MODULE 8 -SOLUTIONS

REF: CHAPTER 9 OF TEXTBOOK

SOLUTIONS

TOPICS COVERED :

- ✓CHARACTERISTIC OF SOLUTIONS
- ✓SOLUBILITY
- ✓SOLUTION FORMATION
- ✓SOLUBILITY RULES
- ✓SOLUTION CONCENTRATION
- ✓CONCENTRATION: PERCENTAGE OF SOLUTE (M/M: V/V M/V), PARTS PER MILLION AND PARTS PER BILLION
- ✓MOLARITY
- ✓DILUTION

CHARACTERISTIC OF SOLUTIONS

- A SOLUTION IS A SPECIAL TYPE OF HOMOGENEOUS MIXTURE COMPOSED OF TWO OR MORE SUBSTANCES. I
- IN SUCH A MIXTURE, A SOLUTE IS A SUBSTANCE DISSOLVED IN ANOTHER SUBSTANCE, KNOWN AS A SOLVENT.

- THE ***SOLUTE*** IS THE COMPONENT THAT IS DISSOLVED – THAT IS, THE LEAST ABUNDANT COMPONENT OF THE SOLUTION.
- THE ***SOLVENT*** IS THE DISSOLVING AGENT OR THE MOST ABUNDANT COMPONENT IN THE SOLUTION.

9 TYPES OF TWO COMPONENT SOLUTIONS

GAS SOLUTIONS:	EXAMPLE:
• GAS DISSOLVED IN GAS	DRY AIR
• LIQUID DISSOLVED IN GAS	WET AIR*
• SOLID DISSOLVED IN GAS	MOTHBALLS IN AIR*
LIQUID SOLUTION	
• GAS DISSOLVED IN A LIQUID	SODA
• LIQUID DISSOLVED IN A LIQUID	VINEGAR OR CLEANING SOLUTION
• SOLID DISSOLVED IN A LIQUID	SALT WATER

9 TYPES OF TWO COMPONENT SOLUTIONS

SOLID SOLUTIONS

- GAS DISSOLVED IN SOLID
- LIQUID DISSOLVED IN SOLID
- SOLID DISSOLVED IN SOLID

EXAMPLES

HYDROGEN IN PLATINUM

AMALGAM DENTAL FILLINGS

STERLING SILVER

Solubility describes the maximum amount of solute that will dissolve in a specified amount of solvent.

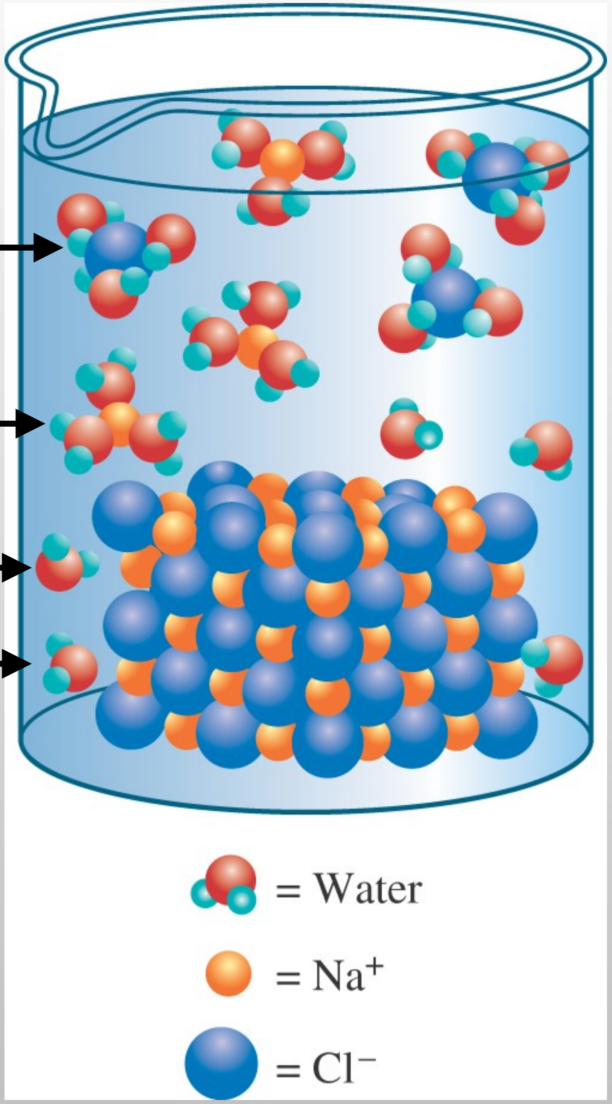
Nature of Solvent-Type of Solute & type of solvent, temperature, particle size and agitation all are factors in determining solubility of solids in liquids.

Dissolution of sodium chloride in water.

The hydrated ions slowly diffuse away from the crystal to become dissolved in solution.

Polar water molecules are attracted to Na^+ and Cl^- ions in the salt or crystal, weakening the attraction between the ions.

As the attraction between the ions weakens, the ions move apart and become surrounded by water dipoles.



EFFECT OF TEMPERATURE ON THE SOLUBILITY OF A SOLID IN A LIQUID

- SOLUBILITY IS EXPRESSED AS GRAMS OF SOLUTE PER 100G OF SOLVENT.
- FOR MOST SOLIDS DISSOLVED IN A LIQUID, AN INCREASE IN TEMPERATURE RESULTS IN INCREASED SOLUBILITY.
  - SOME SOLIDS INCREASE IN SOLUBILITY ONLY SLIGHTLY WITH INCREASING TEMPERATURE.
  - SOME SOLIDS DECREASE IN SOLUBILITY WITH INCREASING IN TEMPERATURE.

As temperature increases, so does the solubility of a solid in a liquid.

Solubilities of Various Compounds in Water at 0°C, 50°C, and 100°C

	Solubility (g solute/100 g H_2O)		
Solute	0°C	50°C	100°C
Lead(II) bromide ($PbBr_2$)	0.455	1.94	4.75
Silver sulfate (Ag_2SO_4)	0.573	1.08	1.41
Copper(II) sulfate ($CuSO_4$)	14.3	33.3	75.4
Sodium chloride (NaCl)	35.7	37.0	39.8
Silver nitrate ($AgNO_3$)	122	455	952
Cesium chloride (CsCl)	161.4	218.5	270.5

TEMPERATURE AND SOLUBILITY OF GASES IN LIQUIDS

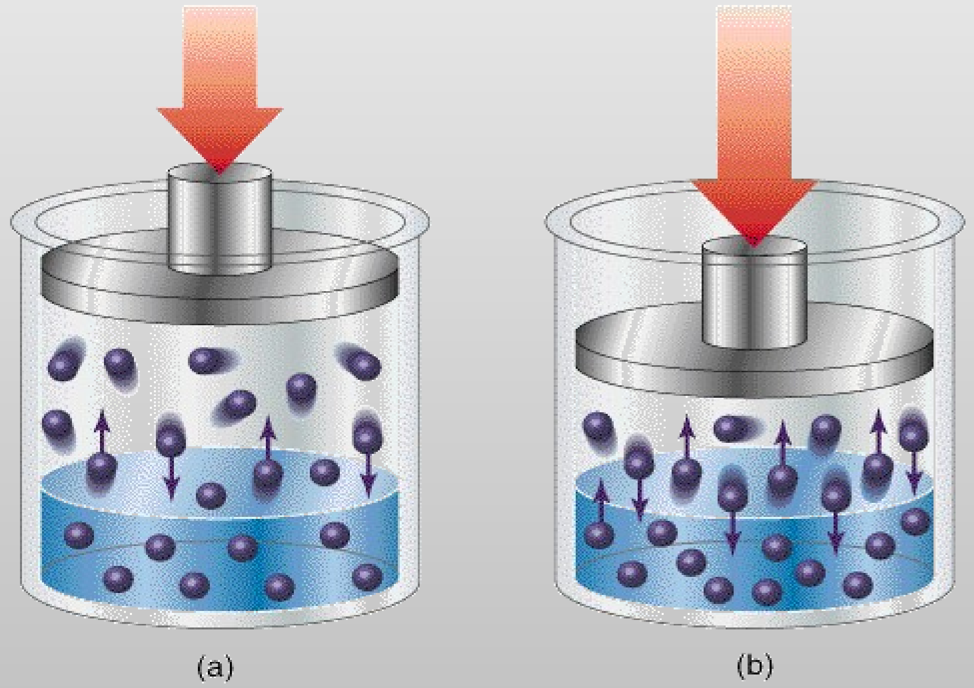
- AS THE TEMPERATURE GOES UP, THE SOLUBILITY OF GASES DECREASES.
  - THE EXTRA ENERGY FROM THE HEAT PROVIDES ENOUGH ENERGY FOR THE GAS MOLECULES TO BREAK THE INTERMOLECULAR FORCES HOLDING THEM IN SOLUTION ALLOWING THEM TO ESCAPE.

Pressure Effects

Solubility of a gas in a liquid is also a function of the pressure of the gas.

The higher the pressure, the more molecules that are close to the liquid's surface and the greater the solubility of the gas.

The lower the pressure, the fewer molecules of gas are close to the liquid's surface and the lower the solubility.



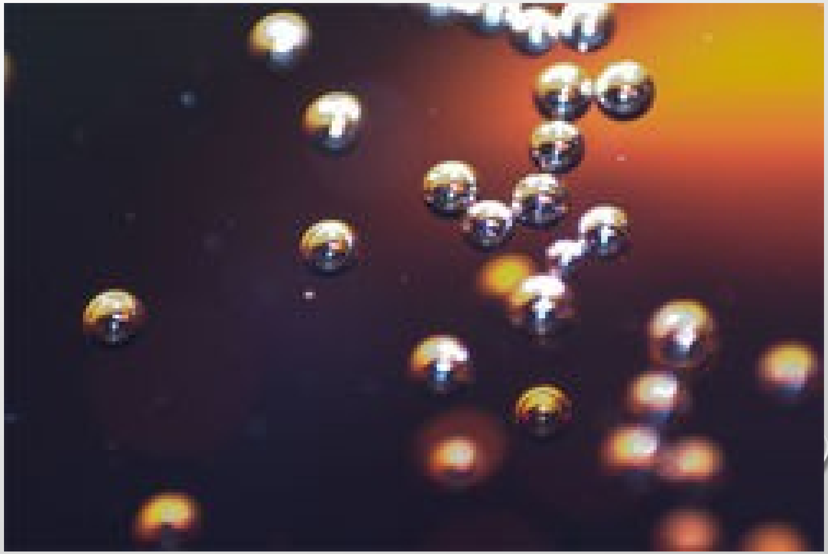
Small pressure changes have little effect on the *solubility* of liquids and solids.

PRESSURE AND SOLUBILITY

SOLIDS AND LIQUIDS ARE NOT INFLUENCED BY CHANGES IN PRESSURE THE SAME WAY AS GASES.

Increase in pressure results in an increase in the solubility of gases.

That's why soda is packed under pressure.



- Terms that describe the extent of solubility of a solute in a solvent:
  - VERY SOLUBLE – GREATER THAN 10g/100g SOLVENT
  - SOLUBLE – 1-10g/100g SOLVENT
  - SLIGHTLY SOLUBLE – 0.1-1g/100g SOLVENT
  - INSOLUBLE – LESS THAN 0.1g/100g SOLVENT

Nature of Solvent -The general rule for predicting solubility is “like dissolves like”.

- POLAR COMPOUNDS TEND TO BE MORE SOLUBLE IN POLAR SOLVENTS THAN NONPOLAR SOLVENTS.

– NaCl (sodium chloride) is
  - soluble in water
  - slightly soluble in ethyl alcohol
  - insoluble in ether and hexane

Solvent Polarity

- NONPOLAR COMPOUNDS (REMEMBER WAX?) TEND TO BE MORE SOLUBLE IN NONPOLAR SOLVENTS THAN IN POLAR SOLVENTS.

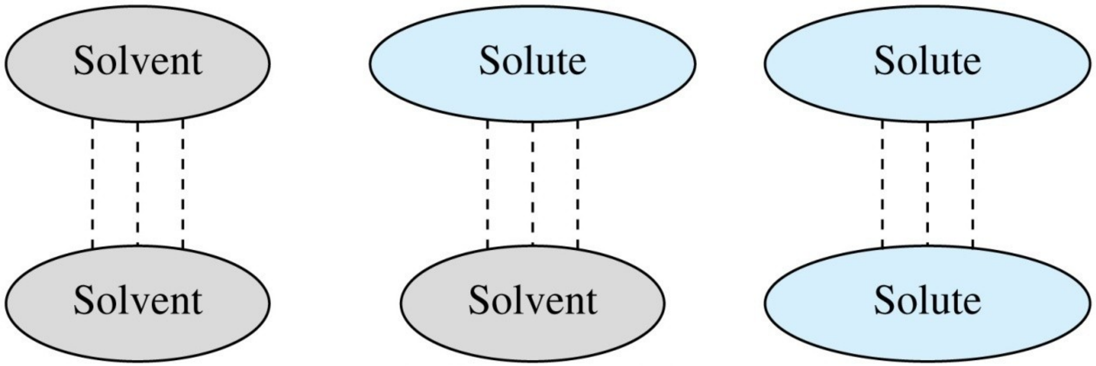
Solvent Polarity

- benzene is:
  - insoluble in water
  - soluble in ether, hexane

On your next test, you will be expected to know how to use the solubility rules in Table 13.4, p. 570 of 11th edition, 10th edition page 572. Table will be provided.

INTERACTIVE FORCES PLAY A ROLL IN DETERMINING SOLUBILITY.

If the solute-solute interactions, solute-solvent interactions and the solvent-solvent interactions exhibit the same types of intermolecular forces and of similar strength (magnitude), then the substance will be forming a homogeneous mixture – a solution



INTERMOLECULAR FORCES AND SOLUBILITY

"Like Dissolves Like" doesn't always work.

The magnitude of the solute-solute interaction (ion-ion forces) and the solute-solvent interaction (ion-dipole forces) play a big role in solubility.

Charge and Size

Table 7.1 General Solubility Rules for Aqueous Solutions

Ion	Rule	Exceptions	
Li^{+} Na^{+} K^{+} NH_4^{+}	soluble	---	
NO_3^{-} CH_3COO^{-}	soluble	---	
Cl^{-1} Br^{-1} I^{-1}	soluble except with …	Ag^{+} Hg_2^{2+} Pb^{2+}	
$SO4^{-2}$	soluble except with …	Ag^{+} Hg_2^{2+} Pb^{2+}	Ca^{2+} Sr^{2+} Ba^{2+}
S^{-2} O^{-2} OH^{-}	insoluble except with …	Li^{+} Na^{+} K^{+} NH_4^{+}	Ca^{2+} Sr^{2+} Ba^{2+}
$CO3^{-2}$ $PO4^{-3}$ $CrO4^{-2}$	insoluble except with …	Li^{+} Na^{+} K^{+} NH_4^{+}	

* *Solubilities cover a wide range from completely soluble to somewhat soluble to completely insoluble. These rules are simply a guide to be used for predicting the products of a reaction.*

* *Ra ions have the same solubility rules as calcium, strontium, and barium. Rb, Cs, and Fr ions have the same solubility rules as lithium through potassium.*

At a specific temperature there is a limit to the amount of solute that will dissolve in a given amount of solvent.

When this condition occurs the solution is said to be saturated.

Saturated solution is a solution that contains maximum amount of solute that can be dissolved under the conditions at which the solution exists.

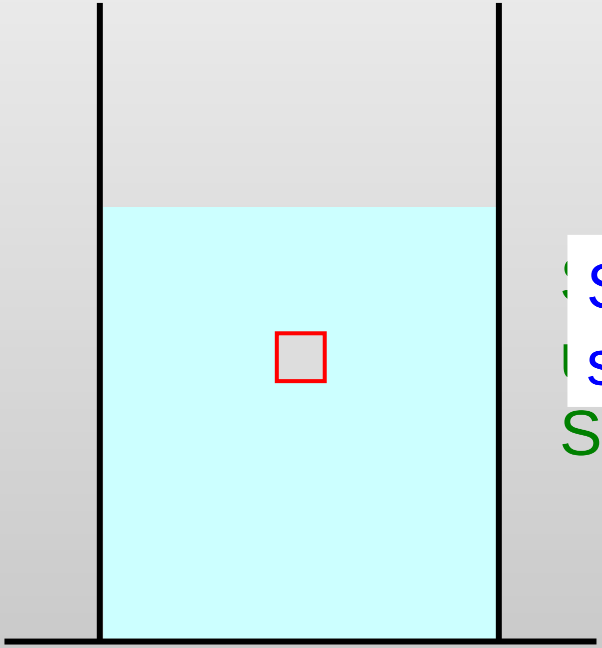
An Unsaturated solution is a solution that contains less solute than the maximum amount that could dissolve.

Note- Lab Solutions are Unsaturated ones

A Supersaturated solution is a solution that contains more dissolved solute than needed for a saturated solution.

Dissolving a Solid in a Liquid

35 g KCl



100 g H_2O

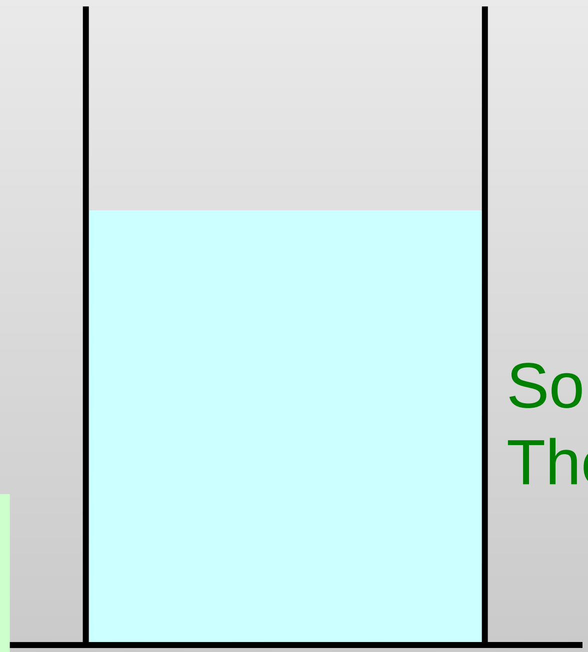
20^oC

Solution is saturated.

No more KCl can dissolve.

Dissolving a Solid in a Liquid

A solution that is saturated at one temperature may not be saturated at another temperature.



Raise temperature

35 g KCl

Solute dissolves

The solution is unsaturated

It may increase or decrease depending on the solute-solvent system.

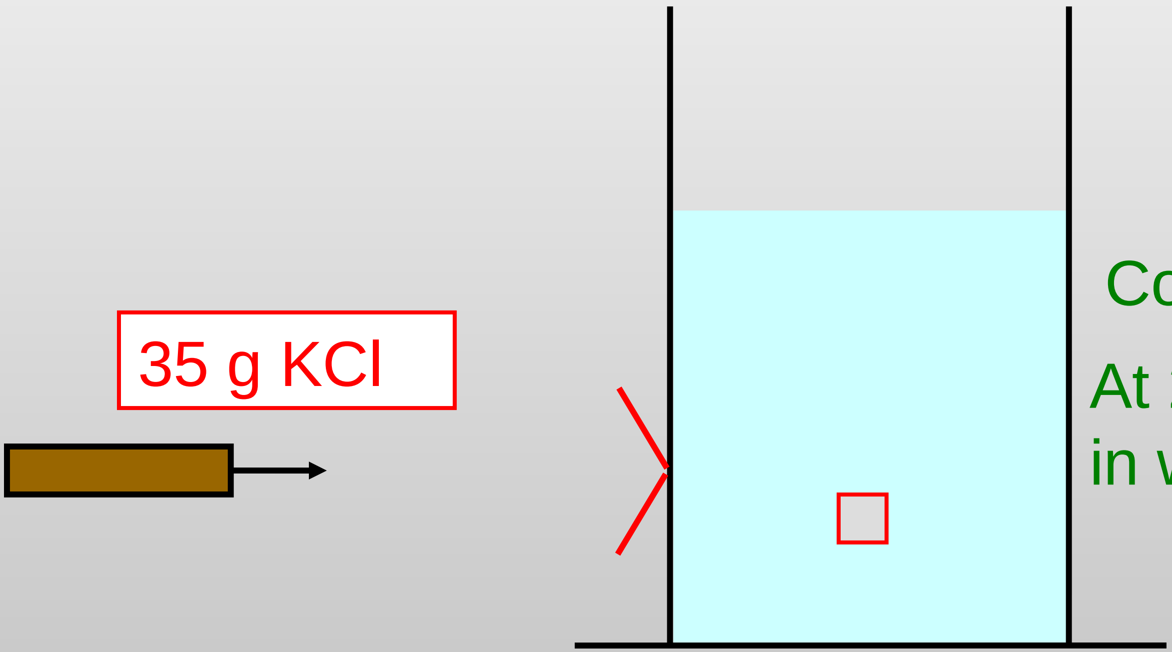
with temperature.

100 g H_2O

50°C

Dissolving a Solid in a Liquid

A stress to the system will cause the solute in excess of the saturation limit to come out of solution.



Cool Solution to 20°C

At 20°C the solubility of KCl in water is 34 g/100 g H_2O.

100 g H_2O

20°C

The solution contains 1 gram of KCl in excess of the solubility limit.

Recap: What factors affects the solubility of solids in liquids?

- NATURE OF SOLVENT

- Generally “like dissolve in like” means polar or ionic compounds (solute) will dissolve in polar solvent and non-polar compound in nonpolar solvent but there are some exceptions also to this rule.

- PARTICLE SIZE
  – Decreasing particle size increases the rate of dissolution (more surface area)

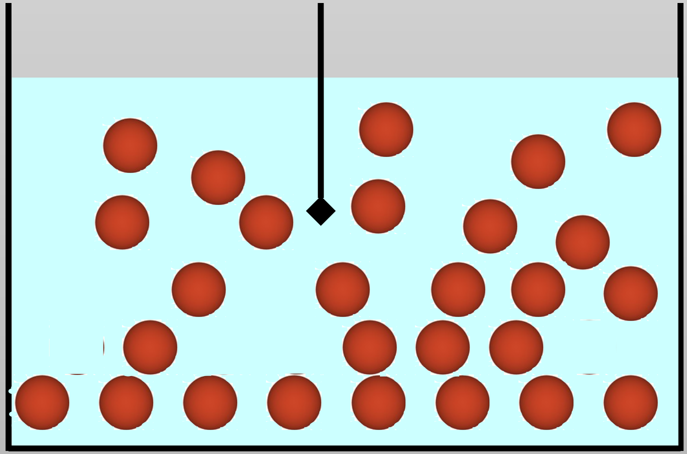
- TEMPERATURE

– In most cases,

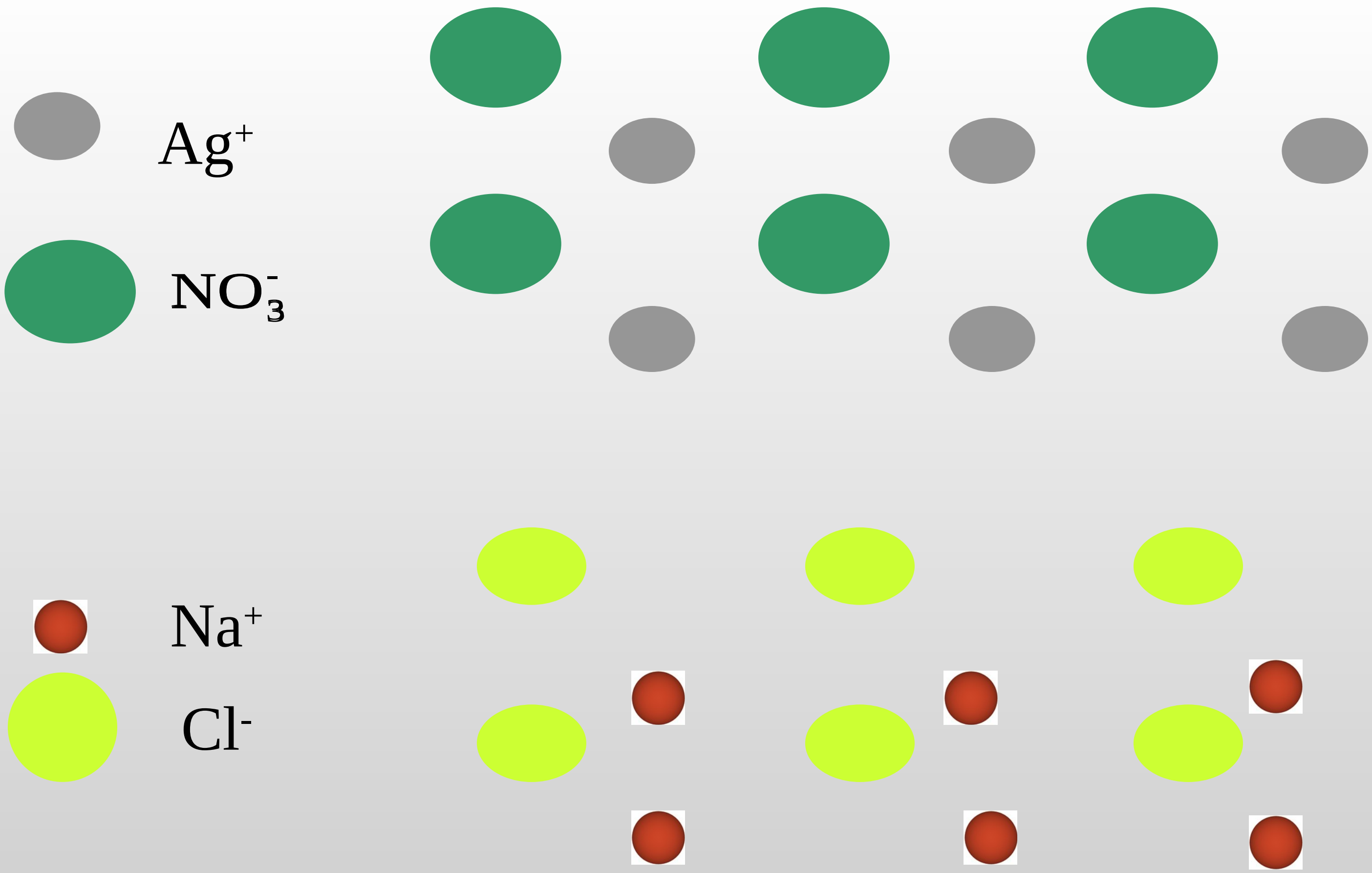
– the rate of dissolving of a solid increases with temperature.

– This occurs because solvent molecules strike the surface of the solid more frequently and harder, causing the solid to dissolve more rapidly.

- AGITATION OR STIRRING.
  - When a solid is first put into water, it comes in contact only with water. The rate of dissolution is then at maximum.
  - Stirring distributes the dissolved solute throughout the water, more water is in contact with the solid, causing it to dissolve more rapidly.



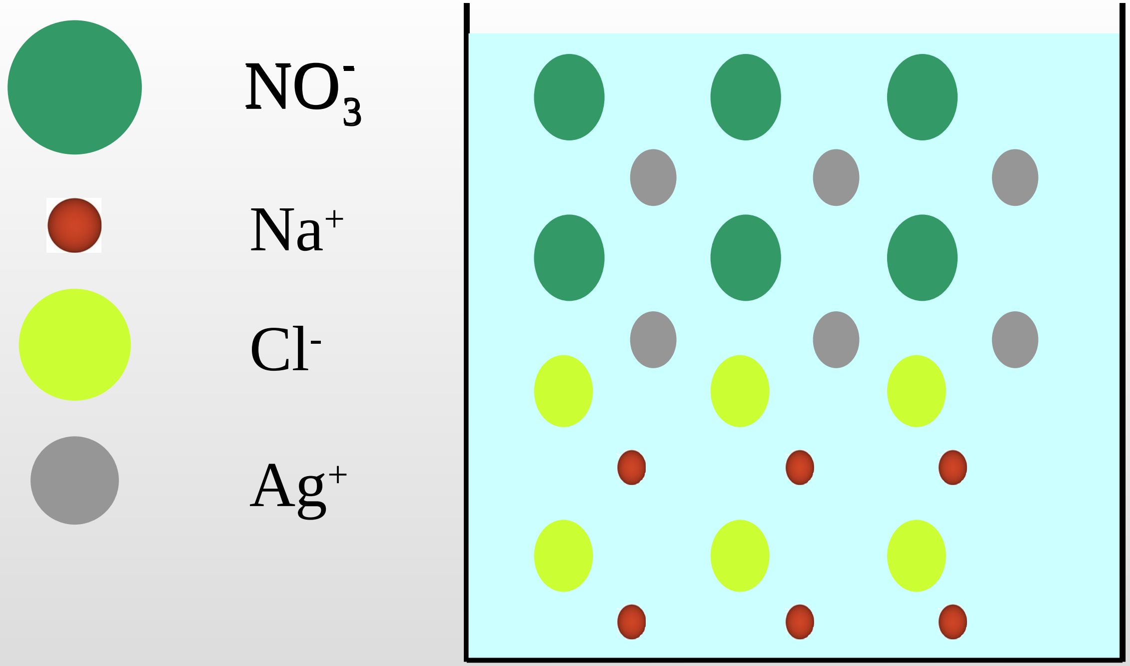
MANY SOLIDS MUST BE DISSOLVED INTO SOLVENT (SOLUTION) TO UNDERGO APPRECIABLE CHEMICAL REACTIONS.



$$NaCl(s) + AgNO_3(s) \rightarrow \text{no reaction}$$

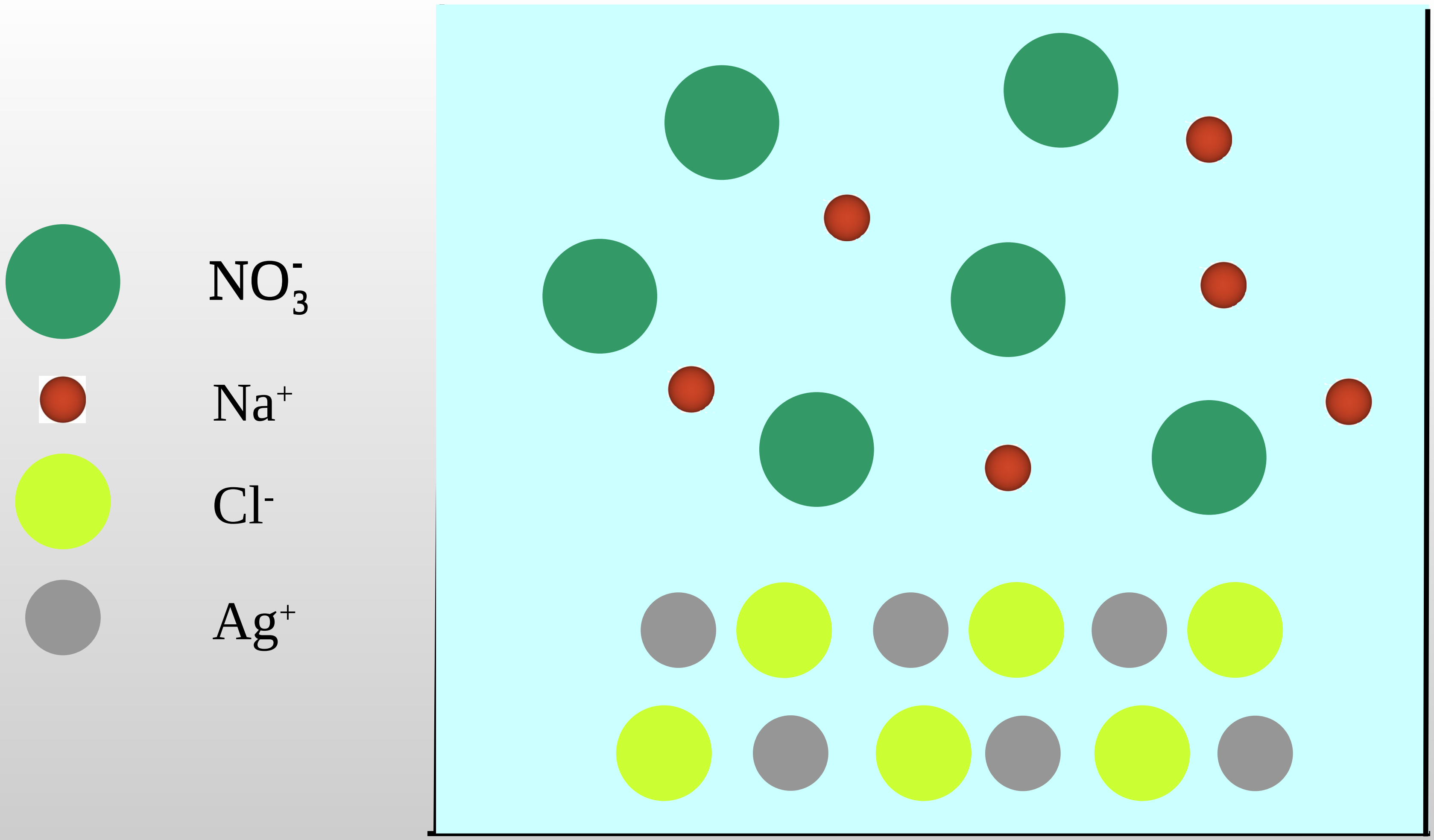
If the reactants are in the solid phase no reaction occurs.

NaCl(s) and AgNO$_3$(s) do not react because their ions are securely locked in their crystal lattices.



If the reactants are dissolved in water an immediate reaction occurs.

$$NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$



$$NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

Mobile Ag^+ and Cl^- ions come in contact and form insoluble AgCl which precipitates.

Na^+ and NO_3^- remain in solution.

AQUEOUS AND NON AQUEOUS SOLUTIONS

- A *NON AQUEOUS SOLUTION* IS A SOLUTION IN WHICH A SUBSTANCE OTHER THAN WATER IS THE SOLVENT. E.G. ALCOHOL-BASED SOLUTIONS ARE OFTEN USED IN A MEDICAL SETTINGS.
- IN A SOLUTION, SOLUTE PARTICLES ARE UNIFORMLY DISPERSED THROUGHOUT THE SOLVENT.

The concentration of a solution expresses the amount of solute dissolved in a given quantity of solution.

- THE TERMS *DILUTE* AND *CONCENTRATED* ARE QUALITATIVE EXPRESSIONS OF THE AMOUNT OF SOLUTE PRESENT IN A SOLUTION.

- A dilute solution contains a relatively small amount of dissolved solute.
- A concentrated solution contains a relatively large amount of solute.

MASS PERCENT (m/m) IS THE MASS OF SOLUTE DIVIDED BY THE TOTAL MASS OF SOLUTION MULTIPLIED BY 100 (TO PUT THE VALUE IN TERMS OF PERCENTAGE).

$$\text{mass percent} = \frac{\text{g solute}}{\text{g solute + g solvent}} \times 100 = \frac{\text{g solute}}{\text{g solution}} \times 100$$

1. What is the mass percent of sodium hydroxide in a solution that is made by dissolving 8.00 g NaOH in 50.0 g H_2O?

grams of solute (NaOH) = 8.00 g

grams of solvent (H_2O) = 50.0 g

$$\text{mass percent} = \left(\frac{\text{g solute}}{\text{g solute} + \text{g solvent}}\right) \text{x } 100$$

$$\left(\frac{\mathbf{8.00\ g\ NaOH}}{\mathbf{8.00\ g\ NaOH + 50.0\ g\ H_2O}}\right) \mathbf{x\ 100 = 13.8\%\ NaOH\ solution}$$

2. What masses of potassium chloride and water are needed to make 250. g of 5.00% solution?

The percent expresses the mass of the solute.

250.g = total mass of solution

$$\text{mass percent} = \left(\frac{\text{g solute}}{\text{g solution}}\right) \text{x } 100$$

Dissolving 12.5 g KCl in 238 g H_2O gives a 5.00% KCl solution.

$$\left(\frac{\text{mass percent x g solution}}{100}\right) = \text{g solute}$$

$$\left(\frac{5.00 \text{ x } 250.\text{ g}}{100}\right) = 12.5 \text{ g KCl solute}$$

$$250.\text{g} - 12.5\text{ g} = 238 \text{ g } H_2O$$

3. A 34.0% sulfuric-acid solution has a density of 1.25 g/mL. How many grams of H_2SO_4 are contained in $\boxed{1.00\text{ L}}$ of this solution?

Step 1. Determine grams of solution.

Grams of solution are determined from the solution density.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Density x Volume = Mass

$$\boxed{1.00\text{ L}} = 1.00 \times 10^3\text{ mL}$$

$$\left(\frac{1.25\text{ g}}{1\text{ mL}}\right)(1.00 \times 10^3\text{ mL}) = 1250\text{ g (mass of solution)}$$

3. A 34.0% sulfuric-acid solution has a density of 1.25 g/mL. How many grams of H_2SO_4 are contained in 1.00 L of this solution?

Solve the mass percent equation for grams of solute.

$$\text{mass percent} = \left(\frac{\text{g solute}}{\text{g solution}}\right) \times 100$$

$$\text{g solute} = \frac{\text{mass percent x g solution}}{100}$$

mass of solution = 1250 g

$$\mathbf{g\ H_2SO_4 = \frac{(34.0\ \ H_2SO_4)(1250\ g)}{100}} = 425\ \text{g}\ H_2SO_4$$

MASS-VOLUME PERCENT (M/V) IS THE MASS OF SOLUTE (IN GRAMS) DIVIDED BY THE TOTAL VOLUME OF SOLUTION (IN ML) MULTIPLIED BY 100

$$\text{mass/volume percent} = \frac{\text{g solute}}{\text{mL solution}} \times 100$$

A 3.0% **m/v** H_2O_2 solution is commonly used as a typical antiseptic to prevent infection. What volume of this solution will contain 10 g of H_2O_2?

Solve the mass/volume equation for grams of solute.

$$\textbf{mass/volume percent} = \frac{\textbf{g solute}}{\textbf{mL solution}} \times 100$$

$$\text{mL solution} = \left(\frac{\text{g solute}}{\text{m/v percent}}\right) \times 100$$

$$\text{mL solution} = \frac{(10 \text{ g } H_2O_2)}{(3.0 \text{ m/v percent})} \times 100 = 330 \text{ mL}$$

The volume percent (v/v) is the volume of solute divided by the total volume of *solution* multiplied by 100.

$$\text{volume percent} = \frac{\text{volume of liquid in question}}{\text{total volume of solution}} \times 100$$

Parts per million (ppm) can be expressed as 1 mg of solute per Kg of solution.

$$\text{ppm of component} = \frac{\text{mass of component in soln}}{\text{total mass of soln}} \times 10^{6}$$

Parts per billion (ppb) are 1 µg of solute per kilogram of solution.

$$\text{ppb of component} = \frac{\text{mass of component in soln}}{\text{total mass of soln}} \times 10^{9}$$

MOLARITY OF A SOLUTION IS THE NUMBER OF MOLES OF SOLUTE PER LITER OF SOLUTION.

Similar like mass/volume calculations but use moles instead of grams and is not a percent

$$\boxed{\text{molarity} = M = \frac{\text{moles of solute}}{\text{liter of solution}} = \frac{\text{moles}}{\text{liter}}}$$

MOLARITY CAN BE CALCULATED FROM GRAMS OF SOLUTE BY CONVERTING TO MOLES OF SOLUTE.

$$\text{molarity} = \frac{\text{number of moles of solute}}{\text{liter of solution}} = \frac{\text{moles}}{\text{liter}}$$

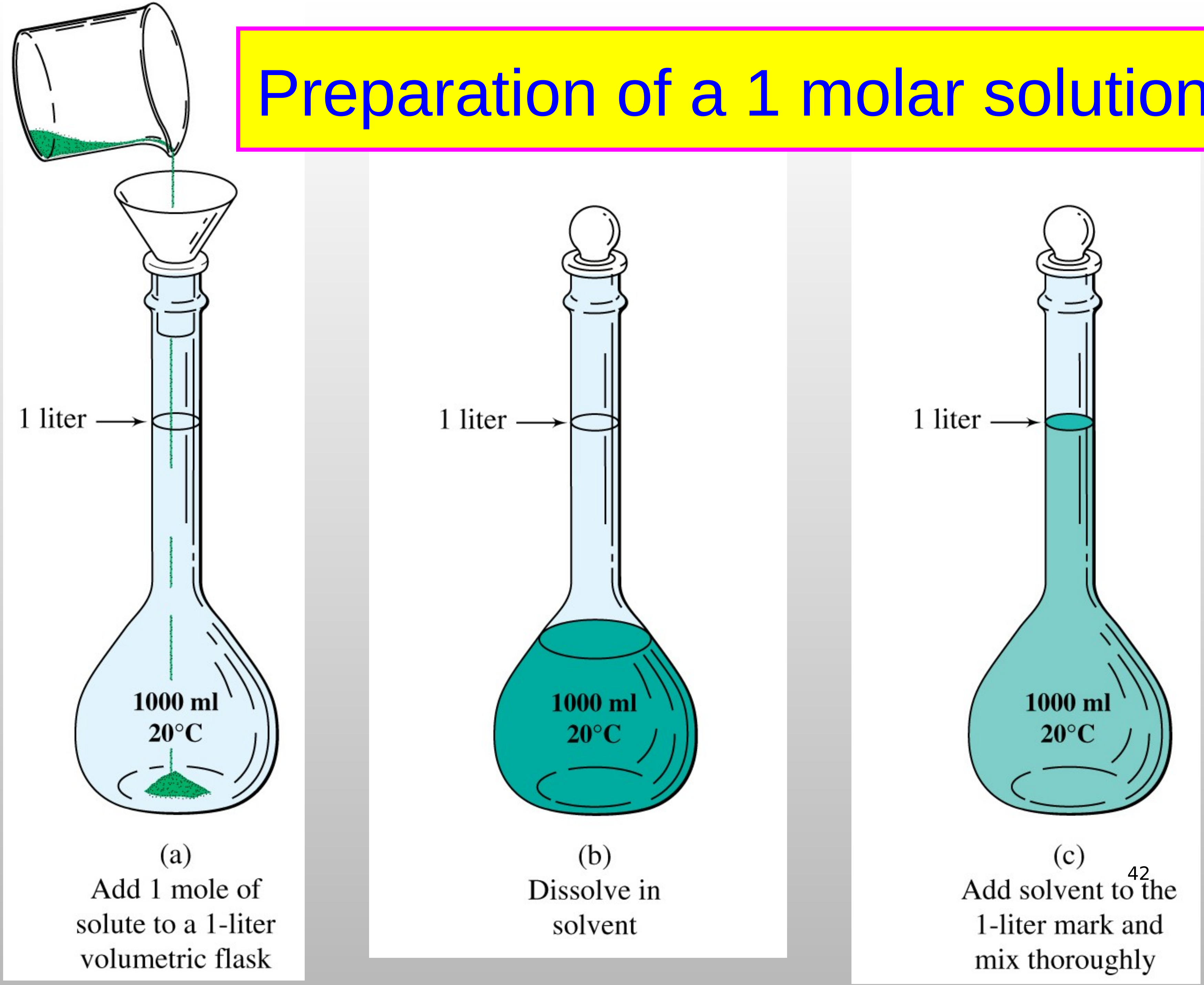
$$\text{moles solute} = \frac{\text{g solute}}{\text{molar mass}}$$

$$\text{Molar mass} = \frac{\text{g}}{\text{mole}}$$

$$\text{Molarity} = \frac{(\text{g solute})\,\frac{(1\ \text{mole})}{(\text{molar mass g})}}{\text{Liter of solution}} = \frac{\text{moles}}{\text{liter}}$$

$$\boxed{\text{molarity} = \frac{\text{g solute}}{\text{molar mass x liter of solution}} = \frac{\text{moles}}{\text{liter}}}$$

Preparation of a 1 molar solution



1. What is the molarity of a solution containing 1.4 mol of acetic acid ($HC_2H_3O_2$) in 250. ml of solution?

It is necessary to convert 250. mL to L since molarity = mol/L.

The conversion is: $\frac{\text{mol}}{\text{mL}} \rightarrow \frac{\text{mol}}{\text{L}} = \text{M}$

$$\left(\frac{\mathbf{1.4\ mol}}{\mathbf{250\ \cancel{mL}}}\right)\left(\frac{\mathbf{1000\ \cancel{mL}}}{\mathbf{L}}\right) = \frac{\mathbf{5.6\ mol}}{\mathbf{L}} = \mathbf{5.6\ M}$$

2. How many grams of potassium hydroxide are required to prepare 600. mL of 0.450 M KOH solution?

Convert: mL $\rightarrow$ L $\rightarrow$ mol $\rightarrow$ g

The data are:

volume = 600 mL

$$M = \frac{0.450\ \text{mol}}{\text{L}} \qquad \text{molar mass KOH} = \frac{56.11\ \text{g}}{\text{mol}}$$

The calculation is:

$$(600\ \cancel{\text{mL}})\left(\frac{1\ \cancel{\text{L}}}{1000\ \cancel{\text{mL}}}\right)\left(\frac{0.450\ \cancel{\text{mol}}}{\cancel{\text{L}}}\right)\left(\frac{56.11\ \text{g KOH}}{\cancel{\text{mol}}}\right) = 15.1\ \text{g KOH}$$

3. Calculate the number of moles of nitric acid in 325 mL of 16 M HNO_3?

Use the equation: moles = liters x M

Convert: mL $\rightarrow$ L

$$(325\ \cancel{\text{mL}})\left(\frac{1\ \text{L}}{1000\ \cancel{\text{mL}}}\right) = 0.325\ \text{L}$$

Substitute the data given in the problem and solve:

$$\text{moles} = (0.325\ \cancel{\text{L}})\left(\frac{16\ \text{mol HNO}_3}{1\ \cancel{\text{L}}}\right) = 5.2\ \text{mol HNO}_3$$

4.What volume of 0.250 M solution can be prepared from 16.0 g of potassium carbonate?

Convert: g $K_2CO_3 \rightarrow$ mol $K_2CO_3 \rightarrow$ L solution

The data are:

$$\text{mass } K_2CO_3 = 16.0 \text{ g}$$

$$M = \frac{0.250 \text{ mol}}{\text{L}} \qquad \text{molar mass } K_2CO_3 = \frac{138.20 \text{ g}}{\text{mol}}$$

The conversion is:

$$(16.0 \cancel{\text{g}}\, K_2CO_3)\left(\frac{1 \cancel{\text{mol}}\, K_2CO_3}{138.2 \cancel{\text{g}}\, K_2CO_3}\right)\left(\frac{1 \text{ L}}{0.250 \cancel{\text{mol}}\, K_2CO_3}\right) = 0.463 \text{ L}$$

5. How many mL of 2.00 M HCl will react with 28.0 g NaOH?

Step 1 Write and balance the equation for the reaction.

$$HCl(aq) + NaOH(s) \rightarrow NaCl(aq) + H_2O(l)$$

Step 2 Find the number of moles of NaOH in 28.0 g NaOH.

Convert: g NaOH → mol NaOH

$$(28.0\ \cancel{g}\ NaOH)\left(\frac{1\ mol}{40.0\ \cancel{g}}\right) = 0.700\ mol\ NaOH$$

5. (contd.) How many mL of 2.00 M HCl will react with 28.0 g NaOH?

Step 3 Solve for moles and volume of HCl.

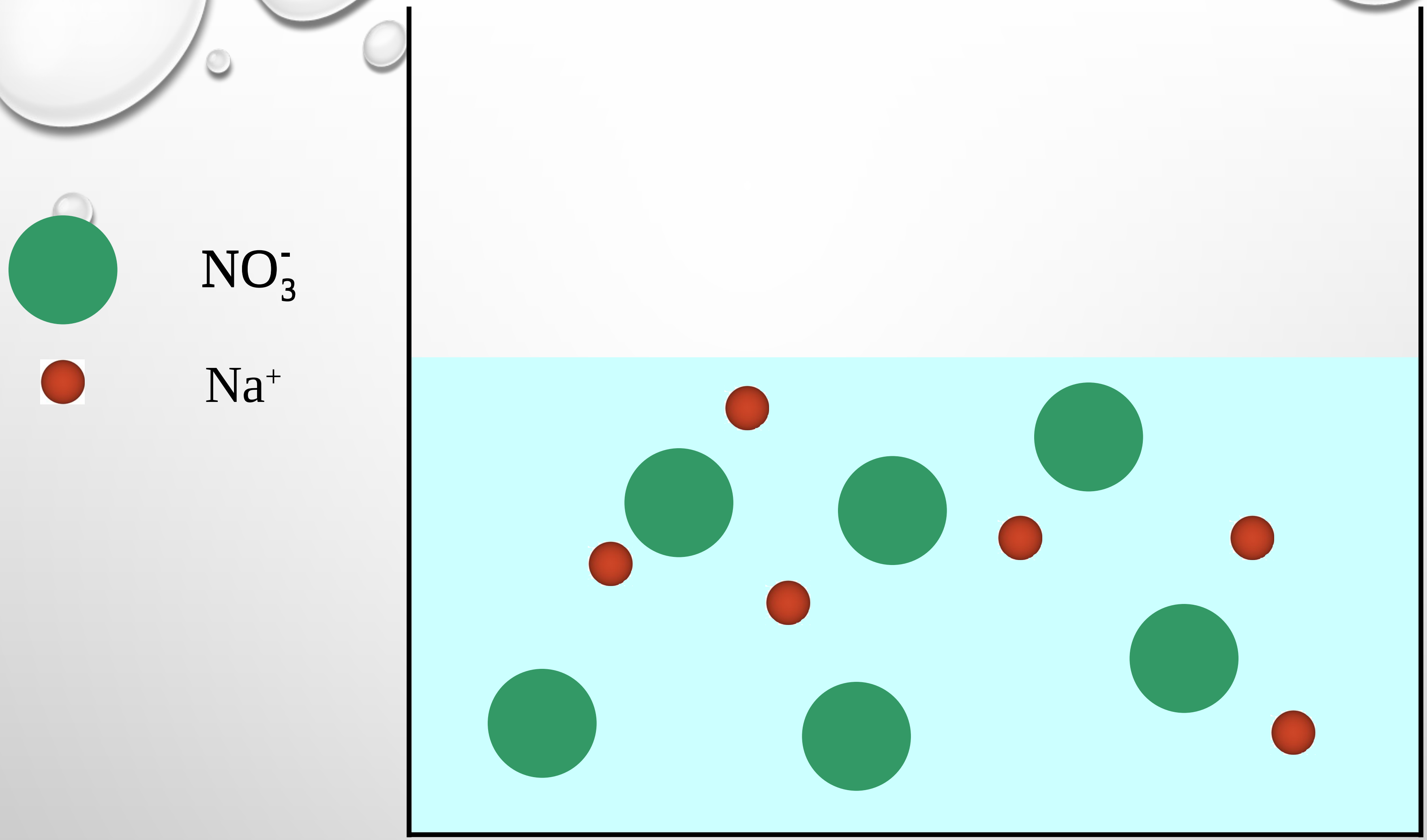
Convert: mol NaOH → mol HCl → L HCl → mL HCl

$$(0.700\ \cancel{\text{mol}}\ \text{NaOH})\left(\frac{1\ \cancel{\text{mol}}\ \text{HCl}}{1\ \cancel{\text{mol}}\ \text{NaOH}}\right)\left(\frac{1\ \text{L HCl soln}}{2.00\ \cancel{\text{mol}}\ \text{HCl}}\right) = 0.350\ \text{L HCl}_{\text{soln}}$$

$$0.350\ \cancel{\text{L}}\ \text{HCl}_{\text{soln}}\left(\frac{1000\ \text{mL}}{1\ \cancel{\text{L}}}\right) = 350\ \text{mL HCl soln}$$

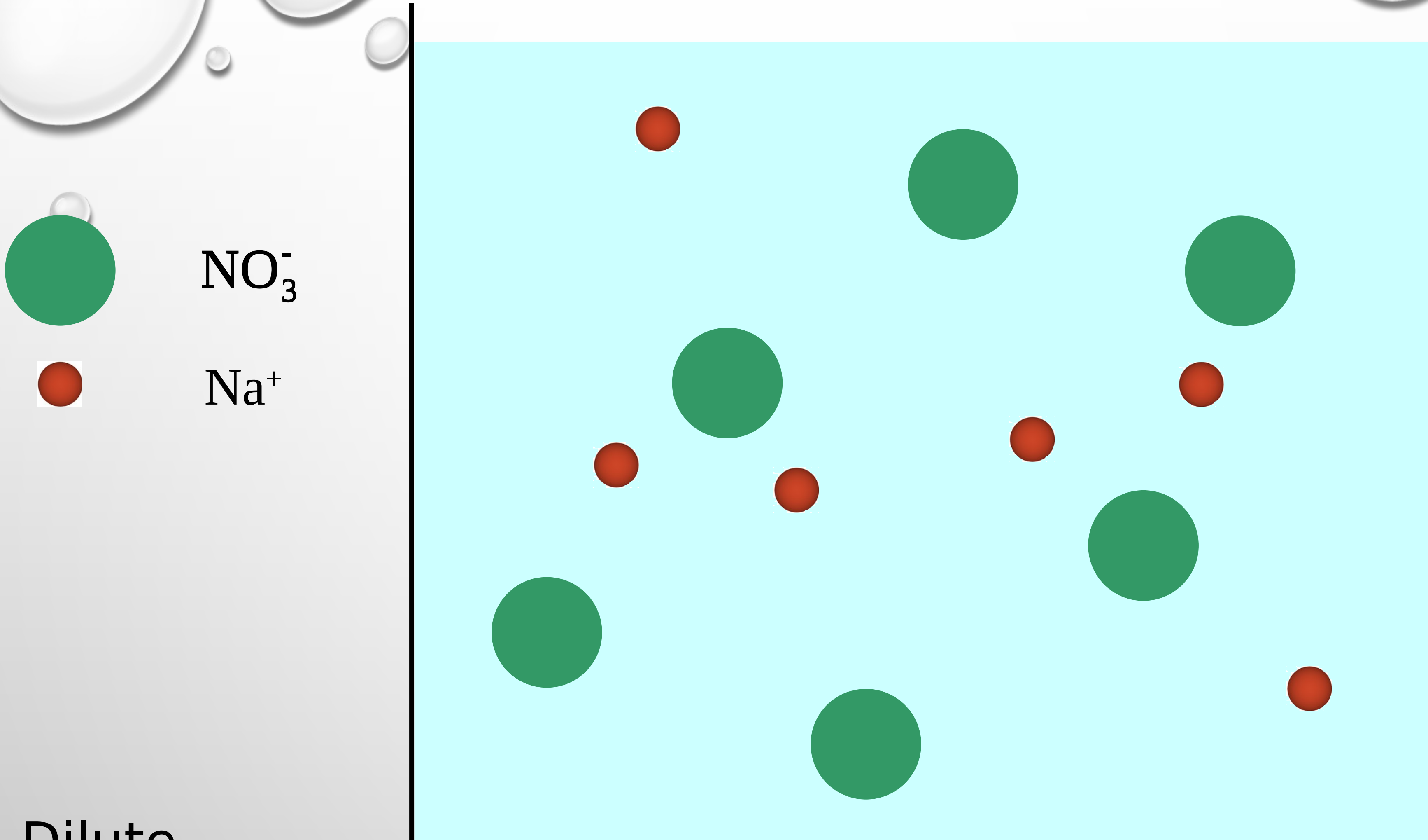
Dilution is the process of preparing a less concentrated solution from a more concentrated one.

moles of solute before dilution = moles of solute after dilution



$NaNO_3$ solution

Conc. solution



Dilute Solution

Solution volume is doubled.

Solution concentration is halved.

Moles of solute remain the same.

Another way of understanding this is:

moles of solute before dilution = moles of solute after dilution

or: $M_1 \times V_1 = M_2 \times V_2$

or: $M_{conc} V_{Conc} = M_{dil} V_{Dil}$

Note - Volume of solvent or water =V_2 -V_1

Click on the below link and watch video on Dilution.

https://www.youtube.com/watch?v=v6dnEp58mVk

1. Calculate the molarity of a Sodium hydroxide solution that is prepared by mixing 100. mL of 0.20 M NaOH with 250. mL of water. Assume volumes are additive.

$V_1 = 100.\ \text{mL} \qquad M_1 = 0.20\ \text{M}$

$V_2 = 250.\ \text{mL} \qquad M_2 = \text{unknown}$

$$\mathbf{V_1 \times M_1 = V_2 \times M_2}$$

$$(100.\ \text{mL})(0.20\ \text{M}) = (250.\ \text{mL})M_2$$

$$M_2 = \frac{(100.\ \cancel{\text{mL}})(0.20\ \text{M})}{250\ \cancel{\text{mL}}} = 0.080\ \text{M NaOH}$$

2. Calculate the amount of 12.0 M green solution you will need and the amount of water you will need to prepare 10 mL of 3.00 M solution ?

V_1 = Unknown

V_2 = 10 mL

M_1 = 12.0 M

M_2 = 3.00 M

$$V_1 \times M_1 = V_2 \times M_2$$

(V_1) (12.0 M) = (10 mL) (3.00 M)

$$V_1 = \frac{(10\ \text{mL})\ (3.00\ \text{M})}{(12.0\ \text{M})} = 2.5\ \text{mL}$$

Note: Volume of solvent or water =V_2-V_1

Volume of Water = 10 mL – 2.5 mL = 7.5 mL