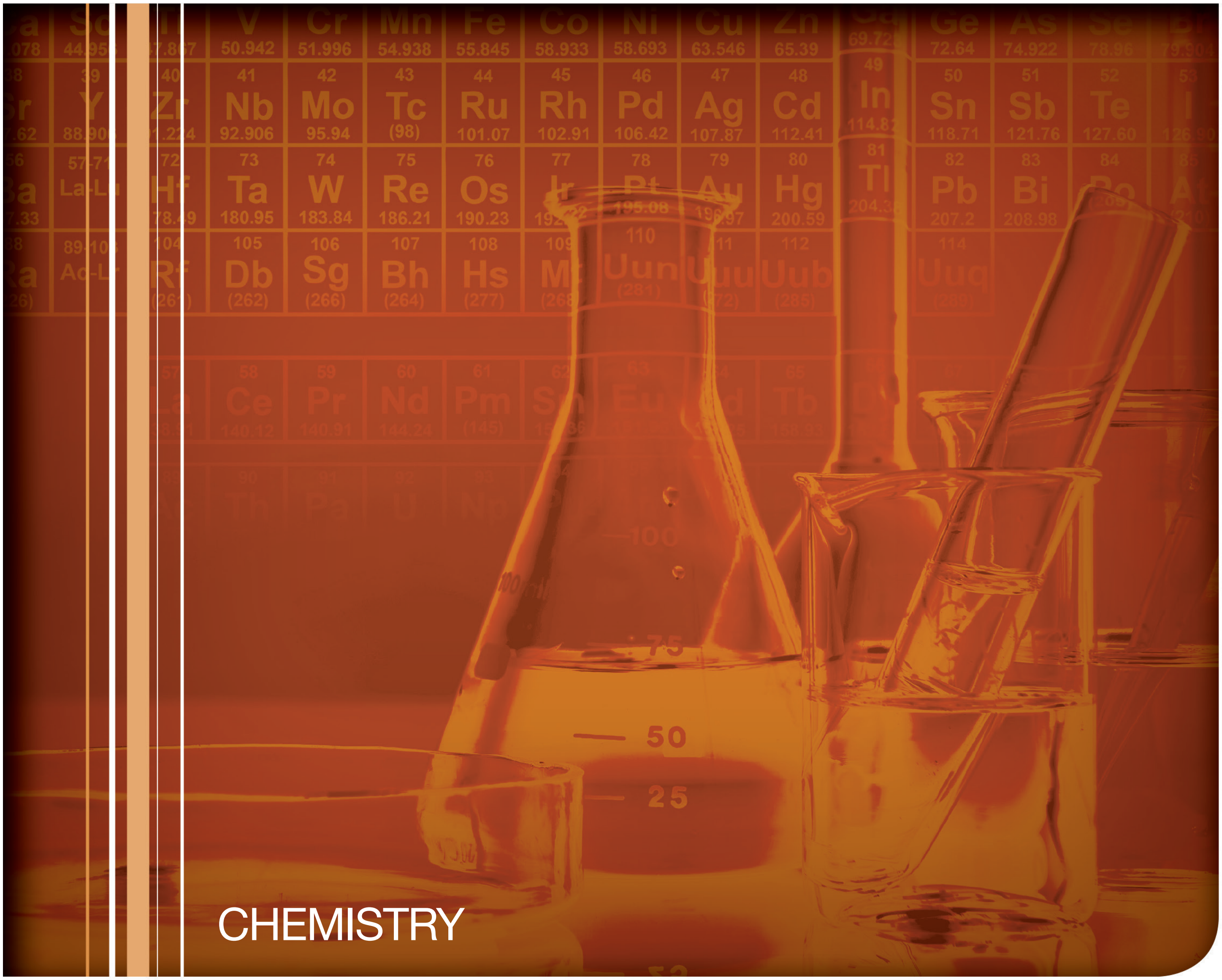


Estimating Avogadro's Number

Investigation Manual

CAROLINA
DISTANCE LEARNING

ESTIMATING AVOGADRO'S NUMBER

Table of Contents

Overview

Estimate the number of stearic acid molecules in a mole of stearic acid based on measurements of the volume of a known mass of stearic acid. This requires that a monolayer film of stearic acid molecules be created on a water surface, allowing the area of a single molecule of stearic acid to be calculated. Avogadro's number will also be estimated by calculating the number of aluminum atoms in a known volume and mass of aluminum foil.

Objectives

- Practice calculations using volume, mass, moles, and molecules to calculate density, concentration, molecular mass, and Avogadro's number
- Determine Avogadro's number using molecular monolayer techniques
- Calculate the number of stearic acid molecules in a monolayer
- Calculate the moles of stearic acid in a monolayer

Time Requirements

Preparation .... 15 minutes

Activity 1: Determination of Avogadro's Number
Using Stearic Acid Monolayer .... 30 minutes

Activity 2: Determination of Avogadro's Number
Using Aluminum Foil.................................. 15 minutes

Key

Personal protective equipment (PPE)

goggles gloves apron

follow link to video

photograph results and submit

stopwatch required

warning corrosion flammable toxic environment health hazard

Background

Avogadro's Number

Atoms are inherently small and have a mass that cannot be measured by traditional methods. Scientists have defined the mass of a single proton or neutron as 1.00 amu or atomic mass units (electrons weigh much less). The mass of a single carbon-12 atom that contains 6 protons and 6 neutrons is 12.00 amu. To connect the atomic or molecular world to the macroscopic world, the concept of the mole was developed. One mole of atoms has been defined by scientists as the number of atoms of carbon-12 that have a mass of 12.00 g. There are 6.022×10^{23} atoms of carbon-12 in a mole. This number of particles in a mole is called Avogadro's number. It is named after the early 19th century Italian scientist, Amedeo Avogadro, who first proposed that the volume of a gas is proportional to the number of atoms or molecules regardless of the nature of the gas.

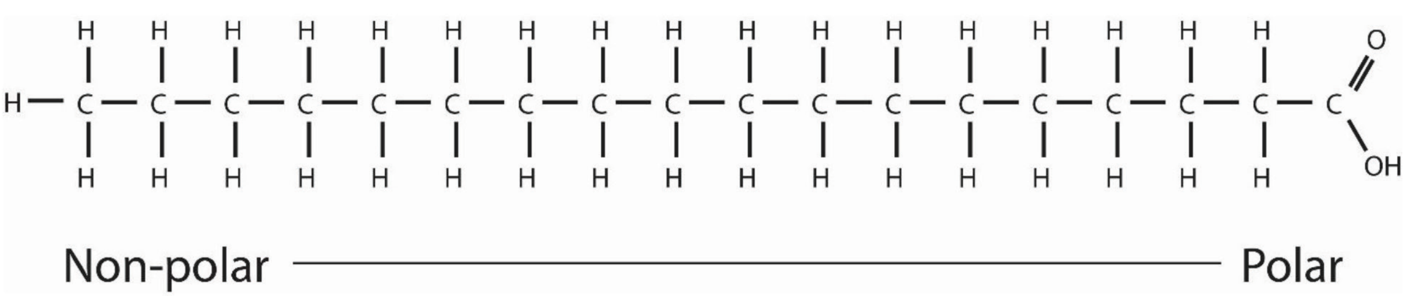
Avogadro's number and the concept of the mole are so important to scientists that the mole is one of the seven base units in the International System of Units (SI). Avogadro's number is represented by N_a and has the accepted value of 6.02214×10^{23} particles/mole. A mole of any substance contains Avogadro's number of particles. The value of Avogadro's number has been determined experimentally since the early 1900s.

In this investigation, Avogadro's number will be first determined by calculating the amount of stearic acid in a monolayer based on the area and the number of moles of stearic acid. It will also be determined by calculating the number of aluminum atoms in a known volume and mass of aluminum. Both of these determinations rely on several assumptions and an estimation of the size of these molecules. Therefore, this investigation will provide an estimation of Avogadro's number that should be within an order of magnitude of the actual number.

Stearic Acid

Stearic acid is a fatty acid that has the condensed structural formula $CH_3(CH_2)_{16}CO_2H$ (see Figure 1).

Figure 1.



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Background continued

Fatty acids are a natural product; can be extracted from many plant sources, such as corn, soybeans, and peanuts; and have many commercial applications. The structure of the molecule is responsible for its unique properties, one of which is its solubility in water. The acid end of the molecule is polar and soluble in water but the hydrocarbon portion of the molecule is non-polar and is hydrophobic, or not water-soluble. Therefore, if a small amount of stearic acid is added to water, the polar ends of the molecule will be soluble in the water and non-polar portion of the molecule will stick out of the water as shown in Figure 2.

When stearic acid is carefully layered on top of water as shown in Figure 2, it is called a monolayer. In a monolayer of a fatty acid such as stearic acid, the molecules are arranged vertically as close as possible in a single layer. If the area of the monolayer and the mass of stearic acid are both measured and the area of a single molecule of stearic acid is known, then the number of molecules in the monolayer can be calculated.

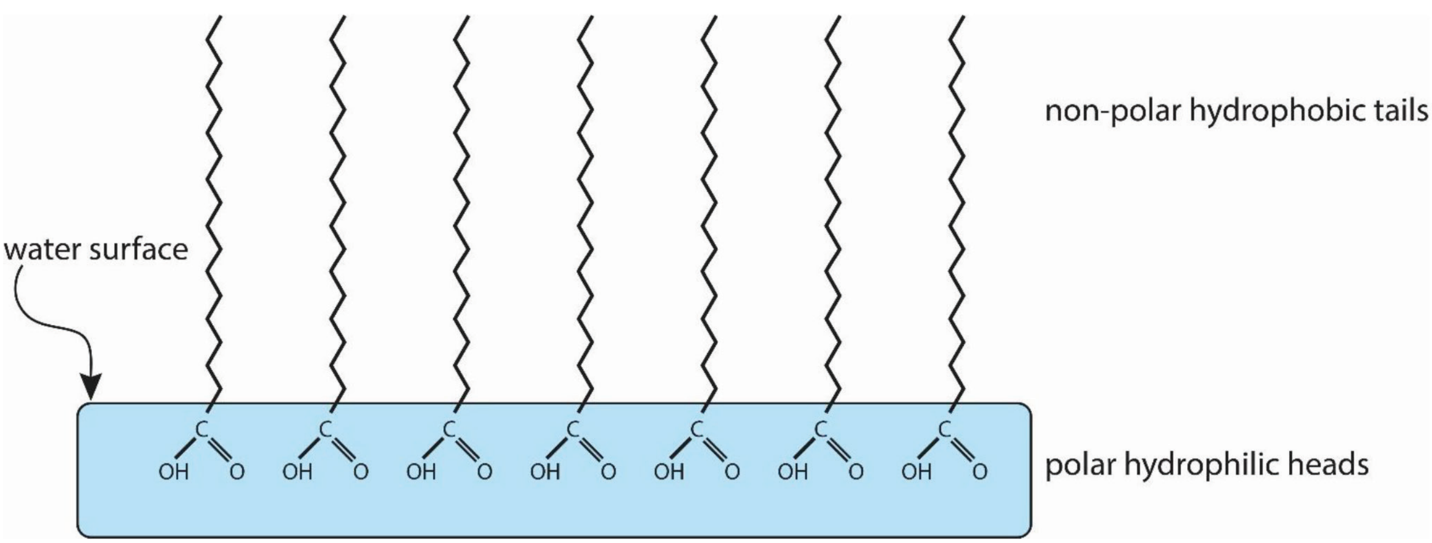
In this investigation, a solution of stearic acid in hexane is used. Hexane, C_6H_{14}, is a non-polar hydrocarbon that is insoluble in water and also very volatile (it readily evaporates). Carefully adding drops of the stearic acid solution to water will create a monolayer of stearic acid molecules once the hexane evaporates.

Sample Calculations

The calculations necessary to estimate the number of molecules in a mole using this procedure are demonstrated in this sample calculation. The following sample experimental data will be used in the calculations.

- The concentration of stearic acid in hexane is 0.10 g/L
- 0.53 mL of stearic acid solution is used
- A 100-cm-long thread loop is used

Figure 2.



Mass and Moles of Stearic Acid

Step 1: Determine the mass of stearic acid that is added to the water, multiply the volume and concentration.

$$\frac{\text{mass}}{\text{volume}} = \text{concentration}$$

$$\text{mass} = \text{volume} \times \text{concentration}$$

$$\text{mass} = 0.53\text{ mL} \times \frac{1\text{ L}}{1{,}000\text{ mL}} \times \frac{0.1\text{ g}}{1\text{ L}}$$

$$\text{mass} = 0.000053\text{ g}$$

Step 2: Determine the number of moles of stearic acid using the molecular weight of stearic acid (284.5 g/mol).

$$\text{moles} = \frac{\text{grams}}{\text{molecular weight}}$$

$$\text{moles} = \frac{5.3 \times 10^{-5}\text{ g}}{284.5\text{ g/mol}}$$

$$\text{moles} = 1.86 \times 10^{-7}\text{ mol}$$

Area of the Stearic Acid Monolayer

The stearic acid will be contained inside a loop of thread so the area can be easily calculated. When the loop is completely filled with a monolayer of stearic acid, it will form a circle, which is the most efficient shape in that it has the greatest area-to-perimeter ratio. If the circumference of the circle is known, then the area inside the circle is also known. If the length of thread used in the experiment is 100 cm long, then the circumference of the circle is 100 cm.

Step 1: Determine the radius of the circle.

Circumference of circle = 2 π r (where π is 3.14 and r is the radius)

$$100.0\text{ cm} = 2 \times 3.14 \times r$$

$$15.9\text{ cm} = r$$

Step 2: Determine the area of the loop.

$$\text{Area} = \pi r^2$$

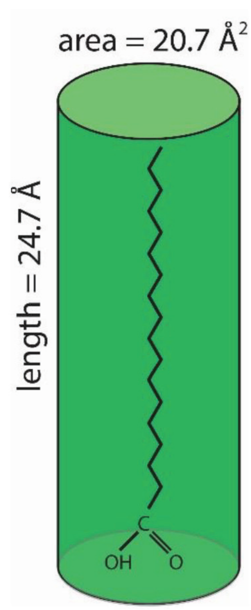
$$\text{Area} = 3.14 \times (15.9\text{ cm})^2$$

$$\text{Area} = 794\text{ cm}^2$$

Area of One Stearic Acid Molecule

Scientists have determined from x-ray diffraction and advanced calculations from space-filling models that the length of a stearic acid molecule in a monolayer is 24.7 Å and the area is 20.7 $Å^2$. One angstrom (Å) is 10^{-10} meters or 10^{-8} cm. Therefore, one stearic acid molecule occupies 20.7×10^{-16} cm^2.

Figure 3.



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Background continued

Calculation of Number of Stearic Acid Molecules

If a monolayer is formed, then the number of stearic acid molecules × the area of one stearic acid molecule should equal the area of the circular loop.

$$\text{Total Area} = (\text{\# of Stearic Acid Molecules}) \times (\text{area of one Stearic Acid Molecule})$$

$$749\ \text{cm}^2 = (\text{\# of Stearic Acid Molecules}) \times (20.7 \times 10^{-16}\ \text{cm}^2)$$

$$(\text{\# of Stearic Acid Molecules}) = 3.62 \times 10^{17}\ \text{molecules}$$

Calculation of Avogadro's Number

The number of stearic acid molecules in a known quantity of moles of stearic acid is now known. Avogadro's number can be determined using a simple ratio.

$$\frac{\text{Avogardo's number}}{1\ \text{mole}} \times \frac{3.62 \times 10^{17}\ \text{molecules}}{1.86 \times 10^{-7}\ \text{moles}}$$

Avogadro's number = 1.95×10^{24} molecules

Aluminum Metal

The second activity will test your math skills and ability to estimate Avogadro's number. Use a sample of aluminum foil and develop a step-by-step procedure and calculations to determine Avogadro's number and to estimate the layers of aluminum atoms in the sheet of aluminum foil. The following data are required to solve these problems.

Density of aluminum: 2.70 g/cm^3

Volume of a sphere = $(4/3)\ \pi\ r^3$

Atomic mass of aluminum: 26.98 g/mol

Atomic radius of aluminum: 143 pm (picometer = 10^{-12} meters)

Materials

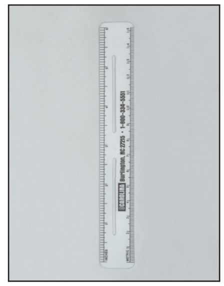
Included in the materials kit:

Stearic acid in a hexane solution, 6 mL

Thread

Syringe, 1 mL

Needed from the equipment kit:



Ruler

Pipets

Weighing boats

Electronic balance

Needed but not supplied:

- Medium-size glass dish or plate (a round plate at least 8" in diameter or a 9 × 9" square glass baking dish will work well)
- Toothpick or pin
- Bottled or purified water
- Aluminum foil
- Scissors

Bottled or purified water should be used because they lack most of the impurities that are found in tap water. Water that has been filtered through a water purifier (e.g., Brita® or PUR®) works well.

Reorder Information: Replacement investigation kit for Estimating Avogadro's Number Investigation, item number 580334, can be ordered from Carolina Biological Supply Company.

Call 800-334-5551 to order.

ACTIVITY

Safety

Wear your goggles, gloves, and lab apron at all times while conducting this investigation.

Read all of the instructions for this laboratory activity before beginning. Follow the instructions closely. Observe established laboratory safety practices, including the use of appropriate personal protective equipment (PPE) as described in the Safety and Activity sections.

The stearic acid in hexane solution is a flammable liquid. Keep away from all flames and heat sources. Use the hexane solution in a well-ventilated area.

Do not eat, drink, or chew gum during this activity. Wash your hands with soap and water before and after the activity. Clean the work area with soap and water after completing the investigation. Keep pets and children away from lab materials and equipment.

Preparation

1. Read the activities.
2. Obtain all materials.

ACTVITY 1

A Determination of Avogadro's Number Using Stearic Acid Monolayer

1. Lay a towel on the counter to catch excess water during the experiment.

> The water level should be as high as possible. Water will form a slight curved surface above the container due to surface tension. This slight dome will help keeping the monolayer within the thread loop.

2. Fill the glass plate or dish with purified water until the water level is slightly overfilled.
3. Cut a piece of thread approximately 25 cm long.
4. Create a loop by tying the two ends together using a double knot.
5. Cut any excess thread from the knots. Trim the ends as close to the knot as possible.
6. Measure and record the length of the loop of thread. It is easiest to pull the loop tight and measure this length, then multiply this length by two.
7. Carefully place the thread loop on the surface of the water.

   See how to create the stearic acid monolayer loop.
   http://players.brightcove.net/17907428001/HJ2y9UNi_default/index.html?videoId=4886981687001

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ACTIVITY 1 continued

The thread loop should easily float on the surface of the water. Try to spread the loop out using a toothpick or pin. The thread should not overlap itself. Avoid pushing the thread under the water or completely wetting it.

8. Inspect the thread to ensure that all parts of the thread are in contact with the water.

If the thread is not touching the surface, it may kink. Manipulate the thread loop to make sure the thread is touching the water in all places. The thread loop is essentially a floating dam to retain the monolayer. It is essential that there are no gaps between the thread and the surface through which the monolayer can escape.

9. Fill the syringe with the stearic acid solution. Fill the syringe almost full with solution and then remove any air bubbles by squirting out a small amount of solution.
10. Practice using the syringe to release only one drop of solution at a time.
11. Record the starting volume of solution in Data Table 1.
12. Slowly add a few drops of solution into the center of the loop area. Add drops one at a time.
13. After a few drops, the thread loop should form a firm circle. At this time, stop adding stearic acid solution.
14. The hexane will begin to evaporate and the thread loop should begin to contract, forming a non-circular shape.
15. Continue to add a drop or two of stearic acid solution until a perfect circle is formed and remains a circle even after the hexane has evaporated.
16. A sustained, firm circle of thread indicates that a monolayer of stearic acid has been formed inside this circle. If an added drop of stearic acid solution strikes the surface, remains on top of the monolayer, and requires a prolonged period of time to disappear, then the monolayer is complete.
17. Record the ending volume of solution in Data Table 1.
18. Verify the diameter of the circle by holding a ruler just above the surface of the water.
19. Dispose of the water, stearic acid, and thread in your plate or dish.
20. Repeat this procedure for an additional trial.
21. Calculate the mass of stearic acid for each trial and record in Data Table 1.

    Mass = concentration × volume

22. Calculate the moles of stearic acid for each trial and record in Data Table 1.

    Moles = mass/mol weight

    Mol Weight = 284.5 g/mol

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ACTIVITY 1 continued

23. Record the area of stearic acid for each trial in Data Table 1.

Area of Stearic Acid = Area of Loop

24. Calculate the number of stearic acid molecules for each and record in Data Table 1.

Number of Stearic acid molecules = Area of Stearic Acid/Area of One Stearic Acid Molecule

25. Calculate Avogadro's Number for each trial and record in Data Table 1.

Avogadro's Number = Number of Stearic Acid Molecules/Moles of Stearic Acid

ACTVITY 2

A Determination of Avogadro's Number Using Aluminum Foil

The following activity is intended as an extension activity and requires the application of concepts from the Background and Activity 1 to solve a mathematical problem.

1. Cut a piece of aluminum foil about 12 inches in length.
2. Trim the aluminum foil using the straight edge of a ruler to ensure that both edges are straight. The straighter the edges, the easier it is to accurately measure the length of the foil.
3. Carefully measure the length and width of the aluminum foil in centimeters. Record the values in Data Table 2.
4. Fold the aluminum foil so that it fits on the balance.
5. Weigh the aluminum foil and record the mass in Data Table 2.
6. Calculate Avogadro's number using a procedure similar to that used during the stearic acid monolayer activity.
7. Calculate the number of layers of aluminum atoms in the aluminum foil sheet assuming each aluminum atom is stacked on top of one another and are touching.

Disposal and Cleanup

1. Open up the bottle containing the stearic acid/hexane solution and allow the hexane to evaporate. Next, seal the bottle and dispose of it in the trash.
2. Clean and dry all of the equipment, and return all items to the equipment kit.

Data Table 1.

	Trial 1	Trial 2
Length of Thread Used *Note: Measure after the loop is made. This will be the circumference of the circle.*		
Radius of Loop Circumference = 2 π r π = 3.14		
Area of Loop Area = π r^2		
Initial Volume of Stearic Acid Solution in Syringe [mL]		
Final Volume of Stearic Acid Solution in Syringe [mL]		
Volume of Stearic Acid Dispensed [mL]		
Concentration of Stearic Acid in Hexane	0.0001 g/mL	0.0001 g/mL
Mass of Stearic Acid Mass = concentration × volume		
Moles of Stearic Acid Moles = mass/mol weight Mol Weight = 284.5 g/mol		
Area of Stearic Acid Area of Stearic Acid = Area of Loop		
Area of One Stearic Acid Molecule	20.7×10^{-16} cm^2	20.7×10^{-16} cm^2
Number of Stearic Acid Molecules Area of Stearic Acid/Area of One Stearic Acid Molecule		
Avogadro's Number Number of Stearic Acid Molecules/Moles of Stearic Acid		

ACTIVITY

Data Table 2.

	Trial
Length of Aluminum Foil	
Width of Aluminum Foil	
Area of Aluminum Foil	
Mass of Aluminum Foil	
Density of Aluminum	2.70 g/cm^3
Atomic Mass of Aluminum	26.98 g/mol
Atomic Radius of Aluminum	143 pm (picometer = 10^{-12} meters)
Number of Layers of Aluminum Atoms	
Number of Aluminum Atoms	
Avogadro's Number Number of Aluminum Atoms/Moles of Aluminum	

NOTES

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NOTES

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