

Data Tables

Table 1. Calibration of the Drop Counter

Data	Trial 1	Trial 2
Initial volume of cyclohexane in the graduated cylinder (mL)	5.00mL	6.00mL
Final volume of cyclohexane in the graduated cylinder (mL)	6.00mL	7.00mL
Volume of cyclohexane added (mL)	1.00mL	1.00mL
Number of drops of cyclohexane added	79 drops	80 drops
Volume/drop cyclohexane (mL/drop)	0.0127mL/drop	0.0125mL/drop
Average volume/drop cyclohexane (mL/drop)	0.0126mL/drop	

Observations:

It was evident while performing the lab that each drop wasn't the exact same size, even if we tried to keep the plastic pipette at the same angle for every drop and apply the same pressure for every drop.

When we placed drops of stearic acid on the water, they floated on the surface of the water briefly, appearing like a contact lens sitting on water. The first 4-5 drops the stearic acid dissipated across the surface of the water fairly quickly and each drop formed an interesting star-like shape as it dissipated to form a monolayer. We also noticed the drops would dissipate much more quickly near the edge of the petri dish rather than in the middle. The 6th drop of stearic acid, however, took much longer than 30 seconds to disappear, so we concluded that the number of drops required to form a monolayer was 5 drops.

Table 2. Calculation of the Length of the Stearic Acid Molecule

Data	Trial 1	Trial 2
Diameter of the water surface in the dish (cm)	8.80cm	8.80cm
Number of drops required to make a monolayer	5	5
Concentration of stearic acid from bottle (g/mL)	1.36×10^{-4} g/mL	1.36×10^{-4} g/mL
Density of stearic acid (g/mL)	0.847g/mL	0.847g/mL
Volume of solution required to form a monolayer (mL)	0.0629mL	0.0629mL
Mass of stearic acid in that volume (g)	$8.55 \cdot 10^{-6}$ g	$8.55 \cdot 10^{-6}$ g
Volume of stearic acid, V (mL)	$1.01 \cdot 10^{-5}$ mL	$1.01 \cdot 10^{-5}$ mL
Area of the monolayer, A (cm ²)	60.8cm ²	60.8cm ²
Thickness of the monolayer, t (cm)	$1.66 \cdot 10^{-7}$ cm	$1.66 \cdot 10^{-7}$ cm

Table 3. Calculation of the Volume of a Carbon Atom and Avogadro's Number

Data	Trial 1	Trial 2
A. Volume of a Carbon Atom Based Upon a Linear Array		
Diameter of a carbon atom assuming the 20 balls are joined in a straight line (cm)	$8.30 \cdot 10^{-9}\text{cm}$	$8.30 \cdot 10^{-9}\text{cm}$
Volume of a carbon atom using this diameter (cm^3)	$3.00 \cdot 10^{-25}\text{cm}^3$	$3.00 \cdot 10^{-25}\text{cm}^3$
B. Volume of a Carbon Atom Based Upon the Actual Bond Angle		
Value of e from Figure in Step 10 of calculations in Lab 1 (cm)	$8.30 \cdot 10^{-9}\text{cm}$	$8.30 \cdot 10^{-9}\text{cm}$
Diameter of a carbon atom using the value of e (cm)	$1.01 \cdot 10^{-8}\text{cm}$	$1.01 \cdot 10^{-8}\text{cm}$
Volume of a carbon atom using this diameter (cm^3)	$5.45 \cdot 10^{-25}\text{cm}^3$	$5.45 \cdot 10^{-25}\text{cm}^3$
Volume per mol of carbon atoms (cm^3/mol)	$3.42\text{cm}^3/\text{mol}$	$3.42\text{cm}^3/\text{mol}$
Avogadro's Number from A. (mol^{-1})	$1.14 \cdot 10^{25}\text{mol}^{-1}$	$1.14 \cdot 10^{25}\text{mol}^{-1}$
Percent Error	1800%	1800%
Avogadro's Number from B. (mol^{-1})	$6.27 \cdot 10^{24}\text{mol}^{-1}$	$6.27 \cdot 10^{24}\text{mol}^{-1}$
Percent Error	942%	942%

Sample Calculations (Trial one)

1. Volume of Cyclohexane added: (Trial one)

$$\begin{aligned}V_{\text{Cyclohexane}} &= V_{\text{Final of Graduated Cylinder}} - V_{\text{Initial of Graduated Cylinder}} \\ &= 6.00\text{mL} - 5.00\text{mL} \\ &= 1.00\text{mL}\end{aligned}$$

2. Volume per drop of cyclohexane:

$$\begin{aligned}V_{\text{per drop of cyclohexane}} &= \frac{V_{\text{Cyclohexane in trial 1}} + V_{\text{Cyclohexane in trial 2}}}{\text{Number Drops in trial 1} + \text{Number Drops in trial 2}} \\ &= \frac{1.00\text{mL} + 1.00\text{mL}}{79 \text{ drops} + 80 \text{ drops}} \\ &= \frac{2.00\text{mL}}{159} \\ &\doteq 0.012579113 \frac{\text{mL}}{\text{drop}} \\ &\doteq 0.0126 \frac{\text{mL}}{\text{drop}}\end{aligned}$$

-0.25
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3. Volume of solution required to form a monolayer: (Trial one)

$$\begin{aligned}V_{\text{Solution required to form monolayer}} &= V_{\text{per drop of cyclohexane}} \times \text{Number of drops}_{\text{stearic acid solution}} \\ &= 0.012579113 \frac{\text{mL}}{\text{drop}} \times 5 \text{ drops} \\ &\doteq 0.062895569\text{mL} \\ &\doteq 0.0629\text{mL}\end{aligned}$$

4. Mass of stearic acid in that volume: (Trial one)

$$\begin{aligned}m_{\text{stearic acid in that volume}} &= V_{\text{solution required to form monolayer}} \times \text{Concentration}_{\text{stearic acid}} \\ &= 0.062895569\text{mL} \times 1.36 \cdot 10^{-4} \frac{\text{g}}{\text{mL}} \\ &\doteq 8.553797468 \cdot 10^{-6}\text{g} \\ &\doteq 8.55 \cdot 10^{-6}\text{g}\end{aligned}$$

5. Volume of stearic acid: (Trial one)

$$\begin{aligned}V_{\text{stearic acid}} &= \frac{m_{\text{stearic acid in that volume}}}{\rho_{\text{Stearic acid}}} \\ &= \frac{8.553797468 \cdot 10^{-6}\text{g}}{0.847 \frac{\text{g}}{\text{mL}}} \\ &\doteq 1.009893444 \cdot 10^{-5}\text{mL} \\ &\doteq 1.01 \cdot 10^{-5}\text{cm}^3\end{aligned}$$

6. Area of the monolayer: (Trial one)

$$\begin{aligned}A_{\text{Monolayer}} &= \pi r^2 \\ &= \pi \left(\frac{\text{diameter}}{2} \right)^2 \\ &= 3.14159 \left(\frac{8.80\text{cm}}{2} \right)^2 \\ &\doteq 60.82123377\text{cm}^2 \\ &\doteq 60.8\text{cm}^2\end{aligned}$$

7. Thickness of the monolayer: (Trial one)

$$\begin{aligned}t_{\text{monolayer}} &= \frac{V_{\text{Stearic Acid}}}{A_{\text{Monolayer}}} \\&= \frac{1.009893444 \cdot 10^{-5} \text{ cm}^3}{60.82123377 \text{ cm}^2} \\&\doteq 1.660429066 \cdot 10^{-7} \text{ cm} \\&\doteq 1.66 \cdot 10^{-7} \text{ cm}\end{aligned}$$

8. Diameter of the carbon atom from A: (Trial one)

$$\begin{aligned}\text{Diameter}_{\text{Carbon atom}} &= \frac{t_{\text{monolayer}}}{\text{number}^{\text{"balls" of equal diameter per length of stearic acid molecule}}} \\&= \frac{1.660429066 \cdot 10^{-7} \text{ cm}}{20} \\&\doteq 8.302145329 \cdot 10^{-9} \text{ cm} \\&\doteq 8.30 \cdot 10^{-9} \text{ cm}\end{aligned}$$

9. Volume of the carbon atom from A: (Trial one)

$$\begin{aligned}V_{\text{Carbon atom}} &= \frac{4\pi \left(\frac{\text{Diameter}_{\text{carbon atom}}}{2}\right)^3}{3} \\&= \frac{4 \times 3.14159 \times \left(\frac{8.302145329 \cdot 10^{-9} \text{ cm}}{2}\right)^3}{3} \\&\doteq 2.996191838 \cdot 10^{-25} \text{ cm}^3 \\&\doteq 3.00 \cdot 10^{-25} \text{ cm}^3\end{aligned}$$

10. Avogadro's Number from A: (Trial one)

$$\begin{aligned}N_A &= \frac{\frac{V}{\text{mol}}_{\text{Carbon}}}{V_{\text{Carbon atom}}} \\&= \frac{3.42 \frac{\text{cm}^3}{\text{mol}}}{2.996191838 \cdot 10^{-25} \text{ cm}^3} \\&\doteq 1.141448941 \cdot 10^{25} \text{ mol}^{-1} \\&\doteq 1.14 \cdot 10^{25} \text{ mol}^{-1}\end{aligned}$$

11. Percent Error: (Trial one)

$$\begin{aligned}\% \text{ Error} &= \frac{|\text{Actual} - \text{Experimental}|}{\text{Actual}} \times 100\% \\&= \frac{|6.022 \cdot 10^{23} \text{ mol}^{-1} - 1.141448941 \cdot 10^{25} \text{ mol}^{-1}|}{6.022 \cdot 10^{23} \text{ mol}^{-1}} \times 100\% \\&\doteq 1795.464863 \% \\&\doteq 1.80 \cdot 10^3 \%\end{aligned}$$

12. Value of e from B: (Trial one)

$$\begin{aligned}e &= \frac{t_{\text{monolayer}}}{\text{number}_{\text{atoms of equal diameter per length of stearic acid molecule}}} \\&= \frac{1.660429066 \cdot 10^{-7} \text{ cm}}{20} \\&\doteq 8.302145329 \cdot 10^{-9} \text{ cm} \\&\doteq 8.30 \cdot 10^{-9} \text{ cm}\end{aligned}$$

13. Diameter of the carbon atom from the value of e from B: (Trial one)

$$\begin{aligned}
 \text{Diameter}_{\text{Carbon atom from value } e} &= \frac{e}{\sin \theta} \\
 &= \frac{8.302145329 \cdot 10^{-9} \text{ cm}}{\sin 55^\circ} \\
 &\doteq 1.013504805 \cdot 10^{-8} \text{ cm} \\
 &\doteq 1.01 \cdot 10^{-8} \text{ cm}
 \end{aligned}$$

14. Volume of the carbon atom from B: (Trial one)

$$\begin{aligned}
 V_{\text{Carbon atom}} &= \frac{4\pi \left(\frac{\text{Diameter}_{\text{carbon atom}}}{2} \right)^3}{3} \\
 &= \frac{4 \times 3.14159 \times \left(\frac{1.013504805 \cdot 10^{-8} \text{ cm}}{2} \right)^3}{3} \\
 &\doteq 5.450998448 \cdot 10^{-25} \text{ cm}^3 \\
 &\doteq 5.45 \cdot 10^{-25} \text{ cm}^3
 \end{aligned}$$

15. Avogadro's Number from B: (Trial one)

$$\begin{aligned}
 N_A &= \frac{\frac{V}{\text{mol}}_{\text{Carbon}}}{V_{\text{Carbon atom}}} \\
 &= \frac{3.42 \frac{\text{cm}^3}{\text{mol}}}{5.450998448 \cdot 10^{-25} \text{ cm}^3} \\
 &\doteq 6.274079938 \cdot 10^{24} \text{ mol}^{-1} \\
 &\doteq 6.27 \cdot 10^{24} \text{ mol}^{-1}
 \end{aligned}$$

16. Percent Error: (Trial one)

$$\begin{aligned}
 \% \text{ Error} &= \frac{| \text{Actual} - \text{Experimental} |}{\text{Actual}} \times 100\% \\
 &= \frac{| 6.022 \cdot 10^{23} \text{ mol}^{-1} - 6.274079938 \cdot 10^{24} \text{ mol}^{-1} |}{6.022 \cdot 10^{23} \text{ mol}^{-1}} \times 100\% \\
 &\doteq 941.8598369 \% \\
 &\doteq 942 \%
 \end{aligned}$$

Discussion:

In this laboratory experiment, a monolayer of a stearic acid was created on the surface of water and the thickness of the monolayer was calculated in order to obtain a value for Avogadro's constant. Assuming the carbon atoms in stearic acid were in a linear array, Avogadro's constant was calculated as approximately $1.14 \cdot 10^{25} \text{mol}^{-1}$, which gives a percent error of approximately 1800%. Taking into consideration the angle of the bonds of carbon atoms in stearic acid, the value for Avogadro's constant was much smaller, around $6.27 \cdot 10^{24} \text{mol}^{-1}$ and giving a percent error of 942%. This is clear indication that the atoms of carbon in a long chain molecule such as stearic acid form bonds at 109° angles, rather than having a linear arrangement.

For most experiments, this type of percent error would be preposterous; however, as will be shortly explained, this is in fact a very reasonable result for this laboratory experiment. One important source of error observed were the varying sizes of the drops of solution from the plastic pipette. Although the angle at which the pipette was held and the pressure applied to the pipette were kept as constant as possible (despite the fact that the human hand isn't a very accurate measuring tool for angle and pressure), it was evident that not every drop was the same size, and as a result, varying amounts of stearic acid entered the petri dish of water with every drop. This meant the measurement taken for the volume of stearic acid used to form a monolayer was extremely rough and quite inaccurate. Another major source of error was the possible evaporation of cyclohexane from the stearic acid solution. The concentration of stearic acid in the solution was already extremely low ($1.36 \cdot 10^{-4} \text{g/mL}$), and so even the slightest bit of evaporation of cyclohexane would cause a great increase in the concentration of stearic acid, thus causing more stearic acid to be added to the petri dish than what was measured. This results in a fewer number of drops being needed to form a monolayer. A third and possibly most important source of error was the formation of the monolayer of stearic acid on water. Although the petri dish was thoroughly cleaned and the water used was distilled, it is still very possible that there were very small amounts of impurities in the water, and this can greatly obstruct the formation of a monolayer, or, in this case, give the impression that a monolayer of stearic acid has formed after only 5 drops of solution have entered the petri dish. By having such a small number of drops form the monolayer, the diameter of a carbon atom was calculated to be much smaller than it is in reality. This diameter is cubed when finding the volume of a carbon atom, so the error is cubed as well, thus greatly increasing the error. As a result, the percent error calculated for all trials of this lab were well beyond what we are used to, but considering all the sources of error, the results of this experiment were actually very reasonable. It is not uncommon for the percent error of this lab to reach 10000%; nevertheless, the lab is an excellent illustration of how an extremely large number such, as Avogadro's constant, can be calculated by very simple means. Had this lab been conducted with much more accurate equipment and in a cleaner environment, a much more accurate value could have been calculated for N_A . This is a very important concept because the Avogadro's constant is the basis of stoichiometry and one of the most important ways of measuring quantities of atoms and molecules, rather than having to count individual particles.

Conclusion:

The value obtained for Avogadro's constant when using the linear array for the arrangement of carbon atoms in a stearic acid molecule was approximately $1.14 \cdot 10^{25} \text{mol}^{-1}$ with a percent error of approximately 1800%. The value obtained for Avogadro's number when using the actual bond angle of carbon atoms in a stearic acid molecule was approximately $6.27 \cdot 10^{24} \text{mol}^{-1}$ with a percent error of approximately 942%.

