Microfluidic Droplets Lab
Instructor Guide

Learning Objectives

- Understand how the polarity of a substance affects its physical properties of boiling point and surface tension.
- Test how the concentrations of liquids in two-component solutions affect the interaction of individual solution droplets.
- Explain how molecular shape and polarity of individual particles.
- Understand how differences in substances in a two-component solution affect the interaction of the microfluidic droplets.
- Understand how the movement of two-component solutions is used to in the development of microfluidic devices.

Alignment to NGSS Standards

- MS-PS1-1. Develop models to describe the atomic composition of simple molecules and extended structures.
- MS-PS1-3. Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.
- HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.
- HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

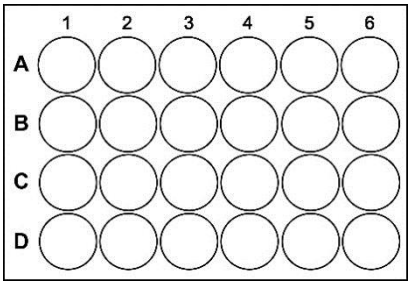
Materials

- Propylene glycol. ***An alternative to using propylene glycol is to dilute food coloring containing propylene glycol with deionized water.***
- {8} 24-well plates with food coloring and propylene glycol. ***Alternative: Wax paper with test tubes of food coloring and propylene glycol.***
- {8} Bunsen burners
- {24} Glass microscope slides
- {16}Tweezers
- {8} Empty beakers or ceramic plates for cooling microscope slides
- {8} 20 µL and 200 µL micropipettes with appropriately sized tips. ***Alternative: plastic micro-thin stem pipets.***
- {8} Sharpie markers
- {8} Wash bottle for clean up
- {8} Rulers
- White paper

Instructor Pre-Lab Procedures

Preparing {12} 24-well plates:

1. Place 400 µL of propylene glycol in well A1.
2. Place 2 mL of blue food coloring in well B1.
3. Place 2 mL of red food coloring in well C1.
4. Place 2 mL of green food coloring in well D1.



http://www.cellsignet.com/media/plates/24.jpg

Note: Each group will have slightly more propylene glycol and food coloring than required for the experiment.

Alternative: Wax paper with test tubes of food coloring and propylene glycol can be used for distributing materials and making dilutions.

For: (i) Observation of Microfluidic Droplets Activity

Each group of 3-4 students need:

- 24-well plate with food coloring and propylene glycol. **Alternative:** Wax paper with test tubes of food coloring and propylene glycol.
- 1 Bunsen burner
- 1-2 glass slides
- 1 Tweezer
- 1 empty beaker or ceramic plate for cooling slide
- 1-20 µL micropipette (use 3 µL setting) with appropriately sized tips. ***Alternative: Plastic micro-thin stem pipets***.
- Sheet of white paper
- Wash bottle for clean up

For: (ii) Investigating the Effect of Propylene Glycol Concentration Microfluidic Droplets

Each group of 3-4 students need:

- 24 well plate with food coloring and propylene glycol. **Alternative:** Wax paper with test tubes of food coloring and propylene glycol.
- 1 Bunsen burner
- 1-2 glass slides
- 1 Tweezer
- 1 empty beaker or ceramic plate for cooling slide
- 1-20 µL micropipette (use 3 µL setting) and 20-200 µL micropipette with appropriately sized tips. **Alternative:** Plastic micro-thin stem pipets can be used to combine different numbers of drops of food coloring and propylene glycol to create a concentration curve.
- Sheet of white paper
- 1 Sharpie marker
- 1 Ruler
- 1 Wash bottle for clean up

Report Answer Key

Pre-Lab Questions

1. What is a solution?

   A solution is a homogeneous mixture with two or more components.

2. What are the solutes and solvent in food coloring?

   Solutes in food coloring are the chemical dye compound and sometimes propylene glycol. The solvent is water.

3. What are some of the properties of water?

   Water is polar; cohesive with other polar molecules (hydrophilic molecules); adheres or sticks to other water molecules, greater density as a liquid (molecules are closest together as a liquid – form a crystal lattice as a solid), high specific heat (absorbs energy); capillary action.

4. How does the structure of water relate to these properties?

   A water molecule is composed of one oxygen atom and two hydrogen atoms covalently bonded together. The oxygen atom is more electronegative than the hydrogen atoms resulting in the oxygen atom having a net negative charge and hydrogen atoms having a net positive charge. The dipole moment allows for stronger intermolecular forces or hydrogen bonding.

Vocabulary

Chemotaxis: The movement of a motile cell or organism, or part of one, in a direction corresponding to a gradient of increasing or decreasing concentration of a particular substance.

Concentration: The amount of dissolved substance in a given volume of solvent.

Evaporation: The process of a substance in the liquid state changing to a gaseous state, often under the influence of heat.

Fluid: A state of matter, such as liquid or gas, in which the component particles (generally molecules) can move past one another.

Hydrophilic: Having a tendency to mix with or dissolve in water (polar molecule).

Hydrophobic: Tends to repel or fail to mix with water.

Intermolecular Force: The forces of attraction or repulsion which act between neighboring particles (atoms, molecules, or ions).

Marangoni Effect: The flow from lower to higher surface tension.

Microfluidics: The science of designing, manufacturing, and formulating devices and processes in micro- channel networks for the purpose of microscale analytical chemistry and electronics.

Non-polar molecule: A molecule with even distribution of negative and positive charges within the molecule.

Polar molecule: A molecule having a net dipole or an unequal distribution of negative and positive charges within the molecule.

Solubility: A chemical property referring to the ability for a given substance, the solute, to dissolve in a solvent.

Solution: A liquid mixture in which the minor component (the solute) is uniformly distributed within the major component (the solvent).

Surface Tension: the tension of the surface film of a liquid caused by the attraction of the particles in the surface layer by the bulk of the liquid, which tends to minimize surface area.

Wetting: Controlling and influencing liquids spreading on a surface.

(i) Observation of Microfluidic Droplets

Data and Results

1. What is the shape of a drop of water? What is the shape of the droplet of food coloring?

   The droplet of pure water flattens and spreads quickly on the slide. The concentrated food coloring forms a more sphere-shaped droplet.

   Why?

   The water on the droplet surface evaporates faster than propylene glycol, and at the same time, has a higher surface tension. These differences result in a symmetric internal water flow inside the droplet that stabilizes it and stops spreading.

2. How would you describe the motion of the droplets?

   Individual food coloring droplets move on the slide. They move slowly and then join with similar droplets.

   Why?

   The motion of droplets towards each other is the result of the water evaporation from one droplet influencing the water evaporation of the second droplet, leading to an imbalance of the stabilizing internal water flow. The resulting asymmetry starts the movement of the droplets toward each other.

3. Is there a pattern to the droplet movement?

   Some droplets appear to follow or chase other droplets. The reason for this chasing behavior is the difference in surface tension of the two droplets. Lower-surface-tension droplets (droplets with higher concentration of food color) will chase the drop with higher surface tension (droplets that have lower food-coloring concentration).

4. What are some possible explanations for the movement of the colored droplets?

   Student explanations may differ.

(ii) Investigating the Effect of Propylene Glycol Concentration Microfluidic Droplets

Data Analysis

1. Calculate the percent of propylene glycol in each sample.

   Volume propylene glycol/total volume x 100 = 5 %, 10 %, 15 %, 20 %, 25 %

2. Which droplets merged?

   Droplets that are similar in propylene glycol concentration merge.

3. Which droplets chased another droplet?

   Droplets with a significant difference in propylene glycol concentrations should exert forces on each other.

4. Which droplet contains the highest concentration of water?

   Most food coloring contains small amounts of propylene glycol. The concentration of propylene glycol differs with different manufacture and may differ with different dyes based on their solubility. For our purposes, the pure food coloring contains the lowest concentration of propylene glycol.

   An alternative way to conduct this experiment would be to dilute food coloring with pure water. This alternative would eliminate the need for having pure propylene glycol.

5. Is there a difference between the red and green food coloring?

   Answers may vary.

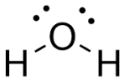
6. What are some possible explanations for the movement of the colored droplets?

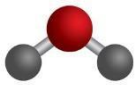
   Answers may vary.

Discussion questions

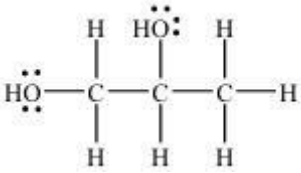
1. Draw the Lewis structure of water and propylene glycol.

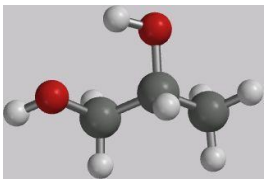
   WATER:





   PROPYLENE GLYCOL:





   http://www.chem.ucla.edu/~harding/IGOC/P/propylene_glycol.html

   Which compound is more polar?

   Water: more polar because it is a smaller molecule.

2. What intermolecular forces exist between water and propylene glycol molecules?

   Intermolecular forces for both molecules are hydrogen bonding and London Dispersion Forces. Water has greater polarity.

3. Based on polarity, which molecule has the greatest surface tension?

   Water has greater surface tension.

4. How does surface tension affect the movement of a droplet?

   The water molecule should exhibit drag molecule as it moves across the surface. This is at the front edge of the moving droplet.

5. Based on polarity, which molecule has the highest evaporation rate? Why?

   Water is a smaller molecule and has a higher evaporation rate.

6. In mixed droplets, how might the differences in evaporation rates affect molecules within a droplet?

   Water molecules at the edge of the droplet evaporate at a high rate increasing the concentration of propylene glycol. This is followed by water molecules at the center of the droplet moving to the outside to re-establish an equilibrium.

7. How does the evaporation rate of water molecules in one droplet affect another droplet?

   The water on the droplet surface evaporates faster than propylene glycol, and at the same time, has a higher surface tension. These differences result in a symmetric internal water flow inside the droplet that stabilizes it and stops spreading.

Artificial Chemotaxis Challenges

Pre-Lab Questions

1. What is chemotaxis?

   Chemotaxis is a cell or organisms movement in response an increasing or decreasing concentration gradient of a specific substance.

2. Where does chemotaxis occur in ordinary living systems?

   Chemotaxis is responsible for organism or cell movement towards food sources well as the movement of organism and cells away harmful substances. Examples:

   - *Plants secrete molecules promoting efficient colonization of the rhizosphere by microorganisms.*
   - *The immune system uses cells like neutrophils and macrophages to detect infectious organisms and neutralize them, relying on chemotaxis to sniff out chemicals produced by these cells so it can track them down.*
   - *Chemotaxis allows sperm to migrate toward an egg.*

Procedure Challenges Notes

Chasing – Short Range Interactions:

Short range interactions result from differences in the vapor surface tension.

Self –alignment – Long Range Interaction:

Long range droplet interaction result from the water vapor of one droplet absorbing to the glass and changing the microenvironment between droplets. This changes the vapor surface tension and creates an imbalance in the adjacent droplet resulting in a net force of attraction between molecules.

Self-Assembly – Sorting:

A result of surface tension.