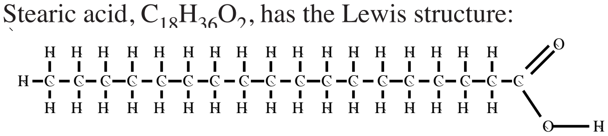
Avogadro's Number

INTRODUCTION

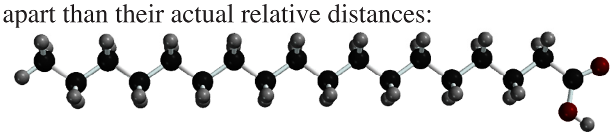
Avogadro's number, the number of particles in a mole, is most reliably determined by X-ray diffraction of crystals. In 1986, based on studies of silicon crystals, the number was defined as 6.0221367×10^{23}. At the beginning of this century, scientists devised ingenious methods to try to estimate the size of the number. Albert Einstein calculated the number of collisions that must take place between air molecules and a small particle to cause the small particle to drop as slowly as it does through the air. Perhaps you know that if a feather is dropped in a vacuum, it falls as rapidly as a rock. When the feather drops in the air, it is slowed by the many collisions it has with air molecules. By calculating how many collisions must occur to slow the fall, he concluded that there must be about 5×10^{23} particles in a mole. After Robert Millikan measured the charge of an electron in 1915, this value was divided into the charge of a mole of electrons to get 6.02×10^{23} as the number.

In this experiment, you will use an interesting method to get a very rough idea of the value of the Avogadro number.

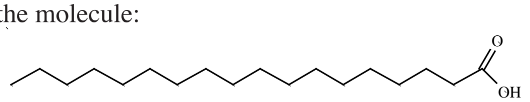
Stearic acid, $C_{18}H_{36}O_2$, has the Lewis structure:



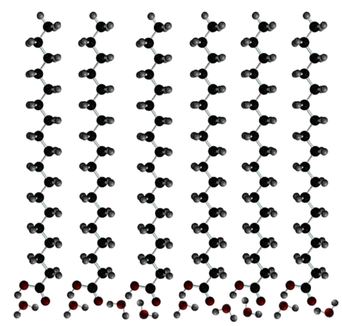
The right side of the molecule is polar and is capable of hydrogen bonding with water.The bonds were drawn in an exaggerated way to emphasize this. The rest of the molecule is a hydrocarbon, completely nonpolar.
An expanded structural model of stearic acid shows the proper angles between atoms, but places the atoms farther apart than their actual relative distances:



We will call the right side of the molecule the head and the rest of the molecule the tail. Here is a shorthand notation for the molecule:

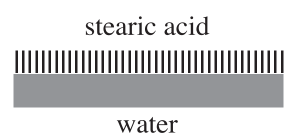


If stearic acid molecules are placed on a water surface, the polar head of the molecule hydrogen bonds to the water molecules on the surface. The rest of the molecule, the nonpolar tail, is not attracted to the water, but rather, is attracted to the tails of nearby stearic acid molecules. As a result, the molecules line up on the surface of the water with polar heads on the surface, and nonpolar tails sticking up away from the surface:



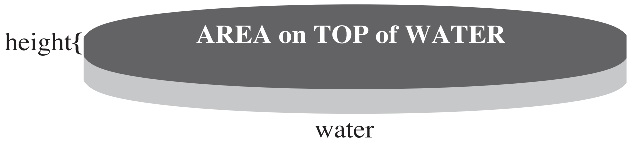
Water molecules, H-bonding to the COOH of stearic acid

If a small number of stearic acid molecules is placed on water, they cover the water with a layer one molecule thick. If more molecules are added, they begin to pile up on top of one another, but the first ones added form a monomolecular layer:



The height of the stearic acid molecules above the water is the length of the molecule. The length is considerably shorter than the wavelength of visible light, so light striking the monomolecular layer does not interact with it and the layer is invisible to the eye. However, once the additional molecules added begin to pile up on top of one another, the thicker part of the layer becomes visible.
You will add, drop by drop, a dilute solution of stearic acid in hexane, a volatile solvent, to a surface of water. As each drop hits the water, the hexane will evaporate, leaving the stearic acid to spread out on the water. When the surface is entirely covered, additional drops of the stearic acid/hexane solution will cause the stearic acid to pile up and you will see a visible trace of the acid on the surface. That will be the signal to stop adding drops of solution. By counting the drops of solution required to cover the surface, you will calculate the mass of stearic acid added. From the mass, you will use

the density of stearic acid to calculate its volume. You will measure the area of the water surface. Knowing the volume of stearic acid and the area of the surface over which it has spread, you will calculate the height of the layer:



The height corresponds to the length of the stearic acid molecule, which has 18 carbon atoms, all of them presumed to be sticking out of the water. Dividing the height by 18 gives the height of one carbon atom. Cubing this gives the volume of one carbon atom. Dividing this into the volume of a mole of diamond, which is pure carbon, will give how many atoms of carbon must be in a mole.

The calculations are based on a number of assumptions that are only approximately true. Among these are the following:

- The carbon atoms actually stick up in a zigzag fashion, not in a straight line as the calculations assume.
- The diamond crystalline structure includes some empty space between atoms. The calculations assume that there is no empty space.
- Carbon atoms are spherical. The calculations assume that they are cubic.

Even with these assumptions, you should get a value for the Avogadro number that is within an order of magnitude of the book value. Since an order of magnitude is a 1000% variation, do not think in % error terms in this experiment. Think of the interesting nature of the investigation.

EQUIPMENT

Special supplies:

- 1 large watch glass (see instructions below)
- 1 fine tip dropping pipet

From your drawer:

- 1-600 ml, 1-50 ml beaker
- 1 rubber bulb from a medicine dropper
- 1 10 ml graduated cylinder
- 2 small test tubes

EXPERIMENT

Set the 600 ml beaker on the lab bench. The watch glasses are soaking in a methanol-NaOH solution which cuts the grease from the glass surface. Take a piece of paper towel to the soaking tub, and use the tongs next to the tub to pick up a watch glass. While still holding onto the watch glass with the tongs, dip the watch glass into the container of deionized water provided. Place the watch glass on the paper towel held in your hand. *Do not touch the top of the watch glass with your hand.* Take the watch glass back to your lab station, and rinse it well with tap water, then give a final rinse with deionized water. Set it on the 600 ml beaker. Pour deionized water into the watch glass from a beaker until the watch glass is brim full.

Calibration of the dropper: You will need to know how many drops of hexane per milliliter the pipet delivers. *Do not use water on the pipet, graduated cylinder, or test tubes used to hold hexane or the stearic acid/hexane solution.* Use a clean and dry 10 ml graduated cylinder to bring 2.5 ml of pure hexane to your work area. Place the rubber bulb from your drawer onto the fine tipped pipet. The bulb should fit snugly. If it does not, see the instructor. Have a small test tube handy. Support it in a 50 ml beaker. Place the pipet tip in the hexane in the graduated cylinder; squeeze and release the bulb a number of times. This saturates the air space in the pipet with hexane vapor, and prevents unwanted dripping of the hexane out of the pipet. Use the pipet to transfer hexane out of the graduated cylinder into the test tube until the level of hexane in the graduated cylinder is at the 1.00 ml mark. Now, taking hexane from the test tube, and holding the pipet straight up, count how many drops it takes to fill the graduated cylinder up to the 2.00 ml mark. Record this number in the data table. If you lose count, transfer the hexane out of the cylinder to the 1.00 mark, and count again. Pour the hexane into the waste container provided.

Adding the Stearic Acid Solution to the Water Surface: Use the mark on the transfer pipet attached to the bottle of stearic acid/hexane solution to place 1 ml of the solution in a small, clean and dry test tube. Record the strength of the solution, which is written on the label, in the data table. Draw up some of the solution into the calibrated pipet. Hold the pipet straight up, and squeeze one drop of the solution onto the center of the water in the watch glass. Watch as the solution spreads out and evaporates. *Make sure each drop completely evaporates before adding the next drop.* Get an angle of view that allows you to clearly see the drop evaporating. Now add another drop, and wait until it evaporates. Continue to do this, counting the drops. You will notice that the drops begin to take longer and longer to evaporate. This happens as the surface gets more and more crowded with stearic acid molecules. Finally, you will see a very small amount of sediment, sort of a whitish scum, on the surface where a drop just evaporated. This is the multimolecular pile of stearic acid molecules that occurs after the surface has been covered by the monomolecular layer. Do not count the last drop, and record how many drops have been placed on the water surface up to that last drop. You might have to vary your angle of view of the surface so that the light is right to help you to see the deposit on the surface.

Use a ruler to measure the diameter of the water surface. Record the value to the nearest 0.1 of a centimeter.

You are finished with the experimental measurements. Slide the beaker holding the watch glass over to the sink, and dump the water into the sink. Return the watch glass to the soaking tub. Pour the excess stearic acid solution into the waste container provided. Pull the bulb off of the pipet. *Do not rinse the pipet with water.* Return the pipet to the cart. Clean up your area, and proceed to the calculations.

DATA AND CALCULATIONS

(Use significant figures correctly. Drops counted are exact numbers. Note that ml = cm^3)

1. Drops of hexane per milliliter _____
2. Stearic acid solution strength ________g/L
3. Drops needed to form the monolayer ____
4. Diameter of water surface _______cm
5. Volume to form monolayer (#3/#1) _______cm^3
6. Area of water surface _____cm^2
7. g of stearic acid added (change #2 data to g/cm^3, then #5 x# 2) _______g (this should be a small number)

   The density of stearic acid is 0.85 g/cm^3. Use this information to calculate the volume of stearic acid in the monolayer. Use the grams from #7, and make sure the units in the answer are in cm^3.

8. Volume of stearic acid added _____cm^3
9. Thickness of monolayer (#8/#6) ________cm

(For the next calculation, remember that there are 18 carbon atoms sticking up from the water)

10. Height of one carbon atom _______________cm

11. Volume of carbon atom $(\#10)^3$ _______________

The density of diamond is 3.51 g/cm^3. Carbon has a molar mass of 12.0 g/mol.

12. The volume of a mole of carbon is _______

Use the answers in #11 and #12 to calculate a number with the units: (one number will divide into the other)

Write this number in entry #13 with 10^{23} as the exponent (4.0×10^{24} would be written 40×10^{23})

13. The number of atoms in a mol from your data ________________

14. Divide answer #13 by 6.02×10^{23} ________________

Is the number in answer 14 between 0.1 and 10? If so, you are within an order of magnitude of the book value for the Avogadro number. If not, did you notice any mechanical errors in your experiment?

Name____ Grade___________ Date ___________

QUESTIONS

1. If a gumdrop is 1.5 cm^3 in volume, what would the volume of a dozen gumdrops be?

2. If a raindrop is 0.05 cm^3 in volume, what would the volume of an Avogadro Number of raindrops be?

3. If this volume were in a cubic container, what would the length of one side of the box be? Give your answer in cm, km, and miles. (1.6 km equals one mile)

4. Soap is sodium stearate. A sodium ion replaces the hydrogen on the oxygen in stearic acid. Show the Lewis structure for soap.

5. Soap cleans things by allowing oil and water to mix. The process is called emulsification. The CH_2 part of the molecule resembles oil in polarity and dissolves in the oil, while the COO^- part of the molecule resembles water in polarity and attaches to water molecules. Draw a picture showing 10 stearate ions immersed in a grease glob surrounded by water. Use the shorthand notation for the molecule from page 91. Show it with a (-) sign taking the place of the right-hand H. The heads of the stearate ions will line the outer surface of the glob, and all of the tails will point to and almost meet in the center of the glob.

6. Lauric acid is used to make the detergents found in shampoo and toothpaste. Lauric acid is similar to stearic acid, but only has 12 carbons. Show the Lewis structure for lauric acid.