Avogadro’s Number and the Mole

# Introduction

The word *stoichiometry* comes from Greek, meaning ‘element measure’. We use stoichiometry to convert from what we can measure – mass or volume – to what we need, which is the number of particles in a sample. Because atoms and molecules are so very small, we need a large aggregate of them to create a measurable amount. Therefore, just as a *dozen* means 12 or a *ream* means 500, the *mole* is a useful counting number in chemistry.

The mole is defined as the number of atoms such that the mass of the atoms in grams is numerically equal to its atomic mass. For example, the mass of a single hydrogen atom is 1.01 u, where u is defined as the ‘unified atomic mass unit’ (1). A mole of hydrogen atoms has a mass of 1.01 grams. Since the periodic table shows the relative masses of atoms, a mole of oxygen atoms with a relative mass of 16.00 u will have a mass of 16.00 grams. Therefore, even though the atomic mass shown on the periodic table is the average atomic mass of the isotopes of an element, the numerical value is also the *molar mass* of the element, or the average mass in grams of one mole of the element.

Since mass is conserved, we can use the molar masses of elements to our advantage. The molecular mass of water, H2O, is the atomic mass of oxygen plus twice the atomic mass of hydrogen: O + 2H = 16.00 + 2(1.01) = 18.02 u. Therefore, it must also be true that the molar mass of water will be 18.02 g/mole. Once the molar mass of a compound is calculated from the periodic table, we can then use it to convert from mass to an amount in moles.

Given the importance of the mole as a concept, it is reasonable to ask, how large is it? The numerical value is not unique in that we arbitrarily chose the unit of ‘gram’ to represent a mole of a substance. If we chose to let the atomic mass unit of the element to be the same as the mass in kilograms, or ounces, or tons, the logic of the mole would still work for converting from mass to amount, but the number of atoms needed to create a mole would be different.

For one mole of atoms equal to that mass in grams, the value is called Avogadro’s number and is equal to 6.02 x 1023 atoms (or molecules, or particles, or items) (2).

Avogadro’s number written as a decimal is 602,000,000,000,000,000,000,000. In this experiment, we are going to estimate the size of the mole. We will do that by two independent methods. In both cases we will determine the size of a single unit and compare it to the size of a mole’s worth of units. In the first part, we will estimate the volume of a single molecule of oleic acid and compare it to the ‘molar volume’ of oleic acid. In the second part, we will compare the charge of an electron (measured in Coulombs) to the charge of a mole of electrons.

If we let ‘a’ represent the value of a single particle and ‘A’ represent the value for a mole of particles, then it must be true:

A = NA a

where NA is standard notation for Avogadro’s number.

We will make several simplifying assumptions for the calculation of Avogadro’s number for both estimations. For example, we will assume that oleic acid molecules are cubic in shape, although they probably aren’t. In the second part, we will assume that the molar volume of hydrogen gas is 24.4 liters under lab conditions. We also state, without proof, that it takes one mole of electrons to produce one mole of hydrogen gas. Both claims can be justified from chemical principles encountered later in the course sequence, so we are asking you to accept these claims at face value for now.

PART 1: Oleic Acid

# Introduction

In this part, a drop of a solution containing oleic acid dissolved in ethanol is placed on a pan of water. Oleic acid is less dense than water and floats on the top, spreading out into a single layer (or monolayer) of molecules. Ethanol dissolves in water, and therefore it disperses when the drop is added to the pan.

The volume of a single drop of solution is found by counting the number of drops needed to fill 2.0 mL of a graduated cylinder. The actual volume of oleic acid in the drop is calculated from the solution’s concentration.

The edges of the monolayer of oleic acid are found by sprinkling powder on the water surface first. From the volume of oleic acid contained in the drop added to the pan of water, and from the area of the ‘oil slick’, we estimate the thickness of the monolayer (h). We will assume that oleic acid molecules are basically cube-shaped, so that the volume of a single molecule will be h3. From the density and molar mass of oleic acid, we calculate the volume of a mole of acid. The number of molecules needed to fill a volume of acid equal to one mole will be an estimate of Avogadro’s number.

# Materials and Methods

A large tray

50 mL beaker, 10 mL graduated cylinder, and a narrow opening plastic pipet

Oleic acid solution

Talcum powder or baby powder

# Procedure

1. Obtain a plastic pipet with a narrow opening, a 10-mL graduated cylinder, and water in a 50-mL beaker.

2. Count the number of drops needed to fill the cylinder to the 2.00 mL mark with water from the beaker. Record the value on the Report Sheet. Expel the remaining water from the pipet (for Step 4).

3. Obtain a large tray and fill it with a layer of water. Sprinkle powder from a shaker as lightly as possible on the surface so that you can just barely see the powder on the surface when looking at an angle. Hold the shaker almost horizontally about one inch above the surface of the water. Tap the top edge of the rim until a small amount of powder exits the shaker and falls lightly onto the surface of the water. The powder should not clump: the less powder on the surface, the better the results.

4. Obtain the oleic acid solution and use the pipet to add one single drop of oleic acid solution at the center of the tray. The powder will be pushed out toward the edges of the tray.

5. Use a meter stick to measure the radius of the circle formed, (or alternatively, the length and width of the rectangle formed) and record the measurements on the Report Sheet.

# Data and Results

1. Find the volume of one drop of solution by dividing 2.00 mL by the number of drops.

2. The concentration of the oleic acid solution is 0.005 v/v (volume per volume), or two-thousandths of the volume of a drop. Therefore, take the volume of one drop and multiply by 0.005 to determine the volume of oleic acid in one drop of solution (v) in mL = cm3.

3. Calculate the area of the oleic acid on the surface of water, in cm2. If the ‘oil slick’ is shaped more like a circle, used the formula A = πr2; if it is more like a rectangle, use A = l\*w.

4. Divide the volume of oleic acid by the area of the ‘oil slick’ to determine the thickness of the monolayer (h=v/A), in cm.

5. We will assume that oleic acid is in the shape of a cube. Estimate the volume of one molecule of oleic acid by cubing the thickness of the monolayer (vol = h3).

6. The molar mass of oleic acid is 282.5 g/mol, and its density is 0.895 g/mL. Record these values on the Report Sheet. Multiple or divide the two values appropriately (you figure out how) to determine the molar volume of oleic acid (Vol) in units of mL/mol = cm3/mol.

7. Divide the molar volume of oleic acid by the molecular volume of oleic acid to estimate Avogadro’s number (NA = Vol/vol).

## Clean Up

Empty the water from the tray in the sink and return the pipet, beaker, cylinder and oleic acid solution to their original locations.

PART 2: Electrolysis of water

# Introduction

Electrolysis is the chemical decomposition of a substance produced by the passing of electric current through a liquid containing ions. (OED) When current is passed through an aqueous solution, water molecules are decomposed into hydrogen and oxygen gas. The hydrogen gas is produced at the cathode and oxygen gas at the anode. In this experiment, other reactions besides the production of oxygen are occurring at the anode, but hydrogen from the splitting of water is still being produced at the cathode. ~~Because the ratio of hydrogen to oxygen in water is 2:1, the rate of gas production at one of the two electrodes will appear to be twice as fast as the other; that is the location of hydrogen gas production.~~

In this experiment, we ~~are going to~~ collect the hydrogen gas ~~produced by the electrolysis of water~~. Multiplying the ~~average~~ current flowing during electrolysis by the ~~total~~ time of decomposition will measure the total charge used in the decomposition. From the volume of hydrogen gas produced and the approximation that 1.00 mole of hydrogen gas at room temperature and pressure has a volume of 24.4 L = 24,400 mL, we can calculate the charge that would be required to produce a mole of hydrogen gas.

It takes one mole of electrons to produce a mole of hydrogen; therefore, the charge needed to produce one mole of hydrogen is also the charge of one mole of electrons. Since the known charge of the electron has been measured experimentally to be 1.6 x 10-19 C [Needs Citation], dividing the charge of a mole of electrons by this value is a second estimate of Avogadro’s number.

# Materials and Methods

Plastic centrifuge tube

Evaporating dish

Timer

**[**Power supply

Ammeter

3 leads, a copper hook and a copper wire]*Can we just call this the electrolysis apparatus, since it will already be set up?*

Saturated sodium chloride solution (salt water)

# Procedure

The following steps occur in the fume hood. The power supply, ammeter and electrotrodes will already be assembled and ready to use.

1. Obtain around 100 mL of salt water in a 150 mL beaker. Fill a centrifuge tube to the top with the solution and cap it. When inverted, there should be NO air bubbles in the tip.

2. Fill the evaporating dish at least half full with the solution. Place the inverted tube in the dish and remove the cap: no air bubbles should enter the tube. Remove the cap from the dish. Use a clamp to hold the tube in place. It will be helpful if the divisions on the tube are facing forward so that they are readable.

3 Insert the copper hook under the tube so the exposed metal is completely contained in the tube.

4. The other copper lead must be in the solution to complete the circuit, so leave it out of the dish until timing begins. Turn on the power supply and set the initial voltage reading to around 7.0 volts. (The value will drop once the reaction starts.)

5. Start a timer (either one provided or use a timer app on a phone) and place the second copper lead into the evaporating dish solution. Bubbles will form on the copper hook; a discoloration of the solution will occur at the other lead, but the copper surface will remain shiny.

6. The voltage and current will fluctuate during the electrolysis, so record the current on the Report Sheet every fifteen seconds to at least two significant figures. Note that the upper divisions on the ammeter for the scale form 0.0 - 1.0 A are every 0.02 A.

7. Continue the reaction for 300 seconds (five minutes). Stop the reaction by removing the second lead. Turn off the power supply and allow a few minutes for the hydrogen bubbles to finish rising in the tube. Record the volume of hydrogen gas produced on the Report Sheet to the closest 0.1 mL. (Note that the numbers on the centrifuge tube are upside-down.)

# Data and Results

1. The total charge is the current multiplied by the time: Qtotal = IΔt. We recorded an average current every 15 seconds. Multiply each current by 15 and add the results.

Example: Suppose 4.2 mL of hydrogen gas were produced over five minutes. Values for the current recorded once every minute (60 seconds) instead of every 15 seconds were: 0.125, 0.130, 0.130, 0.140, and 0.125.

Qtotal = (0.125)(60) + (0.130)(60) + (0.130)(60) + (0.125)(60) + (0.140)(60) = 39 C

2. Calculate the ratio of charge to gas volume by dividing the total charge, Qtotal , from (1) by the volume of hydrogen gas (volume) produced.

Example: Ratio = Qtotal /volume = (39/4.2) = 9.3 C/mL

3. Calculate the total charge needed to produce a mole of hydrogen gas by multiplying the volume of a mole of hydrogen gas, 24400 mL by the ratio obtained from (3).

Example: Qmole = (24400 mL) x (9.3 C/mL) = 226000 C

4. The known charge of an electron, Qe = 1.6 x 10-19 C. Divide the total charge, Qmole calculated in (4) by this number to estimate Avogadro’s number, NA.

Example: NA = Qmole / Qe = 226000/1.6 x 10-19 = 1.4 x 1024

## Clean Up

Discarding the saltwater solution in the sink. Rinse out the centrifuge tube and evaporating dish and wipe up any saltwater spills.

# Conclusions

1. In your opinion, which of the two methods provided the *better* estimate of Avogadro’s number? (Do not assume that the closer of the two estimates from your experiments must be the better method. If you repeated the experiments, the results might be quite different from your current calculations.)
2. Oleic acid molecules are not cube-shaped; their actual geometry is oblong, like a capsule. Would this improvement to the procedure cause your revised estimate to be larger or smaller than your current one?
3. An ideal gas at 25 Celsius and 101.3 kPa of room pressure has a volume of 24.4 L. At higher temperatures, gases expand; at higher pressures, gasses contract. If room temperature was warmer than 25.0 Celsius, would your revised estimate of Avogadro’s number be larger or smaller than your current one? If room pressure was smaller than 101.3 kPA, would your revised estimate of Avogadro’s number be larger or smaller than your current one?

# References

Not yet formatted references:

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