Arrhenius Acid-Base Concept

Svante Arrhenius, 1884

- Acids and bases are electrolytes.

- Acids are substances that produce hydrogen ion, $H^+(aq)$, in solution.

- Bases are substances that produce hydroxide ion, $OH^-(aq)$, in solution.

Monoprotic vs. Polyprotic Acids

- Monoprotic acids can produce only one $H^+(aq)$ ion per acid molecule.

- Polyprotic acids can produce more than one $H^+(aq)$ ion per acid molecule.

Monoprotic:

$HCl(aq)$ 6 $H^+(aq) + Cl^-(aq)$

Diprotic:

$H_2SO_4(aq)$ 6 $H^+(aq) + HSO_4^-(aq)$

$HSO_4^-(aq)$ 6 $H^+(aq) + SO_4^{2-}(aq)$

Triprotic:

$H_3PO_4(aq)$ 6 $H^+(aq) + H_2PO_4^-(aq)$

$H_2PO_4^-(aq)$ 6 $H^+(aq) + HPO_4^{2-}(aq)$

$HPO_4^{2-}(aq)$ 6 $H^+(aq) + PO_4^{3-}(aq)$

Arrhenius Bases

- An ionic hydroxide is always a base.

$$NaOH(s)\ 6\ Na^{+}(aq) + OH^{-}(aq)$$

- Molecular substances like ammonia and amines are bases because they produce hydroxide in solution.

$$NH_3(aq) + H_2O(l)\ \text{º}\ NH_4^{+}(aq) + OH^{-}(aq)$$
$$CH_3NH_2(aq) + H_2O(l)\ \text{º}\ CH_3NH_3^{+}(aq) + OH^{-}(aq)$$

- Molecular compounds that contain the OH group are usually not Arrhenius bases.

<u>Not Bases</u>

CH_3OH - methanol

C_2H_5OH - ethanol

$HOCH_2CH_2OH$ - ethylene glycol

Strong and Weak Acids and Bases

1. The following common acids are strong: HCl, HBr, HI, HNO_3, $HClO_4$, H_2SO_4

   The following are some less common acids that are also strong: $HClO_3$, $HBrO_3$, HIO_3, H_2SeO_4

K Assume all other acids are weak unless told otherwise.

   Some weak acids: HF, HNO_2, $HClO_2$, $[H_2SO_3] = SO_2 + H_2O$, $HC_2H_3O_2$ = HOAc

2. All ionic hydroxides are strong bases, regardless of solubility. Bases that do not contain OH^- are weak.

   Some strong bases: LiOH, NaOH, KOH, RbOH, CsOH, $Mg(OH)_2$, $Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$

   Some weak bases: NH_3, CH_3NH_2, $C_2H_5NH_2$

   Not a base: CH_3OH, C_2H_5OH

Nonmetal Oxides as Acids

- Oxides of nonmetals, when dissolved in water, typically form acidic solutions.
  - Nonmetal oxides are sometimes called **acid oxides** or **acid anhydrides** because they dissolve in water to give solutions identical to those produced by their related oxoacids.

$$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq) \rightarrow H^+(aq) + HCO_3^-(aq)$$

$$H_2CO_3(aq) \rightarrow H^+(aq) + HCO_3^-(aq)$$

$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq) \rightleftharpoons H^+(aq) + HSO_4^-(aq)$$

$$H_2SO_4(aq) \rightleftharpoons H^+(aq) + HSO_4^-(aq)$$

$$N_2O_5(g) + H_2O(l) \rightarrow 2HNO_3(aq) \rightleftharpoons 2H^+(aq) + 2NO_3^-(aq)$$

$$HNO_3(aq) \rightleftharpoons H^+(aq) + NO_3^-(aq)$$

Metal Oxides as Bases

- Metal oxides are typically ionic compounds containing the oxide ion, O^{2-}.
  - In water, the oxide ion is hydrolyzed to hydroxide ion:

$$O^{2-}(aq) + H_2O(l) \rightarrow 2OH^-(aq)$$

  - Metal oxides are sometimes called **basic oxides** or **base anhydrides**, because they dissolve in water to give solutions identical to the metal hydroxide.

$$Na_2O(s) + H_2O(l) \rightarrow 2Na^+(aq) + 2OH^-(aq)$$

$$NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$$

$$CaO(s) + H_2O(l) \rightarrow Ca^{2+}(aq) + 2OH^-(aq)$$

$$Ca(OH)_2(aq) \rightarrow Ca^{2+}(aq) + 2OH^-(aq)$$

Neutralization

- Neutralization is the fundamental reaction between an acid and a base in which H^+ from the acid is transferred either to OH^- from the base or to the base itself (if a weak base).

- Water is a product when $H^+(aq)$ and $OH^-(aq)$ combine:

$$H^+(aq) + OH^-(aq) \text{ 6 } H_2O(l)$$

- A cation results when $H^+(aq)$ is transferred to a weak base:

$$NH_3(aq) + H^+(aq) \text{ 6 } NH_4^+(aq)$$

- When a weak acid is neutralized, hydrogen ion must break away from the acid to combine with $OH^-(aq)$:

$$CH_3CO_2H(aq) + OH^-(aq) \text{ 6 } CH_3CO_2^-(aq) + H_2O(l)$$

Three Ways of Writing a Neutralization

Molecular equation:

$$\underset{\text{acid}}{HCl(aq)} + \underset{\text{base}}{NaOH(aq)} \rightarrow H_2O(l) + \underset{\text{salt}}{NaCl(aq)}$$

Ionic Equation:

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

(Spectator ions shown in blue.)

Net ionic equation:

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

Writing Neutralization Equations for Weak Acids or Weak Bases

U In solutions of weak acids and weak bases, the principal species is the undissociated molecules.

U The ions that weak acids and bases form are only minor components of the solution composition.

K *Weak acids and all other weak electrolytes are shown in molecular form when writing ionic or net ionic equations.*

Molecular equation:

$HOAc(aq) + NaOH(aq) \rightarrow H_2O(l) + NaOAc(aq)$

Ionic Equation:

$HOAc(aq) + Na^+(aq) + OH^-(aq) \rightarrow H_2O(l) + Na^+(aq) + OAc^-(aq)$

Net Ionic Equation:

$HOAc(aq) + OH^-(aq) \rightarrow H_2O(l) + OAc^-(aq)$

Net Ionic Equations of Some Common Gas-Forming Reactions

$$HCO_3^-(aq) + H^+(aq) \rightarrow CO_2(g) + H_2O(l)$$
$$CO_3^{2-}(aq) + 2H^+(aq) \rightarrow CO_2(g) + H_2O(l)$$

$$SO_3^{2-}(aq) + 2H^+(aq) \rightarrow SO_2(g) + H_2O(l)$$

$$S^{2-}(aq) + 2H^+(aq) \rightarrow H_2S(g)$$

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

Strong, Weak, or Non-Electrolyte?

1. All ionic compounds are strong electrolytes, because they mostly break up into ions as they dissolve in water.

   L Even insoluble ionic compounds (e.g., AgCl, $PbSO_4$, $CaCO_3$) are strong electrolytes, because the small amounts that do dissolve in water do so principally as ions; i.e., there is virtually no undissociated form of the compound in solution.

Strong, Weak, or Non-Electrolyte?

2. Molecular compounds may be non-electrolytes, weak electrolytes, or strong electrolytes, depending on whether they dissolve without ion formation, a little ion formation, or mostly ion formation, respectively.

Examples:

Compound	Type	Soln Species
sucrose	nonelectrolyte	molecules
CH_3COOH	weak electrolyte	molecules + ions
HCl	strong electrolyte	ions

Strong, Weak, or Non-Electrolyte?

3. Strong acids and strong bases are strong electrolytes [e.g., HCl(*aq*), H_2SO_4 (*aq*), $HClO_4$(*aq*); NaOH(*aq*)]. There are virtually no molecules of a strong acid or base in solution, only ions.

Rules for Writing Ionic and Net Ionic Equations

1. Write all molecular compounds in molecular form.
   Examples:
   $C_{11}H_{22}O_{11}(aq)$ $H_2O(l)$ $CO_2(g)$

2. Write all weak electrolytes in molecular form.
   Examples:
   $CH_3CO_2H(aq)$ **Not** $H^+(aq) + CH_3CO_2^-(aq)$
   $NH_3(aq)$ **Not** $NH_4^+(aq) + OH^-(aq)$

3. Write soluble strong electrolytes as ions and insoluble strong electrolytes as combined solids (i.e., "molecular" form).
   Examples:
   $NaCl(aq) = Na^+(aq) + Cl^-(aq)$
   $AgCl(s) = AgCl(s)$