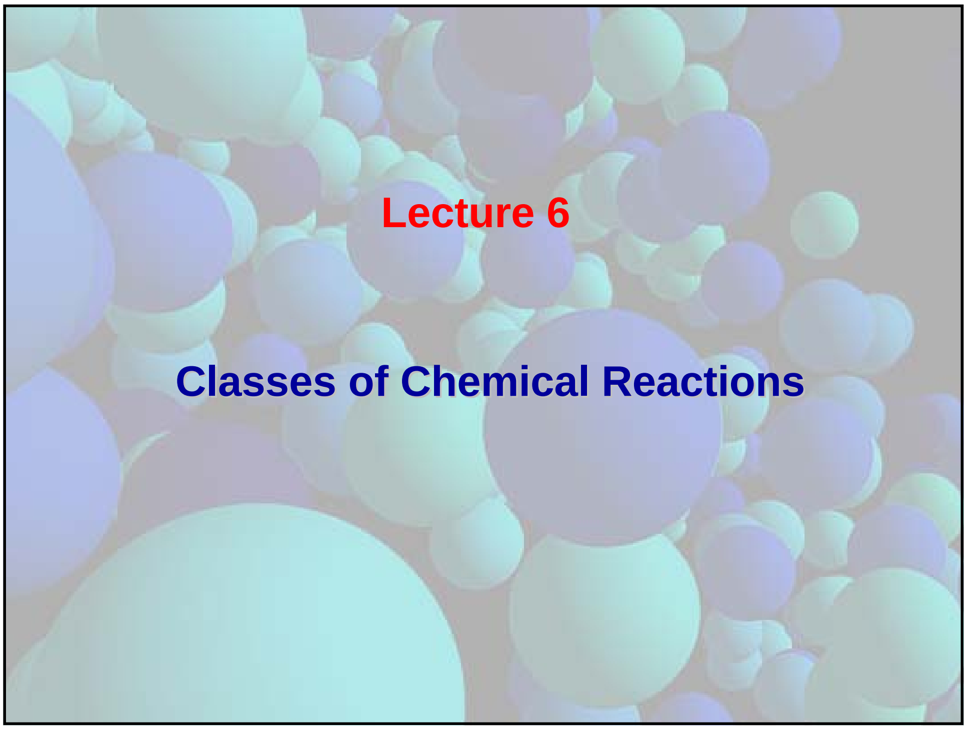
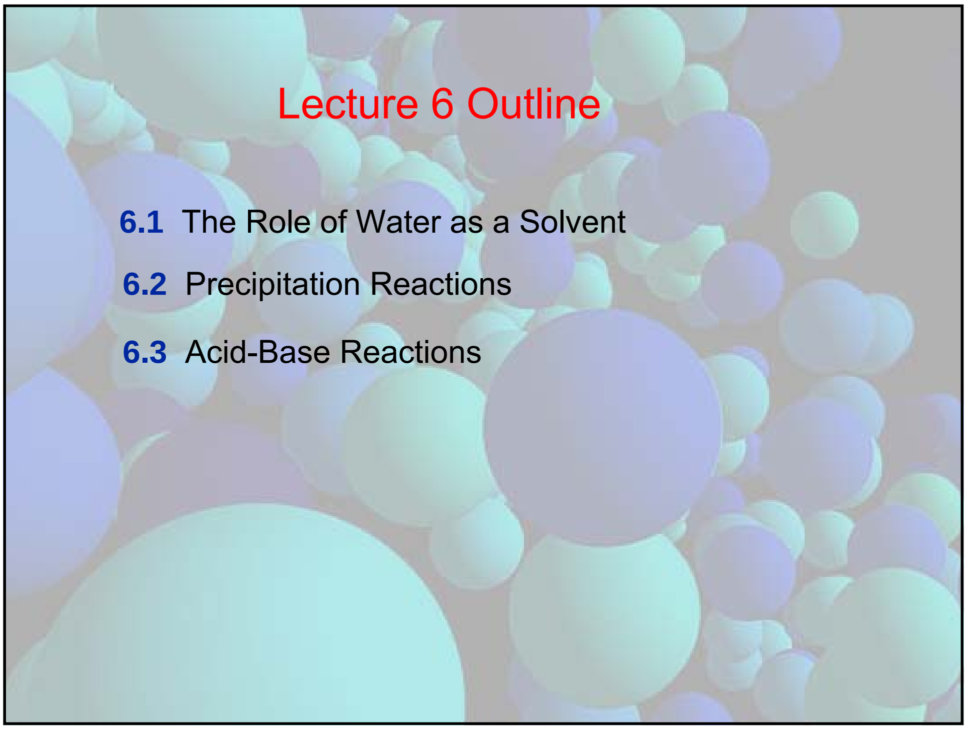


Lecture 6

Classes of Chemical Reactions



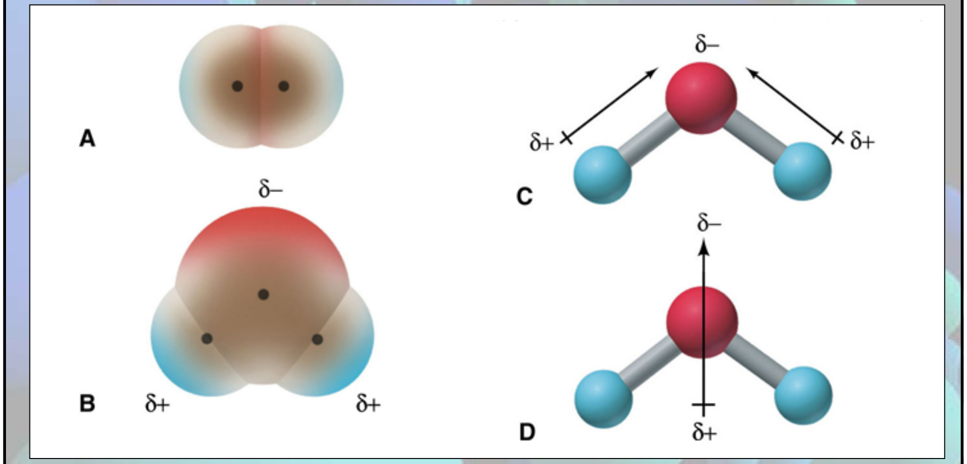
Lecture 6 Outline

6.1 The Role of Water as a Solvent

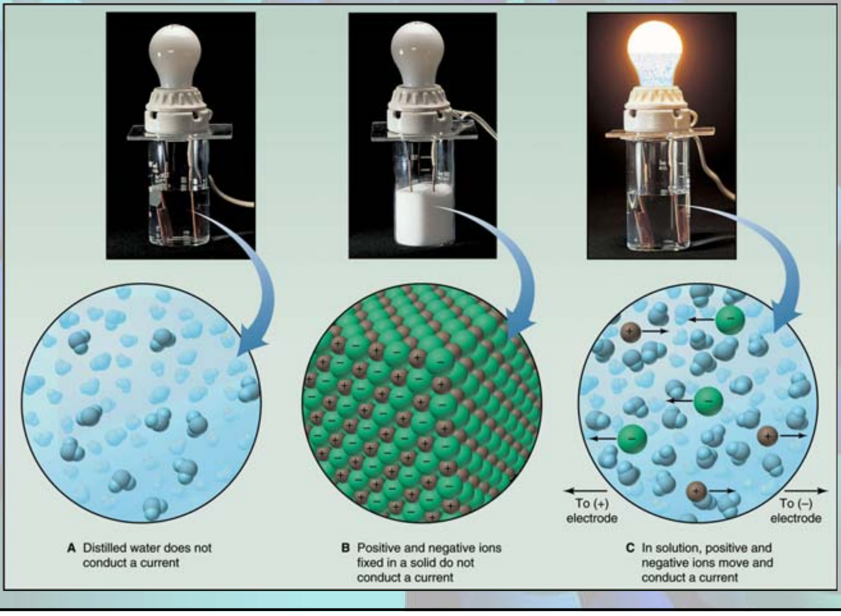
6.2 Precipitation Reactions

6.3 Acid-Base Reactions

Electron distribution in molecules of H_2 and H_2O



The electrical conductivity of ionic solutions

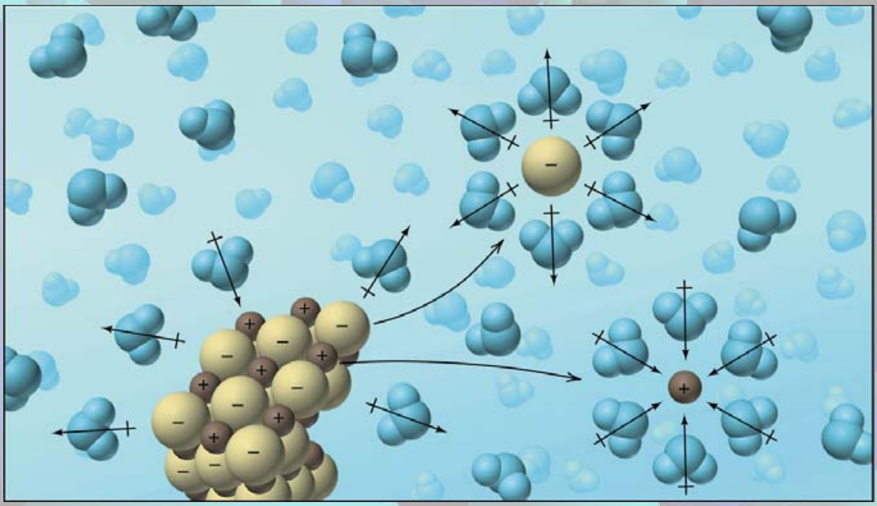


A Distilled water does not conduct a current

B Positive and negative ions fixed in a solid do not conduct a current

C In solution, positive and negative ions move and conduct a current

The dissolution of an ionic compound



A substance that conducts a current when dissolved in water is an electrolyte. Ionic compounds are strong electrolytes

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Sample Problem: Determining Moles of Ions in Aqueous Ionic Solutions

PROBLEM: How many moles of each ion are in the following solutions?

(a) 5.0 mol of ammonium sulfate dissolved in water

(b) 78.5g of cesium bromide dissolved in water

(c) $7.42\text{x}10^{22}$ formula units of copper(II) nitrate dissolved in water

(d) 35mL of 0.84M zinc chloride

$n = m/M$ $c = n/V$

SOLUTION: **(a)** $(NH_4)_2SO_4(s) \longrightarrow 2NH_4^+(aq) + SO_4^{2-}(aq)$

5.0mol $(NH_4)_2SO_4$ $\longrightarrow$ 10.mol NH_4^+ 5.0mol SO_4^{2-}

Sample Problem **continued**

Determining Moles of Ions in Aqueous Ionic Solutions

(b) $CsBr(s) \longrightarrow Cs^+(aq) + Br^-(aq)$

CsBr: 78.5g/ 212.8g/mol = 0.369mol CsBr

= 0.369mol Br^-

= 0.369mol Cs^+

(c) $Cu(NO_3)_2(s) \longrightarrow Cu^{2+}(aq) + 2NO_3^-(aq)$

$$\frac{7.42x10^{22}\text{ formula}}{6.022x10^{23}\text{ formula units}} = 0.123\text{mol } Cu(NO_3)_2$$

= 0.123mol Cu^{2+}

= 0.246mol NO_3^-

(d) $ZnCl_2(aq) \longrightarrow Zn^{2+}(aq) + 2Cl^-(aq)$

n = c V

$ZnCl_2$ 0.035L x 0.84mol/L = $2.9x110^{-2}$mol $ZnCl_2$

= $2.9x110^{-2}$mol Zn^{2+}

= $5.8x110^{-2}$mol Cl^-

Precipitation Reactions

CHEMICAL BEHAVIOR
OF MAIN-GROUP ELEMENTS

Formation of
Lead Iodide

Precipitation Reactions

Precipitate – insoluble solid that separates from solution

molecular equation $Pb(NO_3)_2\,(aq) + 2NaI\,(aq) \longrightarrow PbI_2\,(s) + 2NaNO_3\,(aq)$

precipitate

ionic equation $Pb^{2+} + \cancel{2NO_3^-} + \cancel{2Na^+} + 2I^- \longrightarrow PbI_2\,(s) + \cancel{2Na^+} + \cancel{2NO_3^-}$

net ionic equation $Pb^{2+} + 2I^- \longrightarrow PbI_2\,(s)$

Na^+ and NO_3^- are ***spectator*** ions

Sample Problem **Determining the Molarity of H^+ Ions in Aqueous Solutions of Acids**

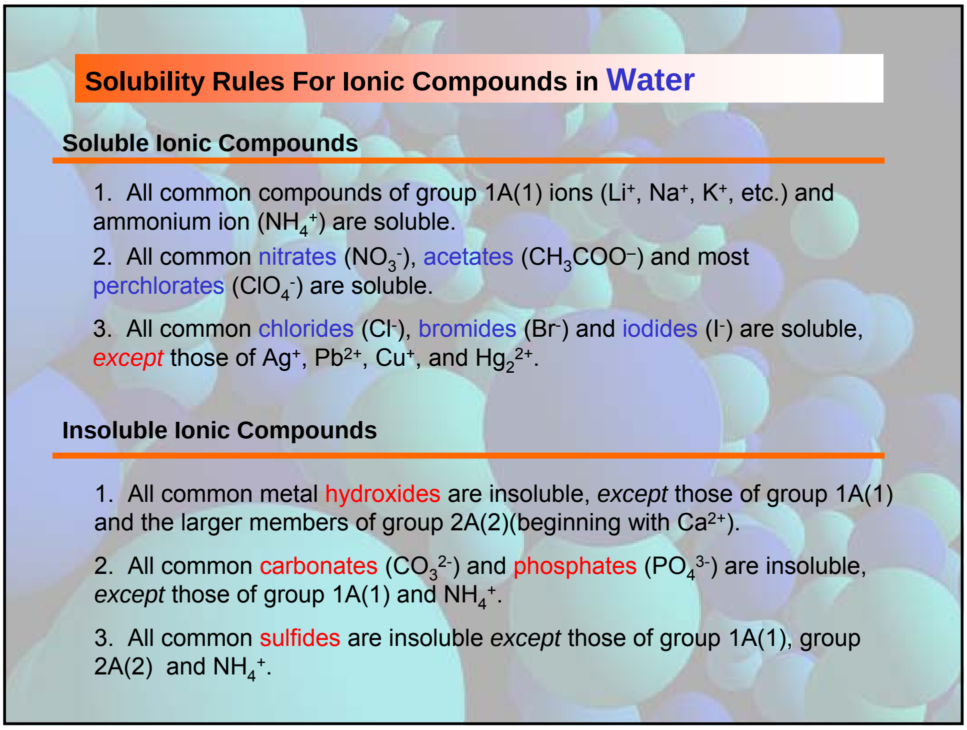
PROBLEM: Nitric acid is a major chemical in the fertilizer and explosives industries. In aqueous solution, each molecule dissociates and the H becomes a solvated H^+ ion. What is the molarity of $H^+(aq)$ in 1.4M nitric acid?

PLAN: Use the formula to find the molarity of H^+.

SOLUTION: Nitrate is NO_3^-.

$$HNO_3(l) \longrightarrow H^+(aq) + NO_3^-(aq)$$

1.4M $HNO_3(aq)$ should have 1.4M $H^+(aq)$.



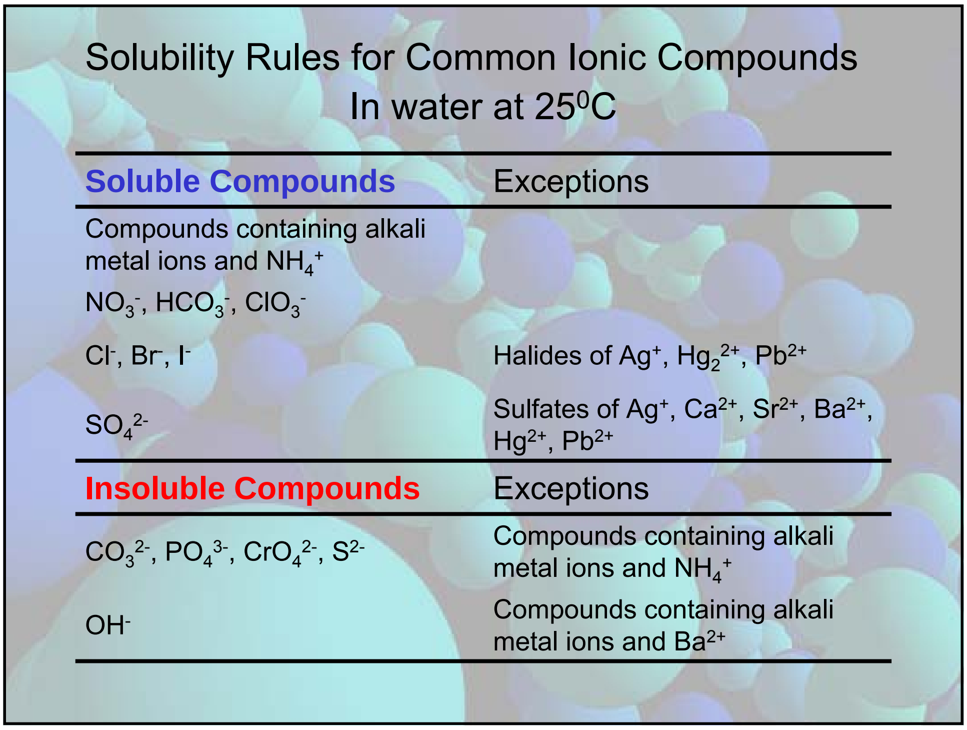
Solubility Rules For Ionic Compounds in Water

Soluble Ionic Compounds

1. All common compounds of group 1A(1) ions (Li^+, Na^+, K^+, etc.) and ammonium ion (NH_4^+) are soluble.
2. All common nitrates (NO_3^-), acetates (CH_3COO^-) and most perchlorates (ClO_4^-) are soluble.
3. All common chlorides (Cl^-), bromides (Br^-) and iodides (I^-) are soluble, *except* those of Ag^+, Pb^{2+}, Cu^+, and Hg_2^{2+}.

Insoluble Ionic Compounds

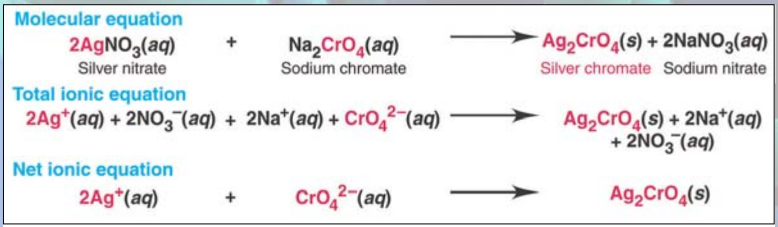
1. All common metal hydroxides are insoluble, *except* those of group 1A(1) and the larger members of group 2A(2)(beginning with Ca^{2+}).
2. All common carbonates (CO_3^{2-}) and phosphates (PO_4^{3-}) are insoluble, *except* those of group 1A(1) and NH_4^+.
3. All common sulfides are insoluble *except* those of group 1A(1), group 2A(2) and NH_4^+.



Solubility Rules for Common Ionic Compounds In water at 25^{0}C

Soluble Compounds	Exceptions
Compounds containing alkali metal ions and NH_4^+	
NO_3^-, HCO_3^-, ClO_3^-	
Cl^-, Br^-, I^-	Halides of Ag^+, Hg_2^{2+}, Pb^{2+}
SO_4^{2-}	Sulfates of Ag^+, Ca^{2+}, Sr^{2+}, Ba^{2+}, Hg^{2+}, Pb^{2+}
Insoluble Compounds	**Exceptions**
CO_3^{2-}, PO_4^{3-}, CrO_4^{2-}, S^{2-}	Compounds containing alkali metal ions and NH_4^+
OH^-	Compounds containing alkali metal ions and Ba^{2+}

A precipitation reaction and its equation



Molecular equation

$2AgNO_3(aq) + Na_2CrO_4(aq) \longrightarrow Ag_2CrO_4(s) + 2NaNO_3(aq)$

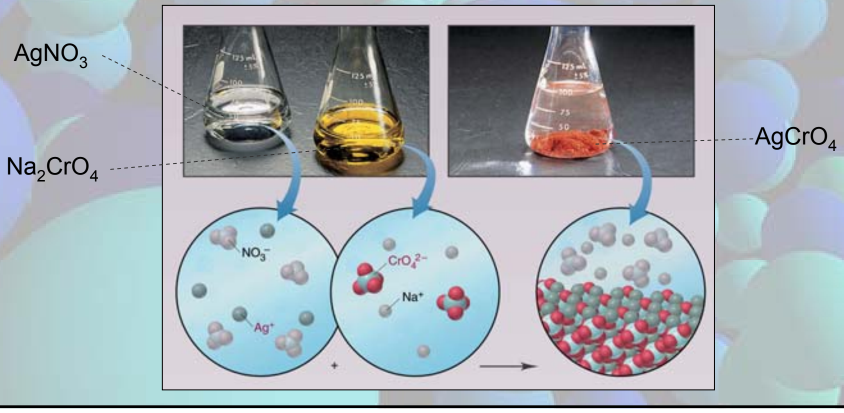
Silver nitrate, Sodium chromate, Silver chromate, Sodium nitrate

Total ionic equation

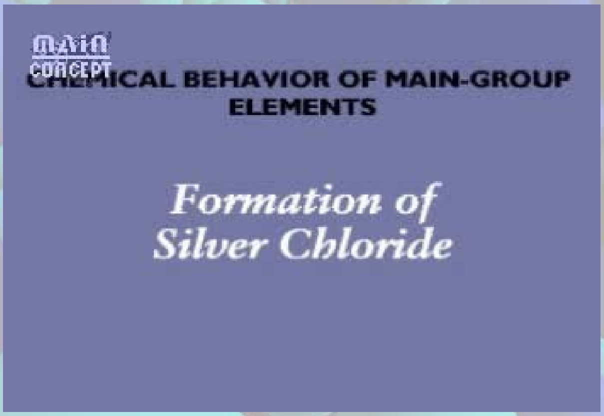
$2Ag^+(aq) + 2NO_3^-(aq) + 2Na^+(aq) + CrO_4^{2-}(aq) \longrightarrow Ag_2CrO_4(s) + 2Na^+(aq) + 2NO_3^-(aq)$

Net ionic equation

$2Ag^+(aq) + CrO_4^{2-}(aq) \longrightarrow Ag_2CrO_4(s)$



Formation of Silver Chloride



MAIN CONCEPT

CHEMICAL BEHAVIOR OF MAIN-GROUP ELEMENTS

Formation of Silver Chloride

Formation of Silver Chloride, Silver Bromide, Silver Iodide

$Ag(NO_3)_3 + NaCl \longrightarrow AgCl\downarrow + Na^+_{(aq)} + NO_3^-{}_{(aq)}$

white

Dissolves again in diluted NH_3

$Ag(NO_3)_3 + NaBr \longrightarrow AgBr\downarrow + Na^+_{(aq)} + NO_3^-{}_{(aq)}$

slightly yellow

Dissolves again in concentrated NH_3

$Ag(NO_3)_3 + NaI \longrightarrow AgI\downarrow + Na^+_{(aq)} + NO_3^-{}_{(aq)}$

yellow

Does not dissolve in NH_3

Writing Net Ionic Equations

1. Write the balanced molecular equation.
2. Write the ionic equation showing the strong electrolytes
3. Determine precipitate from solubility rules
4. Cancel the spectator ions on both sides of the ionic equation

Write the net ionic equation for the reaction of silver nitrate with sodium chloride.

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

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

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

Sample Problem **Predicting Whether a Precipitation Reaction Occurs; Writing Ionic Equations**

PROBLEM: Predict whether a reaction occurs when each of the following pairs of solutions are mixed. If a reaction does occur, write balanced molecular, total ionic, and net ionic equations, and identify the spectator ions.

(a) sodium sulfate(*aq*) + strontium nitrate(*aq*) ⟶

(b) ammonium perchlorate(*aq*) + sodium bromide(*aq*) ⟶

SOLUTION:

(a) $Na_2SO_4(aq) + Sr(NO_3)_2(aq) \longrightarrow 2NaNO_3(aq) + SrSO_4(s)$

$2Na^+(aq) + SO_4^{2-}(aq) + Sr^{2+}(aq) + 2NO_3^-(aq) \longrightarrow$
$2Na^+(aq) + 2NO_3^-(aq) + SrSO_4(s)$

$SO_4^{2-}(aq) + Sr^{2+}(aq) \longrightarrow SrSO_4(s)$

(b) $NH_4ClO_4(aq) + NaBr(aq) \longrightarrow NH_4Br(aq) + NaClO_4(aq)$

All reactants and products are soluble so no reaction occurs.

Reactions in Water

….. Solvation in Water

Hydration: Formation of ions that are surrounded by water

Dissociation I: Dissociation of ionic compounds (hydration energy)

$$NaCl + H_2O \rightleftharpoons Na^+_{(aq.)} + Cl^-_{(aq.)}$$

Dissociation II: Heteropolar dissociation caused by the reaction with water (protolysis).

$H^{\delta+}$◄$Cl^{\delta-}$

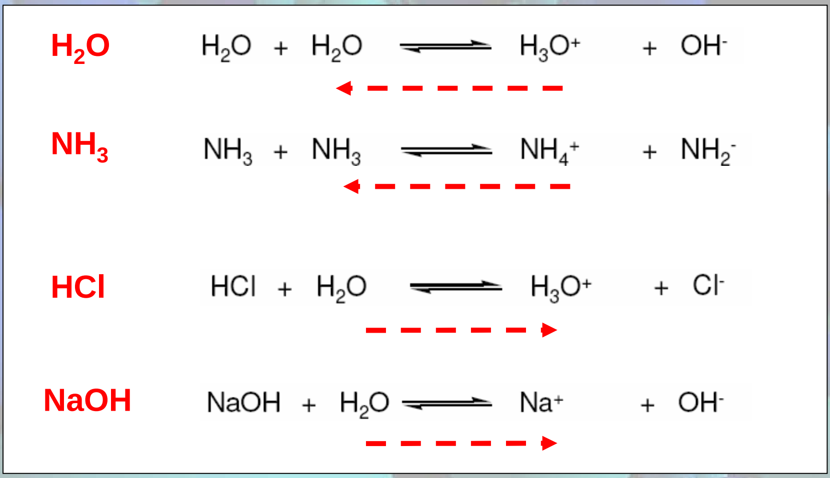
$$HCl + H_2O \rightleftharpoons H_3O^+_{(aq.)} + Cl^-_{(aq.)}$$

Hydronium Ion

Electrolytes: Substances that show electrical conductivity after dicossiation

Acid and Base Reactions

Equilibrium



H_2O $H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$

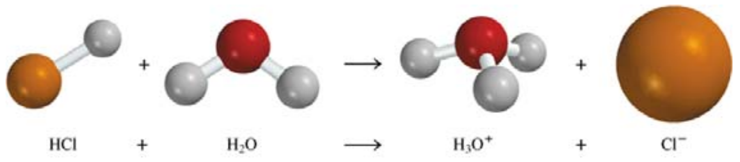
NH_3 $NH_3 + NH_3 \rightleftharpoons NH_4^+ + NH_2^-$

HCl $HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$

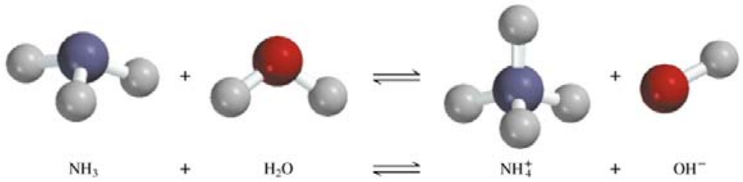
NaOH $NaOH + H_2O \rightleftharpoons Na^+ + OH^-$

Arrhenius (1883)

Arrhenius acid is a substance that produces H^+ (H_3O^+) in water



Arrhenius base is a substance that produces OH^- in water



Acid-Base Theory of Brönsted (1923)

Acid: donate protons (H^+)

Base: accept protons (H^+)

Corresponding acid and base

Acid 1		Base 1		Acid 2		Base 2
HCl	+	H_2O	$\rightleftharpoons$	H_3O^+	+	Cl^-
H_2SO_4	+	H_2O	$\rightleftharpoons$	H_3O^+	+	HSO_4^-
HSO_4^-	+	H_2O	$\rightleftharpoons$	H_3O^+	+	SO_4^{2-}
NH_4^+	+	H_2O	$\rightleftharpoons$	H_3O^+	+	NH_3
HCO_3^-	+	H_2O	$\rightleftharpoons$	H_3O^+	+	OH^-

Acid Strength

Base Strength

Neutralization Reaction

acid + *base* ⟶ *salt* + *water*

$$\text{HCl}\ (aq) + \text{NaOH}\ (aq) \longrightarrow \text{NaCl}\ (aq) + H_2O$$

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

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

Monoprotic **acids**

(H_2O neglected for clarity)

$HCl \longrightarrow H^+ + Cl^-$	Strong electrolyte, strong acid
$HNO_3 \longrightarrow H^+ + NO_3^-$	Strong electrolyte, strong acid
$CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$	Weak electrolyte, weak acid

Diprotic **acids**

(H_2O neglected for clarity)

$H_2SO_4 \longrightarrow H^+ + HSO_4^-$	Strong electrolyte, strong acid
$HSO_4^- \rightleftharpoons H^+ + SO_4^{2-}$	Weak electrolyte, weak acid

Triprotic **acids**

(H_2O neglected for clarity)

$H_3PO_4 \rightleftharpoons H^+ + H_2PO_4^-$	Weak electrolyte, weak acid
$H_2PO_4^- \rightleftharpoons H^+ + HPO_4^{2-}$	Weak electrolyte, weak acid
$HPO_4^{2-} \rightleftharpoons H^+ + PO_4^{3-}$	Weak electrolyte, weak acid

Selected Acids and Bases

Acids

Strong

- hydrochloric acid, HCl
- hydrobromic acid, HBr
- hydroiodic acid, HI
- nitric acid, HNO_3
- sulfuric acid, H_2SO_4
- perchloric acid, $HClO_4$

Weak

- hydrofluoric acid, HF
- phosphoric acid, H_3PO_4
- acetic acid, CH_3COOH (or $HC_2H_3O_2$)

Bases

Strong

- sodium hydroxide, NaOH
- potassium hydroxide, KOH
- calcium hydroxide, $Ca(OH)_2$
- strontium hydroxide, $Sr(OH)_2$
- barium hydroxide, $Ba(OH)_2$

Weak

- ammonia, NH_3

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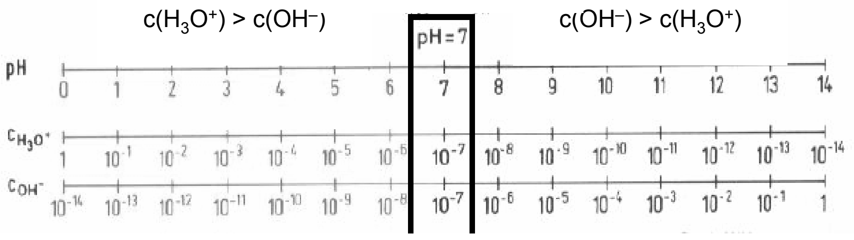
pH -value

$pH = -\log c_{H^+}$ $\qquad pOH = -\log c_{OH^-}$ $\qquad pH + pOH = 14$

Neutral
$c(OH^-) = c(H_3O^+)$

Acid
$c(H_3O^+) > c(OH^-)$

Basic
$c(OH^-) > c(H_3O^+)$



Strength of an acid

$$HA + H_2O \rightleftharpoons H_3O^+ + A^-$$

$$\boxed{K_S = \frac{[H_3O^+][A^-]}{[HA]}} \Rightarrow \boxed{pK_S = -\log K_S}$$

Strength of a base

$$B + H_2O \rightleftharpoons HB^+ + OH^-$$

$$\boxed{K_B = \frac{[HB^+]\ [OH^-]}{[B]}} \Rightarrow \boxed{pK_B = -\log K_B} \qquad \boxed{pK_S + pK_B = 14}$$

pks value:

HCl	-7,0	H_2S	+6,99
H_2SO_4	-3,0	HSO_3^-	+7,20
HNO_3	-1,37	HCN	+9,21
H_3PO_4	+2,16	H_2O_2	+11,65
CH_3CO_2H	+4,75	OH^-	+29

Sample Problem **Writing Ionic Equations for Acid-Base Reactions**

PROBLEM: Write balanced molecular, total ionic, and net ionic equations for each of the following acid-base reactions and identify the spectator ions.

(a) strontium hydroxide(*aq*) + perchloric acid(*aq*) →

(b) barium hydroxide(*aq*) + sulfuric acid(*aq*) →

PLAN:

reactants are strong acids and bases and therefore completely ionized in water

products are

water

spectator ions

SOLUTION:

(a) $Sr(OH)_2(aq) + 2HClO_4(aq) \rightarrow 2H_2O(l) + Sr(ClO_4)_2(aq)$

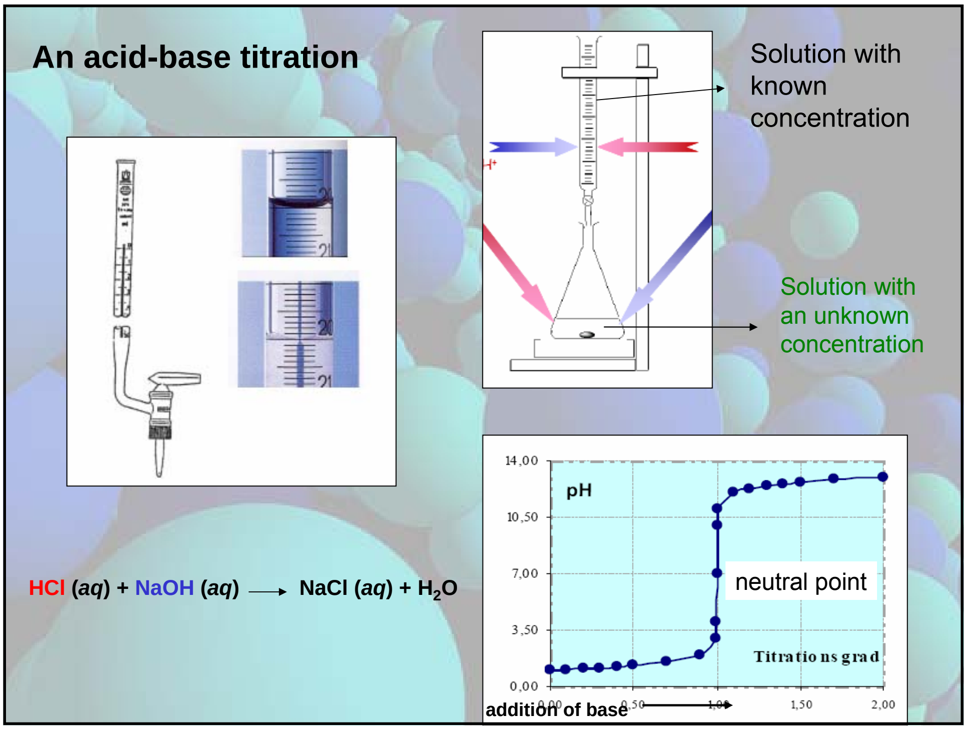
$Sr^{2+}(aq) + 2OH^-(aq) + 2H^+(aq) + 2ClO_4^-(aq)$
$2H_2O(l) + Sr^{2+}(aq) + 2ClO_4^-(aq)$

$2OH^-(aq) + 2H^+(aq) \rightarrow 2H_2O(l)$

(b) $Ba(OH)_2(aq) + H_2SO_4(aq) \rightarrow 2H_2O(l) + BaSO_4(s)$

$Ba^{2+}(aq) + 2OH^-(aq) + 2H^+(aq) + SO_4^{2-}(aq)$
$2H_2O(l) + BaSO_4(s)$

$2OH^-(aq) + 2H^+(aq) \quad 2H_2O(l)$

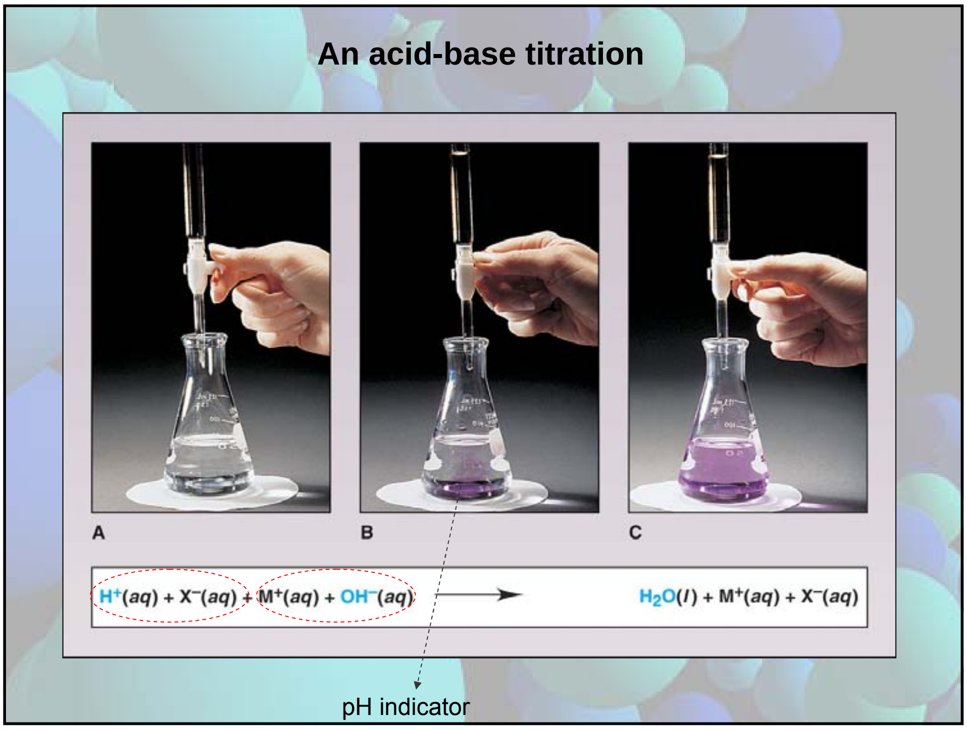


An acid-base titration

Solution with known concentration

Solution with an unknown concentration

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



An acid-base titration

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

pH indicator

Sample Problem **Finding the Concentration of Acid from an Acid-Base Titration**

PROBLEM: You perform an acid-base titration to standardize an HCl solution by placing 50.00mL of HCl in a flask with a few drops of indicator solution. You put 0.1524M NaOH into the buret, and the initial reading is 0.55mL. At the end point, the buret reading is 33.87mL. What is the concentration of the HCl solution?

SOLUTION:

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

At the neutral point: 1 mol (NaOH) = 1 mol (HCl)

mol NaOH: $c = n/V$ $n = c V$ 0.03332L X 0.1524M = 5.078×10^{-3}mol

Molar ratio is 1:1

c (HCl): $c = n/V$ HCl: $\frac{5.078 \times 10^{-3}\text{mol}}{0.050\text{L}}$ = 0.1016M

As previously indicated: for these tiration “exercises” you often apply the two simple formula:

$$c = n/V \qquad n = m/M$$

…………. see practical course