Unit 5

On completion of the unit you should be able to:

1. write the number of particles in a mole.
2. calculate the formula (or molecular) mass of compounds.
3. solve problems involving conversions between the mass, the number of moles, the number of formula units and the volume (for gaseous substances at standard temperature and pressure).
4. given the formula of a compound calculate the percent composition.
5. given the composition of a compound calculate the empirical formula.
6. given the composition and molecular mass of a molecular compound calculate the molecular formula.
7. express solution concentration in moles/liter.
8. do calculations involving solutions which have concentrations expressed in moles/liter.
9. solve dilution calculation.

Today's focus.

THE MOLE CONCEPT	
5.1 **Mole concept**	5.7 **Molar volume of a gas**
Reading: Hebden – page 78	Reading: Hebden – page 82
5.2 **Formula mass**	5.8 **Percent composition of compounds**
5.3 **Information in chemical formulae**	Reading: Hebden – page 90
5.4 **From amu to gram**	5.9 **Empirical formula**
5.5 **Molar mass**	Reading: Hebden – page 91-95
Reading: Hebden – page 79	5.10 **Molarity and solution preparation**
5.6 **Calculations involving Avogadro's number**	Reading: Hebden – page 96-98
Reading: Hebden – page 81-88	5.11 **Solution dilution**
	Reading: Hebden – page 99

Mole Concept

Avogadro's Number is $6.02x10^{23}$

The **mole unit** is used to express:

1. A mass quantity
2. A counting quantity

1 water molecule

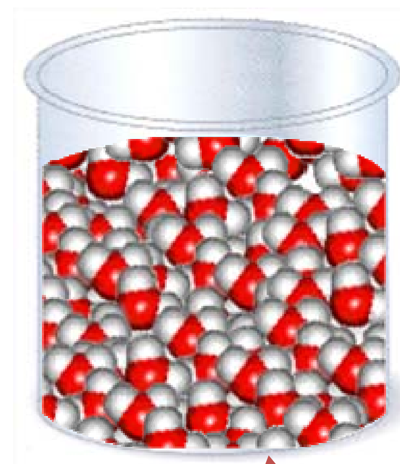
1 mole of water molecules

Conversion Factors:

$6.02x10^{23}$ amu = 1 gram

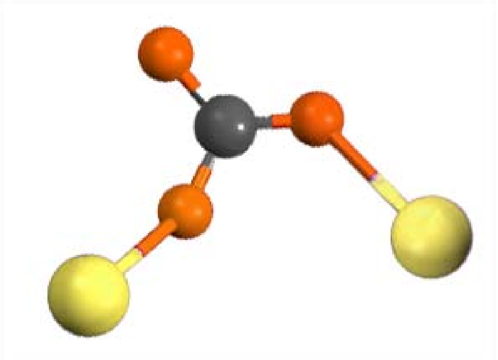
(Scale up so that we can weigh in the lab)

$6.02x10^{23}$ water molecules	=	1 mole of water molecules



$\frac{\text{amu}}{\text{molecule}}$ ← **Formula Mass Units** → $\frac{\text{g}}{\text{mole}}$

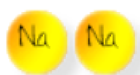
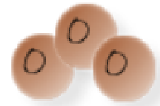
Information in Chemical Formulae



$$Na_2CO_3$$

Number of ratio of atoms: (parts)

Na : C : O

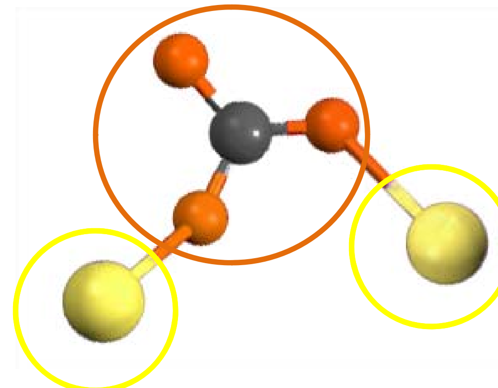
one formula unit	 **two** Na atoms	 **one** C atom	 **three** O atoms
one mole formula units	**2** moles (= 12.044 x 10^{23}) Na atoms	**1** mole (= 6.022 x 10^{23}) C atoms	**3** moles (= 18.066 x 10^{23}) O atoms

2 : 1 : 3

Information in Chemical Formulae

Number of ratio of ions: (parts)

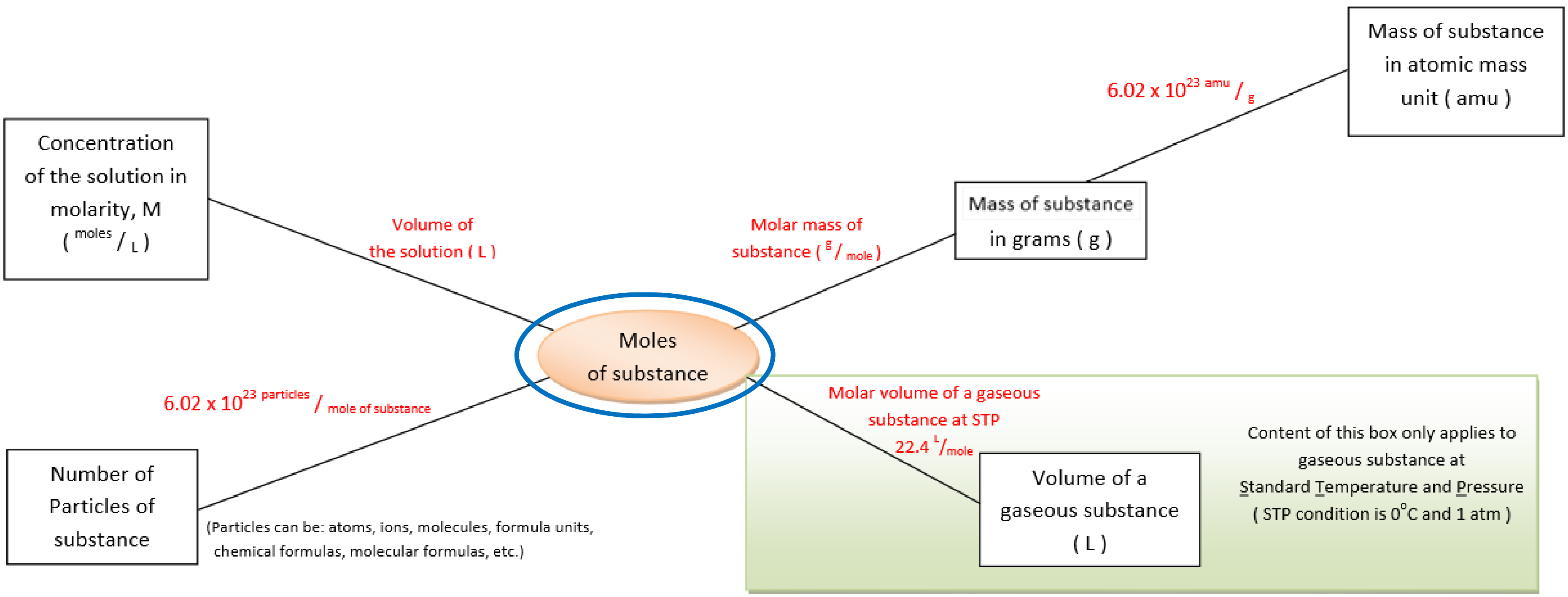
Na_2CO_3



Na^+ CO_3^{2-}

2 : 1

Expanded Road Map for "Mole - Mass - Volume - Particles" Calculations



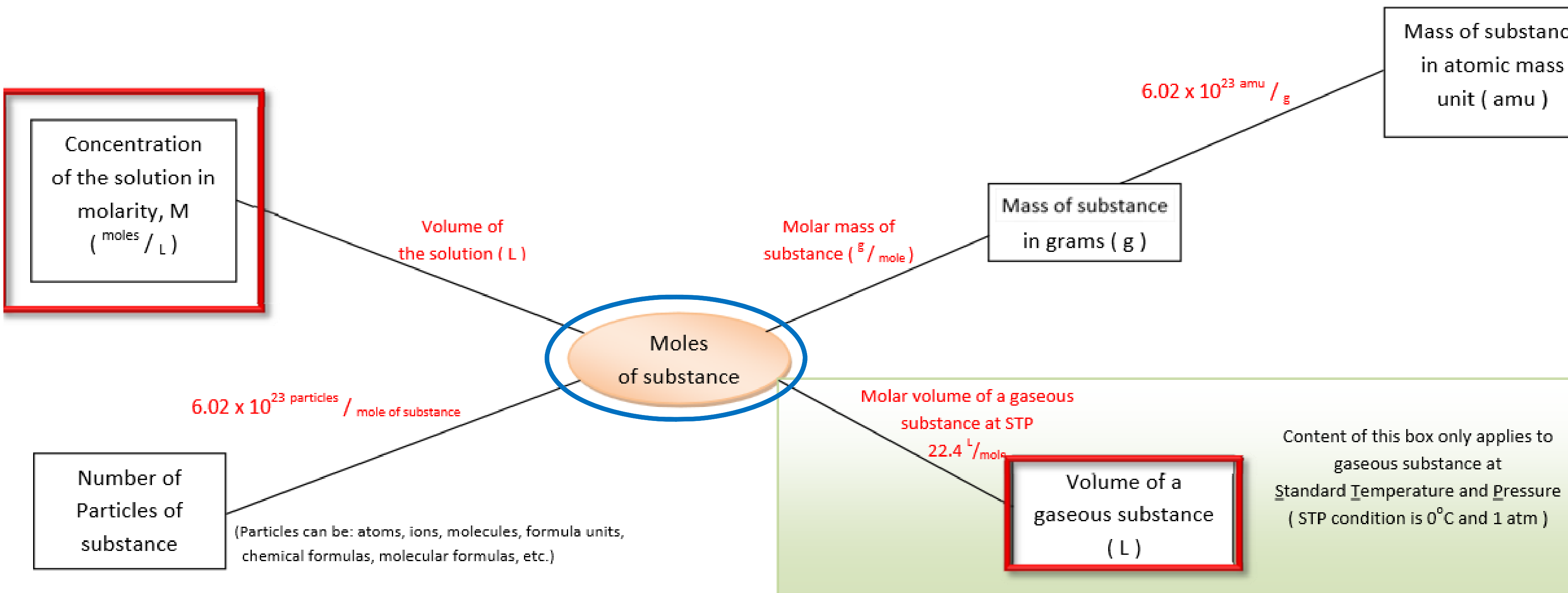
Particles can be:

- # of atoms,
- # of ions,

(# of atoms, # of ions: Parts of a formula unit)

- # of molecules,
- # of formula units

Expanded Road Map for "Mole - Mass - Volume - Particles" Calculations



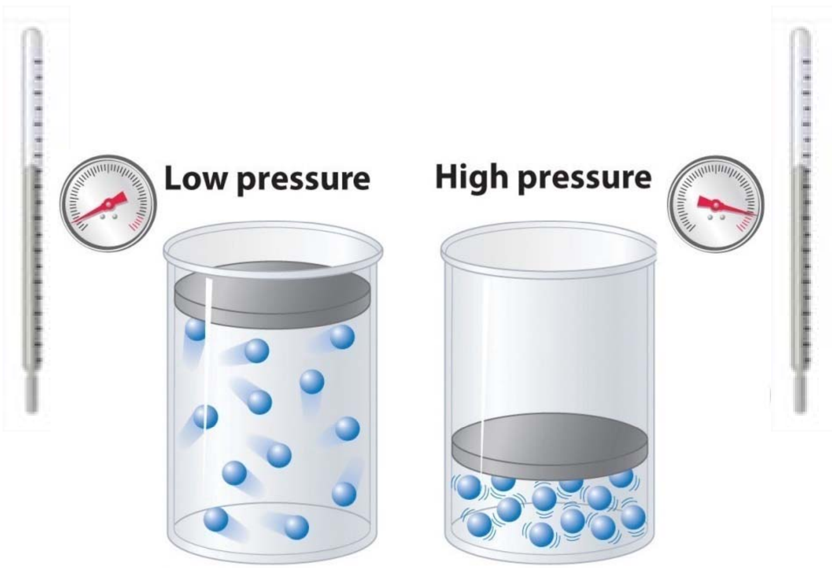
Particles can be:
- # of atoms,
- # of ions,
- # of molecules,
- # of formula units

(# of atoms, # of ions:) Parts of a formula unit

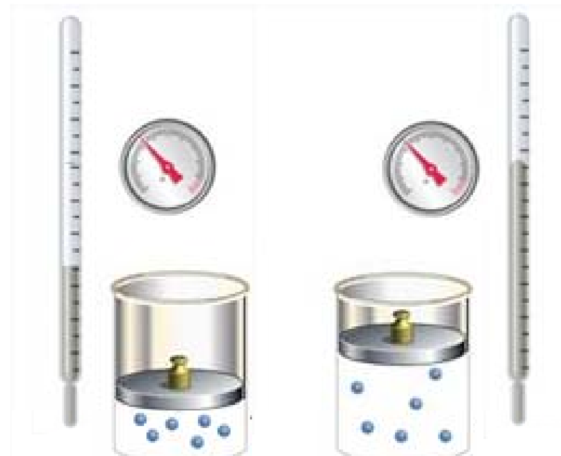
Green box only applies to a gas!!

Molar Volume of a Gas

Volume of a gas is sensitive to both pressure and temperature



Gas occupies larger volume at low pressure, and smaller volume at high pressure.



Gas occupies larger volume at higher temperature.

Molar Volume of a Gas

A common set of conditions that is often used by scientists is called

<u>S</u>tandard <u>T</u>emperature and <u>P</u>ressure or **STP**

Implies: standard temperature is 273 K (or $0^{o}C$).
standard pressure is 1 atm (760 torr)

Molar Volume of a Gas

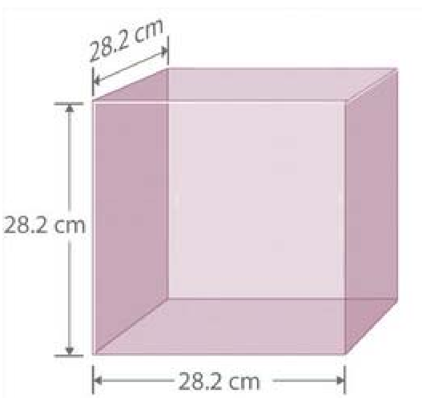
STP condition is 273.15 K and 1 atm

For *any* gas **at STP**, when the molar mass of the gas is divided by the density of the gas, the value "22.4" is always obtained.

$$\frac{\text{molar mass of the gas } (\frac{g}{mole})}{\text{density of the gas } (\frac{g}{L})} = 22.4\ \frac{\text{Liter}}{\text{mole}}$$

What is the unit?

22.4 $^{L}/_{mole}$ is known as the molar volume of a gas at STP.



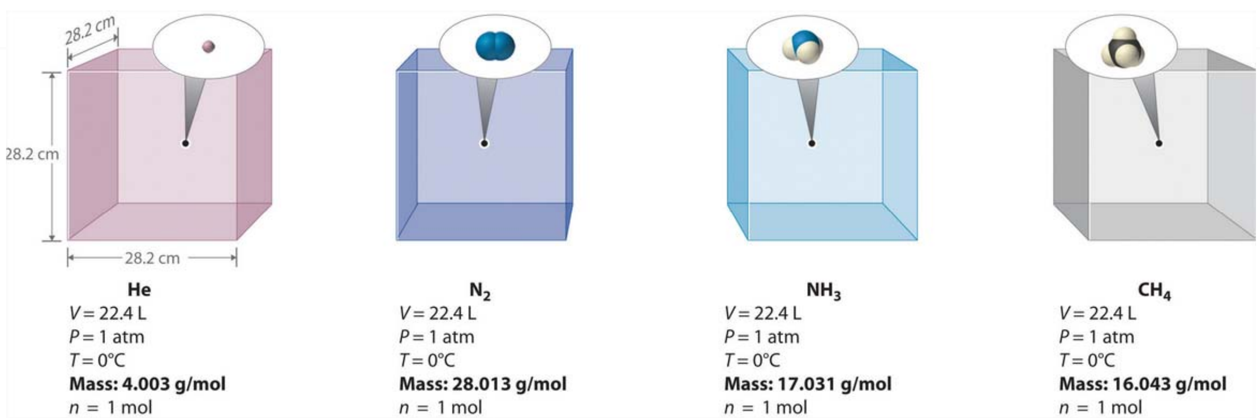
1 mole of gas occupies 22.4 L at STP.

Molar Volume of a Gas

At STP condition is 273.15 K and 1 atm

$$\frac{\text{molar mass of the gas } (\frac{g}{mole})}{\text{density of the gas } (\frac{g}{L})} = 22.4 \ \frac{\text{Liter}}{\text{mole}}$$

Gas	Molar Mass (g/mole)	Density at STP (g/L)	Molar Mass/Density (L/mole)
N_2, nitrogen gas	28.014	1.25	
O_2, oxygen gas	31.998	1.43	
CH_4, methane gas	16.043	0.714	
CO_2, carbon dioxide	44.009	1.96	
H_2, hydrogen gas	2.015	0.090	
Ar, argon gas	39.948	1.78	



Molar Volume of a Gas

$22.4 \frac{\text{Liter}}{\text{mole}}$ **At STP condition is 273.15 K and 1 atm**

Avogadro's Law

At the same T and P,

Volume increases proportionally as the amount of gas increases

i.e. When the amount of gas is doubled, the volume of the gas is doubled.

According to Avogadro's Law, at STP, how much volume does *2 moles* of gas occupy?

$$22.4 \frac{\text{Liter}}{\text{mole}} \times 2 \text{ moles} = 44.8 \text{ Liters}$$

Volume is doubled!

Molar Volume of a Gas

Q: What is the density of O_2 (g) at STP?

$$\frac{\text{molar mass of the gas } (\frac{\text{g}}{\text{mole}})}{\text{density of the gas } (\frac{\text{g}}{\text{L}})} = 22.4\ \frac{\text{Liter}}{\text{mole}}$$

$$\text{density of the gas } (\frac{\text{g}}{\text{L}}) = \frac{\text{molar mass of the gas } (\frac{\text{g}}{\cancel{\text{mole}}})}{22.4\ \frac{\text{Liter}}{\cancel{\text{mole}}}}$$

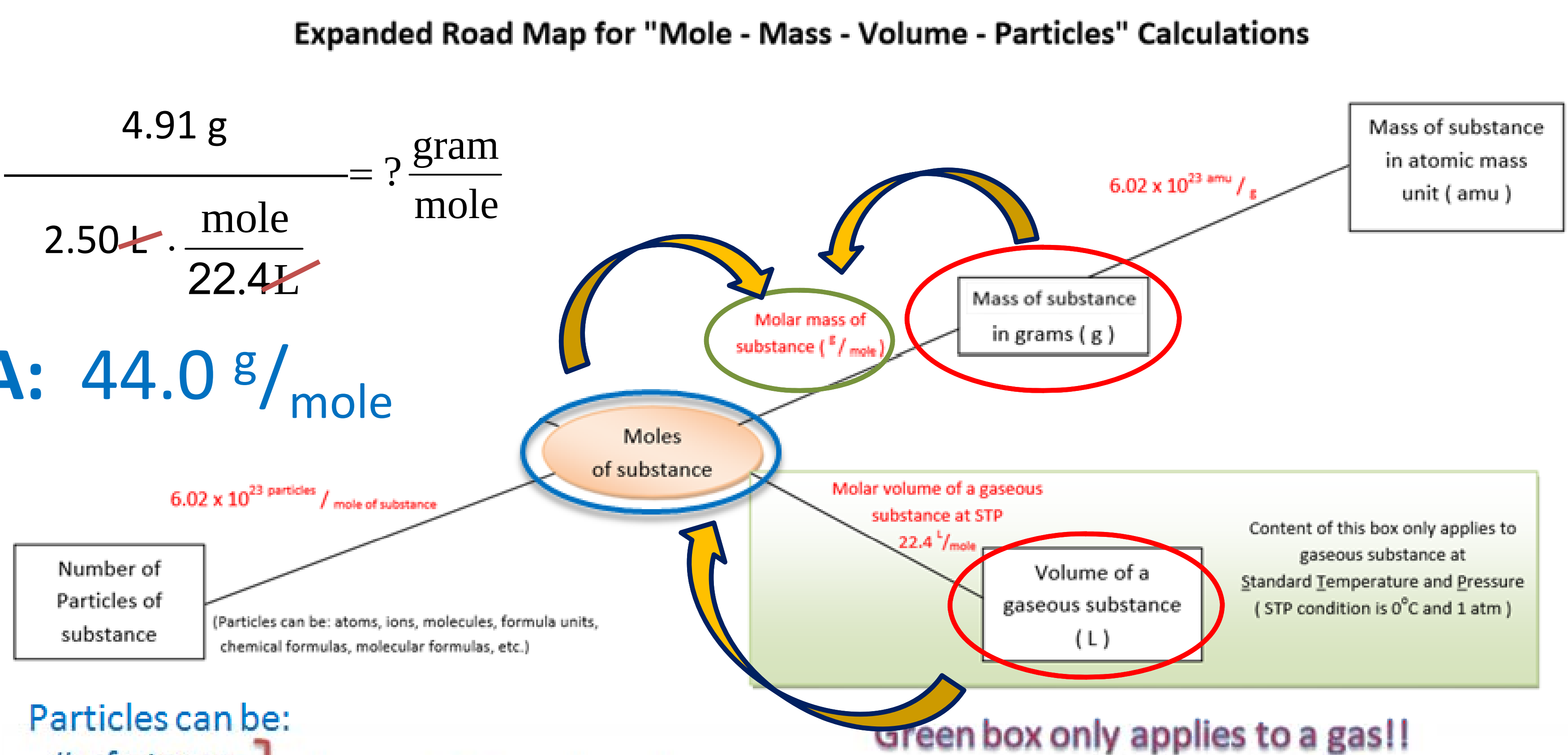
Molar mass of O_2 (g) = 31.9998 $^{g}/_{mole}$

A: 1.43 $^{g}/_{L}$

Q: A 2.50 L container contains 4.91 g of a gas at STP. What is the molar mass of the gas?

$$\frac{4.91\ \text{g}}{2.50\ \cancel{\text{L}} \cdot \dfrac{\text{mole}}{22.4\ \cancel{\text{L}}}} = ?\ \frac{\text{gram}}{\text{mole}}$$

A: 44.0 $^{g}/_{mole}$



Particles can be:
- # of atoms,
- # of ions,
- # of molecules,
- # of formula units

(# of atoms, # of ions: Parts of a formula unit)

Molarity and Solution Preparation

Concentration is expressed in Molarity (M)

(The bigger the number, the more concentrated the solution.)

$$\text{Molarity (M)} = \frac{\text{Amount of solute in moles}}{\text{Total volume of solution in Liters}}$$

Example:

Experiment 5 – Introduction to Separation Techniques II

Solution:

1. 0.5 M lead (II) nitrate, $Pb(NO_3)_2$, solution
2. 0.1 M silver nitrate, $AgNO_3$, solution
3. 0.5 M potassium chromate, K_2CrO_4, solution
4. Dilute hydrochloric acid, HCl

Read:

"0.5 Molar lead (II) nitrate solution"

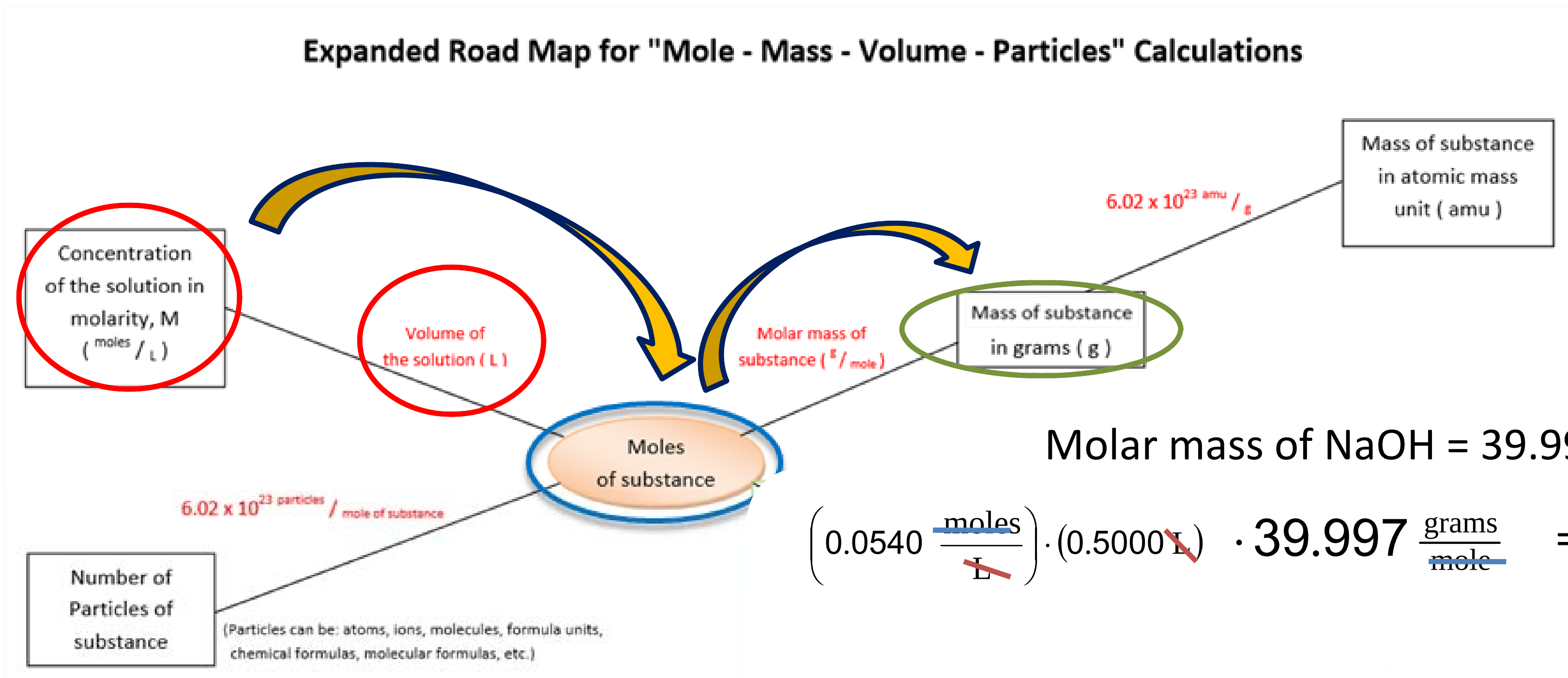
"0.1 Molar silver nitrate solution"

"0.5 Molar potassium chromate solution"

How do we prepare a solution of a known concentration?

Molarity and Solution Preparation

Target: Prepare a 0.0540 M NaOH solution. We want 500.0 mL of this solution.



Molar mass of NaOH = 39.997 $^{g}/_{mole}$

$$\left(0.0540\ \frac{\text{moles}}{\text{L}}\right)\cdot(0.5000\ \text{L})\cdot 39.997\ \frac{\text{grams}}{\text{mole}} = 1.08\ \text{grams}$$

Step 1: Weigh this amount

(Note: This is not the colour of NaOH.)

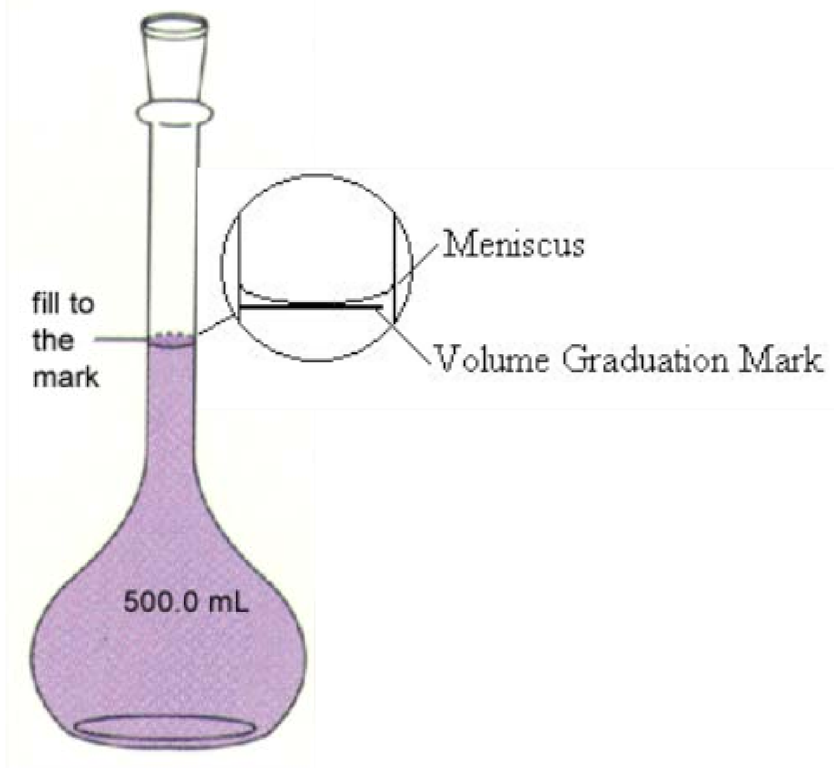
Molarity and Solution Preparation

Target: Prepare a 0.0540 M NaOH solution. We want 500.0 mL of this solution.

Step 2: Transfer the solid to a 250 mL beaker that is partly filled with distilled water. Dissolve the solid in the beaker.

(Note: This is not the colour of NaOH.)

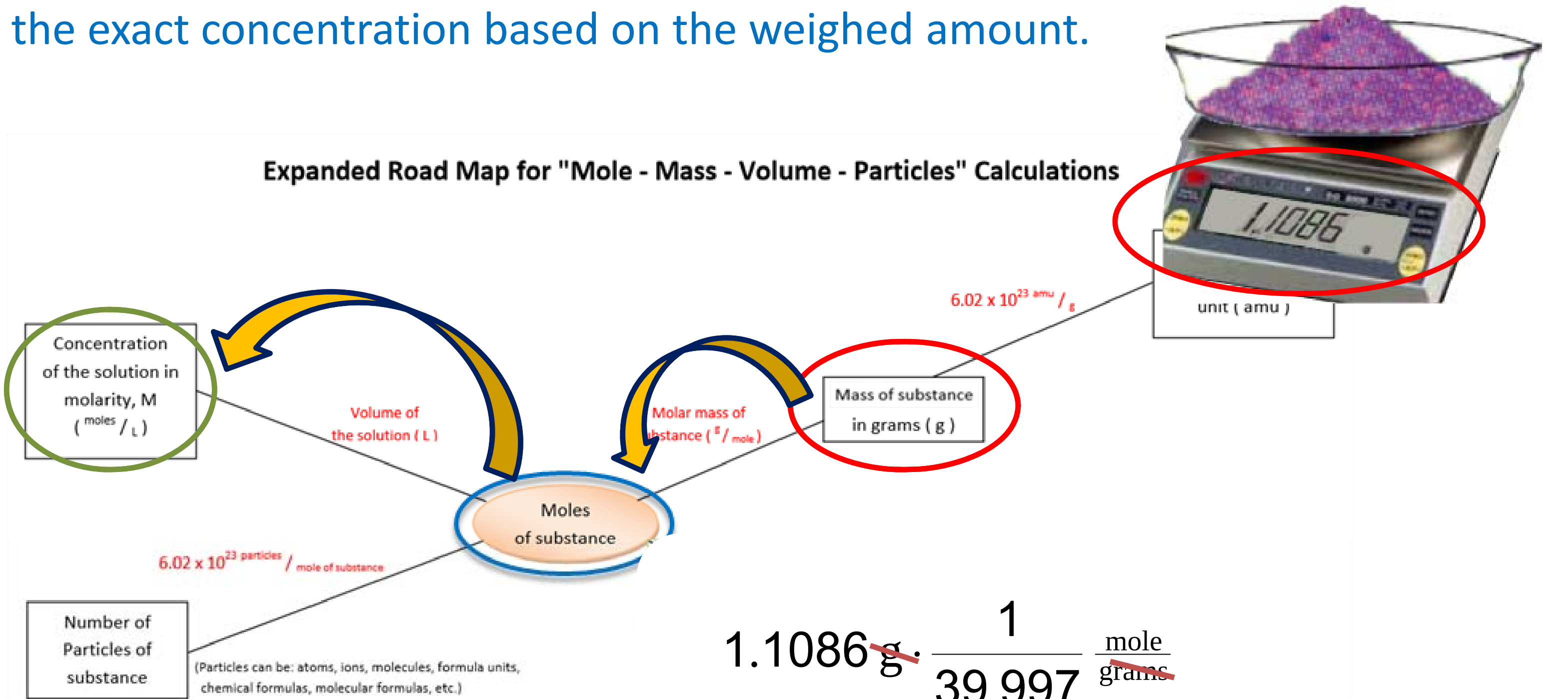
Step 3: *Quantitatively transfer* the solution in the beaker to the volumetric flask. Fill the flask with distilled water up to the mark. Stopper the volumetric flask and **shake vigorously** to ensure the solution is well mixed.



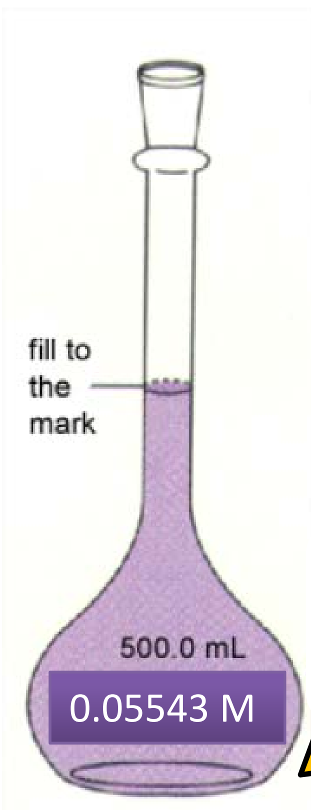
Molarity and Solution Preparation

Target: Prepare a 0.0540 M NaOH solution. We want 500.0 mL of this solution.

Step 4: Calculate the exact concentration based on the weighed amount.



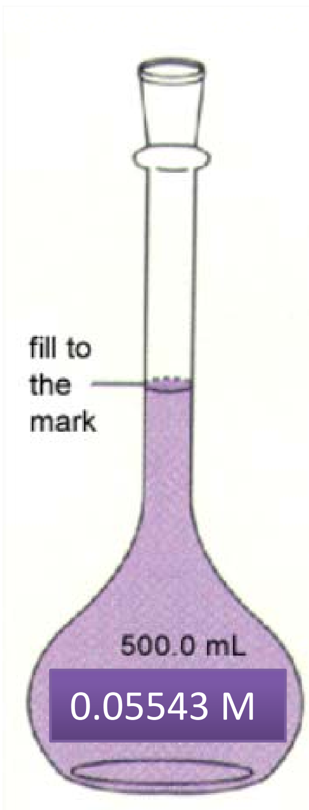
$$\frac{1.1086\,\not{\text{g}}\cdot\frac{1}{39.997}\frac{\text{mole}}{\not{\text{grams}}}}{0.5000\ \text{L}} = 0.05543\ \text{M}$$



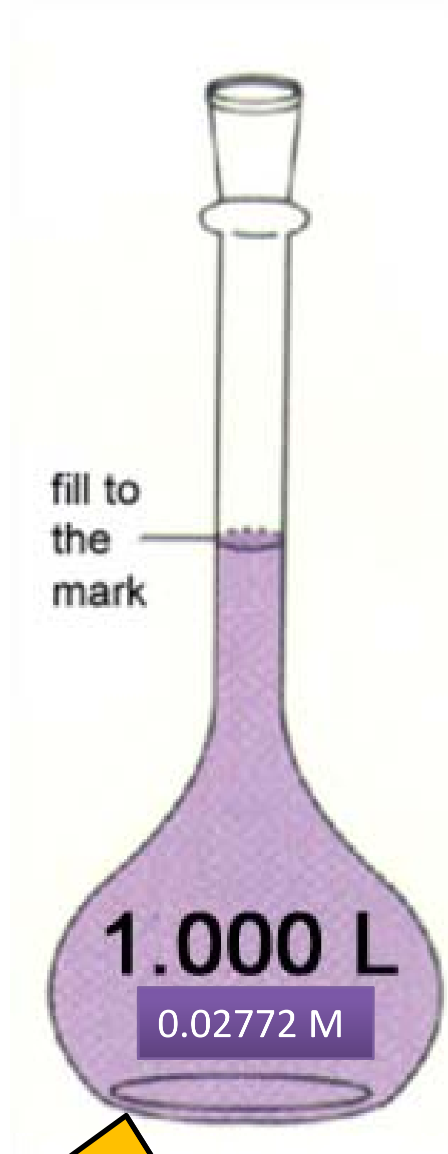
Put a label on the bottle

(Note: This is not the colour of NaOH.)

Solution Dilution

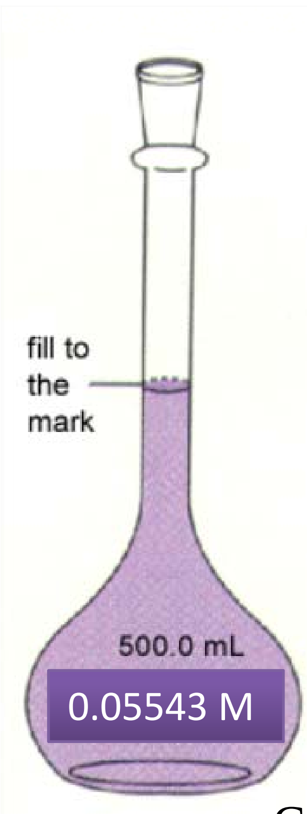


What is the concentration if I dilute the solution by pouring the entire 500.0 mL into a 1 L volumetric flask and filling it to the mark with distilled water?



Solution Dilution

What is the concentration if I dilute the solution by pipetting 15.00 mL of the 0.05543 M solution into a 1.000 L volumetric flask and filling it to the mark with distilled water?



Subscript ‘1’ Solution

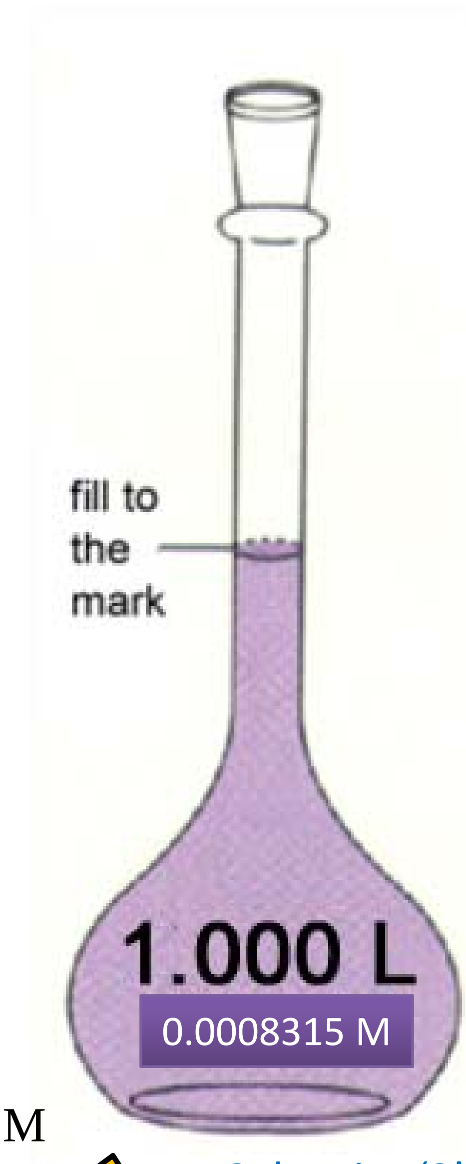
Dilution Formula

$$C_1V_1 = C_2V_2$$

C_1 = 0.05543 M
V_1= 0.01500 L

C_2 = ?M
V_2 = 1.000 L

$$C_2 = \frac{0.05543\,\frac{\text{mole}}{\text{L}} \cdot 0.01500\,\text{L}}{1.0000\,\text{L}} = 0.0008315\,\text{M}$$



Subscript ‘2’ Solution

Solution Dilution

Q: How would you prepare 25.00 mL of 0.2320 M CH_3COOH solution from a 0. 3003 M CH_3COOH solution? Calculate and fill in the plan of action.

Dilution Formula

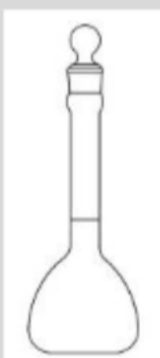
$$C_1V_1 = C_2V_2$$

$C_1 = 0.3003$ M
$V_1 = ?$

$C_2 = 0.2320$ M
$V_2 = 25.00$ mL

$$V_1 \frac{0.2320 \frac{\text{mole}}{\text{L}} \cdot 0.02500 \quad \text{L}}{0.3003 \quad \text{L}} = 0.01931 \quad \text{L}$$

Plan of action (watch significant figures):



I would pipet 19.31 (volume in mL) mL of CH_3COOH from the

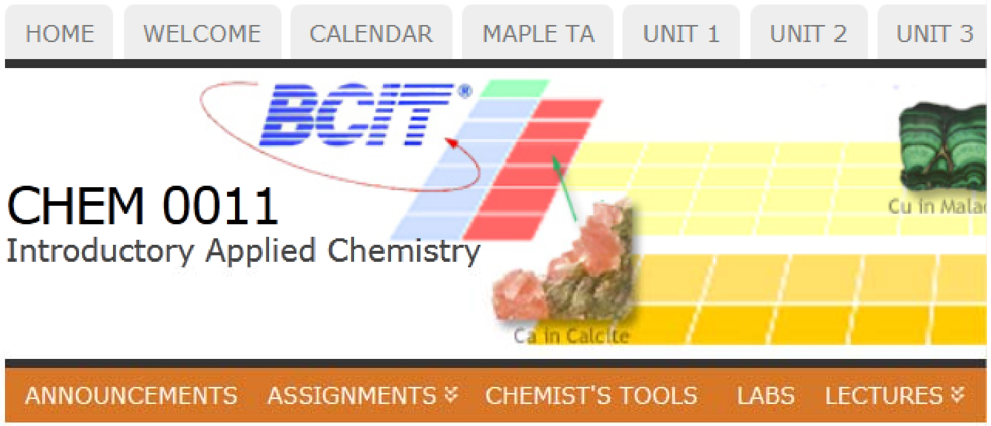
0.3003 (concentration) M CH_3COOH solution into a volumetric flask.

Then I would add water to make the volume up to the mark in the volumetric

flask to obtain a total volume of 0.02500 (volume in L) L of a

0.2320 (concentration) M CH_3COOH solution.

Solution Worksheet



« **DUE:** Paper Assignment 3 due Feb 6 in lecture (Week 5)

Scanned Lecture Notes

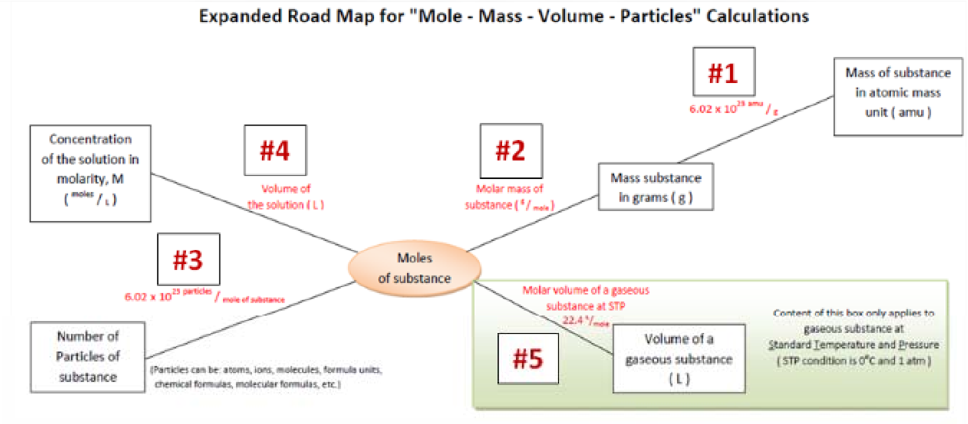
Road Maps:

- Mole – Mass – Volume – Particles conversion
- From Percent Composition to Empirical Formula to Chemical For

Worksheets:

- Lab Report Write up Instructions
- Unit 2 – Density Questions Worksheet
- Unit 3 – Naming Worksheet – Name to Chemical Formula and Ch
- Unit 5 – Mole Concept Worksheet
- Unit 5 – Salt & Sugar Worksheet
- Unit 5 – Percent Composition, Empirical Formula, Chemical Form
- Unit 5 – Solution Worksheet – Maple TA Type Questions
- Unit 5 – Solution Dilution Worksheet
- Unit 6 – From Combustion Analysis of C, H, O containing compou
  TA type problem in Assignment 7
- Unit 6 – Single Replacement Reactions Worksheet (Watch animat

Solution Worksheet



Solution Calculations - Maple TA type questions

For each of the following questions, ask yourself:

Is it a dilution question?

If yes, then the plan of action is:

Use dilution equation $C_1V_1 = C_2V_2$

If no, then the plan of action is:

Locate where you are on the road map and determine the conversion factor(s) needed.

1. Calculate the molarity of the solution that was prepared by diluting 9.46 mL of 1.4 M $BaCl_2$ solution to 91.8 mL?

Plan of Action:

Do the *Solution* Worksheet and *Solution Dilution* Worksheet.
Answers will be posted later in the week.

Try some practice problems in Maple TA.

Use Dimensional Analysis in ALL your calculations!!