

Chemistry 1215 Experiment #5 Determination of Avogadro's Number

Objective

The object of this experiment is to experimentally determine the value of Avogadro's number, to recognize possible experimental errors and to evaluate the effect of these errors on the experimental results.

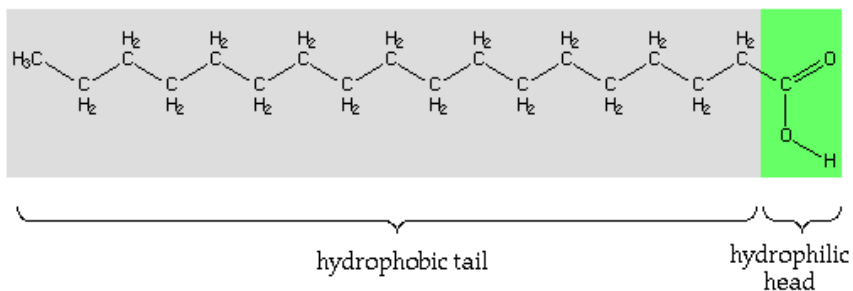
Introduction

Amedeo Avogadro, or more properly, Lorenzo Romano Amedeo Carlo Avogadro di Quaregna e di Cerreto, Count of Quaregna and Cerreto (August 9, 1776 – July 9, 1856) was a member of the Italian nobility, a professor of Physics at the University of Turin, and an eminent scientist. Avogadro is most noted for his contributions to the theory of molarity and molecular weight which were formulated partially based on Avogadro's Law. Avogadro's Law, which was published in 1811, states that the relationship between the masses of the same volume of different gases (at the same temperature and pressure) corresponds to the relationship between their respective molecular weights. Hence, the relative molecular mass of a gas can be calculated from the mass of a sample of known volume.

Through the work of a number of other scientists, especially the work of Stanislao Cannizzaro, Avogadro's Law led to the establishment of the mole concept. A mole is defined as the amount of substance that contains as many elementary particles as there are atoms in exactly 12.00 grams of the carbon-12 (^{12}C) isotope. In honor of Avogadro, the number of elementary particles (atoms, molecules, or ions) in one mole of a substance, 6.022142×10^{23} particles/mol, is known as Avogadro's number.

There are several methods for the experimental determination of Avogadro's number. In this experiment you will estimate this number by an indirect count of the number of molecules present in a monolayer film of fatty acid molecules on water. Stearic acid, which has a molecular formula of $\text{C}_{17}\text{H}_{35}\text{CO}_2\text{H}$, will be used to form the monolayer. Stearic acid (Figure 1) has a long hydrophobic (water hating) carbon chain (the $\text{C}_{17}\text{H}_{35}$ - portion of the molecule) and a hydrophilic (water loving) carboxyl group (the $-\text{CO}_2\text{H}$ portion of the molecule).

Figure 1: stearic acid, $\text{C}_{17}\text{H}_{35}\text{CO}_2\text{H}$



Solid stearic acid, which is a component of vegetable shortening, is insoluble in water because of its long hydrophobic tail. It is, however, soluble in organic solvents such as hexane. To form the desired monolayer, a hexane solution of stearic acid is made and added drop wise to the surface of the water contained in a petri dish. The hydrophilic carboxylic acid group, $-\text{CO}_2\text{H}$, is drawn to the water surface while the hydrophobic hydrocarbon group, $\text{C}_{17}\text{H}_{35}$, is repelled by the water and sticks out from the water surface (Figure 2). Hexane has a high vapor pressure and evaporates quickly leaving behind a solid fatty acid film one molecule thick on the surface of the water. If the right number of drops of the fatty acid-hexane solution is added, the entire water surface will be covered with a unimolecular layer of stearic acid.

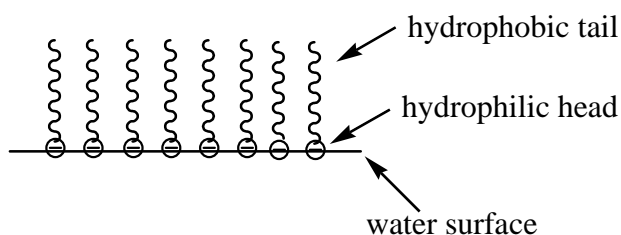


Figure 2: A diagram of stearic acid molecules lined up in a monolayer on a water surface.

A single stearic acid molecule is known to occupy an area of 0.21 nm^2 . Thus, if the surface area of the Petri dish is known, the number of stearic acid molecules in the monolayer can be calculated. Then, from the volume of hexane-stearic acid solution added to form the monolayer and the known concentration of the solution it is possible to determine the number of moles of stearic acid added. Using these two experimentally measured numbers, moles of stearic acid and molecules of stearic acid, it is possible to calculate the number of molecules of stearic acid in a mole.

Procedure

Note: All waste should be discarded in the waste container provided.

I. Calibration of a Pasteur Pipet

1. Obtain a clean and dry 10 mL graduated cylinder. Obtain approximately 5 mL of hexane in a separate container. Fill a Pasteur pipet with hexane and, holding the pipet in a vertical position at all times, carefully drop the hexane into the graduated cylinder counting the number of drops to fill the cylinder to the 1.0 mL mark.
2. Repeat the calibration (you can simply count the number of drops necessary to go from the 1.0 mL mark to the 2.0 mL mark).
3. If the second count differs from the first count by more than 5 drops, pour the hexane out, dry the cylinder, and repeat steps 1 and 2. Save the hexane solution, it can be used to rinse the dropper later in the experiment.

II. Determination of Avogadro's Number

1. Measure the inside diameter of the Petri dish to the nearest 0.1 cm. Perform the measurement twice.
2. Clean the Petri dish with soap and thoroughly rinse it with water for at least one minute. Do not touch the inside of the dish after this step.
3. Fill the Petri dish to the rim with deionized water.
4. Obtain about two milliliters of stearic acid solution in a small, clean, and dry container. Record the concentration of the stearic acid on your data sheet.
5. Fill a dry Pasteur pipet with stearic acid solution.
6. Add the stearic acid solution to the surface of the water in the Petri dish keeping the pipet vertical at all times. Allow a minimum of 15 seconds between drops for the hexane to evaporate and the stearic acid to spread out over the surface of the water. You should not have more than one drop of hexane-stearic acid solution on the water surface at any time. A monolayer has formed when a drop no longer spreads, but instead floats on the water surface for **at least 20 seconds**. Record the number of drops added on your data sheet.
7. Repeat steps 1-6 with a clean Petri dish.

III. Calculations

Show all calculations on a calculation sheet. Label your calculations so that another person can understand your work.

1. Calculate the average number of drops per milliliter of hexane.
2. Calculate the average diameter of the Petri dish.
3. Calculate the surface area, A , of the Petri dish (the monolayer) using the average diameter. Express the area in units of nm^2 . Remember that the surface area of a circle is $A = \pi r^2$ and that $1 \text{ cm}^2 = (1 \times 10^7 \text{ nm})^2 = 1 \times 10^{14} \text{ nm}^2$.
4. For each set of measurements calculate the number of stearic acid molecules, N , in a monolayer from the known surface area of the stearic acid molecule (0.21 nm^2). i.e. $N = A(0.21 \text{ molecules}/\text{nm}^2)$.
5. Calculate the volume of stearic acid solution used to produce the monolayer (number of drops/drops per mL). Remember that the last drop indicated that the monolayer had already formed and should be subtracted from the total number of drops added.
6. Calculate the mass (m) of stearic acid in the monolayer using the volume of stearic acid-hexane added (V) and the concentration (C) of stearic acid in the solution.

$$m(\text{g}) = V(\text{mL}) \times C (\text{g}/\text{mL})$$

7. Calculate the number of moles (n) of stearic acid in the monolayer. The molar mass of stearic acid is $284 \text{ g}/\text{mol}$.
8. Calculate the number of stearic acid molecules per mole, N/n (N from 4 above and n from 7 above). This is your experimentally determined value for Avogadro's number.
9. Calculate the average value of Avogadro's number for the two sets of measurements.
10. Calculate the percent error for your determination.

$$\% \text{Error} = (\text{experimental value} - \text{known value}/\text{known value}) \times 100\%$$

Chemistry 1215 Experiment #5 Data Table

| Pipet calibration | # of drops in 2 mL of hexane | # drops/mL | Average drops/mL |
|--------------------------|------------------------------|------------|------------------|
| | | | |
| | | | |

| Surface Area Measurements | Diameter of Petri Dish, (cm) | Average diameter (cm) | Surface Area, nm ² | # of stearic acid molecules in monolayer |
|----------------------------------|------------------------------|-----------------------|-------------------------------|--|
| Trial 1 | | | | |
| Trial 2 | | | | |

| Monolayer formation | Number of drops of hexane/stearic acid | Volume of stearic acid (mL) | Mass of stearic acid (g) | Number of moles of stearic acid | Avogadro's number (molecules per mole) | Average Avogadro's number (molecules per mole) |
|----------------------------|--|-----------------------------|--------------------------|---------------------------------|--|--|
| Trial 1 | | | | | | |
| Trial 2 | | | | | | |

Calculations

Discussion

Write a discussion of your results including a statement of your results and a discussion of possible errors and how you could minimize them. Determine how each of your experimental errors may have affected the final result.

