Water vs. Hydrocarbons
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In this module the student will:

- Become familiar with the structure of water and methane.
- Understand how the structure influences the polarity of water and methane.
- Be able to identify the intermolecular force associated with each substance.
- Understand how the intermolecular force relates to the properties associated with each substance.
- Understand how the intermolecular force influences the solubility of a solute in a given solvent.
Lesson 1: Structure of water and methane.

Water, \( \text{H}_2\text{O} \), and methane, \( \text{CH}_4 \), are both covalent molecules. A **covalent molecule is a chemical compound that contains covalent bonds.** A **covalent bond is a bond that arises through the sharing of electrons between two atomic nuclei.** In reality the bond is an electrostatic attraction between the protons of one atom and electron(s) of an adjacent atom.

![Diagram of covalent bond](image)

A covalent bond will form when the attractions just barely outweigh the repulsions. Covalent bonds are found between two non-metals or a non-metal and a metalloid. These elements participate in covalent bonds because too much energy would be required for either element to lose electrons to become a cation, which is required for the formation of ionic compounds. In the structure of water you will find that the oxygen atom shares a pair of electrons with each of two hydrogen atoms. Additionally, two lone pairs of electrons are found on the oxygen atom.

![Structure of water](image)

In the structure of methane a carbon atom shares a pair of electrons with each of four hydrogen atoms.

![Structure of methane](image)
The electrons found in the lone pairs and within the covalent bonds are referred to as valence electrons. It is the valence electrons that are responsible for the shape of a covalent molecule. Electrons are negatively charged subatomic particles. What is observed when the negative ends of two magnets are brought in close contact with one another? The repel each other. The same is observed for a molecule’s valence electrons. When they are brought in close proximity to each other they will repel one another. **VSEPR Theory, Valence Shell Electron Pair Repulsion, states that the valence electrons, being negatively charged, will repel each other so that the electrons are as far from one another as possible.** For four electron groups, minimum repulsion is obtained when the pairs of valence electrons point to the corners of a tetrahedron.

![Diagram showing valence electron pair repulsion](image)

**Demonstration:** Use four balloons to show that 4 sets of electrons obtain minimal repulsion when the groups of electrons point to the corners of a tetrahedron. Point out that in a tetrahedral structure the groups are approximately 109.5° from each other.

After demonstration, pass around a model of methane and water made from Styrofoam balls and popsicle sticks. This visual will allow the student to observe the spacing of the atoms and lone pairs in the molecules to prepare for completion of Activity #1.

**Activity #1 – Perfect for homework.**

Although all electrons (bonding groups and lone pairs) participate in repulsion, the shape of the molecule is described by the atoms present. Methane has four bonding groups, its structure is that of the tetrahedron. Water has two bonding groups and two sets of lone pairs, its structure is referred to as bent.
Lesson 2 – Non-polar Covalent Bonds and Polar Covalent Bonds

Even though a covalent bond, which arises through the sharing of electrons, is present in covalent molecules, it does not mean that the electrons in that bond are shared evenly. In reality some elements prefer that the electrons spend a greater amount of time in their vicinity than do other elements. This distribution of the electrons between two atoms can be determined by evaluating each element’s electronegativity. **Electronegativity is the ability of an atom in a molecule to attract the shared electrons in a covalent bond.** Below is a table of electronegativities.

A bond is considered to be a non-polar covalent bond when the difference in the electronegativities of the atoms that make up the bond is between 0 and 0.4. A polar covalent bond arises when this difference is calculated to be between 0.5 and 1.9. Below is an electron density map of a non-polar covalent bond and a polar covalent bond.

### Non-polar Covalent

**Cl₂**

- Cl 3.0
- Cl -3.0
- difference = 0

### Polar Covalent

**HCl**

- Cl 3.0
- H -2.1
- difference = 0.9
Note: in the non-polar covalent bond, the density map is evenly distributed between the two atoms of chlorine, but, in the polar covalent bond the electron density is much greater around the chlorine atom due to the significant differences in atomic electronegativity. Again, this diagram illustrates where the electrons are most likely found within the bond. Since electrons are negative and since they spend a greater amount of time around the chlorine atom, the result is that the chlorine atom takes on a partially negative charge. In the same regard, the electrons are pulled away from the hydrogen atom therefore giving the hydrogen atom a partially positive charge. The difference in the electronegativities of the elements create a dipole. A **dipole is the formation of a negative and positive pole.** An arrow notation is commonly used to illustrate the direction of the electron density within the molecule. The head of the arrow will always be pointed in the direction of the more electronegative atom. The opposite end of the arrow is crossed to represent the partial positive charge possessed by the least electronegative atom.

![Polar Covalent HCl](image)
Lesson 3 – Polar Molecules, Non-Polar Molecules, and Intermolecular Forces

The geometry of a molecule as well as the difference in the electronegativities of the atoms that make up the molecule, determine whether a molecule will have a dipole moment or not. A dipole moment arises when polar bonds reinforce each other causing the molecule to be polarized. If no dipole moment exists, the molecule is considered to be non-polar. Below are diagrams of water and methane.

![Diagram of water molecule]

![Diagram of methane molecule]

The electronegativity difference between oxygen and hydrogen is 1.4, meaning that the electrons within each H-O bond spend a greater amount of time around the oxygen atom. Given the bent shape of a water molecule, the polarities of these two bonds reinforce one another. Water, therefore, has an overall dipole moment in the direction of the oxygen atom. In the methane molecule, each C-H bond has an electronegativity difference of 0.4. The electrons within the C-H bond spend a little more time around the carbon than the hydrogen, causing the bond to be only slightly polarized in the direction of carbon. However, instead of the bonds reinforcing one another they cancel each other out causing methane to be a non-polar molecule.

The polarity of a molecule as well as the connectivity of the atoms within the molecule determines the intermolecular force present. The intermolecular force(s) present in a covalent molecule can be one of three types: hydrogen bonding, dipole-dipole, or London dispersion.

A hydrogen bonding intermolecular force is an attractive force found between polar molecules that contain the criteria of hydrogen directly bonded to a nitrogen, oxygen, or fluorine atom.

A dipole-dipole intermolecular force is an attractive force found between polar molecules.

A London dispersion intermolecular force is an attractive force found between non-polar molecules that results from an instantaneous, temporary dipole caused by electron motion.

The strongest intermolecular force, of the forces listed, is that of hydrogen bonding. Below is a table that compares the strength of the three forces.
<table>
<thead>
<tr>
<th>Force</th>
<th>Strength of Intermolecular Force (energy required to break one mole of molecules apart that contain that force)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Bond</td>
<td>10-40 kJ/mol</td>
<td>Occurs between polar molecules with O-H, N-H, and F-H bonds</td>
</tr>
<tr>
<td>Dipole-Dipole</td>
<td>3-4 kJ/mol</td>
<td>Occurs between polar molecules</td>
</tr>
<tr>
<td>London Dispersion</td>
<td>1-10 kJ/mol</td>
<td>Occurs between all molecules; strength depends on size and polarizability</td>
</tr>
</tbody>
</table>

Water contains the intermolecular force - hydrogen bonding given that the molecule is polar and it contains O-H bonds. The hydrogen bond occurs between the partially negative oxygen of one water molecule and the partially positive hydrogen on an adjacent water molecule.

![Hydrogen bond](image)

Methane contains London dispersion forces since it is a non-polar molecule. The diagram below illustrates London forces within chlorine, Cl₂. Illustration (a) represents the chlorine molecules in their standard state. Because the electrons are in constant motion, a time will come when the chlorine molecule on the left has a temporary dipole. This temporary dipole has a domino effect on its nearest neighbors forcing them to have a temporary dipole as illustrated in diagram (b). The polarity of the molecules will be short lived and soon the molecules will return to their standard state (a).
Activity #2 – builds on the molecules from Activity #1.
Lesson 4 – The effect of intermolecular forces on molecular properties.

Most solids are substances whose constituent particles have an ordered arrangement extending over a long range. Molecular solids are held together by the intermolecular forces described in the previous lesson. The melting point of a solid describes the amount of energy needed to overcome some of these attractions and allow the particles to move more freely in the form of a liquid. Liquids are substances whose particles are still relatively close together but are allowed to move around more freely due to weakened intermolecular forces. Even though these intermolecular forces are weakened, they still exist. The boiling point describes the amount of energy needed to break the remaining attractions and allow the particles to move very freely as gas particles. Because gas particles are very small compared to the amount of space between them, gaseous substances do not contain intermolecular forces.

Many of the properties associated with water can be explained by its intermolecular forces.

Why does water, with a molar mass of 18 g/mol, melt at 0°C while methane, with a fairly similar molar mass of 16 g/mol, melt at -182.5°C? Why does water boil at 100°C while methane boils at -161°C? The answer is found in the intermolecular forces. Water contains hydrogen bonding which is a much stronger intermolecular force than methane’s London forces. Since water contains the stronger intermolecular force it means that a greater amount of energy will need to be added to break two water molecules apart.

Activity #3 – Hands on discovery of additional properties

Intermolecular force also explains cohesion, adhesion, surface tension, and capillary action. **Cohesion, the ability of like molecules to stick together**, will increase with stronger intermolecular forces. Why can a glass be over-filled without the water overflowing? The answer is cohesion. The individual water molecules are attracted to four other water molecules through hydrogen bonding. Because hydrogen bonding is quite strong, it is more difficult to separate the molecules from one another, hence it forms a convex surface. **Adhesion, the ability of dissimilar molecules to stick together due to attractive forces**, increases when the attraction between the dissimilar substances is stronger than the attraction between like molecules. Why will water form a concave surface when in a half-filled glass? The answer is adhesion. The water molecules are attracted to the silicon dioxide of the glass through hydrogen bonding. This
attraction between the water and the glass is stronger than the attraction between the water molecules themselves.

Whether the surface of the liquid is concave or convex it is referred to as a meniscus, a curve at the surface of a molecular substance in response to the surface of the container. Finally, 

**capillary action describes the behavior of liquids in thin tubes.** Capillary action is also related to intermolecular forces. Why does water travel up a small capillary tube? The answer is found within the attraction of the water to the silicon dioxide. This attraction is stronger than the hydrogen bonding between water molecules. Because the attraction is stronger the water creeps up the sides of the capillary tube.

Since methane contains London forces, these observations will be very different.
Overheads
Definitions – Lesson #1

Covalent molecule - a chemical compound that contains covalent bonds

Covalent bond - a bond that arises through the sharing of electrons between two atomic nuclei

VSEPR Theory - Valence Shell Electron Pair Repulsion Theory - states that the valence electrons, being negatively charged, will repel each other so that the electrons are as far from one another as possible
Definitions – Lesson #2

Electronegativity - the ability of an atom in a molecule to attract the shared electrons in a covalent bond

Non-polar covalent bond – a bond in which the difference in the electronegativities, of the atoms that make up the bond, is between 0 and 0.4

Polar covalent bond – a bond in which the difference in electronegativities, of the atoms that make up the bond, is calculated to be between 0.5 and 1.9

Dipole – formation of a negative and positive pole
Definitions – Lesson #3

Dipole moment - arises when polar bonds reinforce each other causing the molecule to be polarized

Hydrogen bonding - an intermolecular force found between polar molecules that contain the criteria of hydrogen directly bonded to a nitrogen, oxygen, or fluorine atom.

Dipole-dipole – an intermolecular force found between polar molecules

London dispersion – an intermolecular force is found between non-polar molecules that results from an instantaneous, temporary dipole caused by electron motion
Definitions – Lesson #4

Solids – substances whose constituent particles have an ordered arrangement extending over a long range

Melting point – describes the amount of energy needed to overcome some of the intermolecular forces found in solids so that the particles are allowed to move more freely in the form of a liquid

Liquids – substances whose particles are relatively close together, contain intermolecular forces, but, whose forces are weaker than those found in solids

Boiling point – describes the amount of energy needed to break the intermolecular forces found in liquids so that the particles are allowed to move very freely as gas particles
Cohesion – the ability of LIKE molecules to stick together due to attractive forces

Adhesion – the ability of DISSIMILAR molecules to stick together due to attractive forces

Capillary action – describes the behavior of liquids in thin tubes associated with adhesion

Convex – curving out or bulging outward

Concave – curving in or hallowed inward

Surface Tension – attraction of one surface molecule in a liquid to additional surface molecules of the liquid associated with cohesion
Non-polar Covalent

\[ \text{Cl}_2 \]

\[
\begin{align*}
\text{Cl} & = 3.0 \\
\text{Cl} & = 3.0 \\
\text{difference} & = 0
\end{align*}
\]

Polar Covalent

\[ \text{HCl} \]

\[
\begin{align*}
\text{Cl} & = 3.0 \\
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**Strength of Intermolecular Force** (energy required to break one mole of molecules apart that contain that force) | Characteristics
---|---
**Hydrogen Bond** | 10-40 kJ/mol | Occurs between polar molecules with O-H, N-H, and F-H bonds
**Dipole-Dipole** | 3-4 kJ/mol | Occurs between polar molecules
**London Dispersion** | 1-10 kJ/mol | Occurs between all molecules; strength depends on size and polarizability
Activities
Activity #1

Introduction:

The purpose of this activity is to develop a visual understanding of the structure of water and of hydrocarbons.

Materials:

Marshmallows (Both Large and Small)
Toothpicks
Redhots

Procedure:

1. Prepare 3 water molecules. Use the toothpicks to represent bonds, the large marshmallows to represent the oxygen atom and the small marshmallows to represent the hydrogen atoms of elements, and the redhots to represent the lone pairs (redhots will need to be licked to stick to the marshmallow). The angles between each external group should be approximately 109° from one another.

2. Prepare 2 methane molecules. Use the toothpicks to represent bonds, the large marshmallows to represent the carbon atom and the small marshmallows to represent the hydrogen atoms. The angles between each external group should be approximately 109° from one another.
3. Prepare 2 propane, $C_3H_8$, molecules. Use the toothpicks to represent bonds, the large marshmallows to represent the carbon atom and the small marshmallows to represent the hydrogen atoms. The angles between each external group should be approximately 109° from one another.
Activity #2

Introduction:

The students will develop a visual understanding of the difference between hydrogen bonding and London forces. They will be able to describe the effect that the intermolecular force has on the properties of melting points and boiling points.

Materials:

Molecules developed previously
Pipe cleaners
Ribbon

Procedure:

1. Attach the oxygen in the one water molecule to the hydrogen in a second water molecule using a pipe cleaner.
2. Attach the carbon in one methane molecule to the carbon in a second methane molecule using ribbon.
3. Attach the three carbons in a propane molecule to the three carbons in a second propane molecule using ribbon.
4. Try to pull the molecules apart.

Observations:

Which is the flimsiest intermolecular force?

List the compounds (water, methane, propane) in order of increasing difficulty to separate completely.

What was the difference between methane and propane, each of which contain London forces?

How do you think that the intermolecular force relates to melting points and boiling points?

Melting point and boiling point describes the energy required to separate molecules.
Procedure:

1. Attach the oxygen in the one water molecule to the hydrogen in a second water molecule using a pipe cleaner.
2. Continue this process until all water molecules are connected together in a circle.

Sketch your result.

Ice floats on water because it is less dense than water. Give an explanation for this statement, taking into account the presence of air in the voids of your drawing above.
Activity #3

Introduction:

The students will understand the properties of cohesion, adhesion, and surface tension and relate these properties to intermolecular forces.

Materials:

Stop Watch (students should spend 10 minutes at each station)
Procedure for each station

Station 1:
Fluted wine glass with string tied to the stem
Piece of light plastic larger than the opening of the glass
Water
Sink

Station 2:
2 regular drinking glasses
Water
Several pieces of small cork

Station 3:
3 to 4 capillary tubes of different diameters
Small beaker
Food coloring
Water

Station 4:
Paper card cut according to diagram
Liquid detergent
Dropper
Metal Pie pan or shallow tray
Water

Station 5:
Small bottles of different size openings
Cheese cloth or screen
Rubberbands
Water
Procedures:

Station 1:
1. Fill the glass mostly full of water.
2. Place the plastic across the opening of the glass.
3. While holding the plastic snuggly to the opening of the glass gently turn the glass upside down.
4. Slowly remove your hand from the plastic.

Station 2:
1. Fill one glass half way with water.
2. Float a cork on the water surface. Observe.
3. Fill the second glass full of water (all but overflow the water)

Station 3:
1. Fill the beaker with water and place a few drops of food coloring in it.
2. Hold three or four capillaries, of different diameters, close to each other and dip them in the water.
3. Observe the water level in each capillary.

Station 4:
1. Fill a shallow tray or pie pan with water.
2. Gently place a boat on top of the water.
3. Add a drop of liquid detergent in the center of the opening of the boat.

Station 5:
1. Use a rubber band to fasten the screen over the open end of the bottle.
2. Pour water through the screen.
3. Invert the bottle and observe.
Data and Conclusions

Station 1:
Did the water form a convex or concave meniscus?

If convex, then the water had greater attraction to itself than to the glass. If concave, then the water had greater attraction to the glass than to itself. Which attraction is the greatest in your opinion?

Using terms of adhesion, cohesion, and/or surface tension, explain what you observed?

Station 2:
Did the water form a convex or concave meniscus when in a half-filled glass?

Where is the water level the highest in the half-filled glass?

Using terms of adhesion, cohesion, and/or surface tension, explain your observations in a half-filled glass?

Where does the cork float when placed in a glass half-filled with water?

Did the water form a convex or concave meniscus when filled above the brim of the glass?

Where is the water level the highest in the glass with the water filled above the brim?
Using terms of adhesion, cohesion, and/or surface tension, why we can fill the glass slightly above the brim without overflowing the water?

Where does the cork float when placed in a full glass of water?

Give an explanation for your observation of the cork with respect to water height.

**Station 3:**
Using terms of adhesion, cohesion, and/or surface tension, explain capillary action.

How does the diameter of the capillary tube affect the rate in which the water rises within the tube?

Given your observation, why do you think a difference was observed depending on the diameter of the capillary opening?

**Station 4:**
Using terms of adhesion, cohesion, and/or surface tension, explain why the paper boat moves forward only when the soap touches the water.
Station 5:
Using terms of adhesion, cohesion, and/or surface tension, explain why the water does not spill out from the inverted bottle.
Science Lead Teacher Institute

Summer 2010

Connecting Biology to Chemistry through Inquiry-based Learning

General Approach

Using the Scientific Method to develop better conceptual knowledge and reasoning skills. Emerson back in 1837 said it best in his essay Nature that…“[we] it experience as Life before [we] comprehend it as truth.”

Objectives

1. Help develop lesson plans for learning outcomes through use of the scientific method.
2. Learn the skills needed to conduct simple investigations using LabQuest and simple, economical instruments with materials that can be bought from Wal-Mart and other retailers.

Each module is broken down into timeframes to help fit into an instructional period.

Steps of Scientific Method and their learning "E” strategy

Step 1. Observation- Engage the student to formulate a Researchable Question (RQ) by making observations.

Strategies

- Engage students to observe a living example of the principle or concept. Write it down.
- Discuss cause-effect relationships about your observations and the biological concept associated with it, then ask a researchable question.
Step 2. **Hypothesis**—*Explore* how to design an experiment to test a hypothesis to answer the RQ.

*Strategies*

- From the RQ, develop a hypothesis—a prediction NOT AN EDUCATED GUESS, about the causes of the observation.
- Explore what variables are needed to test this hypothesis, i.e. independent and dependent, experimental and control groups.
Step 3. **Experiment** - *Explain* the cause and effect relationship of the hypothesis by designing an experiment to test it.

**Strategies**

- *Explain how the results would support your hypothesis by drawing a graph of the expected results.*
- *Explain the procedures and methods used to be used.*
- *What materials are needed, what organism, cell type, or organelle would make the best model?*
- *What test variables are needed for data, how will data be collected and analyzed?*

Step 4. **Results** - *Evaluate* the experiment by analyzing and graphing the results.

**Strategies**

- *Engage students to observe a living example of the principle or concept. Write it down.*
- *Discuss cause-effect relationships about your observations and the biological concept associated with it, then ask a researchable question.*

**Example** *Is light necessary for photosynthesis?*

Step 5. **Conclusion** - *Elaborate* on the biological meaning using the results to justify whether the results support or reject the hypothesis.

**Extension** of the conclusion to a new RQ or to redesign the experiment for further testing.

**Strategies**

- *Engage students to observe a living example of the principle or concept. Write it down.*
- *Discuss cause-effect relationships about your observations and the biological concept associated with it, then ask a researchable question.*

**Example** *Is light necessary for photosynthesis?*

**Resources for Materials**

Wal-Mart
Home Depot
Lowe’s
Carolina Supply
Nasco

Vernier for LabQuest and probes (www.vernier.com)
Module 1. Water – Biology

Dr. Hirrel, Mr. Mimms, and Ms Waggoner

Unique properties of water, adhesion, cohesion, and transpiration

Observation- Engage

Water moves through plants in xylem tissue, which are dead hollow, tube-like cells. Water in the soil is needed for photosynthesis in the leaves. Water in some tall trees may travel several hundred feet to get to the upper most leaves. How is it done?

Principle of evapotranspiration

Activity (15 -20 min). Take class outdoors and find a tree. Estimate its height using the similar triangles technique. Circle the tree at the dripline where most of the active roots are and estimate the distance to the tree. The sum is the distance water must travel to get to the upper leaves.

Activity (15 -20 min). Components of transpiration. Examine xylem tissue and leaf stomata.

What is the range in xylem diameters (30-300μm). Convert μm to cm.

Problem: Can water move up plants by capillary action caused by its adhesion-cohesion properties? height of water, cm= 0.3/ xylem diam., cm

What are stomata and how many are there per cm$^2$ of leaf?

Discussion on how to measure water loss and why its important leading up to formation of researchable question.

RQ: How much water passes through a plant in an hour?
Hypothesis - Explore

Activity (10 -15 min). Based on RQ, formulate a hypothesis based on the type of plant used.

Experiment - Explain

Activity (15 -20 min). Design the experiment to test the hypothesis. What type of plant is needed? What are the independent and dependent variables? How many experimental and control groups are needed? How many replications? What data needs to be collected? How will measurements be standardized (not all plants are the same)?

Activity (10 -15 min). Graph the expected results to support your hypothesis.

Activity (30 -40 min). Conduct the experiment. Prepare a data collection table.

   Gravimetric approach. Use transplants. Use a balance (0.01g) to measure weight loss over time. Wrap roots in cellophane or enclose them in a ziplock bag of suitable size. Measure after 10 min, then again 10-15 min later.
LabQuest approach. Use a tree branch of suitable diameter (~ pen size). Attach a 20-30cm piece of latex tubing to the stem and connect to a Vernier Gas Pressure probe. Attach plant to a stand. Use a small fan to simulate wind. Record pressure every 10-20 sec for 600-900 sec (10-15 min)

Results - Evaluate

Activity (20 -30 min). Evaluate and analyze results. Graph results

Conclusion - Elaborate

Activity (15 -30 min). Do the results support or reject the hypothesis? Quantify the difference in the rates of transpiration between the control and experimental groups.

Activity (out of class). Write a report.

Extension

Activity (15 -20 min). What is the biological meaning or relevance from the conclusion? If supporting hypothesis, then what is the next RQ to answer? If rejecting hypothesis, then how could the experiment be modified to test the hypothesis better?

Problem 1: Based on the results, what is the transpiration rate per cm² leaf, per stomate?

Problem 2: Calculate the amount of water needed to grow some number of plants.
How much water per hour is used by an acre of bell peppers, 12,000 plants/acre.

Essential Equipment & Materials

Meter sticks

Microscope slides of plant xylem, or suitable images.

Epidermal peel of lower leaf surface, or suitable image.

Transplants in 6-pack containers. Vegetables or bedding plants

Latex tubing (5-8mm id)
Small electric fan
LabQuest, data acquisition system
Gas Pressure probe