Aqueous Reactions
(Solutions/ Molarity)

Net Ionic Equations

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Aqueous Reactions

- There are a few general types:

1) **Precipitation:** An insoluble salt forms from the addition of solutions. (Cloudiness is oberved. **Solubility governs**): **(aq) ⟶ (s)**

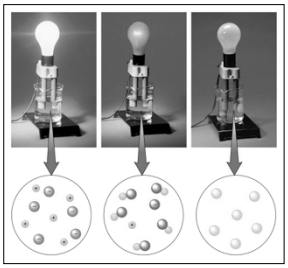
2) **Acid-Base (Neutralization):** generally produces a salt, plus heat + water (l): **(aq) ⟶ (l)**

3) **Oxidation-Reduction (Redox):** there is a change in oxidation numbers between reactants and products

Electrolytes
Ions in an aqueous (water) solution

- **Pure Water** does not conduct electricity.
- A water solution must have **ions** to conduct electricity.
- Aqueous solutions can be categorized into 3 types: non-electrolytes, strong electrolytes or weak electrolytes based on their ability to conduct electricity in a homogeneous aqueous solution (aq).
- Aqueous solutions can be tested for conductivity which will determine the degree of ionization of the solute, that is, the substance dissolved in water.
- It is possible to have full or partial ionization.

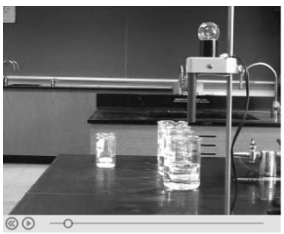
Solution Test Apparatus for Electrolytes (Ions)



Conductivity depends on the amount of ions in solution

strong weak non-

Conductivity



http://chemconnections.org/general/movies/html-swf/electrolytes.htm

Molarity (M) = moles solute / Liter solution

Electrolytes

- Almost all ionic compounds and a few molecular compounds are strong electrolytes.
- Several molecular compounds are weak conductors, most are non-conductors.
- Conductivity is directly related to the amount of ionization, i.e. ions in solution. Table salt, sodium chloride, is completely ionized:

$$NaCl_{(s)} + H_2O_{(l)} \longrightarrow NaCl_{(aq)} \longrightarrow$$

0.10M

$$Na^+_{(aq)} + Cl^-_{(aq)}$$

0.10M 0.10M

Add 5.8g of sodium chloride to water to make 1.0 L of solution = 0.10M = 0.10 mol/L

All of the sodium chloride ionizes to make 1.0 L of solution = 0.10M Na^+ and 0.10M Cl^-

Molarity (M) = moles solute / Liter solution

Electrolytes

- Concentrations:
- $CaCl_{2\,(s)} + H_2O_{(l)} \longrightarrow CaCl_{2(aq)} \longrightarrow$
  $0.10M$
  $Ca^{2+}{}_{(aq)} + 2\ Cl^{-}{}_{(aq)}$
  $0.10M \quad 0.20M$

How many grams of calcium chloride (MM =111 g/mol) should be added to water to make 1.00 L of a 0.10M solution of calcium chloride?

How many grams of calcium chloride (MM =111 g/mol) should be added to water to make 1.00 L of a solution having 0.10M chloride ion?

Molarity (M) = moles solute / Liter solution

Electrolytes

- *Sugars like sucrose are non-ionic, molecular compounds that dissolve but produce no ions.*

$$C_{12}H_{22}O_{11\,(S)} + H_2O_{(l)} \longrightarrow C_{12}H_{22}O_{11\,(aq)}$$

- *Some molecular compounds like acetic acid ionize partially (dissociate) in water*

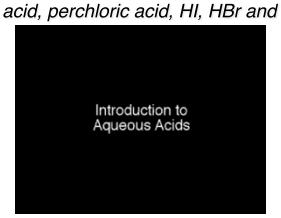
$$HC_2H_3O_{2\,(l)} + H_2O_{(l)} \rightleftharpoons H_3O^{+}{}_{(aq)} + C_2H_3O_2{}^{-}{}_{(aq)}$$

$0.1000M \qquad 0.09987M \qquad 0.013M$

Acetic Acid ($HC_2H_3O_2$)
NOT Completely Ionized
Example of equilibrium

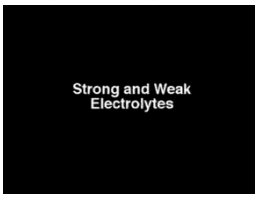
Aqueous Acids

- *Any compound that provides a proton can be considered an acid. Strong acids are sulfuric acid, nitric acid, perchloric acid, HI, HBr and HCl.*

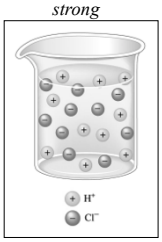


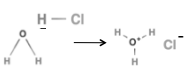
Electrolytes

- *How would the conductivity of acetic acid compare to hydrochloric acid?*



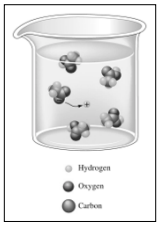
strong

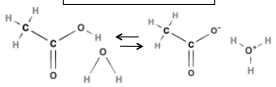




HCl
Completely Ionized

weak





Acetic Acid ($HC_2H_3O_2$)
NOT Completely Ionized
Example of equilibrium

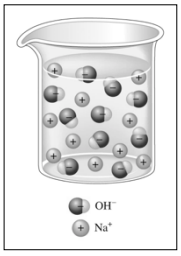
Aqueous Bases

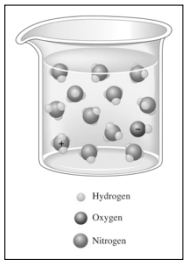
- *Any compound that accepts a proton is a base.*
- *The common bases are group IA & IIA metal hydroxide compounds. They are strong bases, dissociating completely in water.*
- *An example of a weak base is ammonia.*

$$NH_{3\,(g)} + H_2O_{(l)} \rightleftharpoons NH_{3\,(aq)} \rightleftharpoons NH_4^{+}{}_{(aq)} + OH^{-}{}_{(aq)}$$

Consider that aqueous ammonia is in equilibrium with ammonium hydroxide. The names have often been used interchangeably.

strong *weak*





An Aqueous Solution of Sodium Hydroxide

$NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$

Completely Ionized

An Aqueous Solution of Ammonia

$NH_{3\,(aq)} \rightleftarrows NH_4^+{}_{(aq)} + OH^-_{(aq)}$

***NOT** Completely Ionized*

Example of equilibrium

Selected Acids and Bases

Acids

Strong

Hydrochloric acid, HCl
Hydrobromic acid, HBr
Hydriodic 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

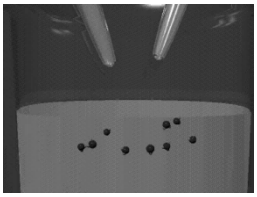
Ammonia, NH_3

QUESTION

All of the following are weak acids *except*:

A) HCNO.
B) HBr.
C) HF.
D) HNO_2.
E) HCN.

Aqueous Reactions: Neutralization



Aqueous Reactions: Neutralization

Net Ionic Equations

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

- $HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$
- $NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$
- $NaCl_{(aq)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)}$

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

$Na^+_{(aq)} + Cl^-_{(aq)} + H_2O_{(l)}$

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

QUESTION

In the balanced molecular equation for the neutralization of sulfuric acid, $H_2SO_{4\,(aq)}$, with sodium hydroxide, the products in the balanced equation are:

A) $NaSO_{4\,(aq)} + H_2O_{(l)}$
B) $NaSO_{3\,(aq)} + 2\,H_2O_{(l)}$
C) $2\,NaSO_{4\,(aq)} + H_2O_{(l)}$
D) $Na_2S_{(aq)} + 2\,H_2O_{(l)}$
E) $Na_2SO_{4\,(aq)} + 2\,H_2O_{(l)}$

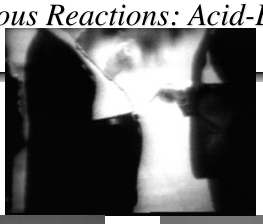
QUESTION

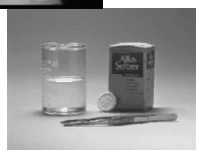
All balanced net ionic equations when reduced to the smallest common stoichiometric number is the same for the neutralization of all acids: eg. sulfuric acid, $H_2SO_{4\,(aq)}$, nitric acid HNO_3, phosphoric acid H_3PO_4 and all others.

A) True
B) False

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

Aqueous Reactions: Acid-Base





QUESTION

If an antacid contains $Al(OH)_3$ it will form $AlCl_3$ upon neutralization of stomach acid. How many moles of Cl^- ions are in 100.0 mL of 0.010 M $AlCl_3$?

A.0.0010 mol
B.0.010 mol
C.0.0030 mol
D.0.030 mol

Molarity (M) = mol $AlCl_3$ / Liter solution

mol $AlCl_3$ = Molarity $AlCl_3$ x Volume solution (L)

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$AlCl_3$ dissociates into 3 moles of Cl^-.

Calculations
*Reactant → **Product***

moles (Reactant) → moles (Product)

$AlCl_3$ dissociates into 3 moles of Cl^-.

$AlCl_{3\,(aq)} \longrightarrow Al^{3+}_{(aq)} + 3\ Cl^-_{(aq)}$

(Volume) 1 L	0.010 mol ($AlCl_3$)	? mol Cl^-	100.0 mL ($AlCl_3$)	= ? mol (Cl -)
(Volume) 1000 mL	1 L ($AlCl_3$)	? mol $AlCl_3$		

"Gatekeepers" from Balanced reaction

The Reaction of $Pb(NO_3)_2$ and NaI

What type of reaction is it?
Double Displacement & Precipitation

Write a balanced equation for the reaction.

$$Pb(NO_3)_{2\,(aq)} + 2\ NaI_{(aq)} \rightarrow 2\ NaNO_{3(aq)} + PbI_{2(s)}$$

How do you know the state of the products: (s) vs. (aq)?

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 $BaSO_4$, $PbSO_4$, Hg_2SO_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-}) salts are only slightly soluble.

QUESTION

Given the insoluble compound $Al_2(CO_3)_3$ predict the ions and coefficients that would be necessary to complete the following net ionic equation:

__ _____ + ____ _____ → $Al_2(CO_3)_3$

A.2 $AlCl_3$ + 3 Na_2CO_3 also include 6 NaCl on right
B.3 Al^{3+} + 2 CO_3^{2-}
C.2 Al^{3+} + 3 CO_3^{2-}
D.2 Al^{3+} 6 Cl^- + 3 CO_3^{2-} + 6 Na^+

Aqueous Reactions: Precipitation

Net Ionic Equations

- *50mL of a 0.1M solution of sodium sulfate is mixed with 50mL of a 0.2M solution of silver nitrate. What is the result?*
- *Molecular Equation:*

$$?Na_2SO_{4(aq)} + ?AgNO_{3(aq)} \rightleftharpoons ?Ag_2SO_{4(s)} + ?NaNO_{3(aq)}$$

1 2 1 2

Aqueous Reactions: Precipitation

Net Ionic Equations

$$Na_2SO_{4(aq)} + 2\ AgNO_{3(aq)} \rightarrow Ag_2SO_{4(s)} + 2\ NaNO_{3(aq)}$$

0.1M 0.2M

Ionic Reaction (Reactants):

$$Na_2SO_{4(aq)} \longrightarrow 2\ Na^+_{(aq)} + SO_4^{2-}{}_{(aq)}$$

$$2\ AgNO_{3(aq)} \rightarrow 2\ Ag^+_{(aq)} + 2\ NO_3^{1-}{}_{(aq)}$$

$$2\ Na^+_{(aq)} + SO_4^{2-}{}_{(aq)} + 2\ Ag^+_{(aq)} + 2\ NO_3^{1-}{}_{(aq)}$$

0.2M 0.1M 0.2M 0.2M

Aqueous Reactions: Precipitation

Net Ionic Equations

$$Na_2SO_{4(aq)} + 2\ AgNO_{3(aq)} \rightarrow Ag_2SO_{4(s)} + 2\ NaNO_{3(aq)}$$

0.1M 0.2M

Ionic Reaction (Products):

$$2\ NaNO_{3(aq)} \longrightarrow 2\ Na^+_{(aq)} + 2\ NO_3^{1-}{}_{(aq)}$$

$$Ag_2SO_{4(s)} \rightarrow \text{Does not dissolve (ionize)}$$

$$2Na^+_{(aq)} + 2NO_3^{1-}{}_{(aq)} + Ag_2SO_{4(s)}$$

0.2M 0.2M solid

Aqueous Reactions: Precipitation

Net Ionic Equations

$$Na_2SO_{4(aq)} + 2\ AgNO_{3(aq)} \rightarrow Ag_2SO_{4(s)} + 2\ NaNO_{3(aq)}$$

Overall Ionic Reaction:

$$2Na^+_{(aq)} + SO_4^{2-}{}_{(aq)} + 2Ag^+_{(aq)} + 2NO_3^{1-}{}_{(aq)} \longrightarrow 2Na^+_{(aq)} + Ag_2SO_{4(s)} + 2NO_3^{1-}{}_{(aq)}$$

Net Ionic Equation: (Subtract Spectator Ions)

$$2Ag^+_{(aq)} + SO_4^{2-}{}_{(aq)} \rightleftharpoons Ag_2SO_{4(s)}$$

How many moles?

$M_{SO_4^{2-}{}_{(aq)}} \times V_{solution} = \text{mol}$ $= M_{Na2SO4} \times V_{Na2SO4}$ / 1:1 stoichiometry

= 0.10M x 0.050 L
= 0.0050 mol

= 0.0050 mol $Ag_2SO_{4(s)}$

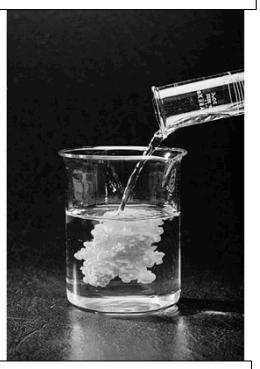
QUESTION

$\underline{?}\ Na_2SO_{4(aq)} + \underline{?}\ Ag(NO_3)_{3(aq)} \longrightarrow \underline{?}\ Ag_2SO_{4\,(s)} + \underline{?}\ NaNO_{3(aq)}$

The balanced net ionic equation for the reaction of sodium sulfate and silver nitrate contains which of the following species?

A) 2 $Na^+(aq)$
B) 2 $NO_3^-(aq)$
C) 2 $Ag^+(aq)$
D) 2 $AgNO_3(aq)$
E) All of the above

The Reaction of $Pb(NO_3)_2$ and NaI



$Pb(NO_3)_{2\,(aq)} + 2\ NaI_{\,(aq)} \rightarrow 2\ NaNO_{3(aq)} + PbI_{\,2(s)}$

Write a balanced Net Ionic equation for the reaction.

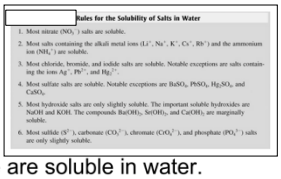
$Pb^{2+}{}_{(aq)} + 2\ I^{1-}{}_{(aq)} \rightarrow PbI_{\,2(s)}$

What are the spectator ions in the reaction?

$2\ Na^{1+}{}_{(aq)}$; $2\ NO_3^{1-}{}_{(aq)}$

QUESTION

Which of the following salts is insoluble in water?



A) Na_2S
B) K_3PO_4
C) $Pb(NO_3)_2$
D) $CaCl_2$
E) All of these are soluble in water.

QUESTION

If you began a reaction with the following ions in solution (all would be written with an (*aq)* subscript how would you represent the proper final net ionic equation? (Consult solubility Table.)

$$6Na^+ + 2PO_4^{3-} + 3Fe^{2+} + 6NO_3^- \rightarrow$$

A. $3Na^+ + PO_4^{3-} + Fe^{2+} + 2NO_3^- \rightarrow$ No Reaction
B. $6Na^+ + 2PO_4^{3-} + 3Fe^{2+} + 6NO_3^- \rightarrow Fe_3(PO_4)_2\,(s) + 6NaNO_3$
C. $3Na^+ + PO_4^{3-} + Fe^{2+} + 2NO_3^- \rightarrow Fe_3(PO_4)_2\,(s) + 6\ Na^+ + 6\ NO_3^-$
D. $2PO_4^{3-} + 3Fe^{2+} \rightarrow Fe_3(PO_4)_2\,(s)$