21 Determining Avogadro's Number Using a Monolayer

Purpose: The amount of a fatty acid needed to make a monomolecular layer is used to determine Avogadro's Number.

Background:

The study of monolayers provides a direct relationship between macroscale (bulk) and microscale or molecular scale quantities. Fatty acids readily form monolayers on water and have even been used to protect water reservoirs from evaporation.

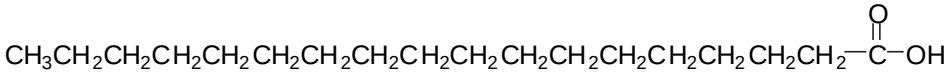
Fatty Acids

Fatty acids (Table 1) are organic acids with long unbranched hydrocarbon chains and an even number of carbon atoms.

Table 1 Fatty Acids

Name	Formula	Molar mass g/mol
Myristic	$CH_3(CH_2)_{12}COOH$	228
Palmitic	$CH_3(CH_2)_{14}COOH$	256
Stearic	$CH_3(CH_2)_{16}COOH$	284

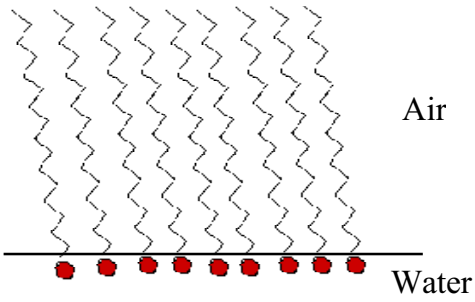
Stearic acid, $CH_3(CH_2)_{16}COOH$, molecules contain a long nonpolar hydrocarbon "tail" and a polar oxygen-containing carboxyl "head".



Molecules like this are often pictured as a zigzag tail connected to a circular head:

Monolayers

The oxygen-containing ends of carboxylic acids are water-soluble. The nonpolar hydrocarbon tails are insoluble. Thus, the polar end of a long-chain carboxylic acid molecule dissolves in water while the nonpolar hydrocarbon tail does not. A single layer of molecules forms, called a monolayer. The fatty acid molecules stand up on the water surface.



Fatty acid monolayers are easy to form, provided all surfaces are free of any foreign particles. The solvent used is a low-boiling mixture of pentanes (C_5H_{12}) and hexanes (C_6H_{14}) called "petroleum ether" that evaporates completely and rapidly.

The fatty acid is applied to the water surface by addition from a solution in a calibrated Pasteur pipette. Although the monolayer is invisible, there is visual evidence to indicate when the molecules are approaching each other. The drops begin to spread a little more slowly. The last drop needed to produce a close-packed monolayer appears to "shatter" as it spreads and the drop after that may look like a contact lens floating on the water surface. Each molecule of stearic acid, and any of the other fatty acids listed in table, occupies 21Å^2. From the area occupied by each molecule it is possible to calculate the number of molecules in one gram molecular weight---Avogadro's Number.

Calculation of Avogadro's Number

Note that you will be using a different size dish and your Pasteur pipet may not be identical to the one in the example below.

Sample Calculation: Suppose the number of drops needed to form the monolayer is 8 and your Pasteur pipet delivers 90 drops for every mL. The concentration of the solution is 0.14 g SA in 1000 mL. The dish used was 10 cm in diameter.

To find the mass of stearic acid in grams, start with the number of drops used to form the monolayer:

$$8 \text{ drops} \times \frac{1 \text{ mL}}{90 \text{ drops}} \times \frac{0.14 \text{ g SA}}{1000 \text{ mL}} = 1.2 \times 10^{-5} \text{ g SA}$$

To find the number of moles of stearic acid, divide by its molar mass, 284 (See Table 1).

$$1.2 \times 10^{-5} \text{ g SA} \times \frac{1 \text{ mol SA}}{284 \text{ g}} = 4.4 \times 10^{-8} \text{ mol SA}$$

The area of the dish is calculated from its diameter, 10 cm and is then divided by 21Å^2 to find the number of molecules in the monolayer.

First, find the area per molecule: convert 21Å^2 to cm^2 (1 m = 10Å and 1 m = 100 cm).

$$21 \text{Å}^2 \times \frac{1 \text{ m}^2}{(10^{10} \text{ Å})^2} \times \frac{(100 \text{ cm})^2}{1 \text{ m}^2} = 21 \times 10^{-16} \text{ cm}^2$$

The area (πr^2) of the dish is divided by the area per molecule, 21 x 10^{-16} cm^2 to find the number of SA molecules:

$$\frac{3.14 \times (5.0)^2 \text{cm}^2}{21 \times 10^{-16} \text{ cm}^2} = 3.7 \times 10^{16} \text{ molecules SA}$$

To calculate Avogadro's Number: $\frac{3.7 \times 10^{16} \text{ molecules}}{4.4 \times 10^{-8} \text{ mol SA}} = 0.84 \times 10^{24} = 8.4 \times 10^{23}$

This result is very good for such a crude method.

Procedure

A. Calibrating Pasteur Pipette

1. A Pasteur pipette is calibrated by counting the drops of petroleum ether needed to reach the 2-mL mark on a 10-mL graduated cylinder. Perform the calibration quickly to diminish errors due to evaporation.

2. Continue trials as needed until the number of drops agrees to within 2-3 drops.
Note: Pasteur pipettes may deliver anywhere from 75 to 100 drops per milliliter, depending upon the angle of delivery. If the pipette is held vertically, it delivers from 92 to 95 drops per milliliter. If the pipette is held at a 45-degree angle, the number of drops delivered covers a broader range, 75 to 85. However, it may be easier to deliver the drops during the experiment while holding the pipette at an angle.

B. Forming the Monolayer

1. The solution to be spread is made by dissolving about 0.14 g stearic acid in 1 L of petroleum ether. If the solution is ready-made for you, record the concentration on the label.

2. Measure the inside diameter of one of the clean large crystallizing dishes provided. Then fill it with distilled or tap water until it nearly overflows. There must be enough water in the dish to allow the surface to be swept free of dust and other surface contamination before forming the monolayer.
Note: Place some paper towels under the dish to absorb water that overflows from the next step.

3. Just before spreading the monolayer, sweep the surface of the evaporating dish with a straight edge. Do this at least three or four times or until no visible particles remain on the water surface.

4. Add the stearic acid solution one drop at a time, pausing for a few seconds after each drop. Practice delivering drops using the same angle that you used in calibrating the Pasteur pipette. The first few drops disappear instantaneously. As the monolayer approaches the close-packed state the drops spread a little more slowly. The last drop needed to produce a close-packed monolayer "shatters" as it spreads. The very next drop persists on the water surface like a shrinking lens that disappears within about 20 seconds.

5. Repeat if time allows

C. Calculating Avogadro's Number

1. Follow the sample calculation on page 2 substituting your data for:
a) The number of drops needed to make the monolayer
b) The number of drops per mL delivered by your pipet
c) The radius (1/2 the diameter) of the large crystallizing dish

2. Retain two significant figures in your result and compare with the actual value for Avogadro's Number, 6.02×10^{23}.

Data and Results Sheet

Name(s) _____ Date _____

Part A: Calibrating Pipette or Dropper; with petroleum ether (PE)

	Trial #1	Trial #2	Trial #3	Average
Drops petroleum ether /2 mL				

Drops petroleum ether /mL _____

B. Forming the Monolayer

Concentration of fatty acid solution: _____ g/L

	Inside Diameter	Radius
Large Crystallizing Dish		

Fatty Acid	Drops sol'n Trial 1	Drops sol'n Trial 2
Stearic		

Part C. Calculating Avogadro's Number

Follow the sample calculation on page 2, using your data from Parts A and B and the diameter of the dish you used.

Questions

1. This experiment could be done more quickly using a smaller Petri dish. How would that affect your result?

2. Compare your result to the measured value of Avogadro's Number.

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Instructor's Guide
(Monolayer and Avogadro's #)

Time: 1 h

Equipment and Materials: per group

Items	**Amount**	**Comment**
20-cm (outside) diam. crystallizing dishes	1	19-cm diam. inside the dish
Pasteur Pipette (glass) and Bulbs	1	
10-mL graduate	1	
30-mL beaker	1	to get sample solution
500-mL beaker	1	to fill crystallizing dish with water
Bottle of stearic acid solution*	1/per class	
Petroleum ether	1L/lab	mixture of hexanes and pentanes
Ruler	1	to sweep surface &measure diameter
Safety glasses	1 per student	
Rubber gloves	1 box per class	

Solutions will be prepared ahead of time.
*To prepare stearic acid solution: dissolve about 0.14 g stearic acid in 1 L of petroleum ether, using a 1 L volumetric flask.
Note: The amount need not be exactly 0.14 g, just known.

Results

Part A: Calibrating Pipette /Dropper; with petroleum ether (PE)

	Trial #1	Trial #2	Trial #3	Average
Drops PE /2 mL				

Drops petroleum ether /mL *80 - 100*

Part B. Forming the Monolayer

Concentration of fatty acid solution: ___*0.14*__ g/L

	Inside Diameter	Radius
Large Crystallizing Dish	*19 cm*	*9.5 cm*

Fatty Acid	Drops sol'n Trial 1	Drops sol'n Trial 2
Stearic	*32*	

Answers to Questions

1. Only 7-8 drops would be needed, and so the area per molecule would have only one significant figure.

2. Most results will be between 5 x 10^{23} to 9 x 10^{23}, remarkably good for this technique.

Variations

Other fatty acids from Table 1 could be used instead of stearic. They all occupy 21 $Å^2$ per molecule in the monolayer.