CALCULATING THE SIZE OF AN ATOM

Introduction:

The atom is so very small that only highly sophisticated instruments are able to measure its dimensions. In this experiment we attempt to obtain the diameter of a carbon atom by using solid BBs as a model. A known volume of BBs will be spread out in a single layer (or monolayer) bound by a piece of string, and the diameter of the monolayer will be measured. The area and thickness of the monolayer can then be calculated using a mathematical formula. The thickness of the monolayer corresponds to the average diameter of a single BB.

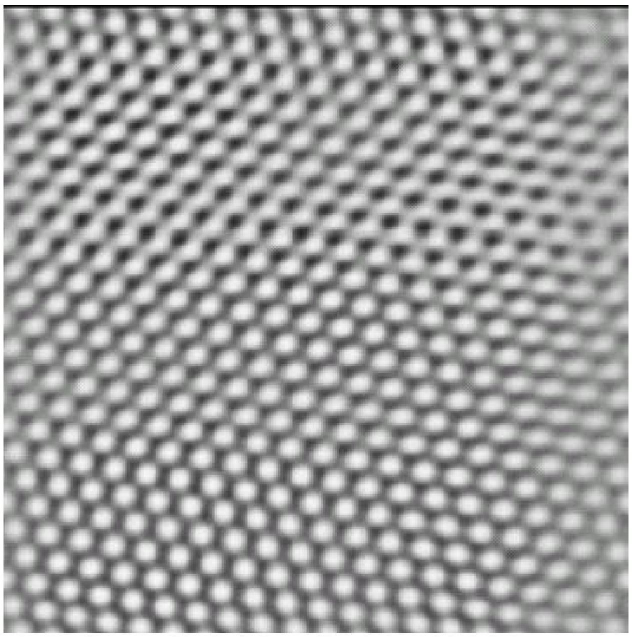


***Figure 1**. 5.0 nm x 5.0 nm Scanning Tunneling Microscope image of a carbon atom surface.*

This procedure will next be applied to vegetable oil, which is made up of oleic acid. Oleic acid is a fatty acid molecule composed of carbon, hydrogen, and oxygen atoms. The molecules will spread out on the surface of the water like the BBs in the tray. Using lycopodium powder as our "string", we will drop a known volume of oleic acid solution onto water and determine the area of the monolayer the same as we did for the BBs. We will then be able to calculate the thickness of the oleic acid monolayer.

An oleic acid molecule (see Appendix) is slightly more complex than a single BB. It is consists of a chain of eighteen carbon atoms. The molecule is hydrophobic and it will not dissolve in water. One end of the chain, however, is hydrophilic and buries itself in the surface of the water. The hydrophobic part stands upright, much like a forest of trees. The thickness of the monolayer actually corresponds to a film that is seventeen carbon atoms thick. Dividing the calculated thickness of the monolayer by 17 should give us the diameter of a single carbon atom.

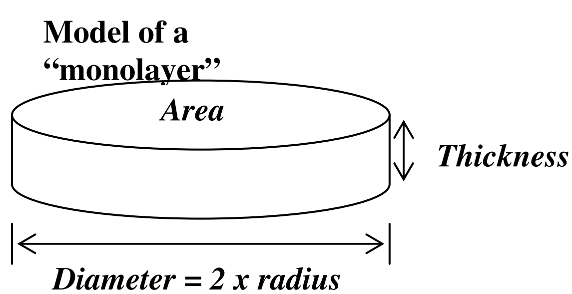
Purpose:

1. To make physical measurements using the metric system (& to practice unit conversion).
2. To perform calculations involving length, area, and volume.
3. To observe the physical characteristics of BBs and use this knowledge as a basis for calculating the size of an atom.
4. To compare experimental results with an authoritative source.

Theory:

In this exercise, the BB (and oleic acid) monolayer will be modeled as a cylindrical "pancake". The thickness, area and volume of the monolayer are related by the following equations:

Area (of a circle) = π * (radius)^2
Volume (of a cylinder) = Area * Thickness
Thickness = Volume / Area



Materials:

- 50 mL graduated cylinder
- 10 mL graduated cylinder
- circular Petri dish
- metric ruler
- eye dropper pipette
- cafeteria (or pizza) tray
- other items as indicated in lab

Part One: Diameter of a sphere

1. Pour a sample of BB's into a small Petri dish. There should be enough to completely cover the bottom of the dish without stacking, the BBs should form a tight monolayer. Measure the diameter of the monolayer of BBs in cm. Note that the ruler scale says "mm," but that the numbers on the scale actually show cm. Record the diameter. Notice that if you have a true monolayer, the calculated thickness of the monolayer will correspond to the diameter of one BB. *(Later, in the analysis, you will use this data to perform the calculation, but for now the idea is just to obtain the measurements.)*

Diameter of the BB monolayer = __________ cm

Observations:

2. Transfer the BB's from the dish to a 50 mL graduated cylinder. Record your exact volume, to the nearest 0.1 mL. Are there any problems associated with attaining this precision using the equipment available? Look at the BBs. Are they round? Are they the same size? What color are they? Record your observations.

Volume of BBs = _______ mL

Observations:

3. Measure the length of a "chain" of 17 BBs in cm and record the length. How did you accomplish this? You will use this measurement to verify the calculated thickness as mentioned in the previous step.

   Length of chain = _________cm

   Observations :

Part Two: Thickness of an Oleic Acid Film

1. Pour enough water into a tray to completely cover the bottom, at least halfway up the side. Obtain a canister of lycopodium powder, and a bottle of oleic acid solution from the community area. Shake out a thin "patch" of lycopodium powder about 20 cm in diameter in the center of the tray. *Describe the lycopodium powder.* How does it behave on the water?

2. Holding the pipette close to the surface of the water, carefully dispense one drop of oleic acid solution in the center of the powder. What does the solution look like? What happens when the solution hits the water? When the oleic acid stabilizes, measure the diameter. Is your monolayer circular? If not, how do you determine an accurate diameter?

% concentration of Oleic Acid solution = ______%

Diameter of the Oleic Acid monolayer = _______

Observations:

3. Using the same style of pipette and a stock of pure ethanol, count the number of drops it takes to reach the 1.0 mL mark in a small graduated cylinder. Be sure to measure from the bottom of the meniscus. Repeat the count for the number of drops to go from 1.0 to 2.0 mL. *Why does the surface of the liquid in the graduated cylinder curve the way it does?*

# of drops to 1.0 mL = _____ **# of drops from 1.0 to 2.0 mL = _____**

Observations:

Analysis:

Use the data you have recorded above to perform the following calculations. Record the calculations in the space provided, and show all work clearly. Use proper units and report answers to the correct number of significant figures. Do "scratch work" on a separate paper.

Part One: BB's

1. Calculate the radius, and then the area of the BB monolayer by substituting your measurement of the diameter into the appropriate equation.

Radius = diameter/2 **Area = π x (radius)^2**

Radius =____________ **Area = ________________**

2. Calculate the thickness of the BB monolayer by substituting your values for area and volume into the appropriate equation. (***Note:*** *the thickness of the layer is equivalent to the diameter of one BB. Watch your units here so that they cancel out properly*)

Thickness = Volume/Area

Thickness = ______________

3. Calculate the diameter of one BB by dividing the measured length of the BB chain by the number of BBs in the chain.

Diameter of BB = ____________

4. Summarize your data in the Data Table below.

Part Two: Oleic Acid

1. Find the average number of drops per mL by adding your two results and dividing by 2.0 mL.

Average drops/mL = _________

2. Now calculate the volume, in mL, of a single drop delivered by your pipette. What you want is the volume in mL. What you've got is 1 drop. Use the average number of drops/mL as a conversion factor to set up a simensional analysis equation.

Volume of 1 drop = ___________

3. The ethanol/oleic acid solution is 0.5% oleic acid by volume. This means that you must multiply the volume of your drop by 0.005 in order to obtain the amount of your drop that was actually oleic acid. Using your above result, calculate the volume of oleic acid in one drop of the 0.5% solution. Show all work.

Volume of O.A. per drop = __________

4. Use your measurement of the diameter of the oleic acid monolayer to calculate its radius and its area. Don't forget to include the appropriate units.

Radius of monolayer= ________

Area of monolayer= __________

5. Use the volume of the oleic acid in one drop (measured above in step 3) and the area of the oleic acid monolayer (in step 4) to calculate the thickness of the oleic acid monolayer. The calculation should closely parallel the calculation you already performed for the thickness of the BB monolayer.

Thickness of O.A. monolayer= ____________

6. Assume the film (oleic acid non-polar region) is seventeen carbon atoms tall, and calculate the diameter of one carbon atom.

Diameter of one carbon atom = ___________

7. Express your answer in step 6 in units of m, nm, Angstroms (A), and inches. Show all your work.

Diameter of one carbon atom = ___________m

Diameter of one carbon atom = ___________nm (1 nm = 1 x 10^{-9} m)

Diameter of one carbon atom = ___________A (1 A = 1 x 10^{-10} m)

Diameter of one carbon atom = ___________in (1 in = 2.54 cm)

Data Table {Tidy up your data. NOT A RAW DATA RECORD}			
Part One: BBs		**Part Two: Oleic Acid**	
Diameter of BB layer		Diameter of film	
Radius of BB layer		Area of Film	
Area of BB layer		Drops/mL	
Volume of BB layer		Volume of Solution/drop	
Thickness of BB layer (i.e. diameter of 1 BB)		Volume of Oleic Acid/drop	
Length of 17 BBs		Oleic Acid Thickness	
Diameter of one BB		Diameter of carbon atom	

Summary Questions:

1. Compare the results of your measured diameter of the BBs with the calculated value for the thickness (diameter) of the BBs by calculating the % Error:

$$\%Error = \frac{(measured\_diameter) - (calculated\_diameter)}{measured\_diameter} \times 100\%$$

2. Consider the following questions:
   a. Is this calculation a measure of precision or accuracy?

   b. How close are the results taken from the calculated thickness of the BB monolayer versus the directly measured diameter of the BBs?

   c. Based on the % error, do you gain confidence that this method will yield good results for the size of a carbon atom?

   d. Considering the precision of the measurement, what kind of accuracy would you predict for this calculation (referring to the carbon atom measurement)?

3. What evidence you have that the oleic acid exists? Draw a diagram showing how the oleic acid *molecules* interact with the surface of the water. (Refer back to the introduction to this lab) Use this diagram to explain why you must divide the calculated thickness of the monolayer by 17 to obtain the diameter of a carbon atom.

4. Using a ruler, measure the diameter of a carbon using Figure 1 on the front page of this hand-out. Can you estimate a range of uncertainty for this value?

5. Compare your experimental results to the "true" diameter of a carbon atom (look up the actual size of a carbon atom in your textbook, on the web, or ask your instructor). Note that in the type of measurement, you have excellent results if your result has the same "order of magnitude" as the actual value.

6. Generally it is possible to come within 2 to 3 angstroms of the true value. How do you explain this accuracy in light of the crudeness of the measurements employed?

7. One of the assumptions made in our model is that all of the carbon atoms are pretty much the same size. Based on your observations of the BBs, is this a reasonable assumption? List at least 2 other assumptions.

Appendix:

1. Structure of Oleic Acid:

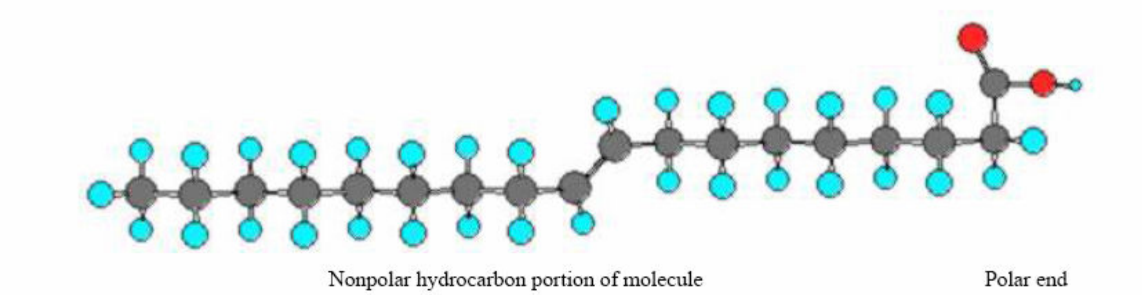


Figure 1. Oleic acid

2. Organization of Oleic Acid on a surface of water