

## **Lab 02: Measuring the Size of a Molecule**

### **Introduction**

Atoms and molecules are small. No, really. So small that you cannot see them with the unaided eye, which makes their size all the more difficult to measure. However, using some simple materials and methods, we can get a pretty reasonable approximation of the size of a molecule. First, though, we will use a similar technique to determine the thickness of a sheet of aluminum foil, which is too thin to measure directly using the meter stick.

### **Objectives**

- Learn to combine direct and indirect methods of measurement
- Become familiar with formula notation for complex molecules
- Further explore the relationship between mass, volume, and density
- Perform calculations using numbers in scientific notation
- Examine experimental results for credibility and identify the limits of experimental accuracy

### **Equipment**

- Square of aluminum foil
- Triple-beam balance
- Ruler
- Oleic acid, motor oil
- Lycopodium powder

- Pan of water
- Transfer pipette

### Activity 01: Thickness of Foil

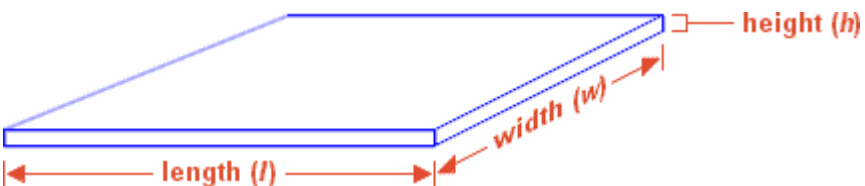
- Using the ruler, measure and record the length and width of the square of aluminum foil.
- Mass the foil on the balance, and record its mass in grams.

### Questions

1. Using  $2.7\text{g}/\text{cm}^3$  as the density of aluminum, calculate the volume of the sheet of foil:

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

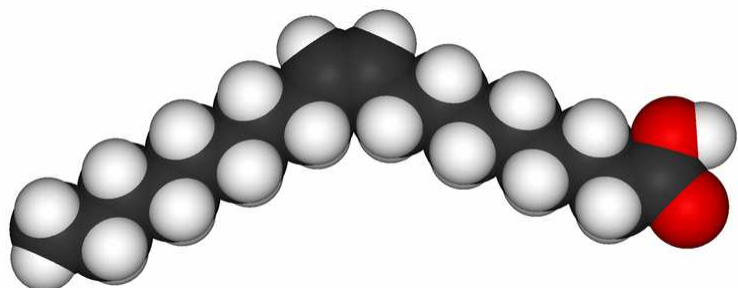
2. The volume of the aluminum is shown below. Use your recorded length and width, along with the volume you just determined, to calculate the height, or thickness of the sheet.

$$\text{height} = \frac{\text{volume}}{\text{length} \cdot \text{width}}$$


The diagram shows a 3D perspective of a thin rectangular sheet of foil. The front edge is labeled 'length (l)' with a red double-headed arrow. The depth of the sheet is labeled 'width (w)' with a red double-headed arrow. The thickness of the sheet is labeled 'height (h)' with a red double-headed arrow and a small square symbol at the end of the arrow indicating a right angle.

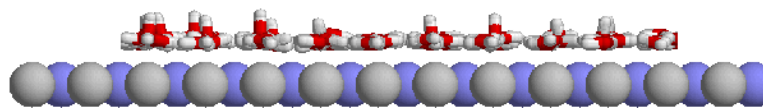
3. Why could we not simply use the ruler to measure how thick the foil is?
4. Is the thickness (height) of the sheet of foil the same as the size of an aluminum atom? In other words, is the sheet of aluminum foil exactly one atom thick?

### Activity 02: The Size of an Oleic Acid Molecule



Oleic acid is a monounsaturated omega-9 fatty acid. *Huh?* Olive oil! Olive oil and grapeseed oil are largely made up of this stuff. This is the fat that does not clog your arteries and kill you, it raises your good cholesterol. Chemically, it has the formula  $C_{18}H_{34}O_2$ , which tells you that it takes a lot of atoms to make one oleic acid molecule. Written this way:  $CH_3(CH_2)_7CH=CH(CH_2)_7COOH$ , it tells you just how all those atoms are stuck together. In fact, it tells you that the molecule is formed by joining multiple molecules together. The molecular structure is shown on the left, and "reads" from left to right, just like the molecular formula.

When a drop of acid is placed on the surface of water, it will spread out. It will continue to spread: the area of the drop gets bigger. But at the same time, the thickness of the drop decreases (because there's no change in the total volume of the oleic acid). When the droplet has spread as far as it can, the oleic acid will exist in a **monolayer** on the surface of the water: the thickness of the spread-out drop will be one molecule. If we know the volume of the acid to begin with, we can measure the area of the spread-out drop, and use the same technique as we used for the foil to determine the thickness. In this case, the thickness will match the size of the molecule of acid.



- Draw some oleic acid into the pipette. Holding the pipette vertically over the flask of acid, allow a drop to form at the tip.
- Quickly but carefully use the ruler to measure the diameter of the drop ( $d_s$ ). Let the drop to fall back into the flask, and repeat with two more drops. Record each of the three drop diameters in millimeters (mm).
- Fill the pan almost full of water.
- Sprinkle a light, even layer of lycopodium powder over the surface of the water. The lycopodium is inert, but you probably don't want to eat it.

- Hold the pipette vertically over the center of the pan, close to the surface, and allow a single drop of oleic acid to fall onto the surface of the water.
- Measure and record the diameter of the spread-out drop of acid in millimeters ( $d_c$ ). Because the circular shape is probably not perfectly regular, measure three diameters in different directions.

### Questions

5. Find the average diameter of the three drops that you measured, and use this to calculate the average radius of an acid drop:

$$r_s = \frac{1}{2}(d_{av})$$

6. Calculate the volume of the spherical drop. The units will be  $\text{mm}^3$ :

$$V_s = \frac{4}{3}\pi r_s^3$$

7. This is not the actual volume of acid; because the solution is only 0.5% oleic acid, 99.5% of that volume is actually something else (methanol)! The volume of acid is, then:

$$V_a = (0.005)V_s$$

8. The spread-out acid is no longer shaped like a sphere; it is now a pancake shape, or a very thin cylinder. However, the entire cylinder will be acid (the methanol evaporates almost instantly). From your three measurements, calculate the average diameter of the cylinder, and use it to find the radius:

$$r_c = \frac{1}{2}(d_{av})$$

9. The volume of a cylinder is defined as:

$$V_c = \pi r_c^2 h$$

But the volume of the spread-out cylinder is exactly the same as the volume of the original acid ( $V_a = V_c$ ), so we can calculate the height of cylinder directly:

$$h = \frac{V_a}{\pi r_c^2}$$

Calculate carefully, and remember to keep track of your values for the sphere and cylinder!

10. Is your answer reasonable? Is it more likely that your answer is too large or too small? Why?
11. A single molecule of motor oil has about twice the diameter of a molecule of oleic acid. If you added a drop of motor oil instead of oleic acid to the pan, would your "pancake" be larger or smaller? Assume that you have initial drops of the same size (for this comparison, also assume that your oleic acid is pure, not diluted with methanol).
12. Now, lets apply this to a "real life" situation. You are wanting to re-tile your kitchen. You have measured the dimensions of your room and it is 15ft x 20 ft. You know that the floor tiles you are wanting to use are 1.5 ft x 1.5 ft. How many tiles will you need to completely cover your floor?
13. An old riddle asks, how many angels can dance on the head of a pin? If we assume that an angel is the same size as an oleic acid molecule, and the circular head of a pin is 2mm across, how many angels will fit? This the same idea as the previous question except assume the angels are circular in area!