Reactions in solution

Precipitation reactions—not all ionic compounds are soluble in water. If $PbSO_4$ is added to water none of the lead(II)sulfate will dissolve (the interaction between Pb^{2+} and SO_4^{2-} is simply stronger than the attraction of the water to either the Pb^{2+} or SO_4^{2-} (entropy also plays a roll, but we will discuss that next semester).) There is a table on page 150 which describes some simple solubility rules.

Simple Rules for the Solubility of Salts in Water

1. Most nitrate (NO_3^-) salts are soluble.
2. Most salts containing the alkali metal ions (Li^+, Na^+, K^+, Cs^+, Rb^+) and the ammonium ion (NH_4^+) are soluble.
3. Most chloride, bromide and iodide salts are soluble. Notable exceptions are salts containing the ions Ag^+, Pb^{2+}, and Hg_2^{2+}.
4. Most sulfate salts are soluble. Notable exceptions are $BaSO_4$, $PbSO_4$, $HgSO_4$, and $CaSO_4$.
5. Most hydroxide salts are only slightly soluble. The important soluble hydroxides are NaOH and KOH. The compounds $Ba(OH)_2$, $Sr(OH)_2$, and $Ca(OH)_2$ are marginally soluble.
6. Most sulfide (S^{-2}), carbonate (CO_3^{2-}), chromate (CrO_4^{2-}), and phosphate (PO_4^{-3}) are only slightly soluble.

If two solutions are mixed together it is possible that two ions could combine to form an insoluble ionic compound.

A solution of silver nitrate is combined with a solution of sodium chloride. The resulting solution contains Na^+, Ag^+, Cl^+, and NO_3^-, but AgCl is not soluble in water. Since Ag^+ is now in solution with Cl^- the two ions will combine to form AgCl, and the AgCl will precipitate from the solution.

The reaction can be described in a number of ways

(1) A "molecular" equation could be used:

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

(2) A complete ionic equation could be used:

$$Ag^{+}(aq) + NO_3^{-}(aq) + Na^{+}(aq) + Cl^{-}(aq) \longrightarrow AgCl\ (s) + Na^{+}(aq) + NO_3^{-}(aq)$$

(3) A net ionic equation could be used.

$$Ag^{+}(aq) + Cl^{-}(aq) \longrightarrow AgCl\ (s)$$

Net ionic equations are found by writing the full equation and then eliminating the *spectator* ions; spectator ions are ions that do not participate in the reaction. In the example above, Na^{+}, and NO_3^{-} are present as both products and reactants; they do not participate in the reaction.

Acid-Base neutralization reactions

First we must recognize what an acid is, and what a base is then we must determine how they react with each other.

For now we will consider two definitions of the terms acid and base. (A third is also commonly used, but will not discuss it until next semester.)

Arrhenius acids and bases—the first (historically) and simplest definition.

An acid is a substance which donates (releases) protons (H^+).

A base is a substance which donates (releases) hydroxide ions (OH^-).

Thus HCl is an acid because in water is ionized to form H^+.

NaOH is a base because it ionizes in water to form OH^-.

However, there are substances that are basic, but they do not contain an ionizable OH^-. For example ammonia is a base. Another definition was created to deal with the observation that not all bases contain an OH^-.

Brønsted -Lowry acids and bases.

An acid is a substance which donates (releases) protons (H^+). Same as Arrhenius

A base is a substance which accepts protons (H^+).

. When ammonia is added to water it accepts a proton from a water molecule.

$$NH_3(g) + H_2O(l) \longrightarrow NH_4^+(aq) + OH^-(aq)$$

Actually, this reaction is like the acetic acid reaction it does not proceed completely to the products, the reaction eventually comes to equilibrium and the concentrations of NH_3, NH_4^+ and OH^- remain constant.

Hydroxide (OH^-) is a Brønsted base because it accepts H^+ to make water.

$$OH^-(aq) + H^+(aq) \longrightarrow H_2O(l)$$

Acid Base Reactions

Acids and bases react to form water. Acid-base reactions are often referred to as neutralization reactions.

$$NaOH(aq) + HCl(aq) \longrightarrow H_2O(l) + NaCl\ (aq)$$

Of course, the reaction could be written differently.
as a complete ionic,

$$H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \longrightarrow H_2O(l) + Na^+(aq) + Cl^-(aq)$$

or...
as a net ionic equation.

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$$

Solution Stoichiometry

Solution stoichiometry problems are the same as regular stoichiometry problems except solutions are used. Since solutions are used moles must be determined using molarity and volume.

e.g.
How many grams of NaOH are require to neutralize 37.0 mL of a 0.500 M H_2SO_4 solution?

To relate an amount of NaOH to an amount of H_2SO_4 a balanced equation must be used.

1. Determine the reaction.

$$NaOH(aq) + H_2SO_4(aq) \longrightarrow H_2O(l) + Na_2SO_4(aq)$$

2. Balance the equation.

$$2\,NaOH(aq) + H_2SO_4(aq) \longrightarrow 2\,H_2O(l) + Na_2SO_4(aq)$$

3. Do the conversions

So, how many moles of H_2SO_4 are being used?

Just use molarity as a conversion factor.

$$37.0\ \cancel{\text{mL } H_2SO_4 \text{ soln}} \times \frac{0.500\ \text{mol } H_2SO_4}{1000\ \cancel{\text{mL } H_2SO_4 \text{ soln}}}$$

How many moles of NaOH are required to react with that much H_2SO_4?

Use the balanced equation as a conversion factor.

$$37.0\ \cancel{\text{mL } H_2SO_4 \text{ soln}} \times \frac{0.500\ \cancel{\text{mol } H_2SO_4}}{1000\ \cancel{\text{mL } H_2SO_4 \text{ soln}}} \times \frac{2\ \text{mol NaOH}}{1\ \cancel{\text{mol } H_2SO_4}}$$

And this would be how many grams?

Use molar mass to convert from moles to grams.

$$37.0 \cancel{\text{mL } H_2SO_4 \text{ soln}} \times \frac{0.500 \cancel{\text{mol } H_2SO_4}}{1000 \cancel{\text{mL } H_2SO_4 \text{ soln}}} \times \frac{2 \cancel{\text{mol NaOH}}}{1 \cancel{\text{mol } H_2SO_4}} \times \frac{40 \text{ g NaOH}}{1 \cancel{\text{mol NaOH}}}$$

= 1.48 g NaOH are needed to neutralize the acid.

Another neutralization reaction

How many mL of a 0.100 M KOH solution are needed to consume 65 mL of a 0.00100 M NaH_2PO_4 solution.

The question is how much KOH is needed to react with H_2NaPO_4, so this is a stoichiometry problem.

To relate KOH to NaH_2PO_4 a balanced equation must be used. Determine the reaction.

$$KOH(aq) + NaH_2PO_4(aq) \longrightarrow H_2O(l) + K_2NaPO_4\ (aq)$$

The reaction is an acid-base neutralization reaction.
The salt that forms is K_2NaPO_4.

Balance the equation.

$$2\ KOH(aq) + NaH_2PO_4(aq) \longrightarrow 2\ H_2O(l) + K_2NaPO_4\ (aq)$$

How much NaH_2PO_4 needs to be consumed?

Start with the number which is measurement,

65 mL of a NaH_2PO_4 soln

and use molarity as a conversion.

$$65 \cancel{\text{mL of a } NaH_2PO_4 \text{ soln}} \times \frac{0.00100 \text{ mol } NaH_2PO_4}{1000 \cancel{\text{mL of soln}}}$$

How much KOH will be needed?

Use the balanced equation to create a conversion factor.

$$65 \cancel{\text{ mL of a } NaH_2PO_4 \text{ soln}} \times \frac{0.00100 \cancel{\text{ mol } NaH_2PO_4}}{1000 \cancel{\text{ mL of soln}}} \times \frac{2 \text{ mol KOH}}{1 \cancel{\text{ mol } NaH_2PO_4}}$$

So, how many mL of KOH; after all, the KOH is coming from a solution...a 0.100 M KOH soln.

Use molarity to convert from mol KOH to mL KOH.

$$65 \cancel{\text{ mL of a } NaH_2PO_4 \text{ soln}} \times \frac{0.00100 \cancel{\text{ mol } NaH_2PO_4}}{1000 \cancel{\text{ mL of soln}}} \times \frac{2 \cancel{\text{ mol KOH}}}{1 \cancel{\text{ mol } NaH_2PO_4}} \times \frac{1000 \text{ mL soln}}{0.100 \cancel{\text{ mol KOH}}} =$$

= 1.3 mL of a 0.100 M KOH solution

are required to neutralize the NaH_2PO_4

extra info

Normality and Molality

Normality is defined as the number of equivalents per liter of solution. A 1.0 M H_2SO_4 solution is a 2.0 N H_2SO_4 solution because 1 mole of H_2SO_4 is capable of releasing 2 moles of H^+, or 2 equivalents. A 1.0 M NaOH solution is 1.0 N because 1 mole of NaOH is capable of reacting with 1 mole of H^+ or 1 equivalent.

Molality is useful when the temperature of a solution is going to be changed. A 1.0 M NaCl solution at 20 ˚C is not 1.0 M at 50 ˚C. The molarity changes because as the solution warms it expands which means that the volume increases. So, the same number of moles are now dissolved in a larger volume solution therefore the concentration in mol/L is lower. Molality however is defined as mol of solute per kg of solution.

$$\text{molal} = \frac{\text{mol solute}}{\text{mass kg solution}}$$

Since the mass of the solution does not change with changing temperature the concentration measured in molality does not change.

Acid Base Titration reactions

Titration reactions are just neutralization reactions. Titrations are used to determine the amount of one substance present by reacting it with a known amount of another substance.
For instance, you can find the molar mass of an acid by titrating the acid with a solution of base of known concentration.

What is the molecular weight of an unknown monoprotic acid if 0.4955 g of the acid are neutralized by 37.00 mL of a 0.1000 M NaOH solution?

What are you actually looking for? You want to find the molar mass so you need to know how many grams of acid are in 1 mole, if you knew how many moles were in the sample above then you could calculate the molecular mass 0.4955 g/ x moles = MM.

So how many moles of acid are there?

Since we need to relate acid to base we need to use an equation, but we do not know the formula of the acid. That is OK; we know how many protons the acid has.

$$H(?)\ (aq) + NaOH\ (aq) \longrightarrow H_2O\ (l) + Na(?)\ (aq)$$

Where to start? Starting with g of acid leads nowhere....

Start with mL of NaOH,

37.00 mL NaOH soln

and use molarity to convert to moles.

$$37.00\ \cancel{\text{mL NaOH soln}} \times \frac{0.1000\ \text{mol NaOH}}{1000\ \cancel{\text{mL NaOH soln}}}$$

To convert from moles of NaOH to moles of acid

use stoichiometry

$$37.00\ \cancel{\text{mL NaOH soln}} \times \frac{0.1000\ \cancel{\text{mol NaOH}}}{1000\ \cancel{\text{mL NaOH soln}}} \times \frac{1\ \text{mol H(?)}}{1\ \cancel{\text{mol NaOH}}} =$$

$$= 0.0037\ \text{mol H(?)}$$

Remember, number of moles of acid is not the answer. You must find molar mass which is grams per mole.

$$MM = \frac{0.4955\ \text{g}}{0.0037\ \text{mol}} = 133.9\ \text{g / mol}$$