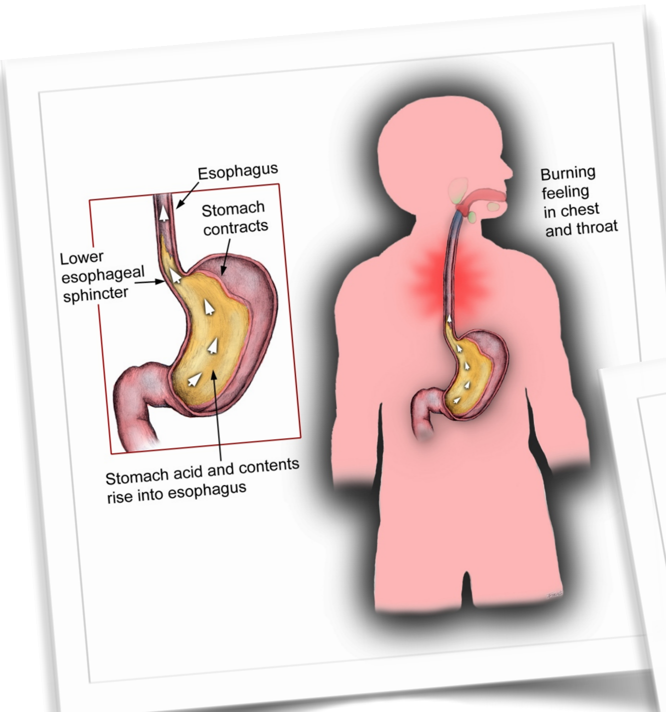
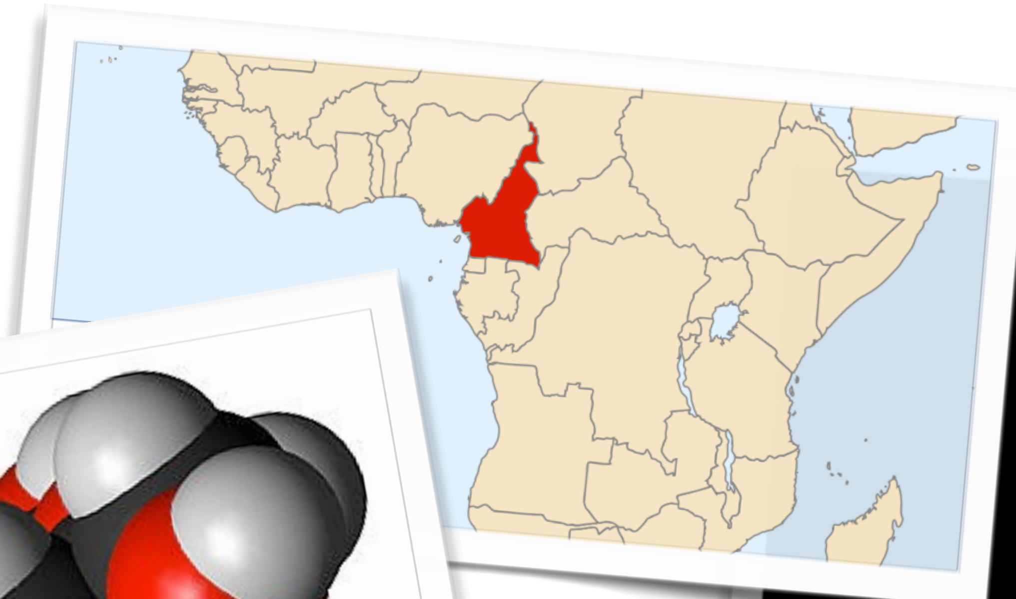
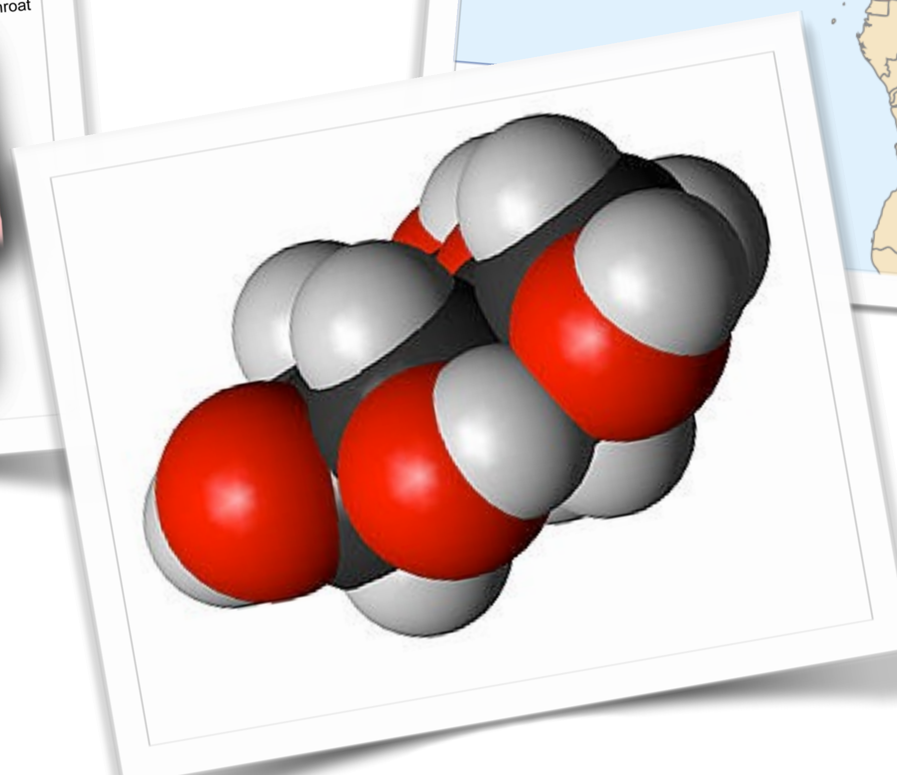
CHEM 100
Principles Of Chemistry







Chapter 6 - Wet Chemistry

6.1 General Characteristics of Solutions

- Solutions may contain dissolved solids, liquids or gases
- In Lake Nyos, Cameroon, CO_2 produced by underground volcanoes dissolves in the lake
- The CO_2 remains poorly-mixed at the bottom of the lake
- Landslides disturb the water and release the CO_2
  - 1700 people and 3500 cattle killed by asphyxiation in 1986

Components of Solutions

- Most of the gases and liquids we encounter are **homogeneous mixtures (solutions)**
- A **solution** is made up of at least two components

1. The **solvent** is the majority phase
2. The **solute** is the substance(s) dissolved
   - Vinegar is a solution of water (solvent) and acetic acid (solute)
   - Soda is a solution of water (solvent), sugar, color and flavors (solutes)

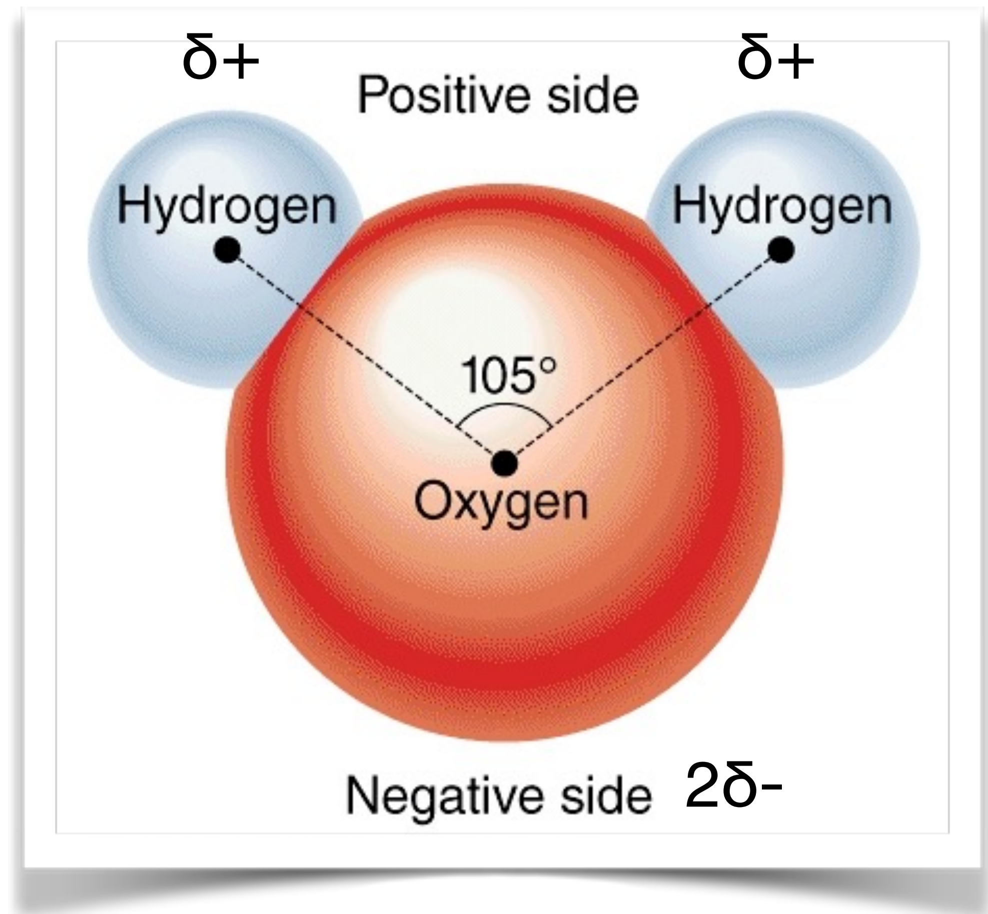
- Solutions may be **dilute** (little solute) or

Common Solutions

Solution Type	Solvent Phase	Solute Phase	Example (Solvent/Solute)
Gaseous	Gaseous	Gaseous	Air (N_2/O_2)
	Gaseous	Liquid	Fog (Air/H_2O)
Liquid	Liquid	Gaseous	Soda (Water/CO_2)
	Liquid	Liquid	Milk (Water/Milk fat)
	Liquid	Solid	Saltwater (Water/NaCl)
Solid	Solid	Gaseous	Styrofoam (Plastic/Air)
	Solid	Solid	Steel (Fe/C)

6.2 The Dissolving Process: Polar or Nonpolar?

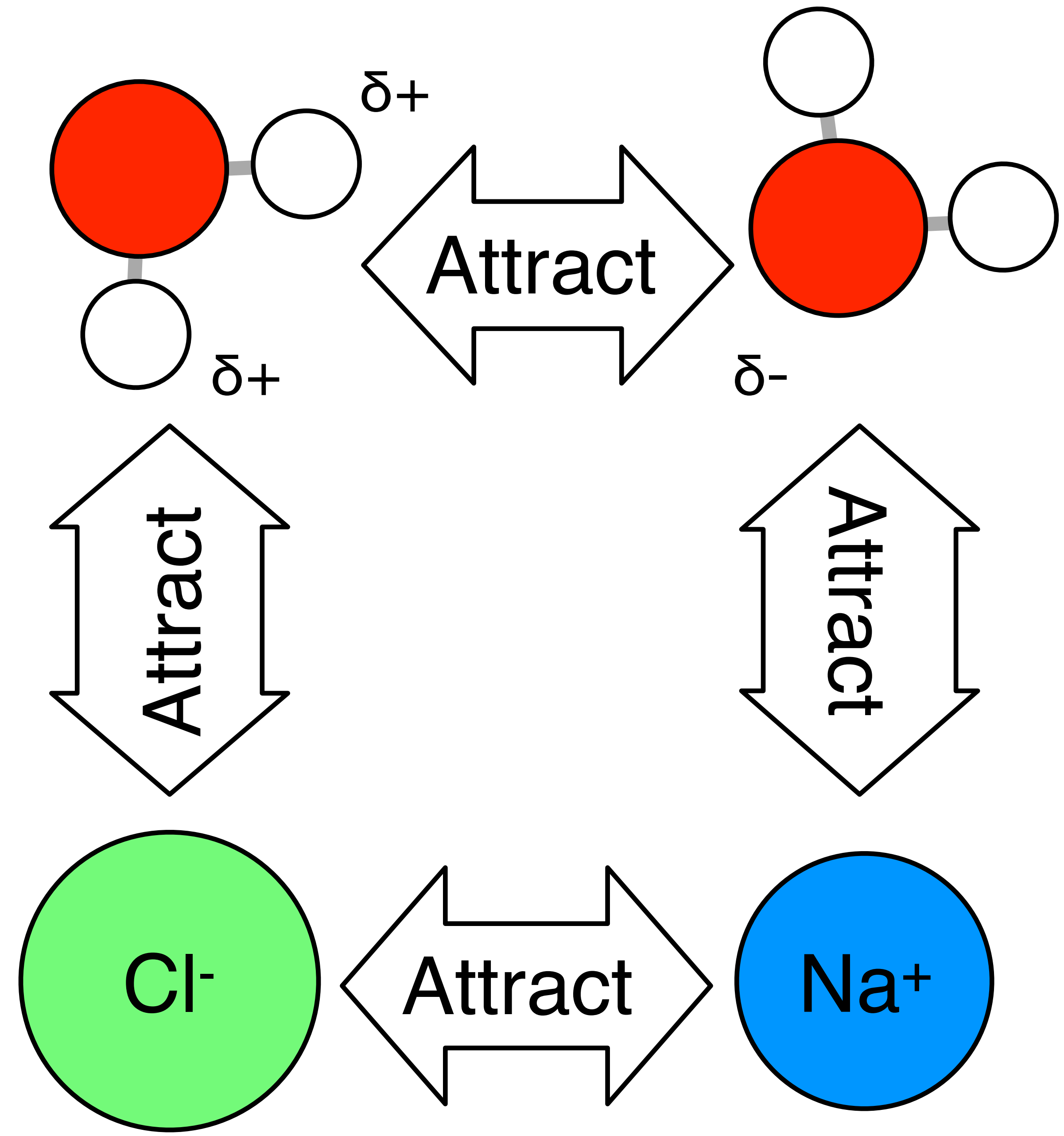
- Molecules like water have an unequal distribution of electrons
  - Some parts of the molecule have a small charge
- The O atom has, on average, slightly more electrons that the H atoms
  - The O atom is labeled 2δ- and the H atoms δ+
- Any molecule with small charges is termed **polar**



Being polar depends on composition and molecular shape

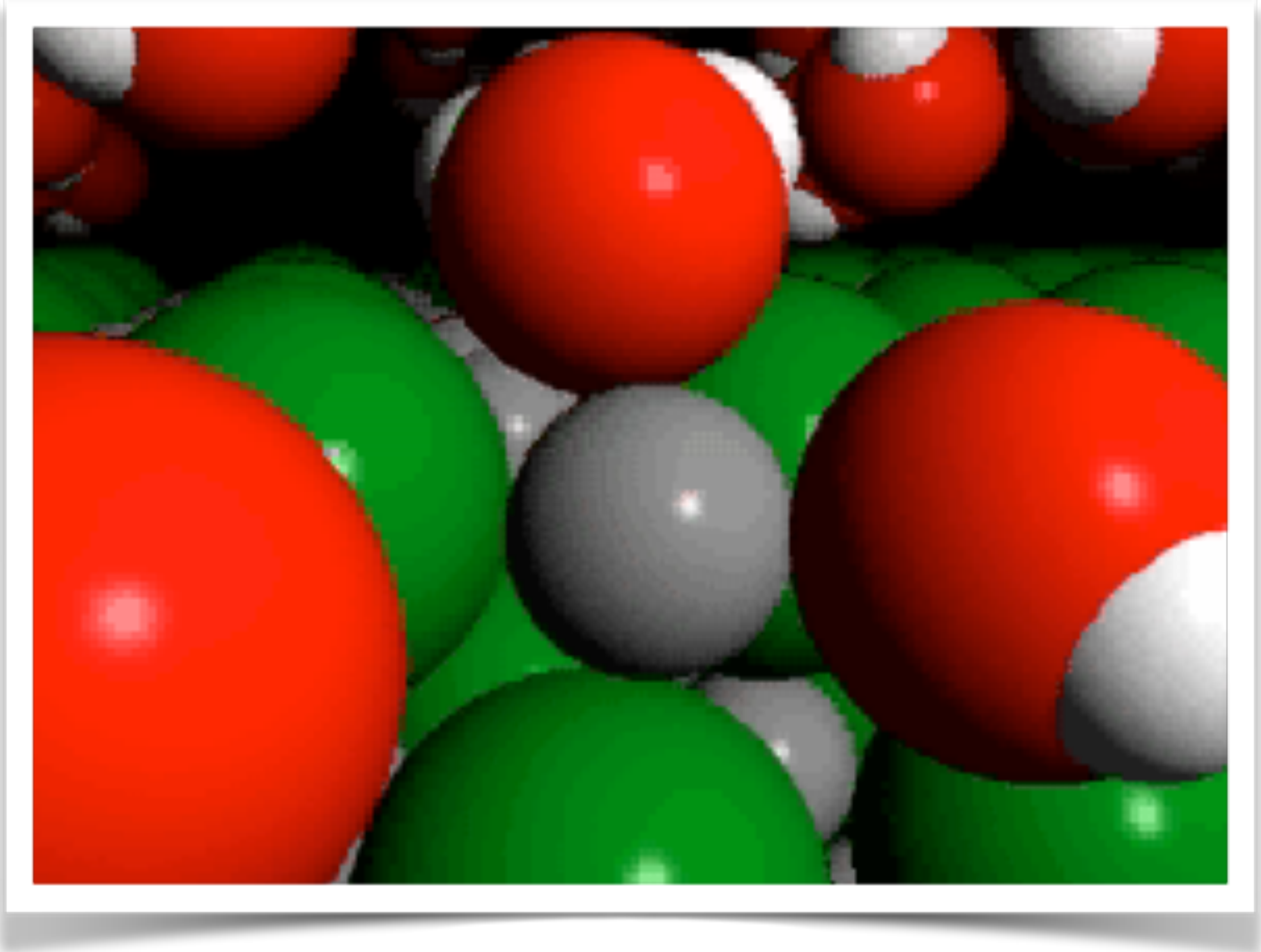
How Polar Solvents Dissolve Solutes

- Polar solvents are very good at dissolving ionic solids
- If the solute-solvent attractions are stronger than the solute-solute and solvent-solvent attractions, the substance dissolves



How Polar Solvents Dissolve Solutes

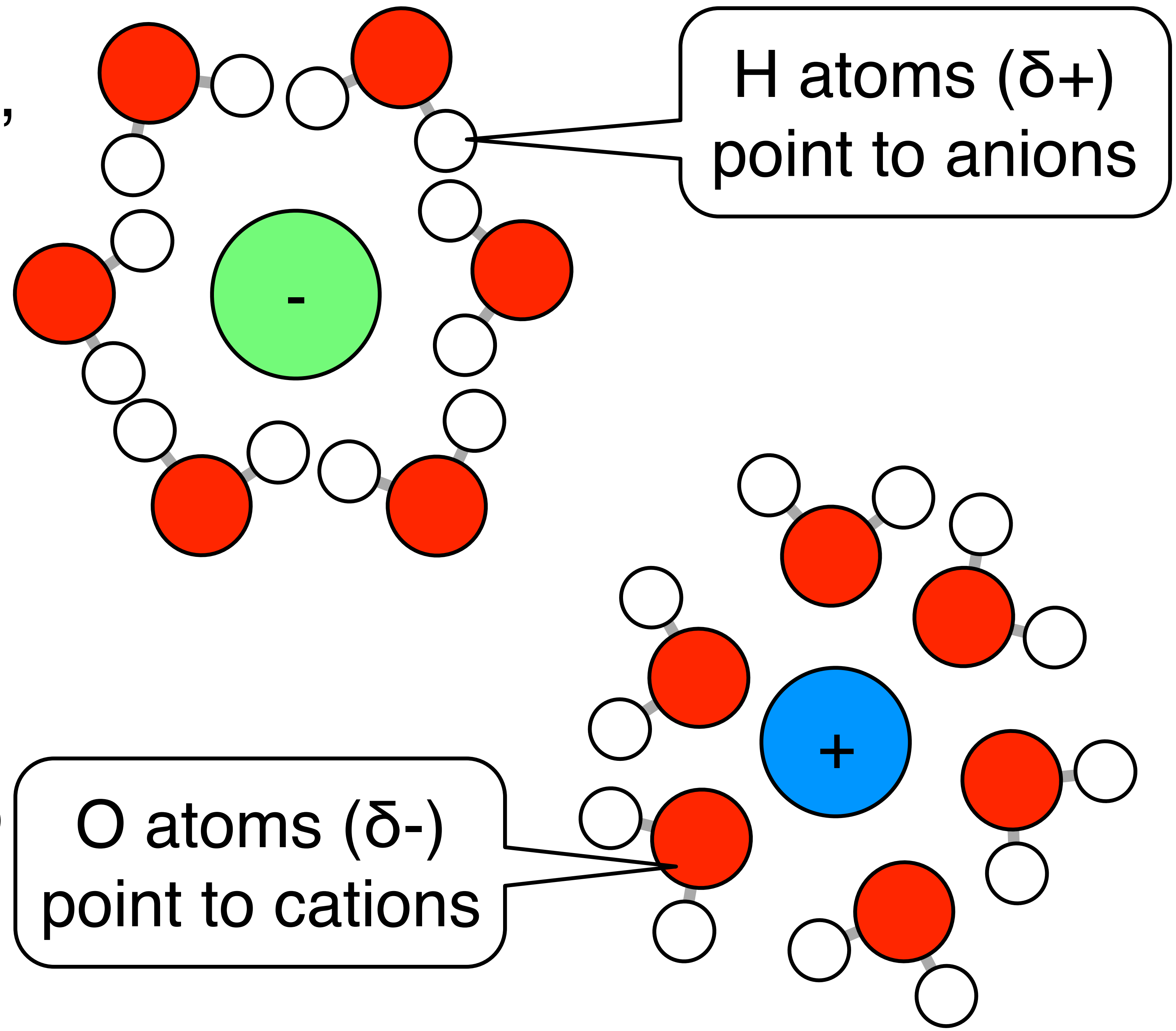
- Sodium chloride dissolves when multiple water molecules cluster around each ion
- This takes some time
  - NaCl doesn't dissolve instantly
- Dissolved substances are indicated with (aq)



Movie of NaCl dissolving

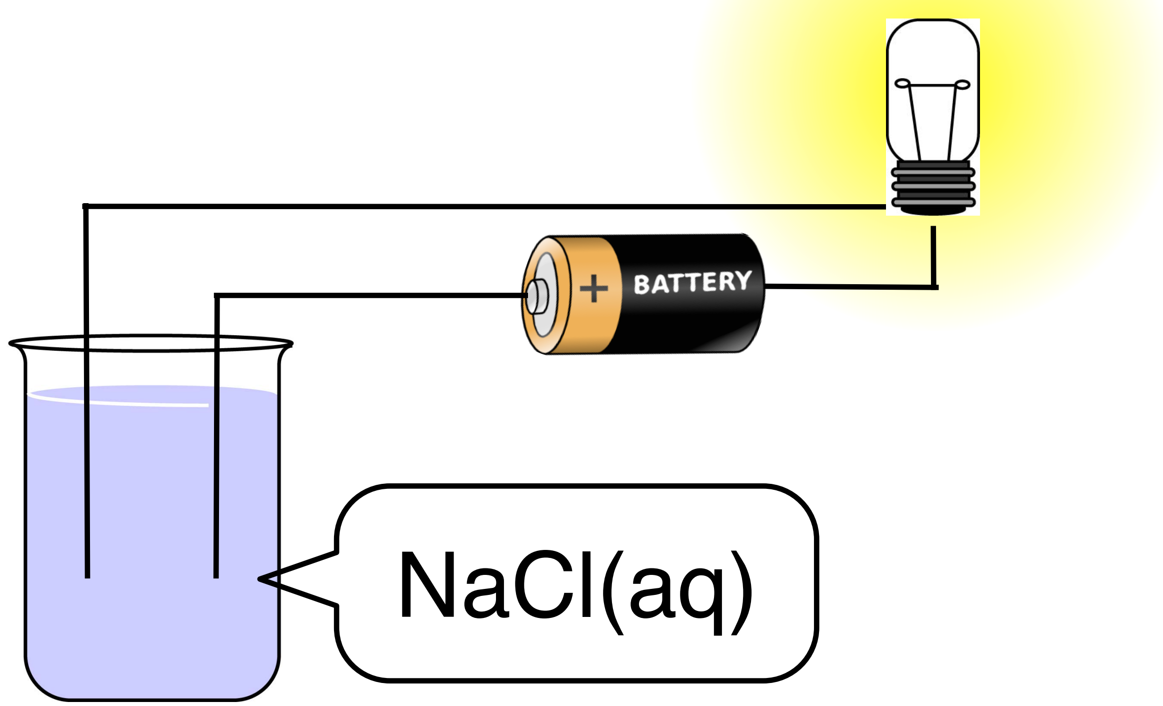
How Polar Solvents Dissolve Solutes

- Once dissolved, the solute is surrounded by solvent molecules (**solvated**)
  - The water molecules orient differently
- Water is able to dissolve both anions and cations



Electrolyte Solutions

- Solutions of dissolved ions conduct electricity and are called **electrolyte solutions**
  - Ions move in solution and current flows
- <u>All</u> solutions of soluble ionic solids are electrolyte solutions



Ionic compounds are added to Gatorade

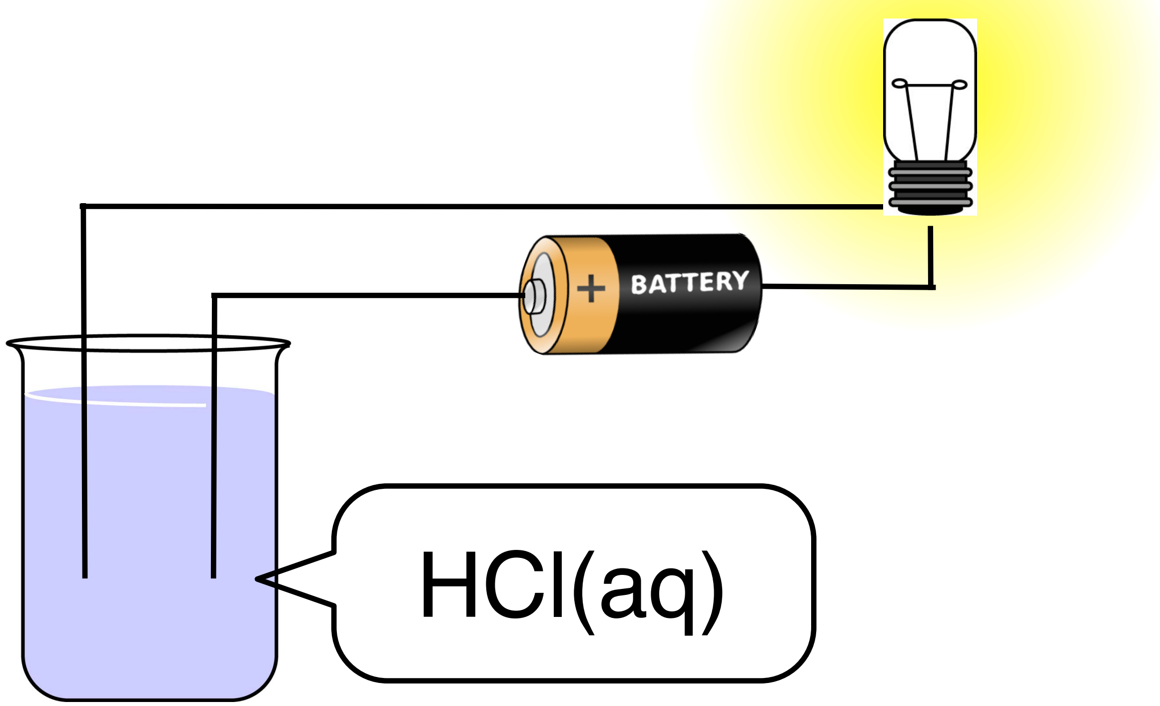
Electrolyte Solutions

- Acids also dissolve in water to make ions

$$HCl(g) \rightarrow H^+(aq) + Cl^-(aq)$$

- <u>All</u> solutions of acids are electrolyte solutions

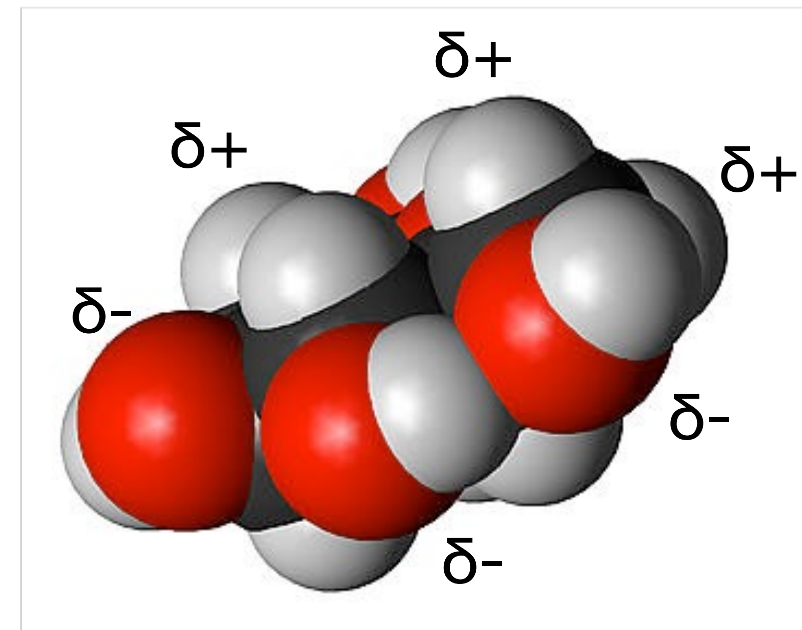
Muriatic acid (HCl) is used to clean decks



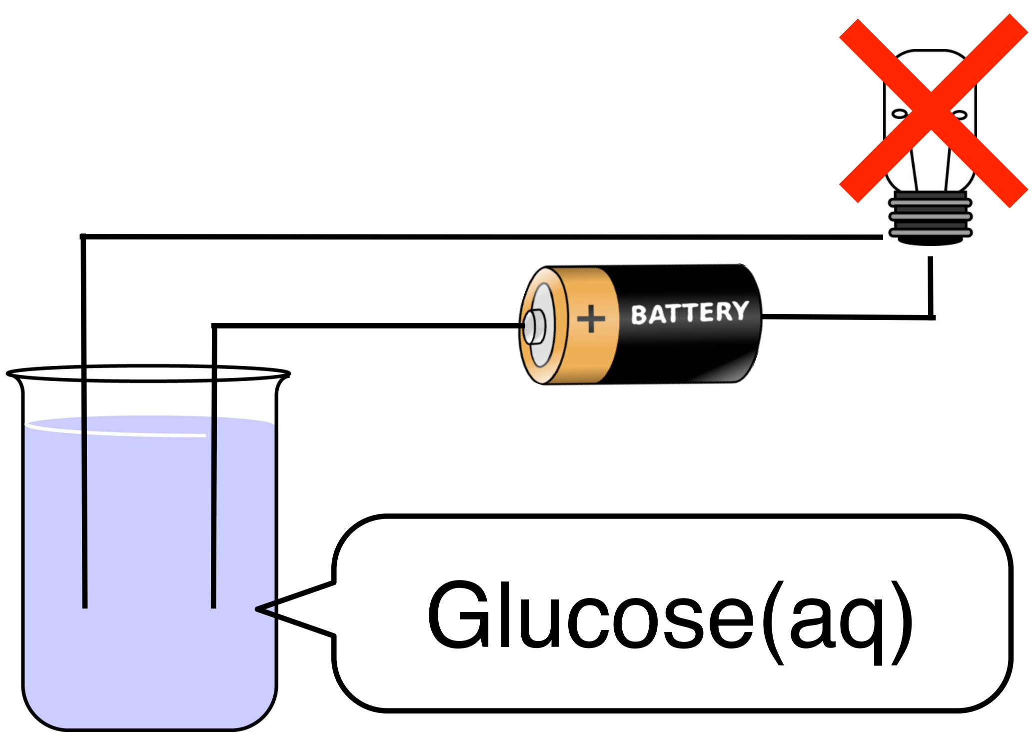
HCl(aq)

Nonelectrolyte Solutions

- Polar sugar dissolves <u>without</u> making ions
- Sugar solutions do not conduct electricity and so are **nonelectrolyte** solutions



Glucose is soluble in water because it is polar but it does not form ions



Dissolving: Polar and Nonpolar Molecules

- Ionic substances with large charges (Al_2O_3, $CaCO_3$) tend to be **insoluble** in water
- Nonpolar molecules (C_8H_{18}, CCl_4) tend to be **insoluble** in water because they are not attracted to water molecules and the water molecules 'stick together'
- Nonpolar molecules tend to be **soluble** in nonpolar solvents because there are no strong attractions between solvent or solute

"Like dissolves like"

6.3 Solution Composition

- We can define whether a solution is dilute or concentrated by using **concentration**
- The **solute mass percent** is

$$\text{Mass \% solute} = \frac{\text{Solute mass}}{\text{Solution mass}} \times 100$$

$$= \frac{\text{Solute mass}}{\text{Solute mass} + \text{Solvent mass}} \times 100$$

- The higher the concentration, the higher the mass percent of solute

Test Yourself: Mass % Solute

Q What is the mass % solute of a solution made by dissolving 2.03 g of NaCl in 50.0 mL of water given the density of water is 0.991 g/mL?

A We have mass of solute but not mass of solution

Use density to find mass of solvent

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

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

$$= \frac{0.991\,\text{g}}{\text{mL}} \times 50.0\ \text{mL} = 49.55\ \text{g}$$

Test Yourself: Mass % Solute

A Finally

$$\text{Mass \% solute} = \frac{\text{Solute mass}}{\text{Solute mass} + \text{Solvent mass}} \times 100$$

$$= \frac{2.03\text{ g}}{2.03\text{ g} + 49.55\text{ g}} \times 100$$

$$= 3.94\ \%$$

Molarity

- When using aqueous solutions, it is more convenient to use a volume-based concentration
- The **molarity** of a solution is

$$\text{Molarity (M)} = \frac{\text{Solute moles}}{\text{Solution volume (L)}}$$

Q What is the molarity of solution made by dissolving 0.277 moles of LiBr in 250 mL of solution?

A We must convert volume to liters (250 mL = 0.250 L)

$$\text{Molarity (M)} = \frac{0.277\ \text{moles}}{0.250\ \text{L}} = 1.11\,\text{M}$$

M = mols/L

Using Molarity

- Chemists frequently need to prepare solutions of a specific concentration

Q What mass of NaCl (58.44 g/mol) must be used to produce 0.500 L of a 0.125 M solution?

A Solution map: Molarity → Moles → Mass

$$\text{Molarity (M)} = \frac{\text{Solute Moles}}{\text{Solution Volume (L)}}$$

$$\begin{aligned}\text{Solute Moles} &= \text{Molarity (M)} \times \text{Solution Volume (L)} \\ &= \frac{0.125\ \text{moles}}{\text{L}} \times 0.500\ \text{L} \\ &= 0.0625\ \text{moles}\end{aligned}$$

Using Molarity To Prepare Solutions

Q What mass of NaCl (58.44 g/mol) must be used to produce 0.500 L of a 0.125 M solution?

A Solution map: Molarity → Moles → Mass

$$\text{Mass NaCl} = 0.0625\ \text{mols} \times \frac{58.44\ \text{g}}{1\ \text{mol}}$$

$$= 3.65\ \text{g}$$

Molar mass

Preparing Solutions

- So how would you prepare 0.500 L of a 0.125 M NaCl solution?

1. Weigh out 3.65 g of NaCl
2. Carefully transfer it to a 500 mL **volumetric flask**
3. Add enough water to bring the total volume to 0.500 L
   – Volumetric flasks have an etched line marking the specified volume

Volumetric flasks are available in many standard sizes

Combining Molarity & Mass % Solute

- We can convert mass % solute to molarity or vice versa if we have density

Q What is the molarity of a 5.0% glucose solution (180.16 g/mol) if the density of the solution 1.02 g/mL?

A Solution map: Mass % solute → Mass/100 g → Moles/mL → Molarity

5.0% means 5.0 g glucose/100 g solution

$$\frac{5.0 \text{ g glucose}}{100 \text{ g solution}}$$

$$\text{Mols} = 5.0 \text{ g} \times \frac{1 \text{ mole}}{180.16 \text{ g}} = 0.0278 \text{ moles}$$

$$\text{Mass} = 100 \text{ g} \times \frac{1 \text{ ml}}{1.02 \text{ g}} = 98.0 \text{ mL}$$

Combining Molarity & Mass % Solute

Q What is the molarity of a 5.0% glucose solution (180.16 g/mol) if the density of the solution 1.02 g/mL?

A Now we can calculate the molarity

$$\text{Molarity (M)} = \frac{\text{Solute moles}}{\text{Solution volume (L)}}$$

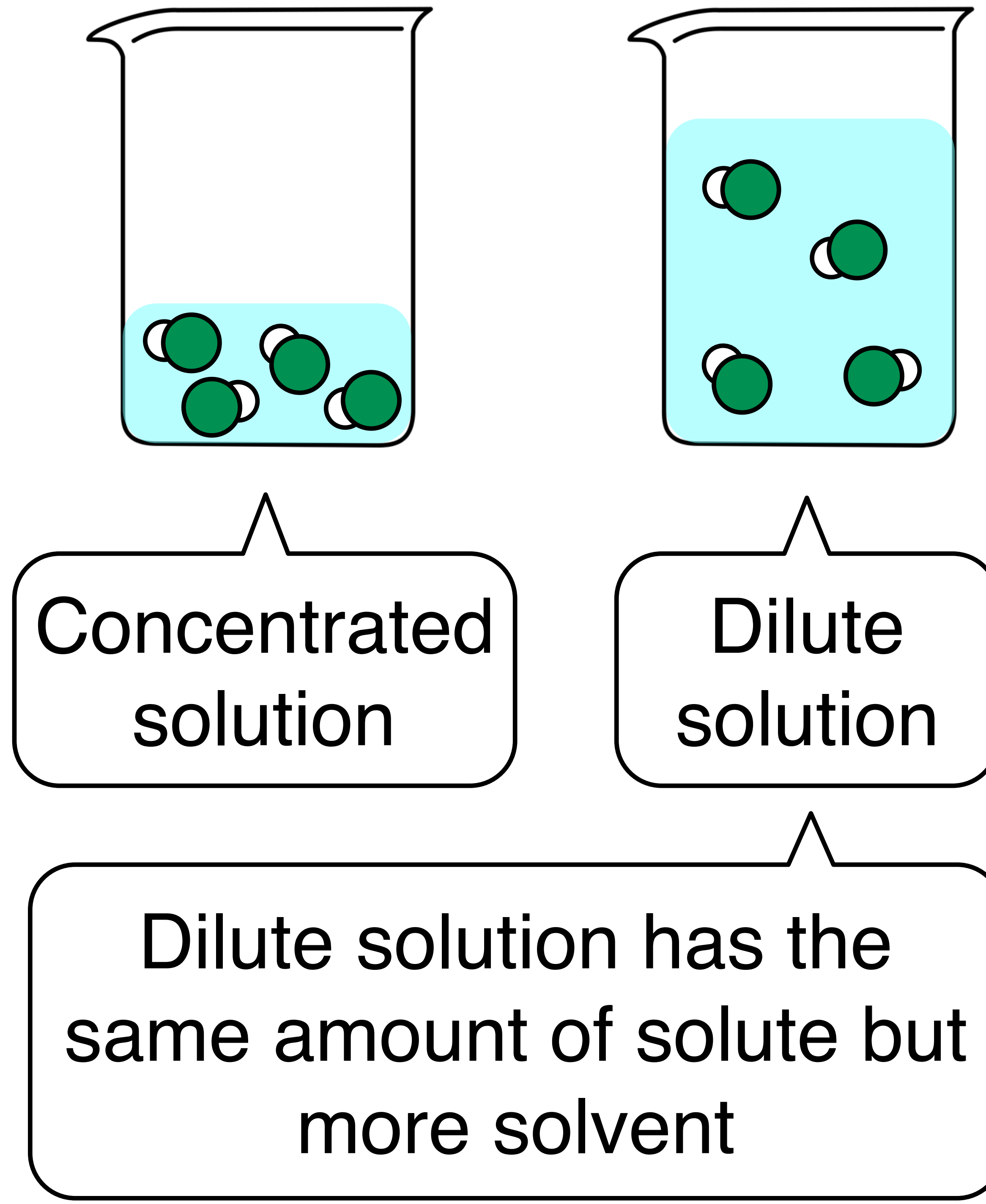
$$= \frac{0.0278 \text{ moles}}{0.0980 \text{ L}}$$

$$= 0.284 \text{ M}$$

5% glucose (dextrose) &
0.9 % saline IV

6.4 Dilutions

- Using molarity simplifies **dilution** calculations
  - **Dilution** is the process of making a concentrated solution less concentrated by adding solvent
- The key is remembering that the total number of moles before dilution and after dilution is the same
  - The solute is simply more ‘spread out’



Dilutions

- We can calculate the initial number of moles of solute

$$\text{Moles solute} = \underbrace{\frac{\text{Moles solute}}{\text{Volume solution}}}_{\text{Molarity}} \times \text{Volume solution}$$

$$= M_1 \cdot V_1$$

- And since the total moles after dilution is the same, we can write

$$\underbrace{M_1 \cdot V_1}_{\text{Moles before dilution}} = \underbrace{M_2 \cdot V_2}_{\text{Moles after dilution}}$$

Dilutions

Q What is the concentration of a solution made by diluting 15 mL of 15.0 M HNO_3 to 90 mL total volume?

A Use the dilution equation $M_1 \cdot V_1 = M_2 \cdot V_2$

We know $M_1 = 15.0$ M, $V_1 = 15$ mL (0.015 L), $M_2 = ?$ and $V_2 = 90$ mL (0.090 L)

Rearranging to solve for M_2

$$M_1 \cdot V_1 = M_2 \cdot V_2$$

$$M_2 = \frac{M_1 \cdot V_1}{V_2}$$

$$= \frac{15.0\ \text{M} \times 0.015\ \text{L}}{0.090\ \text{L}} = 2.5\ \text{M}$$

Note that final solution is less concentrated

Test Yourself: Dilutions

Q How would you prepare 200 mL of a 0.100 M NaCl solution from a 0.500 M NaCl solution?

A Use the dilution equation $M_1 \cdot V_1 = M_2 \cdot V_2$

We know $M_1 = 0.500$ M, $V_1 = ?$, $M_2 = 0.100$ M and $V_2 =$ 200 mL (0.200 L)

$$M_1 \cdot V_1 = M_2 \cdot V_2$$

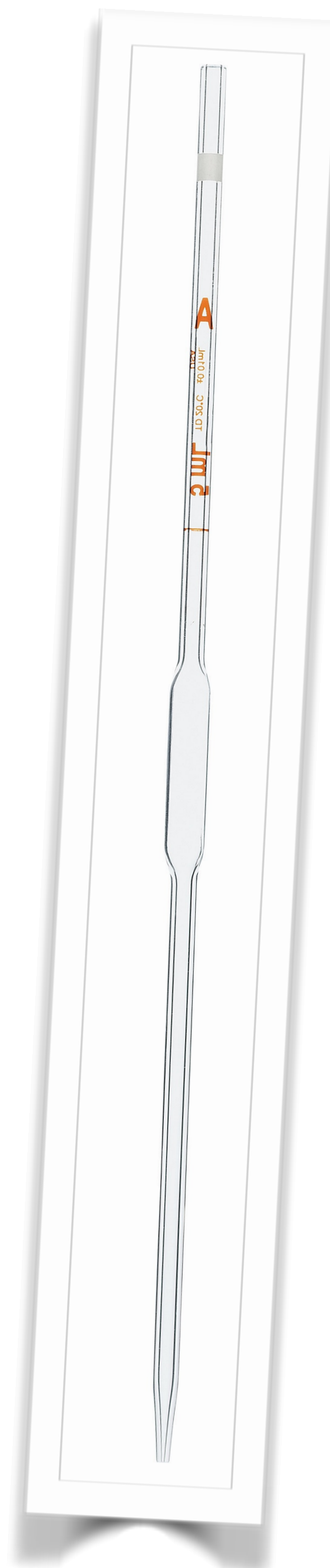
$$V_1 = \frac{M_2 \cdot V_2}{M_1}$$

$$= \frac{0.100\ \mathrm{M} \times 0.200\ \mathrm{L}}{0.500\ \mathrm{M}} = 0.0400\ \mathrm{L}$$

Take 40 mL of 0.500 M solution and add water until the total volume is 200 mL

Dilutions

- **Pipets** are used to dispense exact quantities of liquids
  – Manual pipets use a rubber bulb to suck up and expel liquid
  – Automatic pipets have a calibrated plunger to suck up and expel liquid



Disposable pipet tip

6.5 Solution Stoichiometry

- Molarity is useful in chemical reactions in solutions
- It connects moles of reactants and products with volumes

Q What is the minimum volume of 2.0 M HCl needed to react with 60.0 g of $NaHCO_3$ according to the equation $HCl(aq) + NaHCO_3(s) \rightarrow NaCl(s) + CO_2(g) + H_2O(l)$?

A Solution map: Mass $NaHCO_3$ → Moles $NaHCO_3$ → Moles HCl → Volume HCl

First convert 60.0 g $NaHCO_3$ to moles

$$\text{Moles NaHCO}_3 = 60.0\ \text{g} \times \frac{1\ \text{mole}}{83.978\ \text{g}} = 0.714\ \text{moles}$$

6.5 Solution Stoichiometry

Q What is the minimum volume of 2.0 M HCl needed to react with 60.0 g of $NaHCO_3$ according to the equation $HCl(aq) + NaHCO_3(s) \rightarrow NaCl(s) + CO_2(g) + H_2O(l)$?

A Solution map: Mass $NaHCO_3$ → Moles $NaHCO_3$ → Moles HCl → Volume HCl

$$\text{Moles HCl} = \text{moles NaHCO}_3 \times \frac{1\,\text{mole HCl}}{1\,\text{mole NaHCO}_3} = 0.714\ \text{moles}$$

Finally, convert mols into volume using molarity

$$M = \frac{\text{moles}}{L} \qquad \text{Volume HCl} = \frac{0.714\ \text{mole HCl}}{2.0\ \text{moles / L}} = 0.357\ L$$

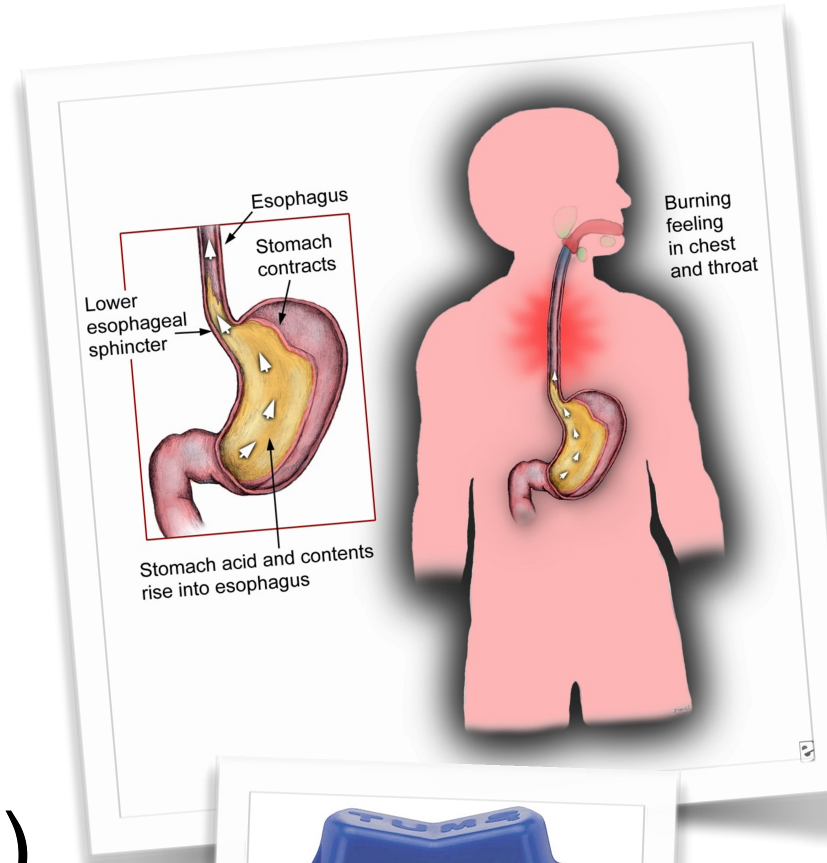
6.6 Acid-Base Reactions

- One useful chemical reactions is an **acid-base** or **neutralization** reaction
- A **base** is a substance that produces OH^- (hydroxide) in water

$$\text{Acid} + \text{Base} \rightarrow \text{Salt} + \text{Water}$$

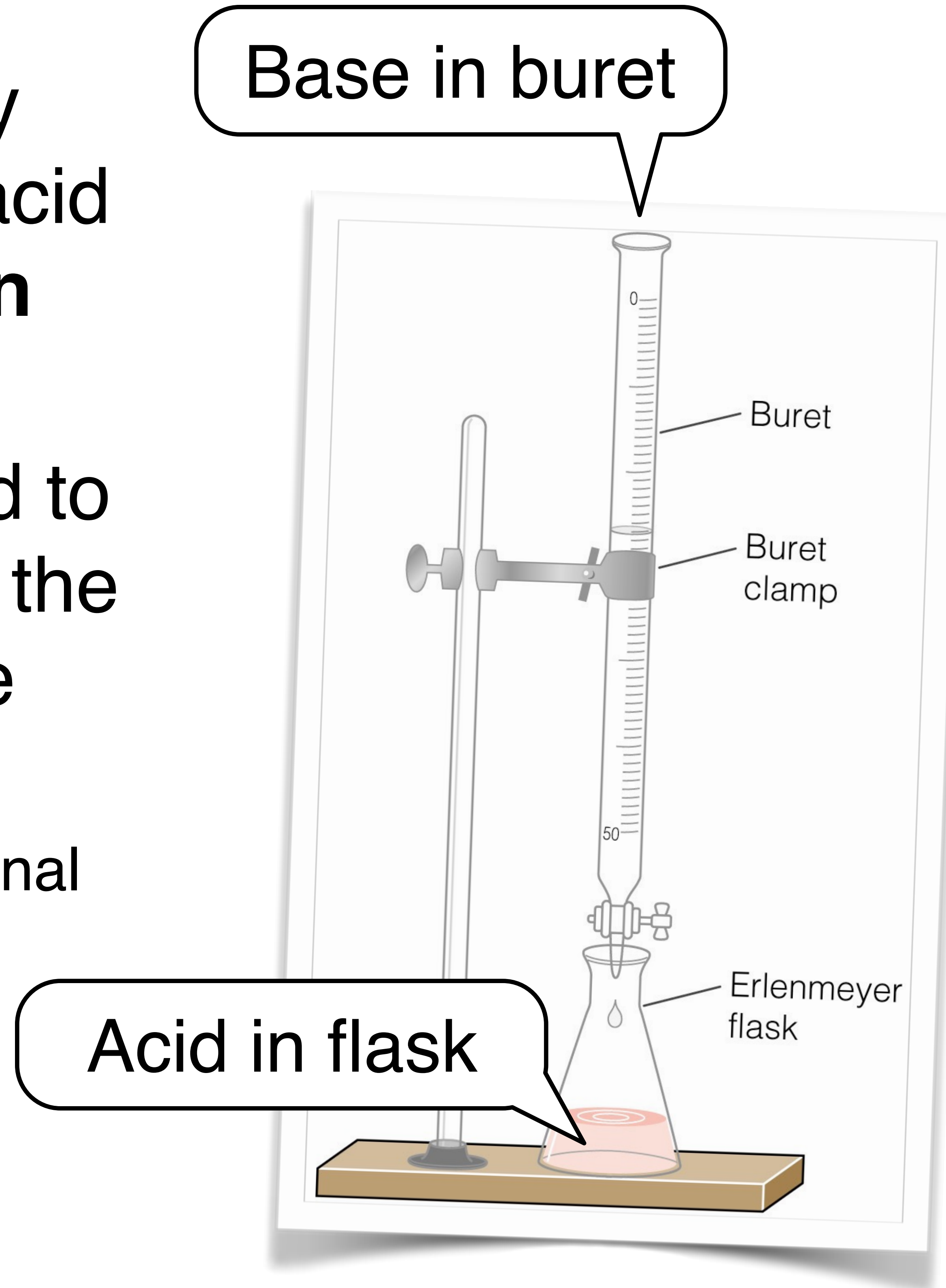
$$HF(aq) + KOH(aq) \rightarrow KF(aq) + H_2O(l)$$

  - The products are a salt and water (a double-displacement reaction)
- Antacids are bases that neutralize the acids that cause heartburn



Acid-Base Titrations

- The method of quantitatively determining the amount of acid (or base) is called a **titration**
- By knowing the volume and concentration of base added to neutralize a volume of acid, the concentration of acid can be calculated
  - An **indicator** changes color to signal neutralization



Acid-Base Titrations

Q 25.0 mL of HNO_3 is neutralized by 16.35 mL of 0.330 M NaOH according to $HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(l)$. What was the molarity of the HNO_3?

A Solution map: (Volume and molarity) NaOH → Moles NaOH → Moles HNO_3 → Molarity HNO_3

First, use molarity and volume to find moles NaOH

$$\text{Molarity} = \frac{\text{Moles}}{\text{Volume (L)}} \qquad \text{Moles} = \text{Molarity} \times \text{Volume (L)}$$

$$\text{Moles NaOH} = 0.330\ \text{M} \times 0.01635\ \text{L} = 0.005396\ \text{moles}$$

Acid-Base Titrations

Q 25.0 mL of HNO_3 is neutralized by 16.35 mL of 0.330 M NaOH according to $HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(l)$. What was the molarity of the HNO_3?

A Solution map: (Volume and molarity) NaOH → Moles NaOH → Moles HNO_3 → Molarity HNO_3

$$\text{Moles } HNO_3 = \text{Moles NaOH} \times \frac{1 \text{ mole } HNO_3}{1 \text{ mole NaOH}}$$

$$= 0.005396 \text{ moles}$$

Acid-Base Titrations

Q 25.0 mL of HNO_3 is neutralized by 16.35 mL of 0.330 M NaOH according to $HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(l)$. What was the molarity of the HNO_3?

A Solution map: (Volume and molarity) NaOH → Moles NaOH → Moles HNO_3 → Molarity HNO_3

$$\text{Molarity } HNO_3 = \frac{\text{Moles } HNO_3}{\text{Volume (L)}}$$

$$= \frac{0.005396 \text{ mols}}{0.0250 \text{ L}}$$

$$= 0.216 \text{ M}$$