Experiment 36A

9/2~~3~~4/2020

DETERMINING THE SIZE OF A SINGLE MOLECULE

MATERIALS: Watchglass, disposable plastic pipet, methanolic NaOH solution, liquid soap and brush, 10-mL graduated cylinder, glass test tube and rack, stock hexane solution of stearic acid (about 0.100 g/L), pure hexane.

PURPOSE: The purpose of this experiment is to both estimate and experimentally determine the physical dimensions (length and cross-sectional area) of a single fatty acid molecule and to estimate the value of Avogadro's number.

LEARNING OBJECTIVES: By the end of this experiment, the student should be able to demonstrate the following proficiencies:
1. Use the concept of intermolecular force to explain how a monolayer of fatty acid molecules forms on the surface of water.
2. Using a reasonable model for the shape of the fatty acid molecules and their solid densities, estimate the cross-sectional area taken up by one molecule.
3. Calibrate the average droplet-size delivered by the disposable pipet.
4. Explain how the endpoint of the monolayer "titration" is recognized.
5. Using the data from the "titration," and the estimate of the cross-sectional area of a single molecule, estimate the value of Avogadro's number.

DISCUSSION:
Intermolecular Forces involving Fatty Acids. Most molecules discussed in general chemistry courses are small enough that they are characterized by a single type of polarity, e.g., polar or non-polar. For example, water is polar and hexane is non-polar. Some molecules are large enough, however, that they are able to exhibit both polar and non-polar characteristics simultaneously. Stearic acid, a naturally-occurring fatty acid with chemical formula $C_{18}H_{36}O_2$ consists of a polar carboxylic acid region at one end of the molecule, with a long non-polar hydrocarbon tail. See Figure 1.

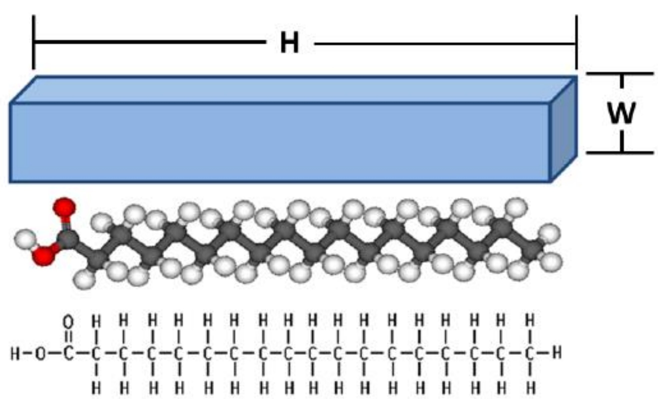


Figure 1. Structure of stearic acid. The molecular structure, ball-and-stick representation, and a block diagram for estimating the volume occupied by a single molecule are shown. Stearic acid is a common component of both animal and vegetable fats.

Of particular interest to this experiment is the ability of stearic acid to form a single layer of molecules on the surface of water. This can be accomplished by depositing stearic acid molecules, dissolved in hexane, on the surface of the water. As the volatile hexane evaporates, the polar regions of the stearic acid molecules are attracted to the polar water, while the non-polar tails of the stearic acid molecules remain above the water. Each stearic acid molecule occupies space on the surface of the water, similar in magnitude to the cross-sectional area of stearic acid molecules when in the solid phase. See Figure 2 below.

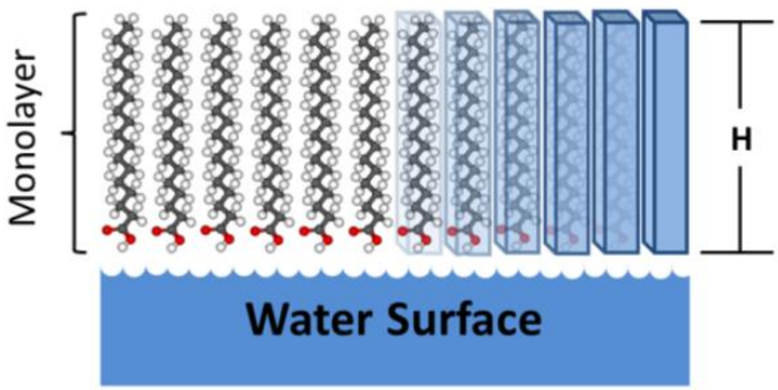


Figure 2. The non-polar regions of fatty acid molecules sticking up from the surface of the water (side view). The top view shows the area occupied by each stearic acid molecule of the monolayer.

We can use the properties of stearic acid – which are driven by intermolecular forces – to model the geometry of the monolayer surface and to make estimates of surface area, number of molecules, and even to calculate Avogadro's number! Figure 3 provides a schematic diagram of the experiment. The hydrocarbon tails of the stearic acid molecules are represented in this illustration (greatly exaggerated, of course) by square towers. Each molecule occupies area on the water surface equivalent to the area of the square.

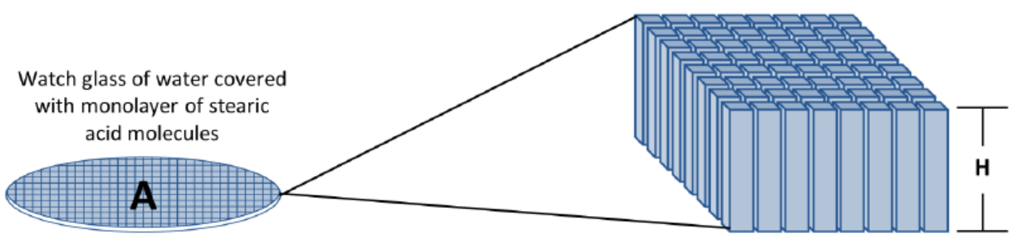


Figure 3. The circle represents the surface of the watchglass holding the water on which the single layer of stearic acid molecules (i.e.,monolayer) forms. Not shown in the Figure are the polar end-groups of each stearic acid molecule which are imbedded in the water surface.

The formation of the monolayer is similar to the endpoint of a titration. As more stearic acid molecules are added, via the placement of droplets of hexane solution on the water surface, the layer becomes more completely occupied, until finally every space on the water surface is occupied. One additional droplet of hexane solution results in an excess of stearic acid molecules, beyond those needed for the monolayer, and exhibits an observable "endpoint of the titration," which appears to the eye as a dull scum on the surface.

PROCEDURE:

Part A. Calibration of the pipet dropper. You will need to know how many drops of hexane per milliliter the pipet delivers. Do not use water in the pipet, graduated cylinder, or test tubes used to hold hexane or the stearic acid/hexane solution.

1. Use a clean and dry 10 mL graduated cylinder to take 2.5 mL of pure hexane to your hood.
2. Place the tip of the disposable pipet in the hexane in the graduated cylinder; squeeze and release the bulb a number of times. This saturates the air space in the pipet with hexane vapor, and prevents unwanted dripping of the hexane out of the pipet.
4. Use the pipet to transfer hexane out of the graduated cylinder into a glass test tube until the level of hexane in the graduated cylinder is at the 1.00 ml mark. TECHNICAL ADVICE: Keep the pipet vertical at all times; tilting it horizontally allows liquid to uncontrollably flow from the tip.
5. Now, taking hexane from the test tube, count how many drops it takes to fill the graduated cylinder up to the 2.00 ml mark. Record this number in the data table. If you lose count, transfer the hexane out of the cylinder to the 1.00 mark, and count again. Repeat until you get three good measurements.
6. DISPOSAL: Pour the hexane into the organic waste container provided.

Part B. Formation of the Stearic Acid Monolayer.

1. Clean a large watch glass thoroughly with ample soap and water. Rinse with deionized water making sure not to touch the upper surface of the watch glass with your hands.
2. Set it on the 600 mL beaker. Pour deionized water into the watch glass from a beaker until the watch glass is brim full.
3. Transfer 1 mL of the stearic acid/hexane solution to a small, clean and dry test tube. Record the concentration of the stearic acid solution in the data section below.
4. Draw up some of the solution into the calibrated pipet. Hold the pipet straight up, and squeeze one drop of the solution onto the center of the water in the watch glass. Watch as the solution spreads out and evaporates. Make sure each drop completely evaporates and dissipates before adding the next drop. Get an angle of view that allows you to clearly see the drop evaporating. TECHNICAL ADVICE: Be sure each drop dispensed is a full drop. If air bubbles are present in the pipet, often only partial drops are dispensed.
5. Now add another drop, and wait until it evaporates. Continue to do this, counting the drops. You will notice that the drops begin to take longer and longer to evaporate. This happens as the surface gets more and more crowded with stearic acid molecules. Do not rush the experiment—wait until each drop has fully evaporated. Finally, you will see a very small amount of sediment, sort of a whitish scum, on the surface where a drop just evaporated. This is the multi-molecular pile of stearic acid molecules that occurs after the surface has been covered by the monomolecular layer. Do not count the last drop, and record how many drops have been placed on the water surface up to that last drop. You might have to vary your angle of view of the surface so that the light is right to help you to see the deposit white scum on the surface.
6. Finally, use a ruler to measure the diameter of the water surface. Record the value to the nearest 0.1 of a centimeter.
7. Repeat Steps 1-6 one more time for a total of two trials.

Note about watchglass cleaning: The watchglass must be very clean in order for this procedure to work properly. Watchglasses will be soaked in a solution of NaOH/methanol overnight and between use during different lab periods. While wearing a pair of Latex gloves, remove a watchglass from the NaOH/methanol solution, and rinse thoroughly (i.e., several times) with distilled water. Avoid touching the watchglass with your fingers. Fingerprints may leave an oily residue which includes molecules that will interfere with the monolayer formation process. Between individual trials, the watchglass should be cleaned with the pink liquid soap solution and a brush. After scrubbing, rinse thoroughly (i.e., several times) with distilled water. When finished using the watchglass, carefully rinse with distilled water, then replace in the NaOH/methanol solution. All rinses can be washed down the drain.

Data Collection:

Part A. Calibration of the pipet.

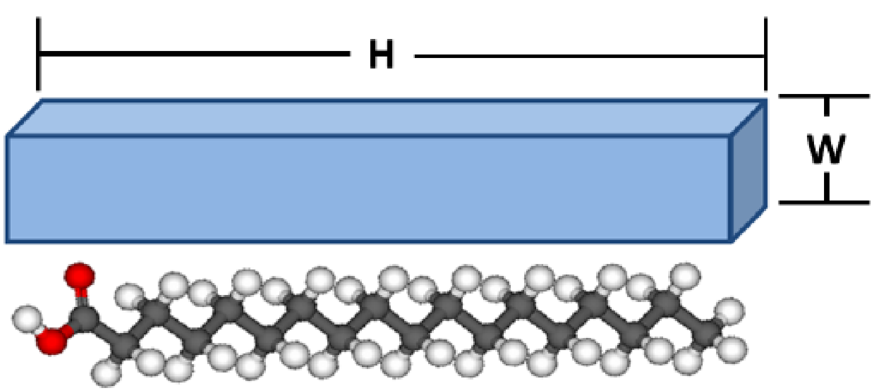
Trial #	Number of drops of hexane to reach 1.00 mL
1	
2	
3	
Average	

Part B. Formation of Stearic Acid Monolayer.

Trial #	Number of drops of stearic acid solution to form monolayer	Diameter of water surface (cm)
1		
2		
Average		

Concentration of the stearic acid solution (g/L) ___________

Use a ruler to measure the scale model of stearic acid shown to determine a height (H) to width (W) ratio for stearic acid.



Height _________cm   Width _________cm

H/W ____________

Data Analysis:

1. Use the average drops/mL determined in Part A to calculate the average volume, in mL, of stearic acid solution needed to reach the endpoint of the titration, i.e. to form the monolayer, in Part B.

2. Use the concentration of the stearic acid solution to calculate the mass, in g, of stearic acid that forms the monolayer.

3. Assuming that solid stearic acid has a density of 0.839 g/cm^3, calculate the volume, in cm^3, of the stearic acid monolayer.

4. Use the average diameter of the water surface to calculate the surface area of the water. Express your answer in cm^2.

5. Use your answers from # 3 and # 4 to determine the height (H) of the monolayer, in cm.

6. Using the H/W ratio you determined above and your answer from #5, calculate the surface area, W^2, in cm^2, occupied by a single stearic acid molecule.

7. Calculate the number of stearic acid molecules in the monolayer on the surface of the water.

8. Using the value for mass determined in #2, calculate the number of moles of stearic acid (284.48 g/mol) in the monolayer.

9. Determine an experimental value for Avogadro's number using the values obtained in #7 and #8.

10. Calculate the % error of your experimental value for Avogadro's number.
N_A=6.022 x 10^{23} molecules/mole

Questions for Consideration

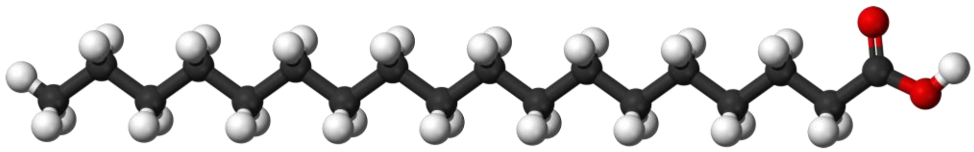
1. What are some sources of systematic error (not human) in this experiment?

2. Suggest possible ways to improve both the accuracy and the precision of your experimental results.

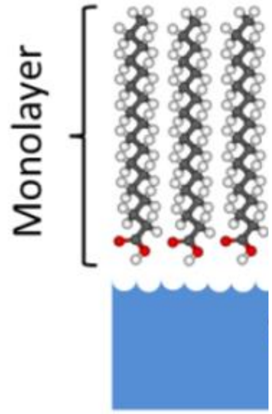
3. Why was it crucial that all glassware be clean and free of oils and soaps before beginning?

Pre-lab for Experiment 36A – Determining the Size of a Single Molecule

1. (2 pts) The structure of stearic acid is shown below. Identify the polar and the non-polar regions.



2. (2 pts) Stearic acid will spontaneously form a monolayer on the surface of water as shown below. List the intermolecular forces:



a. between the separate stearic acid chains (carbon tails).

b. between the water and the stearic acid head groups.

3. (2 pts) How many grams of stearic acid are in 0.75 mL of solution in hexane that has a concentration of 0.150 g/L.

4. (2 pts) If a monolayer of stearic acid has a mass of 2.5 x 10^{-5} g and occupies a surface area of 95 cm^2, what is the height of the monolayer? The density of stearic acid is 0.839 g/cm^3.

5. (2 pts) If the surface area occupied by a single stearic acid molecule is 2.07 x 10^{-7} cm^2, how many molecules could fit onto the surface of a water droplet with a radius of 1.5 cm?