Analytical Chemistry

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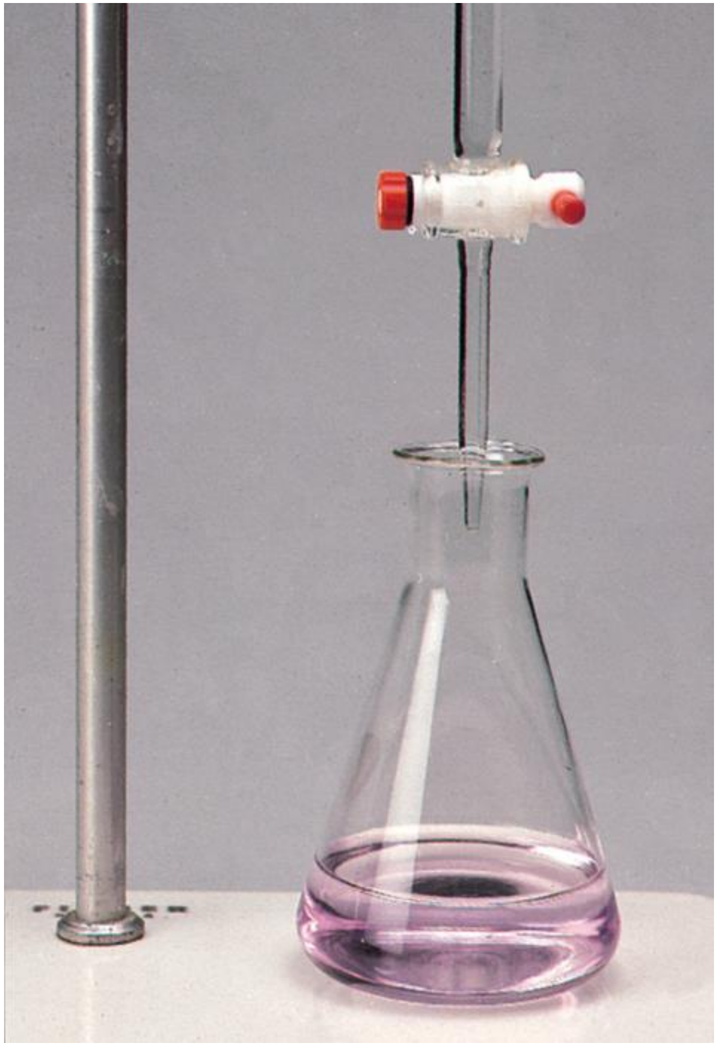
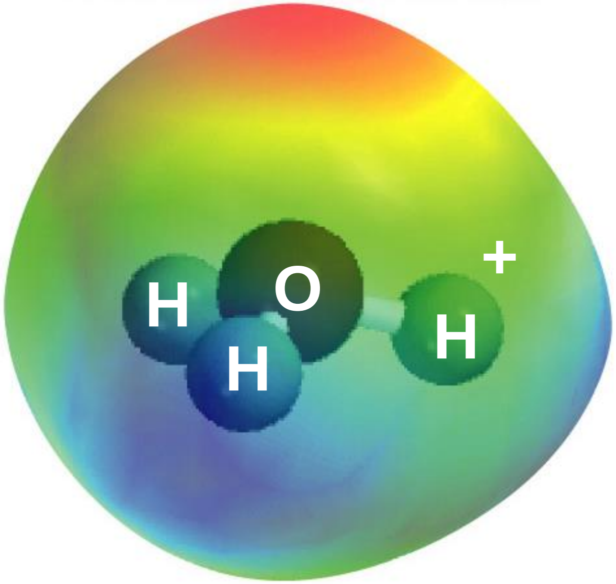


Acid-Base Reactions



H_3O^+ = hydronium ion

Neutralization Reactions

Ex: HCl + NaOH ⟶ NaCl + HOH

Acid-Base Reactions

A very common type of double displacement reaction involves the neutralization of an acid with a base.

Arrhenius and Bronsted-Lowry Definitions

There are several “definitions” of acids or bases, from a chemical standpoint.

The two most important definitions are those given by Svante Arrhenius in the late 19th century, and by J.N. Bronsted and Thomas Lowry, who independently developed similar chemical descriptions of acids and bases in the 20th century.

An **Arrhenius *base*** is a substance that dissociates to produce OH^- ions *in water*

$$NaOH\ (s) \xrightarrow{H_2O} Na^+\ (aq) + OH^-\ (aq)$$

i.e., Arrhenius bases are metal hydroxides that are soluble in water.

An **Arrhenius *acid*** is a substance that ionizes to produce H^+ ions *in water*

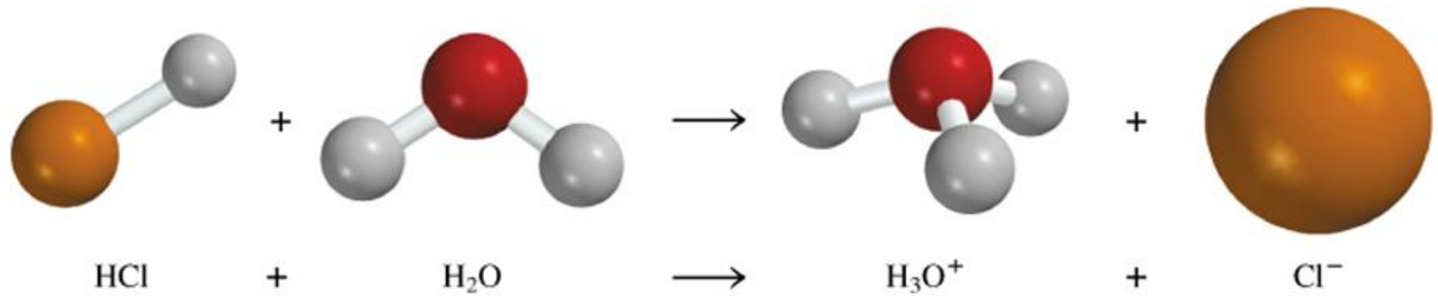
$$HCl\ (g) \xrightarrow{H_2O} H^+\ (aq) + Cl^-\ (aq)$$

Acids and Bases

An H^+ ion is essentially a bare proton – this is an extremely reactive species!

H^+ ions will instantly bond to a water molecule to form the polyatomic cation, ***H_3O^+*, called the *"hydronium ion."***

So, actually, an Arrhenius acid is a substance that produces **H_3O^+** ions in water.



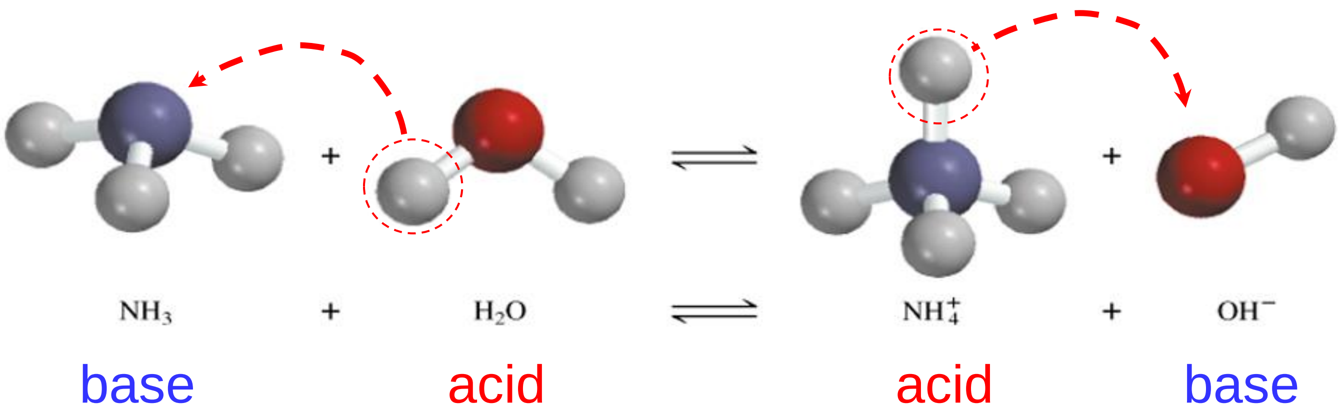
Brønsted-Lowry made use of the fact that H^+ ions are essentially just a proton in their definition of acids and bases:

A ***Brønsted-Lowry acid*** is a proton (H^+) donor

A ***Brønsted-Lowry base*** is a proton (H^+) acceptor

B-L acid and base is a somewhat more "general" definition, since it does not require the presence of water as a solvent. However, one can certainly have an aqueous B-L acid or base!

Consider the reaction between NH_3 and H_2O:



In the forward direction, water acts as the proton donor and NH_3 the acceptor…

… in the reverse direction, NH_4^+ is the proton donor and OH^- is the acceptor.

Acids and Bases

Identify each of the following species as a Brønsted acid, base, or both. (a) HI, (b) OH^- (c) HPO_4^{2-}

$$HI\ (g) + H_2O \longrightarrow H_3O^+\ (aq) + I^-\ (aq)$$ acid

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

$$HPO_4^{2-} + H_2O \rightleftharpoons H_3O^+\ (aq) + PO_4^{3-}(aq)$$ acid

$$HPO_4^{2-} + H_3O^+ \rightleftharpoons H_2PO_4^-(aq) + H_2O$$ base

note that HPO_4^{2-} can act as *both* an acid or a base! Such substances are said to be ***amphoteric.***

Acids with only one ionizable H^+ are said to be monoprotic acids

Acids with 2 ionizable H^+ are said to be diprotic acids

Acids with 3 ionizable H^+ are said to be triprotic acids.

***Monoprotic* acids**

$$HCl \longrightarrow H^+ + Cl^-$$

$$HCN \rightleftharpoons H^+ + CN^-$$

***Diprotic* acids**

$$H_2SO_4 \longrightarrow H^+ + HSO_4^-$$

$$HSO_4^- \rightleftharpoons H^+ + SO_4^{2-}$$

***Triprotic* acids**

$$H_3PO_4 \rightleftharpoons H^+ + H_2PO_4^-$$

$$H_2PO_4^- \rightleftharpoons H^+ + HPO_4^{2-}$$

$$HPO_4^{2-} \rightleftharpoons H^+ + PO_4^{3-}$$

Neutralization Reaction

A neutralization reaction is a special type of double displacement reaction in which an acid reacts with a hydroxide ion (base) to produce an ionic "salt" and water.

$$\text{acid} + \text{base} \longrightarrow \text{salt} + \text{water}$$

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

$$H^+ + \cancel{Cl^-} + \cancel{Na^+} + OH^- \longrightarrow \cancel{Na^+} + \cancel{Cl^-} + H_2O$$

net ionic = $H^+ + OH^- \longrightarrow H_2O$

note that the net ionic equation for all neutralization reactions will be $H^+ + OH^- \longrightarrow H_2O$!

Neutralization Reaction Examples:

$$2\ HC_2H_3O_2 + Ca(OH)_2 \longrightarrow 2\ H_2O + Ca(C_2H_3O_2)_2$$

$$HCN\ (aq) + KOH \longrightarrow H_2O + KCN$$

$$H_2SO_4 + 2\ NaOH \longrightarrow 2\ H_2O + Na_2SO_4$$

$$H_2SO_4 + NaOH$$

$$\Downarrow$$

$$Na_2SO_4 + H_2O$$

Sodium Sulphate

You Try It

- **Complete equation and balance formulas**
- **Balance equation.**
- **Name acid base and salt**

Ex: $KOH + H_2SO_4 \longrightarrow$

$KOH + H_2SO_4 \longrightarrow HOH + K_2SO_4$

Ex: $Mg(OH)_2 + HNO_3 \longrightarrow$

$Mg(OH)_2 + HNO_3 \longrightarrow HOH + Mg(NO_3)_2$

Hydrolysis

- **Opposite reaction to neutralization**

Salt + Water $\longrightarrow$ Acid + Base

Parent Acid/Base

- If you know the salt involved you should be able to determine which acid and base it would form if water is added.

Salt + Water ⟶ Acid + Base

Ex:

NaCl with water (HOH) would form HCl and NaOH

You Try It

- **Name the "parent" acid and base that would be produced from these salts.**

- ***Ex:*** ***Potassium chloride***

  Magnesium carbonate

Not all reactions involving acids and bases are neutralization reactions. For example, ammonia (NH_3), a Bronsted-Lowry base, can react with acids to form aqueous ammonium salts.

$$HCl\ (aq) + NH_3 \rightarrow NH_4Cl\ (aq)$$

Although this IS an acid base reaction, technically it is NOT a neutralization reaction: The aqueous NH_4Cl formed can react with the water present in the solution to produce H_3O^+ :

$$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$$ ⍰ sol’n is still acidic!

Other Reactions with Acids

Acids produce gases when they react with certain salts containing carbonate, bicarbonate, sulfite and sulfide ions.

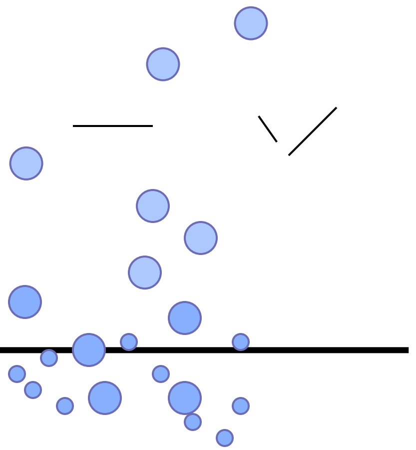
examples:

$Na_2CO_3 + 2\ HCl\ (aq) \longrightarrow 2\ NaCl\ (aq) + H_2O + CO_2\ (g)$

$K_2SO_3 + 2\ HBr\ (aq) \longrightarrow 2\ KBr\ (aq) + H_2O + SO_2\ (g)$

$PbS + 2\ HI\ (aq) \longrightarrow PbI_2\ (s) + H_2S\ (g)$

Note that the reaction with PbS and HI is a simple double displacement reaction. The others involve both double displacement AND decomposition!



ACID

Adds Hydrogen Ions

H^+

Hydrochloric Acid

$$HCl \rightarrow H^+ + Cl^-$$

BASE

Adds Hydroxyl Ions

OH^-

Sodium Hydroxide

$$NaOH \rightarrow Na^+ + OH^-$$

Acid + Base = ?

$H^+ + OH^- \rightarrow H_2O$

$HCl + NaOH \rightarrow H_2O + NaCl + \text{energy}$

acid + base → water + salt + heat

NEUTRAL

Chemical Equation

$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

$H^+Cl^-_{(aq)} + Na^+OH^-_{(aq)} \rightarrow Na^+Cl^-_{(aq)} + H_2O_{(l)}$

Ionic Equation

$H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)}$

ACID-BASE TITRATION

Titration

Quantitative analysis that involves the gradual addition of a chemical solution from a burette to another chemical solution of known quantity in a conical flask.

End point

Is the point in the titration at which the indicator changes colour.