Chapter 4 Reactions in Aqueous Solution Summary

Chemistry by Chang and Goldsby

Chapter 4 – Reactions in Aqueous Solutions
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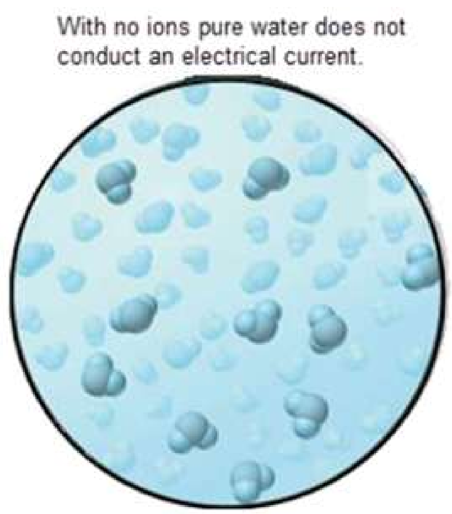
4.1 General Properties of Aqueous Solutions

The terms solute, solvent, electrolyte, dissociation, cation, and anion should be part of your basic vocabulary.

AP Chem also uses the term *dissolution* as the process of dissolving a solute into a solvent to make a solution.

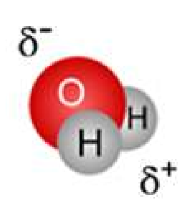
I've added supplemental information not found in the textbook to match the AP Chem curriculum.

Water is a molecular solvent and does not conduct electricity in its pure state.



Water is a molecular substance, and the water molecules are neutral.

Even though a water molecule has no net charge, it is polar. Each neutral water molecule has a separation of charge, a dipole. The oxygen atom of a water molecule has a slight negative charge (δ-) and the hydrogen atoms have a slight positive charge (δ+). Because the overall charge of the molecule is zero there is no net charge to carry an electrical current.



Every AP Chemistry exam has a question where you are required to know the location of the partial charges on a water molecule.

There are three types of solutes that make aqueous solutions:

Nonelectrolytes

Non-Reactive Molecular Solutes

These molecular compounds do not react with water to produce ions.
Examples of nonreactive solutes are oxygen, sugars, and alcohol.
None of these solutions will conduct electricity.

Electrolytes[1]

Aqueous (water) solutions only conduct electricity if ions are present.
Ions can be provided in aqueous solutions by reactions with water (hydrolysis) and dissolution of ionic compounds.

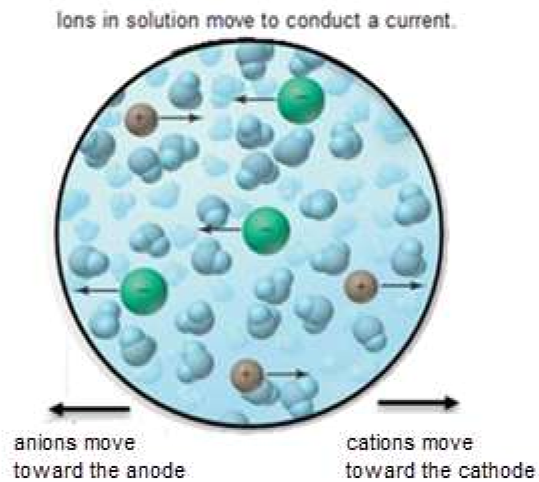
Reactive Molecular Solutes

Some molecular solutes react with water to make ions. These are acids and bases.

Ionic Solutes

Ionic compounds dissociate in water.
These are soluble ionic substances.

The concentration of the ions will determine the degree of conductivity of the solutions.



When the ions reach the electrodes, a chemical reaction occurs. This will be discussed in a later chapter.

Molecular Solutes – nonelectrolytic

Molecular compounds which do not react with water to produce ions on dissolution are nonelectrolytes and thus the solution does not conduct electricity.

Note in the diagram of oxygen dissolving in water, the oxygen molecules are unchanged.

Molecular solutes are described with an (*aq*) after the solute's unchanged molecular formula.

$$O_2(g) \rightarrow O_2(aq)$$

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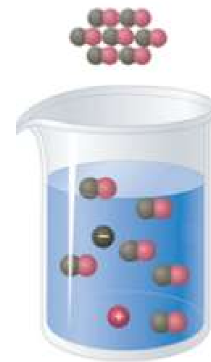
[1] Substances dissolved in water that produce ions are called electrolytes.
Electrolytes are critical in biology because many cell functions such as nerve functions require ion and electrical conductivity. Your brain and entire nervous system depend on electrolytes to produce and carry electrical signals. Every thought and heartbeat is electrolyte dependent.

Molecular Electrolyte Solute Solutions (conduct an electric current)



These molecular solutes **react with water** to form ions.
Note that some of the molecules in the diagram on the right, , have reacted with water to form ions[2].

The reaction with water can produce hydronium ions (acidic) or hydroxide ions (alkaline).

This reaction **creates ions from neutral molecules** and is referred to as **ionization**.

nonconducting molecules before reacting with water		ions that conduct electricity after ionizing
$H_2O + HA$	€	$H_3O^+ + A^-$
$B + H_2O$	€	$HB^+ + OH^-$

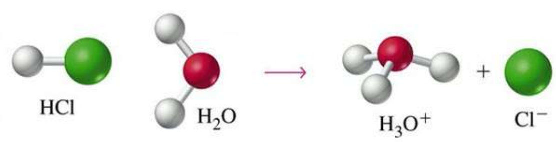
The degree of ionization differentiates strong electrolytes from weak electrolytes.

Molecular substances that **100% ionize** with water are classified as **strong acids or bases**.
The equations for these reactions use an → to indicate a complete reaction.

Molecular substances that ionize less than 5% are classified as **weak acids or bases**.
The equations for these reactions use an € to indicate only a small degree of hydrolysis.

The degree that the solution can conduct electricity is a fast way of determining if a molecular substance is a strong or weak electrolyte.

Hydrogen chloride gas dissolves in water, and immediately reacts with the water to 100% ionize.



$$HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$$

No $HCl(aq)$ is left in solution. Hydrochloric acid doesn't contain any $HCl(aq)$, just $H_3O^+(aq)$ and $Cl^-(aq)$. There is no HCl in $HCl(aq)$. 100% ionization is true for all strong acids and bases.

Memorize the strong acids that 100% ionize with water

Perchloric acid	$HClO_4$
Hydroiodic acid	HI
Hydrobromic acid	HBr
Hydrochloric acid	**HCl**
Sulfuric acid	**H_2SO_4**
Nitric acid	**HNO_3**

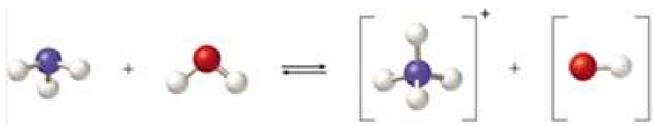
The boldfaced strong acids are commonly used, the other strong acids tend to decompose or are explosive and are rarely seen even in college lab settings.

[2] Again, the diagram does not show the water molecules.

By contrast, aqueous **weak electrolytes** have a small percentage of molecules that ionize. So, the weak electrolytes will be mostly present in its molecular, unreacted form.

Ammonia is a weak molecular electrolyte

$$NH_3(g) + H_2O(l) \text{ € } NH_4^+(aq) + OH^-(aq)$$



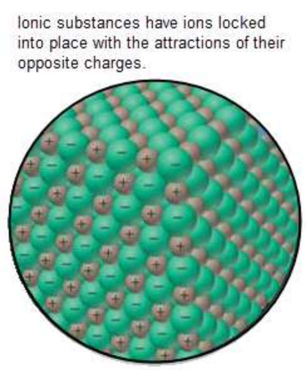
Ionization caused by a weak electrolyte is usually less than 5%. The original molecule, $NH_3(aq)$, is present in much higher concentrations than $NH_4^+(aq)$. A solution of ammonia is mostly $NH_3(aq)$.

Note: The strong and weak designations only refer to the degree of ionization, not the concentration of the solute.

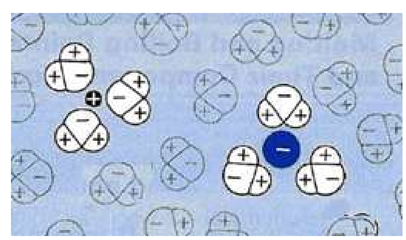
It is possible to have concentrated weak acid or alkaline solutions, and dilute strong acid or alkaline solutions.

Soluble Ionic Solute Solutions (conduct an electric current)

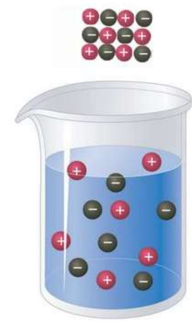
Ionic compounds are composed of ions rather than molecules. As solids, ionic materials will not conduct electricity and are good insulators.



When placed in water, the partial positive (δ+) and negative (δ-) polar portions of water molecule dipoles, neutralize the charges of ions in an ionic compound. The positive ends of water molecules (H δ+) surround the anions and the negative pole of other water molecules (O δ-) surround the cations. There is a video of this at ChemAdvantage. The video is important! Watch and understand. You may have to draw ionic compounds and solutions that result from dipole-ion interactions on the exam!



The ionic solid **dissociates** into the solution. The ion-ion bonds are broken, and new ion-dipole bonds are made. This is **not called ionization** since an ionic compound is already made of ions. The ions are just separated, hence the term **dissociated**. The distinction between dissociation and ionization is not always followed so you may see the terms used loosely. I will try to use the terms correctly.



The dissociated ions surrounded by water dipoles of an ionic compound can move in solution. An aqueous solution of an ionic substance will always be an electrolyte (conduct an electric current).

Soluble ionic compounds almost 100% dissociate and there is almost no NaCl(*aq*) present in solutions less than 1 *M*.[3]

$$NaCl(aq) \rightarrow Na^+(aq) + Cl\text{-}(aq)$$

The ionic attractions (ion-ion bonds) of some ionic substances are so great that water dipoles cannot separate the ions. Dissociation will not take place and these ionic substances will not significantly dissolve. These are **insoluble ionic compounds**.

AP Chemistry students are required to know solubilities of common ionic substances.

For AP Chemistry, all solubility questions are designed to be solved using this simple rule.

"All sodium, potassium, ammonium and nitrate salts are soluble in water."

A more complete set of solubility rules includes other ions. However, these extra ion solubility rules are not necessary for AP Chemistry.

Bottom line: Memorize the AP Chemistry simple, one sentence rule for soluble ionic compounds.

4.2 Precipitate Reactions… always on the AP Chemistry exam

Solids form when ions in solution combine and form a precipitate (solid).

Explained in detail in next assignment ***AP04 C04 Metathesis Reactions*** with a complete description of molecular, ionic, and net ionic equations.

4.3 Acid-Base Reactions

Lightly read these over just to review acid base material. We will be covering these in detail later in the year.

4.4 Oxidation-Reduction Reactions (skip for now will be covered in AP16)

[3] At high concentrations, some Na^+ and Cl^- ions will pair up.

4.5 Concentration of Solutions - Molarity, *M*

$$M = \frac{\text{moles of solute}}{\text{volume of solution in liters}}$$

It is common to use brackets, [ ], when describing the molar concentration. [NaCl] would indicate the molar concentration of NaCl and [0.125] would be 0.125 *M*.

Volumetric flasks are used to make up solutions to a specific volume and molarity.

This diagram shows Waldo helping to make a solution to a specific molar concentration.
The steps of making solutions are important and often tested as a FRQ on the AP Chemistry exam.

(a) Add measured amount of solute to a volumetric flask.
(b) Partially fill volumetric flask with solvent (usually water).
(c) Fully **dissolve solute in solvent by swirling the mixture.** [4]
(d) Fill to the meniscus line of the volumetric flask and then mix the solution to make it homogeneous.

When a solution is made on the addition of a solvent to the solute, there is a change in total volume as the solute interacts with the solvent. For example, 50. mL of water mixed with 50. ml of ethyl alcohol will produce 96 mL of solution. Molar concentration is the **amount of solute distributed in the final volume of a solution**. Therefore, the final volume after mixing, the volume of solution, is used in the calculations.

The amount of solvent used is not relevant in determining molar concentrations.

[4] If the solute generates heat on dissolving, then you should have a significant amount of cold water in the volumetric flask before adding the solute to mitigate the rapid rise in temperature on dilution, especially for sulfuric acid. You should never add water to concentrated sulfuric acid, but rather add the acid to cold water slowly so that the heat of solution is diffused over the larger amount of water present. Lab Rule: Add acid to Water.

Molarity, *M*, is a factor label unit, moles per liter, $M = \frac{x \text{ moles of solute}}{1 \text{ L solution}}$

The definition of molarity, moles per liter, can be used in dimensional analysis to solve concentration problems.

To find mol of solute amount in a given volume of solution.	$\frac{\text{moles of solute}}{\cancel{1 \text{ L solution}}} \times \cancel{\text{volume of solution used in liters}}$ = moles of solute in that volume
To find volume of solution needed for a given mol of solute amount.	$\frac{1 \text{ L solution}}{\cancel{\text{moles of solute}}} \times \cancel{\text{moles of solute}}$ = volume of solution in L having that number of moles

When working solution problems milliliters are often used. So, the mL volume should be changed to L.

How much ammonia is present in 32.0 mL of 0.100 *M* $NH_3(aq)$?

Converting mL to L to get answer in mol

$$32.0 \text{ mL sol'n} \times \frac{1\times 10^{-3} \text{ L}}{\text{mL}} = 0.0320 \text{ L sol'n}$$

$$\frac{0.100 \text{ mol } NH_3}{1\cancel{L}\ \cancel{\text{sol'n}}} \times 0.0320 \cancel{L}\ \cancel{\text{sol'n}} = 0.00320 \text{ mol } NH_3$$

However, it is often easier to keep the volume in mL which will provide the amount value as millimoles.

$$\frac{0.100 \text{ mol } NH_3(aq)}{1\cancel{L}\ \cancel{\text{sol'n}}} \times 32.0 \text{ m}\cancel{L}\ \cancel{\text{sol'n}} = 3.20 \text{ mmol } NH_3(aq)$$

It is easier to write, remember, and do calculations with 3.20 mmol than 0.003200 mol.
Being fluent in millimoles will help you solve problems quickly with less chance for error.
WebAssign understands the unit mmol.

There is another unit of molar concentration which is called molality which is **not covered in AP Chemistry**.

However, molality is part of the CLEP Chemistry test and the MCATs.

Molality is moles of solute per *kilogram of solvent* and is usually referred to as molal.

$$m = \frac{\text{mol solute}}{1 \text{ kg solvent}}$$

Molality is useful in dealing with osmosis and changes in freezing and boiling temperatures of solutions.

Dilution of Solutions:

Start with an initial concentration, C_{initial}, and volume, V_{initial}, and dilute the solution to get a final concentration and volume. The equation is easily remembered.

$$C_{\text{initial}} \times V_{\text{initial}} = C_{\text{final}} \times V_{\text{final}}$$

You can use any concentration or volume unit in this equation as long the units are the same on both sides of the equation.

Solution Stoichiometry

When solutions react, you can use the ICE table or mole ratio method to solve the problems. The only difference is using the molarity equation to find moles rather than molar mass.
However, there is a faster way to deal with stoichiometric reactions in solutions.

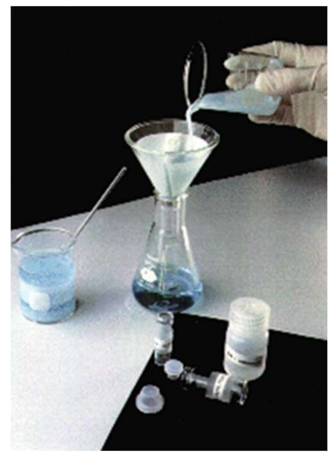
$$a\ \mathrm{A}\ (aq) + b\ \mathrm{B}\ (aq) \rightarrow$$

a and *b* are the coefficients of substances A and B in a balanced reaction.

$$\frac{C_A \times V_A}{a} = \frac{C_B \times V_B}{b}$$

This equation should be memorized and will save you valuable time in solving solution reaction problems.

4.6 Gravimetric Analysis



Gravimetric analysis is an analytical technique based on the measurement of mass.

One type of gravimetric analysis experiment involves the isolation of the desired substance using precipitation and then finding the mass of the desired substance using the precipitate.

- An impure, soluble ionic compound sample weighed and dissolved in water.
- The desired substance is precipitated out of solution using an ion that forms a precipitate.
- The precipitate is filtered, rinsed with pure water to wash out spectator ions, and dried.
- The mass of the dried precipitate is measured, and stoichiometry is used to find the mass of the pure ionic compound that was originally in the mixture.

This is a common FRQ lab problem.

Typical filtration procedures are shown in the APLab Semester 1 list of labs

4.7 Acid Base Titrations (skip for now)

4.8 Redox Titrations (redox is dealt with in AP017)

In the meantime, these solution reactions be dealt with using ICE and the solution stoichiometry equation:

$$a\ \mathrm{A}\ (aq) + b\ \mathrm{B}\ (aq) \rightarrow$$

$$\frac{C_A \times V_A}{a} = \frac{C_B \times V_B}{b}$$