enterprises website: www.rylerenterprises.com. Click on "Instructions and Quizzes," locate the **Organic Chemistry** section, then click on Organic Stereochem-Large Set (ORG-3).

Also, visit the Ryler Enterprises "Chemistry of Sugars" kit available on the Ryler Enterprises website: www.rylerenterprises.com. Click on "Instructions and Quizzes," locate the **Biochemistry** section, then click on Chemistry of Sugars (SUG-1).

General Instructions

Hand out the dichotomous key (found below), and then use the teaching set of molecules to demonstrate the use of the key. The color of the atom in the model identifies the element and, therefore, the number of bonds the atom should make with other atoms. Omit hydrogen atoms from the models in order to simplify building and identification. A peg without an atom attached can be assumed to have a bond with a hydrogen atom unless the number of bonds is satisfied.

Color	Element	# Bonds
Black	Carbon	4
Blue	Nitrogen	3
Red	Oxygen	2
Green	Halogen	1

The teaching/demonstrating set of models follows.

In Fig. 1a which is a model of chloroform ($CHCl_3$), we use a hydrogen atom since we only need one. Model 1b is carbon tetrachloride (CCl_4). These are not isomers since they have different formulas.

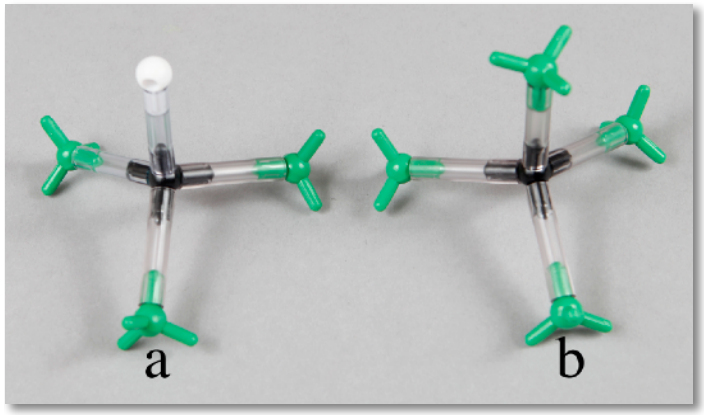


Fig. 1 Chloroform (a), and carbon tetrachloride (b) are not isomers.

Molecules in Fig. 2 are *a* the ketone, acetone, and *b* the aldehyde, propanal (propionaldehyde). The two compounds are constitutional isomers with the same formulas but different properties and connectivities of atoms.

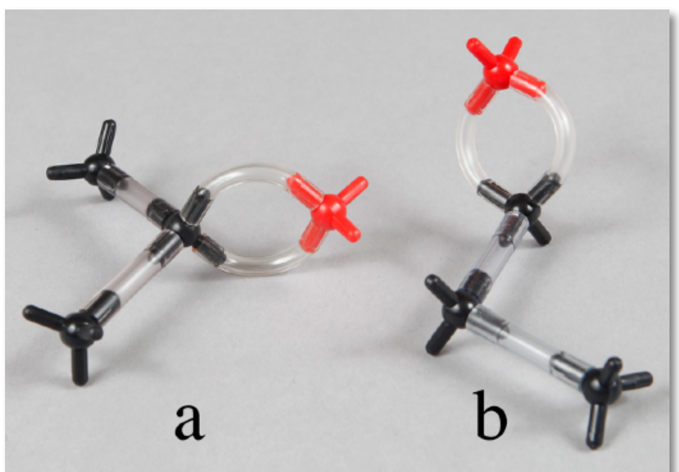


Fig. 2 A ketone (a) and an aldehyde (b) structural isomer.

Fig. 3 shows two different shapes (conformation) of the same molecule. (Configurations have different attachments of the same kinds of atoms in 3-d space. To make one configuration into another, bonds must be broken and different bonds must be made.) One conformation is converted into the other by rotation. Hence these are rotamers.

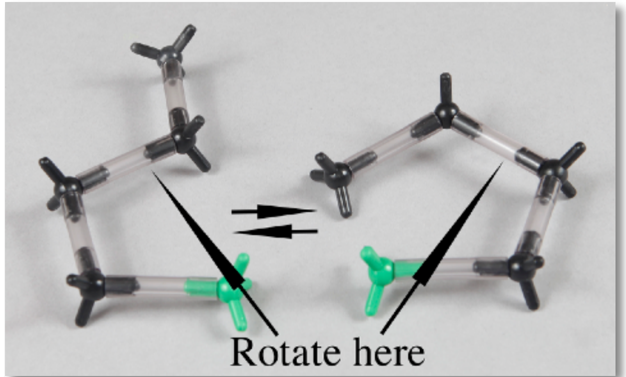


Fig. 3 Twisting the model on the left at one bond forms the second model.

Rotation around a single bond in a molecule depends upon the energy difference between the two participating conformations. It is possible for some molecules to have more than two rotamers as in the five conformations of cyclohexane. In Fig. 4, *a* identifies the planar form which has the highest energy of the molecule. Observing the high-energy strained (curved) bonds shows why this is the least stable form. Molecule *b*, the chair conformer, has the least energy and is the most stable. A chair shape is also a common arrangement other molecules such as ice and diamond.

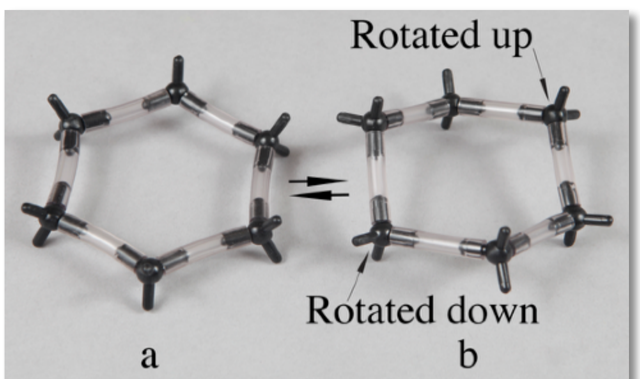


Fig. 4 Planar (a) and chair (b) cyclohexane.

In Fig. 5, the top molecule is the *trans* isomer, and the bottom molecule is the *cis* isomer. Due to the presence of the double bond, rotation around the carbon atoms in the double bond is not possible. One of the isomers cannot be converted into the other, without breaking and making new bonds, and each has its own unique properties.

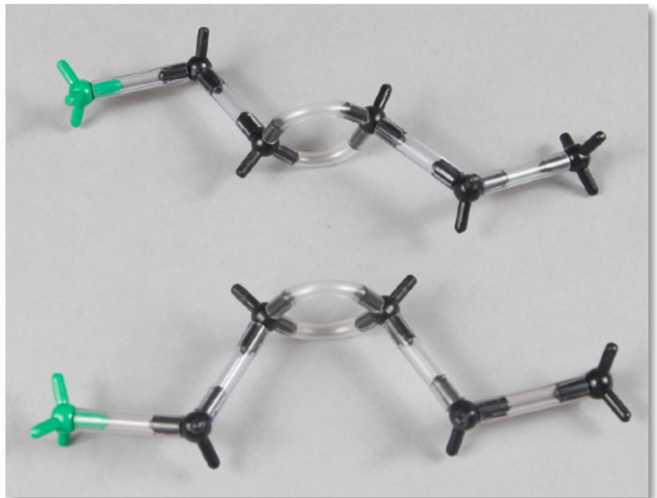


Fig. 5 A *trans* (top) and a *cis* (bottom) isomer.

The two sugar molecules in Fig. 6 are mirror images that are not superimposable, so they are enantiomers (also called optical isomers). Molecule *a* is L-glyceraldehyde, and *b* is D-glyceraldehyde.

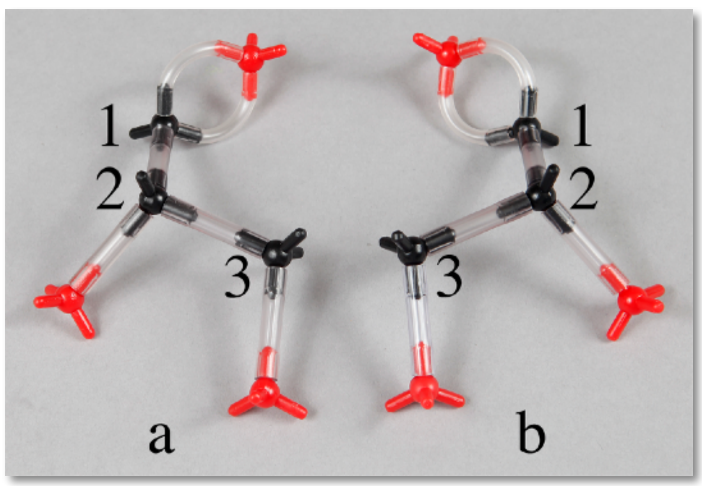


Fig. 6 Left handed glycderaldehyde (a) and right handed glyceraldehyde (b).

Place *b* on top of *a* to see if all of the atoms in both molecules align. Only carbons 1 and 2 and the pegs (which should be bonded to hydrogens) on carbon 2 will align. Now we can do rotation around single bonds to make a better fit. Rotate carbon 1 of model b so the double bonded oxygens overlap. Rotate carbon 2 of model b so that carbon 3 and its oxygen will be in register with the same atoms in model a. Notice that the oxygens on a and b, as well as the pegs on the number 2 carbons are not in register. Models a and b are like a left and right hand: mirror images which are not superimposable. The D form of gyceraldehyde (the simplest sugar) is used by living things, but its enantiomer is not found in nature. The prefix L is for *laevo* (Latin for left), and D is for *dexter* (Latin for right). The labels L and D are usually only used for sugars and amino acids. (S) which stands for *sinister* (left) in Latin and (R) which stands for *rectus* (right) in Latin, are used for other organic compounds; **Λ** (the Greek letter, lambda) and **Δ** (the Greek letter, delta) are used for complex-ion enantiomers. This type of isomerism is very common to biochemicals and drugs. Two sugars found in nature will be used to illustrate a pair of diastereomers. *a* has the same connectivity of atoms as *b,* but their arrangements in space are different. They are not mirror images of each other, and they are not superimposable. In Fig. 7, molecule *a* is D-threose, and *b* is D-erythrose.

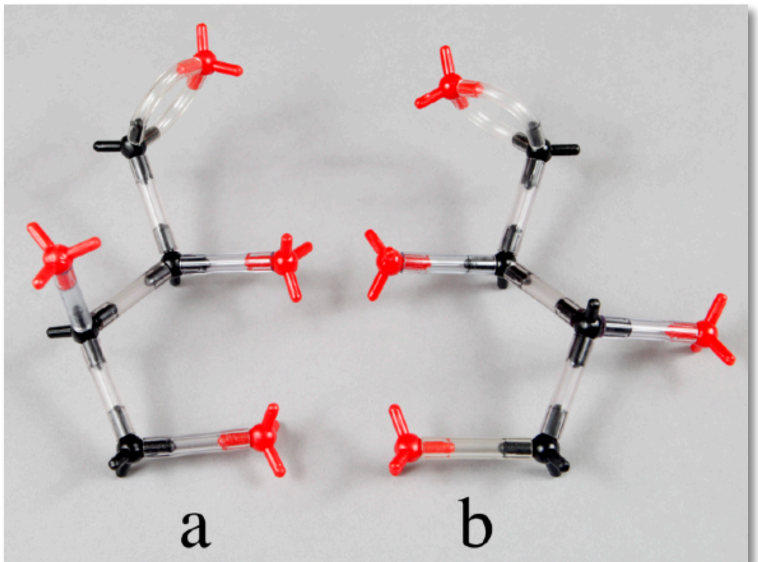


Fig. 7 Molecule a is threose, and b is erythrose.

The final pair of molecules to use to test your students' observational skills is the simplest alpha (α) amino acid, glycine, which has no isomer. In Fig. 8, *a* and *b* are mirror images, but they are exactly the same molecule. For a carbon atom to have a mirror image which is not superimposable, the atom must have four different atoms or groups of atoms bonded to it. Notice that the α carbon has two unused pegs for bonding to two hydrogen atoms. After bonding the two hydrogens, it can be seen that the α carbon only has three different kinds of groups.

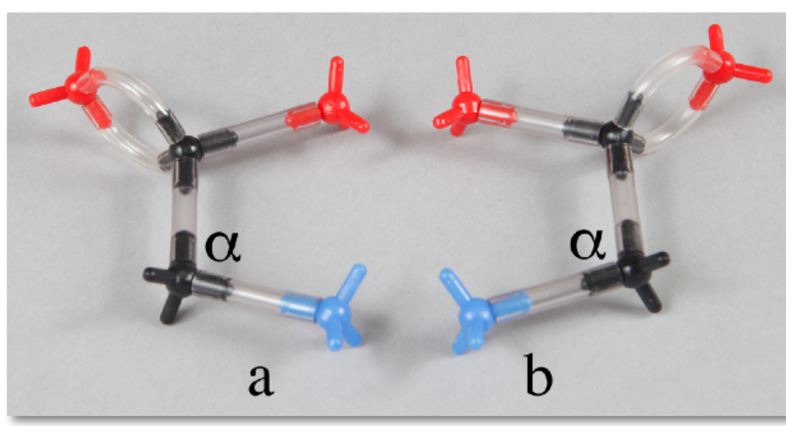


Fig. 8 Two models of glycine which are identical.

Suggestions for lab procedures

1. Form seven groups, and give each group a dichotomous key to use for the procedure. Each group will also receive a pair of molecules to evaluate for isomerism, but they will not be given the isometric identity of the molecules. Tell them the they may rotate atoms around single bonds if they care to, as they examine the models. As each group is finished, they can pass the models to the next group.

The following photos show pairs of compounds which will be used by students, along with the key, to determine which type of isomerism is depicted. STUDENTS WILL NOT BE SHOWN THE LABELED PHOTOS.

The first photo, in Fig. 1, includes a molecule of water and a molecule of ammonia. These are not isomers, since they do not share the same formula. Students should not have to be able to identify the compounds: they only have to compare the atoms of each color in each compound in order to make a comparison.

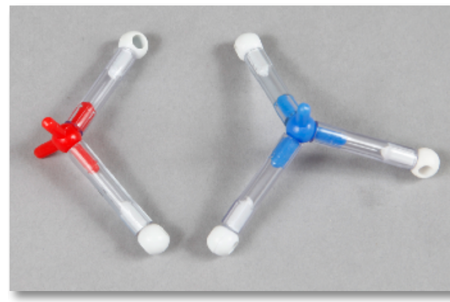


Fig. 1 Non-isomers water and ammonia.

In Fig. 2, the number of black atoms is the same in each molecule as is the number of red atoms. However, there is a difference in the position of the red atom in each molecule, so these are structural isomers.

Fig. 2 Structural isomers.

Each of the two molecules in Fig. 3 can be rotated at one bond to form the other molecule, so these are rotamers.

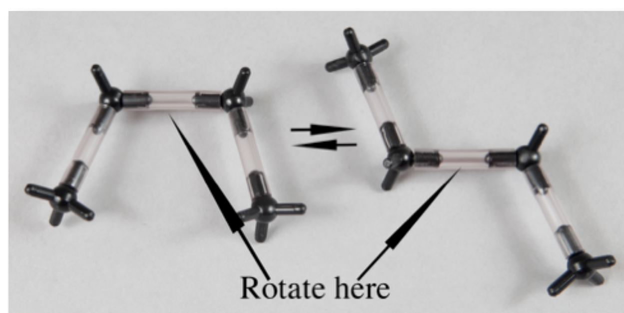


Fig. 3 Two rotamers.

The key also shows a chair and a boat conformation of cyclohexane. In Fig. 4, the chair has one atom rotated up and one rotated down. The boat has two bonds rotated up. These two molecules constitute a pair of molecules to be evaluated.

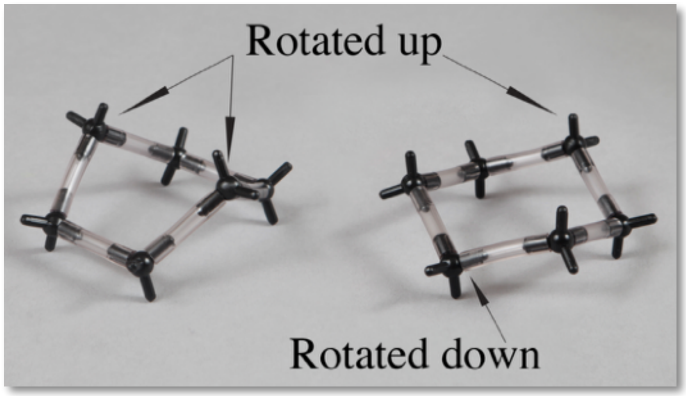


Fig. 4 Cyclohexane in the boat and chair conformations.

Fig. 5 illustrates the difference between *cis* (on the left) and *trans* (on the right) isomers (also called geometric isomers). They are not interconvertible due to the lack of rotation around the double bond.

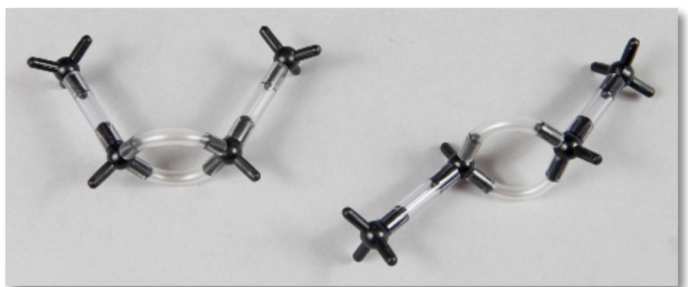


Fig. 5 *cis* and *trans* isomers.

In Fig. 6 you can see the right handed (R) optical isomer (enantiomer) of lactic acid on the right side (labeled *b*). The left handed (S) optical isomer (enantiomer) is shown on the left side of the diagram (labeled *a*). These two isomers are mirror images of each other, and they are not superimposable. That means when one model is placed on top of the other, their parts do not align.

When a molecule has four different types of groups on ONE tetrahedral atom (called a stereogenic center), the resulting structure will have an isomer which will be a non-superimposable mirror image. (Everything has a mirror image…except vampires.) A compound

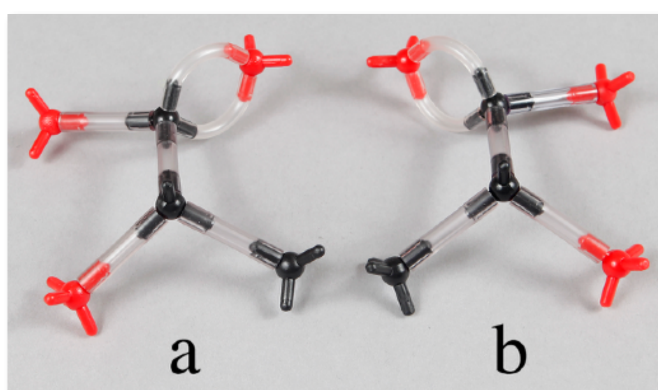


Fig. 6 Two enantiomers of lactic acid.

with more than one stereogenic center may, or may not have, an enantiomer. An example of this condition can be be seen in Fig. 7.

The two molecules of 2,3-dichlorobutane in Fig. 7 are diastereomers. They have the same types of atoms bonded, in the same order, to the same types of atoms, but they are not mirror images of each other (so they are not enantiomers), nor are they superimposable (so they are not identical). All of the atoms, with the exception of one of the chlorines are mirror images. That is the reason the molecules are considered to be diastereomers and not enantiomers. (Technically, *cis-trans* isomers are diastereomers also.)

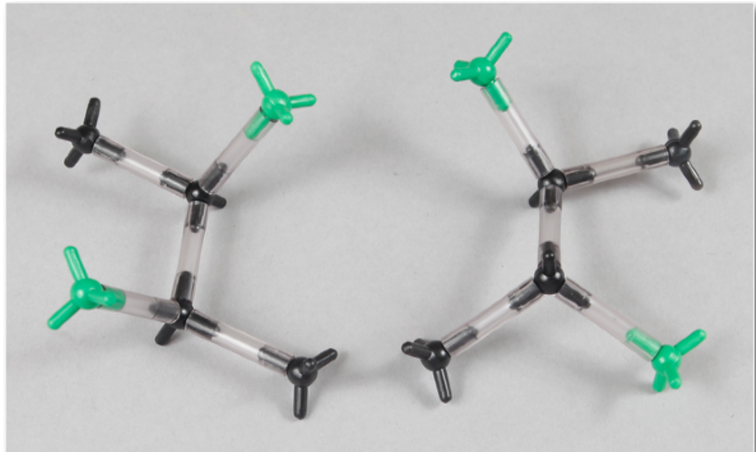


Fig. 7 Two diastereomers of 2,3-dichlorobutane.

2. You can make up all of the 14 models for each group beforehand, and the student groups can follow the above procedure, without the need to exchange model sets.

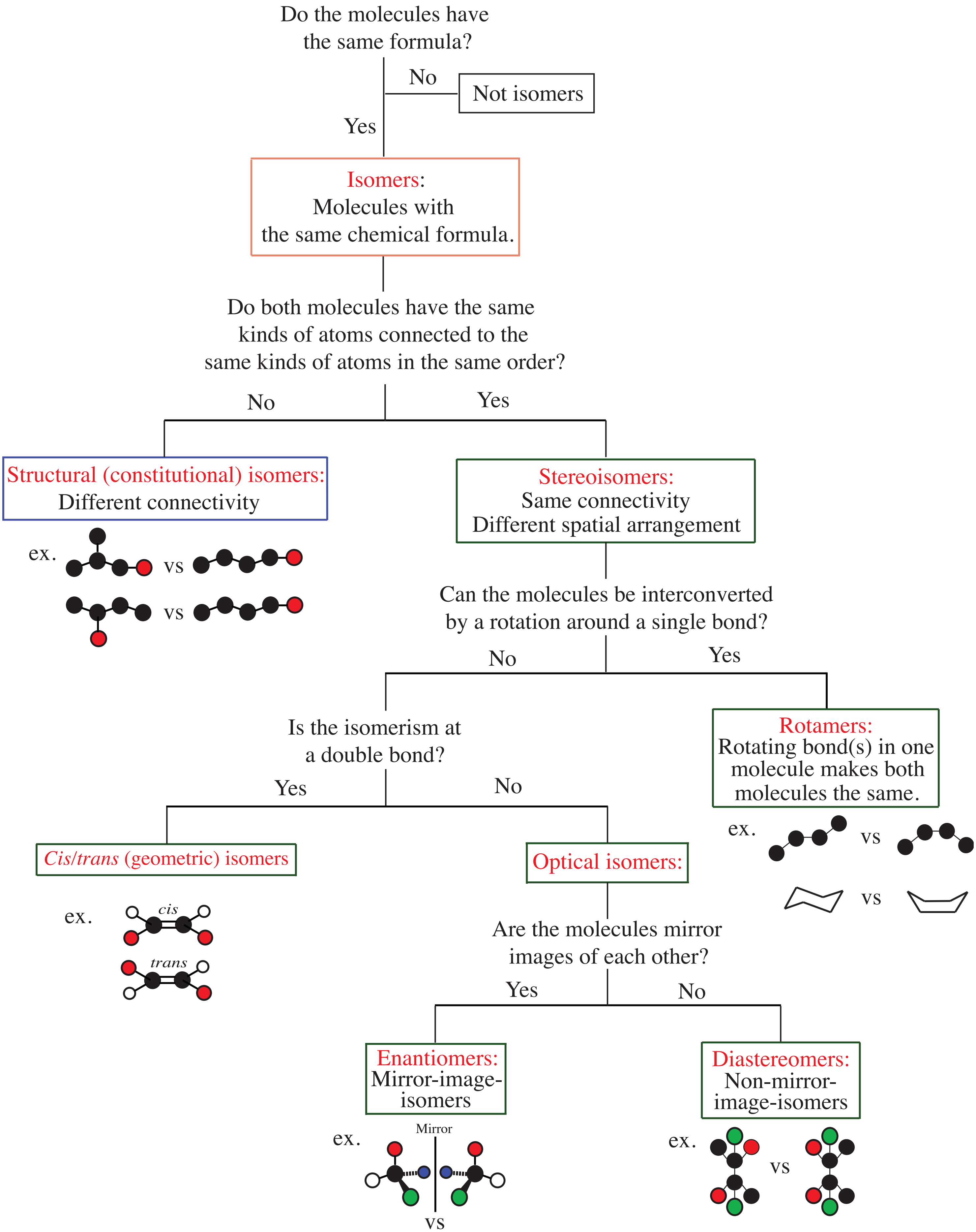
3. You can set up a station for each pair of molecules and give each group a few minutes at each station to identify the isometry.

4. You can hold up each pair of molecules for the entire class to compare.

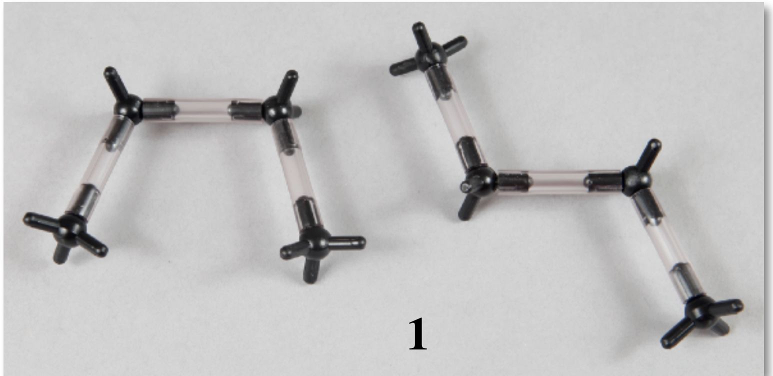
5. Hand out each molecule (there are 14 of them) independently of all the others and have students find isomers. Then use the procedure as in number 1. above.

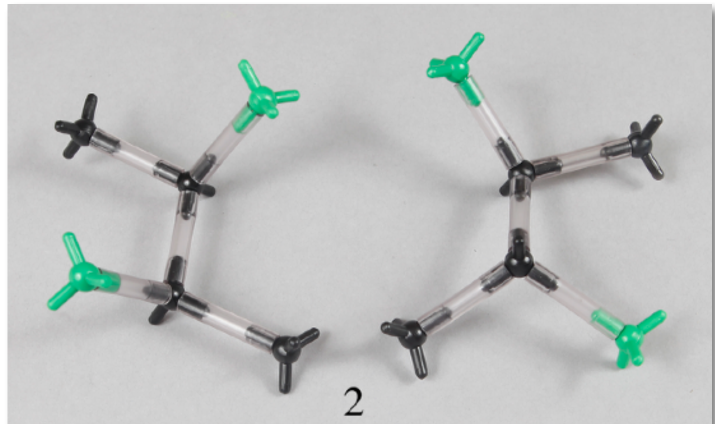
Key:

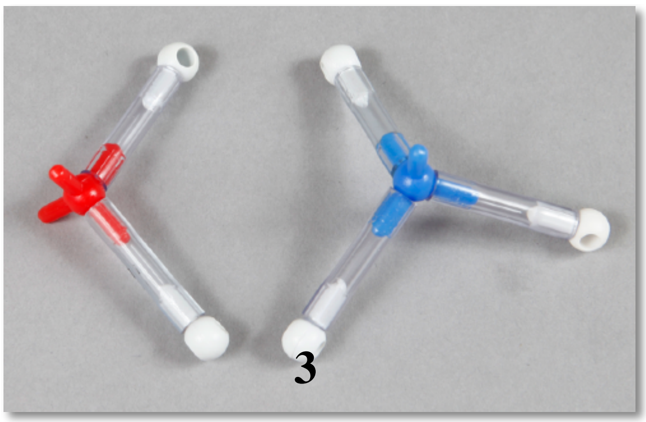
Pair Number	Isomers? Y/N	Type of Isomer
1	Y	rotamers
2	Y	diasteromers
3	N	NA
4	Y	rotamers
5	Y	enantiomers
6	Y	cis/trans
7	Y	structural

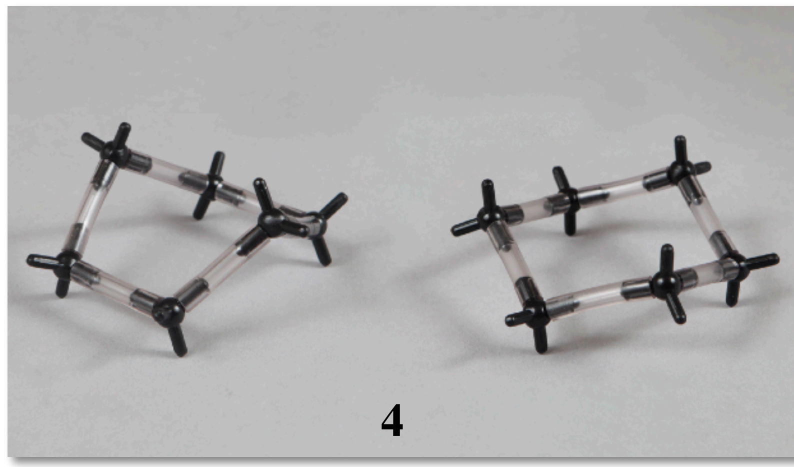

Do the molecules have
the same formula?
No
Not isomers
Yes
Isomers:
Molecules with
the same chemical formula.
Do both molecules have the same
kinds of atoms connected to the
same kinds of atoms in the same order?
No
Yes
Structural (constitutional) isomers:
Different connectivity
ex.
vs
vs
Stereoisomers:
Same connectivity
Different spatial arrangement
Can the molecules be interconverted
by a rotation around a single bond?
No
Yes
Is the isomerism at
a double bond?
Yes
No
Rotamers:
Rotating bond(s) in one
molecule makes both
molecules the same.
ex.
vs
vs
Cis/trans (geometric) isomers
ex.
cis
trans
Optical isomers:
Are the molecules mirror
images of each other?
Yes
No
Enantiomers:
Mirror-image-
isomers
ex.
Mirror
vs
Diastereomers:
Non-mirror-
image-isomers
ex.
vs

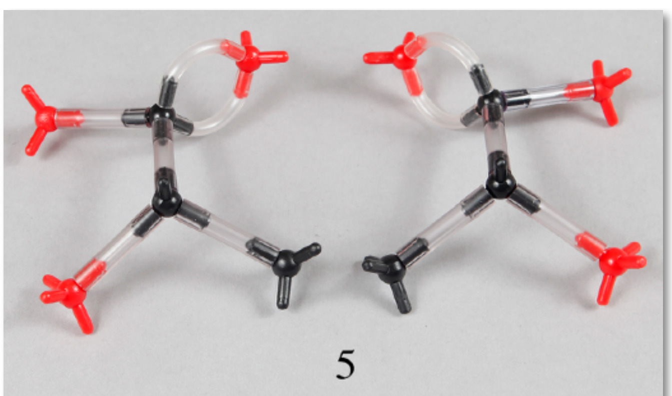
These are the models, with numbers coinciding with the answer key numbers, that will be given to the students.

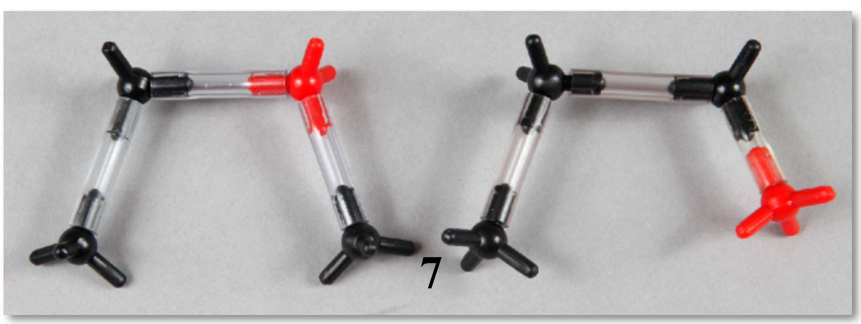












LAB 13: Isomers

Student Procedure

Objective: To compare and classify pairs of molecules as not isomers, or isomers.

To determine the type of isomers a pair of molecules present.

Materials: Your teacher will supply you with several models of molecules to analyze for isomerism. Additionally, you will be given a key to help you in your determinations.

After making your determinations, fill in the following table.

Pair Number	Isomers? Y/N	Type of Isomer
1		
2		
3		
4		
5		
6		
7		