Prelab Briefing and Worksheet

Monolayers and water conservation

Answer the questions posed in this prelab exercise on a separate sheet of paper. The questions are collected on the last sheet of this document. The completed prelab assignment is your ticket for admission to the lab. You won’t be allowed to do the lab without it.

Objective

After completing these exercises, you’ll understand how Avogadro’s number is used to connect macroscopic and microscopic quantities. You’ll also understand how Avogadro’s number and molecular sizes can be estimated from experimental data.

Goals

- Explain what a monolayer is, and how monolayers are used in water conservation.
- Relate mass to moles, given a molecular weight.
- Relate moles of solute to solution volume, given a molarity.
- Estimate the size of a molecule from macroscopic quantities.
- Relate molecules to moles, using Avogadro’s number.

Lab Summary

First, you’ll estimate the number of molecules in a film that is just one molecule thick by dividing the measured area of the film by the estimated area of the molecules. The number of moles in the film will then be determined by measuring the number of drops of stearic acid solution required to form the film. Finally, you’ll estimate Avogadro’s number as the number of molecules per mole in the monolayer.

Some elements of your calculation will then be used to estimate the mass of stearic acid required to form a protective monolayer over a tropical lake.
Background

What are monolayers? If you’ve ever cooked spaghetti, you may have noticed that cooking water sometimes boils over when you drop the pasta into the pot. Why does this happen?

Water molecules are polar (they have a positively charged end and a negatively charged end), and they can strongly attract one another. At the surface of the water, the molecules attract their neighbors beside and below them. The mesh of attracting molecules makes the surface harder to pierce or expand. Pure water doesn't foam when it boils because it's hard to stretch the surface out to make bubbles. The phenomenon is called "surface tension".

Pasta releases organic materials into the water as it cooks. Some of these organics have hydrocarbon parts that don't dissolve in water, and polar parts that do dissolve, much like the stearic acid molecule shown in Figure 1.

The organic molecules collect on the surface of the cooking water, with the polar pieces sticking into the water and the hydrocarbon “tails” pointing upwards, as shown in Figure 2.

This layer of organic material spreads over the surface of the water and disrupts the tight mesh of attracting water molecules there. It becomes much easier to expand the surface into bubbles. As the water boils, foam starts to form on the surface. (Soap makes suds in a similar way.)

If enough organic molecules are present to completely cover the water surface, a film that is just one molecule thick is formed. This film is called a “monomolecular layer” or a monolayer.

Why study monolayers? Monolayers are of great importance in resource management, medicine, biology, and chemistry. Drinking water is an extremely limited resource in some parts of the world. Because drinking water usually must be stored in lakes and reservoirs, much of the water evaporates before it can be used. Monolayers are used in arid regions to slow the rate of evaporation. Because the water will be used for drinking, reservoir managers must
carefully add just enough organic material to form a monolayer; too little will lead to water loss by evaporation, and too much will lead to contamination of the water supply.

Measurements of the area of monolayers formed from disrupted cell membranes lead to our current understanding of the cell membrane as a “phospholipid bilayer”.

Monolayers line the lungs to allow tiny passages to expand when we inhale, and to contract without collapsing when we exhale. (Premature babies aren’t able to produce the organic molecules that build monolayers in their lungs. Artificial monolayers are now used to allow more normal lung function. This therapy has nearly halved the mortality rate for premature babies.)

In this exercise, we’ll use monolayer properties to count the number of molecules in one mole, and to estimate the size of a single molecule.

Counting large numbers of objects. You’ve probably seen contests that involve estimating the number of jelly beans in a large jar. You can’t win the contest by counting the beans directly; you can’t see most of the beans. If you knew the volume of the jar, and you knew the volume of one jellybean, you could easily estimate the number of jellybeans as the volume of the jar divided by the volume of a single bean. “Volume per bean” links the volume of the jar with the actual bean count.

1. Suppose that you have been given $1,000,000 in a suitcase. The money is in unmarked $20 dollar bills. Suppose further that you don’t trust the person who gave you the suitcase, and that it’s urgent that you leave the scene of the transaction before you’ll be able to count the money.

You decide to count the money quickly by weighing it with an analytical balance. What must you measure beforehand to convert the mass of the money into a dollar amount?

2. Suppose that your assistant forgot to bring the analytical balance. He did, however, bring a ruler. How could you count the money?

What is Avogadro’s number? Avogadro’s number, $6.02 \times 10^{23}$, is the number of molecules in one mole. Since quantities like masses and volumes can be converted into moles, Avogadro’s number is a crucial link between experimental measurements and the molecular world. Chemists use Avogadro’s number to count molecules just as you would use volume per bean to count beans were in a jar with known volume.
Example: calculating the number of molecules in a monolayer. Suppose we wanted to know how many molecules were in a monolayer produced by exactly 1 mg of stearic acid. The molecular weight of stearic acid is known to be 284.5 g/mol, so the number of moles is

\[
1 \text{ mg} \times \left( \frac{10^{-3} \text{ g}}{1 \text{ mg}} \right) \times \left( \frac{1 \text{ mol}}{284.5 \text{ g}} \right) = 3.515 \times 10^{-6} \text{ mol}
\]

Then Avogadro's number is used to convert moles to molecules:

\[
3.515 \times 10^{-6} \text{ mol} \times \left( \frac{6.02 	imes 10^{23} \text{ molecules}}{1 \text{ mol}} \right) = 2.12 \times 10^{18} \text{ molecules}
\]

3. How many molecules does a teaspoon of oil contain? Assume that the oil has a mass of about 4.5 g, and the average molecular weight of the oil is 300 g/mol.

In this experiment, you’ll add a solution of stearic acid drop by drop to a dish of water until a complete monolayer is formed on the water’s surface. Any excess stearic acid solution you add will form a visible, bead-like puddle on top of the monolayer. The number of drops required to form the monolayer corresponds to the last drop added before the puddle appears.

The mass of stearic acid monolayer is too small to be weighed directly. The mass will be determined by counting the number of drops of stearic acid solution required to form the monolayer. The stearic acid is dissolved in hexane, a volatile solvent that floats on water. The hexane spreads the stearic acid over the surface of the water and then quickly evaporates, leaving behind a stearic acid monolayer.

You’ll be given the number of drops per mL for the solution and Pasteur pipet supplied to your group. You will also be given the number of milligrams of stearic acid per liter in the hexane solution. This information can be used to compute the mass of the monolayer.

Example: calculating the mass of the monolayer. Suppose that the stearic acid solution contains 130 mg of stearic acid per liter, and the dropper delivers 110 drops/mL. If 15 drops of stearic acid solution was added to the water to complete the monolayer, the mass of stearic acid in the monolayer is

\[
15 \text{ drops} \times \left( \frac{1 \text{ mL}}{110 \text{ drops}} \right) \times \left( \frac{1 \text{ L}}{1000 \text{ mL}} \right) \times \left( \frac{130 \text{ mg stearic acid}}{1 \text{ L}} \right) = 0.0177 \text{ mg stearic acid}
\]
4. What is the mass of the monolayer if 22 drops of stearic acid solution were added to a water surface before a “bead” was observed on the surface? The concentration of the stearic acid solution is 135 mg/L and the dropper delivers 99 drops/mL.

5. How many molecules does the monolayer in the previous problem contain? The molecular weight of stearic acid is 284.5 g/mol.

6. How many drops of stearic acid solution would be required to complete a monolayer over a Petri dish 90 mm in diameter? The concentration of the stearic acid solution is 135 mg/L, and the dropper delivers 99 drops/mL. One stearic acid molecule covers 0.21 nm$^2$.

Hint: Try this strategy.

\[
\text{monolayer area} \rightarrow \text{molecules stearic acid} \rightarrow \text{moles stearic acid} \\
\rightarrow \text{grams stearic acid} \rightarrow \text{mL solution} \rightarrow \text{drops solution}
\]
Prelab Questions

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