The Estimation of Avogadro's Number

I. Introduction. *For background on this experiment you should read section 2.7 of your textbook, Atoms First.* Avogadro's constant is 6.022×10^{23} with units of particles per mole. It is the number of particles that make up one mole of a substance. For instance you can have a mole of water. One mole of water contains 6.022×10^{23} molecules of H_2O and occupies 18.02 mL at 20°C. You can have one mole of helium gas. One mole of helium gas contains 6.022×10^{23} helium atoms and occupies 24.5 L at 298 K. You can even have a mole of electrons or a mole of photons. Whatever type of substance you are studying, 1 mole contains 6.022×10^{23} particles. Just as a dozen eggs has 12 eggs and a dozen donuts has 12 donuts. A mole, like a dozen, is a convenient way to characterize quantities of atoms, molecules, ions or other tiny particles. Avogadro's constant is universally used to define a mole and, like the periodic table, is a fundamental concept of chemistry.

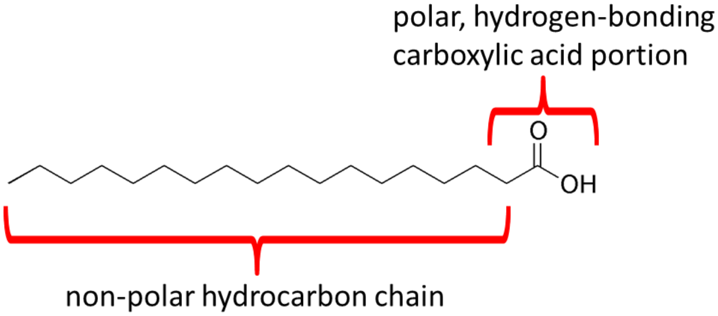

Figure 1. Structure of stearic acid. Stearic acid is a fatty-acid that has both a non-polar portion (tail) and a polar portion (head-group).

In this experiment you will attempt to measure the value of Avogadro's constant by forming a single layer of molecules, called a monolayer, at the air/water interface. To do this, you will use stearic acid, an 18 carbon fatty acid shown in Figure 1. Stearic acid is a fatty acid that will spread out and form a monolayer on the surface of water. The reason that stearic acid forms a monolayer is that it is attracted to surfaces. Another name for molecules such as fatty acids is *surfactant* which is a shortened form of *surface active agent*. A surfactant is a molecule that tends to localize at a surface such as at the surface of a pool of water. Water's surface is actually an interface between liquid water and gaseous air. At the air/water interface, stearic acid can minimize its energy by positioning the polar carboxylic acid headgroup in water. At the same time, stearic acid can lower its energy by allowing the non-polar hydrocarbon chain to interact with the air. Unlike liquid water, air is a low density gas composed mostly of non-polar oxygen and nitrogen molecules so the non-polar portion of the fatty acid interacts favorably with air. The favorable interaction of the polar headgroup with water and the non-polar hydrocarbon chain with air, make the water/air interface an ideal, low-energy, location for a fatty acid molecule.

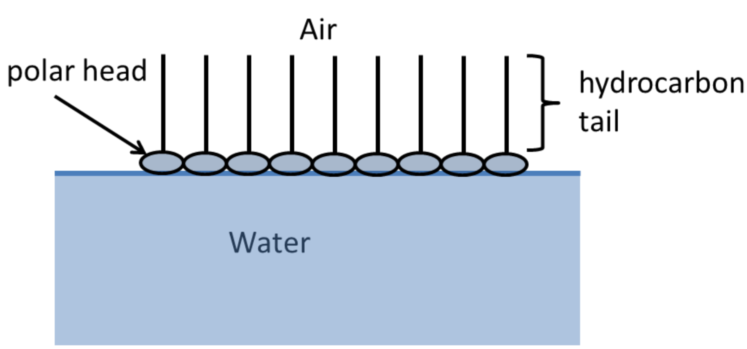

Figure 2. Organization of surfactants/fatty acids at the air water interface.

The lowering of energy is responsible for the formation of a monolayer of surfactant molecules at the air/water interface. A sketch of how fatty acids organize at the interface is shown in Figure 2 and illustrates how the polar portion (head group) interacts with water and the non-polar portion (tail group) interacts with air.

In lab, you will deposit stearic acid on the surface of water sitting in a watch glass. You will determine the mass of stearic acid required to form the monolayer and the area of the monolayer. Using the mass, area and density of stearic acid, you can calculate the thickness of the monolayer. Next you will assume that the eighteen carbons of stearic acid stack vertically, so that one carbon atom has a dimension of 1/18 of the monolayer thickness. This will provide you with an estimate of the volume of a carbon atom. Once you have the volume of a carbon atom you can use the molar volume of pure carbon (calculated from the density of diamond) to calculate Avogadro's constant using the following relationship.

$$N_A = \frac{\text{molar volume } \left(\frac{\text{cm}^3}{\text{mol}}\right)}{\text{atomic volume } \left(\frac{\text{cm}^3}{\text{atom}}\right)} \qquad \text{Equation 1}$$

II. Method

1) Clean your watch glass with base bath and acetone. This is very important since any residual soap or oils on the watch glass can disrupt the formation of the monolayer.
2) After cleaning the watch glass, fill it to near the top with de-ionized water.
3) Set your watch glass on a piece of white paper.
4) Obtain 1.0 mL of 0.1 g/L stearic acid and load a 1.0 mL syringe with the solution.
5) Record the initial volume of the stearic acid solution in the syringe.
6) Carefully add one drop of stearic acid at a time onto the surface of the water in your watch glass. Record the final volume of your syringe. The volume you use will be about 0.03-0.05 mL.
7) The hexane that the stearic acid is dissolved in will evaporate quickly. After letting the sample set for two minutes you are ready to continue to the next steps.

Next you must determine the area of your monolayer. Calculate the area of the watch glass or the outer ring of the water if the water does not go to the edge of the watch glass.

Repeat steps 1-7 for a second trial to complete the experiment. If your two sets of results are not consistent within a few percent you can do the experiment a third time. Only do the experiment a third time if you believe you made a mistake in one of the first two trials and can improve the result by improving your technique. Stop conducting experiments when you have two sets of measurements that you feel were conducted in a reproducible and consistent manner.

III. Data Analysis

1) Begin by calculating the volume of 0.10 g/L stearic acid solution that was used. Next calculate the mass of stearic acid contained in that volume.
2) Using the density of stearic acid, 0.847 g/cm^3, determine the volume of stearic acid that was deposited at the water surface.
3) Now that you know the volume of stearic acid and the area of the monolayer, you may find the thickness of the monolayer through the relationship:

$$\text{area of monolayer} \times \text{thickness of monolayer} = \text{volume of stearic acid}$$

4) Calculate the height of a carbon atom (*C*) by considering stearic acid as a stack of 18 carbon atoms. Under this approximation C = thickness/18.
5) Next assume that a carbon atom is a cube with volume C^3. This provides you with a volume for a single carbon atom.
6) Now you will use the density of diamond to estimate the molar volume of carbon. The density of diamond is 3.51 g/cm^3. Use the molar mass of carbon (12.01 g/mol) to determine the molar volume of carbon in cm^3/mol.
7) With the molar volume of carbon from step six and the volume of a carbon atom from step five, you can now use equation 1, to determine Avogadro's constant, N_A.

The next page is a data sheet. Fill in the data sheet with the observations from your lab notebook, complete the required calculations and enter your calculated values.

When finished you should have a value for Avogadro's number that is within a factor of 10 of the actual value.

Be sure to attach a sheet showing a sample calculation from each step of the analysis.

Cited Literature

1) Budavari, S. (Ed.). (1989). Merck Index: An Encyclopedia of Chemicals, Drugs, and Biologicals (11th ed.). NJ: Merck.

Name ________________________________ TA ________________________________ Time ______________

Fill in the sheets using the indicated units.

		Trial 1	**Trial 2**
Step 1 of Section III.	Initial syringe volume (V_i)		
	Final syringe volume (V_f)		
	Volume of 0.10 g/L of stearic acid solution used (cm^3)		
	Mass of stearic acid in monolayer (g)		
Step 2 of Section III.	Volume of stearic acid in monolayer (cm^3)		
Step 3 of Section III.	Thickness of monolayer, t (cm)		
Step 4 of Section III.	Dimension of carbon atom, t/18 (cm)		
Step 5 of Section III.	Volume of a carbon atom assuming a cube shape (cm^3/atom)		
Step 6 of Section III.	Molar volume of carbon. (cm^3/mol)		
Step 7 of Section III.	Avogadro's Constant		

Questions

1. List three assumptions made in this experiment.

2. How would Avogadro's number change in this experiment if O was used instead of C as the basis for the determination? The radius of O is 73 pm compared to C of 77 pm. Assume the volume remains the same.