Name:____

Chemistry 117 Laboratory
University of Massachusetts Boston

AVOGADRO'S NUMBER

LEARNING GOALS:

1. Obtain practice with calculation using volume, mass, moles and molecules to calculate density, concentration, molecular mass and Avogadro's number.
2. Become familiar with the process of estimation, especially on a molecular scale.
3. Gain an appreciation for the enormity of Avogadro's number.
4. Gain practice in deductive reasoning and problem solving.

This exercise consists of two different strategies for experimentally determining Avogadro's number. You are to work in groups of four on both tasks. We will be estimating Avogradro's number by measuring the volume required to form a monolayer of stearic acid across the surface of water using a 1 mM solution of stearic acid in hexane. In task 2, you will be given a section of aluminum foil, a ruler, an analytical balance, and data on the density, molecular weight and atomic radius of aluminum and asked to devise another strategy for estimating the value of Avogadro's number and the thickness of the aluminum foil in number of layers of aluminum atoms. While you wait for your TA to help you get started with Task 1, you should begin thinking about Task 2.

INTRODUCTION

The concept of the mole

The atomic masses on the periodic table have the units of both amu (atomic mass units) and g/mol. The mass of a single proton or neutron is approximately 1.00 amu. The electrons weigh several orders of magnitude less. Thus, the atomic masses on the periodic table represent the masses of the atoms of a given element in amu. It is based on the average number of proton and neutrons that make up their nuclei. In terms of g/mol, the atomic masses represent the masses in grams of a defined quantity of atoms of a given element. The concept of the mole is useful and convenient because it connects the microscopic and macroscopic world. One mole of atoms is the number of atoms required such that the collective mass of these atoms in grams is equal to the mass in amu of an average atom. There are $6.022 \cdot 10^{23}$ particles (atoms, molecules, formula units, ect) in one mole of particles. This number is called Avogadro's number.

Although we honor him by the name of the quantity, Amadeo Avogadro (1776-1856) did not suggest the concept of the mole and never determined how many particles constituted that unit. A few years after Avogadro's death, a German scientist, Joseph Loschmidt, estimated the size of a molecule which made it possible for others to estimate the number of molecules in a volume of gas. Because Avogadro hypothesized that equal volumes of gases at the same temperature and pressure contained equal numbers of particles, Loschmidt's estimate is only one step away from determining the number of particles in a mole. The French scientist Jean Perrin is credited with determining the first value of Avogadro's number in 1908; he got values in the range of 5.4 to 6.0×10^{23}. Once the American physicist Robert Milliken determined the charge on an electron in 1915, a more accurate value for Avogadro's number was obtained by dividing the Faraday constant (the charge on a mole of electrons) by the charge on a single electron. Finally, modern sophisticated equipment has yielded the most accurate value of Avogadro's number to date:

$$N_A = 6.02214199 \times 10^{23}$$

We'll typically use the number expressed to four significant figures, 6.022×10^{23}.

A mole of anything contains Avogadro's number of particles. For chemical entities – electrons, atoms, ions, molecules – a mole of material is an amount that contains the same number of particles as there are ^{12}C atoms in 12.00000 g of ^{12}C. A sample of a monoatomic element that has a mass equal to its atomic mass, expressed in grams, contain one mole of atoms. Thus 26.98 g of Al contain 6.02×10^{23} atoms of aluminum and hence one mole of aluminum.

One mole of items may consist of…

atoms	examples: 39.95 g Ar per mole Ar atoms or 35.45 g Cl per mole Cl atoms.
molecules	compounds which exist as discrete molecules examples: 70.90 g of Cl_2 per mole of Cl_2 molecules or 342.30 g of $C_{12}H_{22}O_{11}$ per mole of sucrose molecules.
formula units	ionic compound do not form discrete molecules, but we can still state that, for example, there are 58.44 g NaCl per mole of NaCl.

Avogadro's number and the idea of a mole provide us with two of the most important conversion factors we'll use throughout chemistry when we solve quantitative problems dealing with chemical reactions. We use conversion factors in dimensional analysis when we need to convert one quantity into another with different units. In fact, in this experiment you will be using several conversion factors including density (mass/volume), molecular mass (mass/mol) and concentration (mol solute/volume solution) and you will be determining Avogadro's number, which is also a conversion factor that is used to go between the number of particles and moles (particles/mol). Here's the basic idea:

$$\text{Conversion factor} = \frac{\text{desired units}}{\text{starting units}}$$

Conversion factors enable us to calculate the information sought from the information given and using conversion factors in conjunction with dimensional analysis enables us to see the units cancel.

$$\text{information sought} = \text{information given} \cdot \frac{\text{desired units}}{\text{starting units}}$$

EXAMPLES

Density: Convert from volume to mass or mass to volume

What is the mass of 2.0 mL of ethanol (Density is 0.789 g/ mL)?

$$(2.0mL)\cdot\left(\frac{0.789g}{1mL}\right)=1.57_{8}\,g$$

What volume does 1.500 g of glycerol take up? (Density is 1.261 g/ mL)?

$$(1.500g)\cdot\left(\frac{1mL}{1.261g}\right)=1.189_{5}\,mL$$

Molecular Mass: Convert from mass to mol or mol to mass

How many grams of ethanol are in 0.0200 mol of ethanol? Molar mass (FW) of ethanol 46.08 g/ mol?

$$(0.0200mol)\cdot\left(\frac{46.08g}{1mol}\right)=0.921_{6}\,g$$

How many moles of ethanol are in 1.578 g of ethanol? Molar mass (FW) of ethanol 46.08 g/ mol?

$$(1.578g)\cdot\left(\frac{1mol}{46.08g}\right)=0.03424_{5}\,mol$$

Concentration: Convert from volume of solution to moles of solute and from moles of solute to volume of solution

How many moles of acetic acid are present in 20.00 mL of a 0.001000 M solution of acetic acid?

$$(20.00mL)\cdot\left(\frac{1L}{1000mL}\right)\cdot\left(\frac{0.001000mol}{1L}\right)=2.000\cdot 10^{-5}\,mol$$

How many mL of a 0.200 M (mol/L) solution of acetic acid contain 0.0400 mol of acetic acid?

$$(0.0400mol)\cdot\left(\frac{1L}{0.200mol}\right)\cdot\left(\frac{1000mL}{1L}\right)=200mL$$

N_A(Avogadro's number): Convert from the number of particles to moles and from moles to the number of particles

How many atoms of iron are there in 0.150 mol of Fe atoms?

$$(0.150mol)\cdot\left(\frac{6.022\cdot10^{23}}{1mol}\right)=9.03\cdot10^{22}\,atoms$$

How many nmoles of water molecules are contained in $1.50\cdot10^{15}$ water molecules?

$$(1.50\cdot10^{15}\,molec)\cdot\left(\frac{1mol}{6.022\cdot10^{23}\,molec}\right)\cdot\left(\frac{10^{9}\,nmol}{1mol}\right)=2.49nmol$$

Often a problem will require the use of multiple conversion factors:

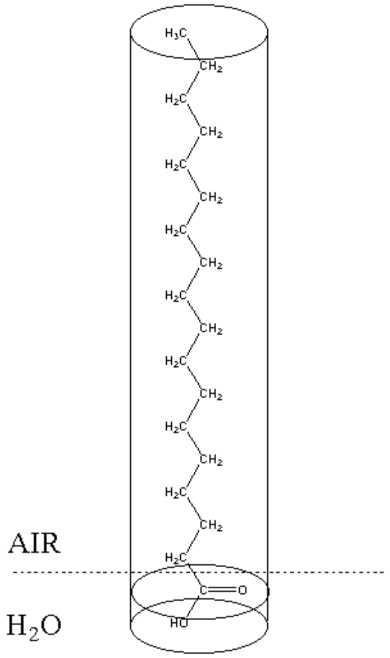
How many molecules of liquid propanol are in 5.00 mL of propanol, given its density is 0.8034 g/mL and its molar mass is 60.10 g/mol?

$$(5.00mL)\cdot\left(\frac{0.8034g}{1mL}\right)\cdot\left(\frac{1mol}{60.01g}\right)\left(\frac{6.022\cdot10^{23}\,molec}{1mol}\right)=4.03\cdot10^{22}\,molec$$

Part 1: Determination of Avogadro's Number from a Stearic Acid Monolayer

You will determine a numerical value of Avogadro's number using a molecule of known size. When it is prepared under controlled conditions, stearic acid forms a monolayer – a film of a substance that is exactly one molecule thick. A solution of known concentration (in mol/L) of stearic acid in a volatile solvent can be used to cast a monolayer; if one knows the amount of stearic acid present and measures the size of the area covered, one can calculate the number of molecules present. Forming a monolayer on water is not really that difficult, and you've probably seen one if you've observed a thin layer of oil spreading on the surface of a puddle after a rainstorm.

Stearic acid is a naturally occurring compound called a long chain fatty acid. The 'long chain' is the fatty part, so named because it is non-polar and hydrophobic ('water-hating'). The acid part of the name refers to the presence on one end of the chain of a carboxylic acid functional group, which is polar and hydrophilic ('water-loving'). The structure of stearic acid is shown in Fig. 1.



Stearic acid is $C_{18}H_{36}O_2$ or $CH_3(CH_2)_{16}COOH$

Its molecular weight is 284.5 g/mol; its density is 0.85 g/cm^3.

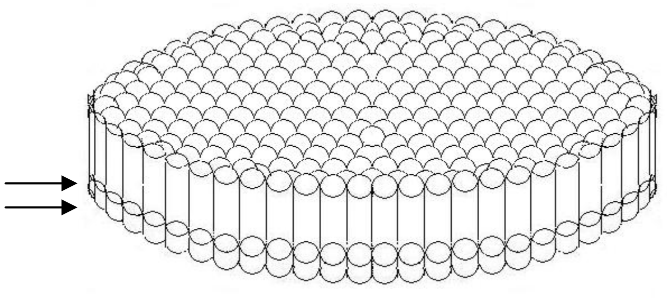
The shape of the molecule is essentially cylindrical if the long hydrocarbon tail is stretched out to its maximum extension.

The drawing has a dotted line that stands for the air-water interface. The hydrophilic carboxylic acid end of the molecule associates preferentially with polar water; the long fatty tail avoids the water. You should be able to envision the molecule inscribing a circular footprint in the water as it spins around.

Figure 1: Formulas and pictures describing the stearic acid molecule.

Almost 85% of the mass of stearic acid is due to the presence of the hydrophobic tail. Consequently the solubility of stearic acid in water is very low. That behavior plays a role in the formation of a stearic acid monolayer at the air-water interface.

Scientists have proposed a model that describes what happens when fatty acids form films on water. We'll use that model to picture what happens in this experiment in which you place drops of a solution of stearic acid in hexane on the surface of water. Hexane is very volatile, so it evaporates, leaving the stearic acid at the air-water interface. Initially, isolated molecules of stearic acid lie on the surface with the carboxylic acid group in contact with the polar water molecules. As more stearic acid molecules are added, they begin to crowd each other so that all the carboxylic acid groups contact the water; this pushes the hydrocarbon tails away from the surface. After enough molecules have been added, the molecules appear to be standing upright on the surface as shown in Fig. 2.



The cylinders represent the molecules of stearic acid as shown in Fig. 1.

The arrows indicate the carboxylic acid at the air-water interface.

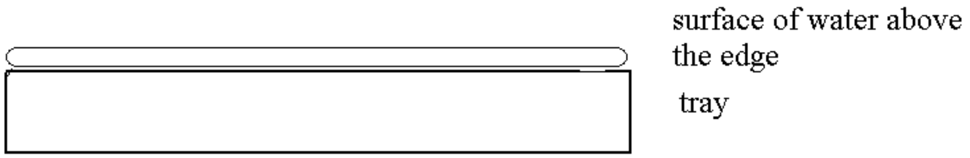
Figure 2. A stearic acid monolayer

PART 1: PROCEDURE

Making the monolayer.

1. Cover a section of the lab bench with paper towels and place a clean plastic tray on them. This will catch excess water and avoid a big mess later.

2. Fill the tray with distilled water until the water level is above the surface of the tray's edge.



3. Get a piece of thread approximately 60 cm long. Tie a double knot, leaving approximately 2 cm long loose ends. Trim the ends as close to the knot as possible without cutting the knot.

4. Carefully place the string on the surface of the water. Avoid dunking the string under the surface of the water. Also make sure your string doesn't overlap itself.

5. Bend down so that the surface of the water is at eye level. Check for any points of the string that may not be in contact with the surface of the water. If the string is not touching the surface, it may look kinked. In places where it does not contact the surface, tap the string down using a glass rod or metal spatula. You're essentially making a floating dam to retain the monolayer. It is essential that there are no gaps between the string and the surface through which the monolayer can escape.

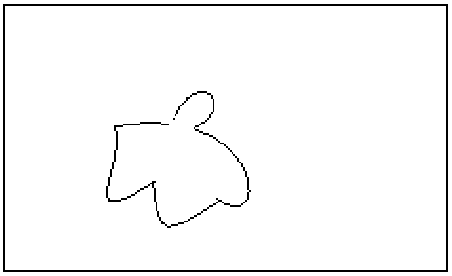
6. Without the tip on the syringe, fill it with the solution of stearic acid in hexane. Place the tip on the syringe and squirt out a small amount of the solution into the sink to fill the tip and rid the syringe of any bubbles. This will make the readings you take more accurate.

7. Hold the syringe with one hand and grasp the plunger with the other. Practice releasing the solution dropwise into the sink until you can repeatedly release one drop at a time, rather than a stream.

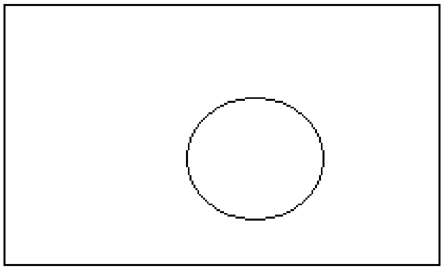
8. Read and record the volume of the fluid in the syringe (#1 in data table below). Note that it is a 1.0 mL syringe. Make sure you use the same reference point on the plunger for future readings.

9. Release a drop of solution into the center of the area on the surface of the water that is enclosed by the string. Add drops one at a time. After a few drops you should notice that the surface tension of the layer of hexane and stearic acid causes the string to tighten to a circle, but then relax again as the hexane quickly evaporates. As you add more drops,

this will continue until a point is reached where the perfect circle remains, after the hexane has evaporated. This means you have a monolayer of stearic acid covering the area of the string on the water in the tray.



The string might start out looking like this ....



but should end up looking like this.

10. **Take the reading on the syringe at this point (#2 on data table).**

11. Measure the diameter of the circle by holding a ruler just above the surface of the water and estimating the dimension (#7 on data sheet)

CLEANUP: Simply scrape the surface of the water with a clean ruler. After doing this, you may have to top off the water in the tray.

Data Sheet: Concentration of Stearic Acid solution: __________ M

	Trial 1	Trial 2
1. initial volume of solution in syringe	________	_________
2. final volume of solution in syringe	________	_________
3. volume used to cover surface	________	_________
4. moles of stearic acid used (mol = $C_{SA} \cdot V$)	________	_________
5. mass (g) of stearic acid used FW of stearic acid (284.5 g/mol)	________	_________
6. volume of stearic acid used (Density of stearic acid = 0.85 g/cm^3)	________	_________
7. diameter of the monolayer (cm) (as measured)	________	_________
8. area of monolayer ($A = \pi r^2$)	________	_________
9. thickness (t) of monolayer ($t = V/A$)	________	_________
10. size of one carbon atom (height of one carbon atom; $h = t/18$)	________	_________
11. volume of one carbon atom, v_{atom} ($v_{atom} = h^3$, volume of a cube)	________	_________
12. volume of one mole of carbon, v_{mol} $v(mol) = (FW_{carbon})(1/D)$ (D, density of diamond, = 3.51 g/cm^3)	________	_________
13. number of atoms per mole $\{NA = v_{mol}/v_{atom}\}$	________	_________

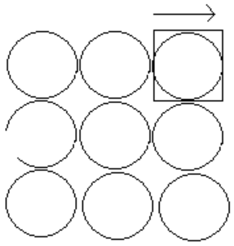
[RECORD YOUR ANSWERS For Avogadro's Number On the board

Notes on the calculations:

The estimation of Avogadro's number requires some assumptions on your part, as well as the use of some additional data.

1.-4. These values are the measurements you made in lab plus a calculation based on the density of stearic acid.

The next series of calculations require you to look at the structure of stearic acid and make some assumptions. Remember the model that describes how molecules of stearic acid stand up on the surface of water. Knowing the volume occupied by the stearic acid and the area of the cylindrical patch of monolayer, you can calculate the thickness of the monolayer. At this point, look at Fig. 1 again. Each stearic acid molecule can be approximated as a cylinder 18-carbons high. From that approximation and the thickness of a monolayer, you can calculate the 'thickness (t),' the 'size,' the dimension of the space occupied by one carbon atom. Now think for a minute about how various shapes pack together. We drew the stearic acid molecule as a cylinder with a circular foot-print. How do circles pack? Like this … see all the empty space?



The dimension of the space occupied by a carbon atom can be considered the volume of a sphere with the same diameter as the circles drawn. To include all that space around the sphere in the calculation, considered a square with an edge the same length as the diameter of the circle.

The volume of the space effectively occupied by a carbon atom is a cube whose edges are the same dimension as the diameter of the cylinder in Fig. 1.

The density of pure carbon as diamond is 3.51 g/cm^3. Using that value and the mass of a mole of carbon, you can calculate the volume that a mole of carbon occupies. You estimated the volume of one carbon from the stearic acid experiment. Knowing the volume occupied by one mole of carbon and the volume occupied by one atom of carbon, you can calculate the number of carbon atoms in one mole.

RESULTS FOR PART 1

Trial	Values for N_A (board)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
	AVERAGE ±stdev

PART 2

You are given a rectangle of aluminum foil, a ruler and a mass balance. The aluminum foil came from a typical 250 sq ft roll you can buy at any supermarket. Using these tools, in conjunction with the following data; atomic mass is 26.98 g/mol, density is 2.7 g/cm^3, atomic radius is 143 pm, and the aluminum atoms pack together with 74 % efficiency (26 % open space between the atoms), devise another strategy for estimating Avogadro's number. HINT: The approach should be analogous to what was done in PART 1. The volume per mole can be derived from the density and atomic mass. The volume per atom can be estimated from the atomic radius and the packing efficiency. Refer to the figure on pg 7 to ponder the concepts of packing efficiency and open space.

By measuring the mass and area of your rectangle, you should be able to perform some calculations that will enable you to estimate the number of layers of aluminum atoms that make up the thin sheet of foil.

Your TAs have been instructed to let you struggle with this. They may help to explain the concept of packing efficiency, but between the four of you, you should be able to figure this out. Start Brainstorming with your group members.

Show work here.

LAB REPORT (do not forget to staple your graded data sheet to your lab report)

Your lab report will consist of a written abstract, a methods section and your data sheet (pg 8, 10 and 11). The abstract is worth 20 points and the methods section is worth 10 points. The data sheet is worth 30 points. The following is a grading rubric for the abstract. See syllabus for information on how to prepare a well-written abstract.

Abstract

Content

2 pts	All of the key pieces of data discussed.
2 pts	The data is interpreted correctly.
2 pts	The conclusions drawn from the data are correct.
2 pts	It is evident that the student understands the main points of the laboratory experiment.
2 pts	It is evident that the student was able to connect the learning goals of the experiment with data obtained in the experiment.

Quality of your writing

2 pts	It is written in complete sentence(s).
2 pts	The sentences are comprehendible to the reader.
2 pts	It summarizes the experiment, calculations and the result and frames the activity in the context of the learning goals.
2 pts	It is an appropriate length; 3-6 sentences.
2 pts	It is written in the passive voice with no pronouns or phrases such as “In this lab we”.

Methods Section (10 pts)

Briefly outline both approaches used to estimate Avogadro’s Number.