Aqueous Reactions

(Solutions/ Molarity)

Electrolytes, Acids, Bases and Calculations

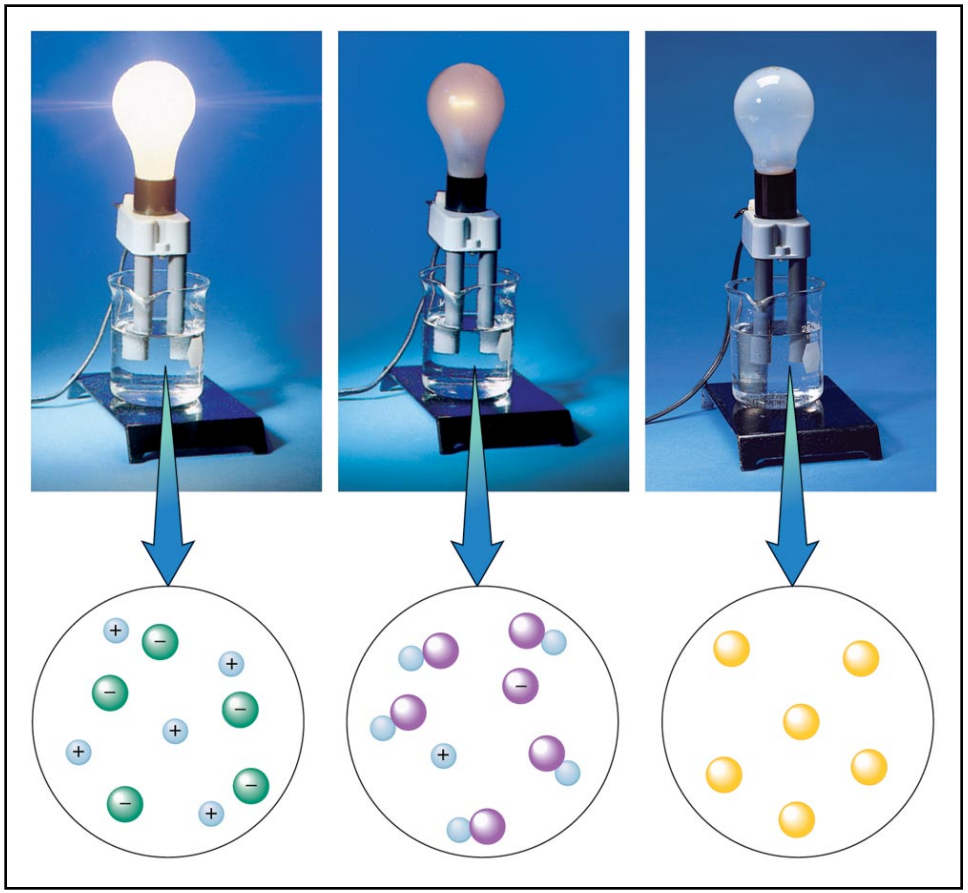
Dr. Ron Rusay

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.*

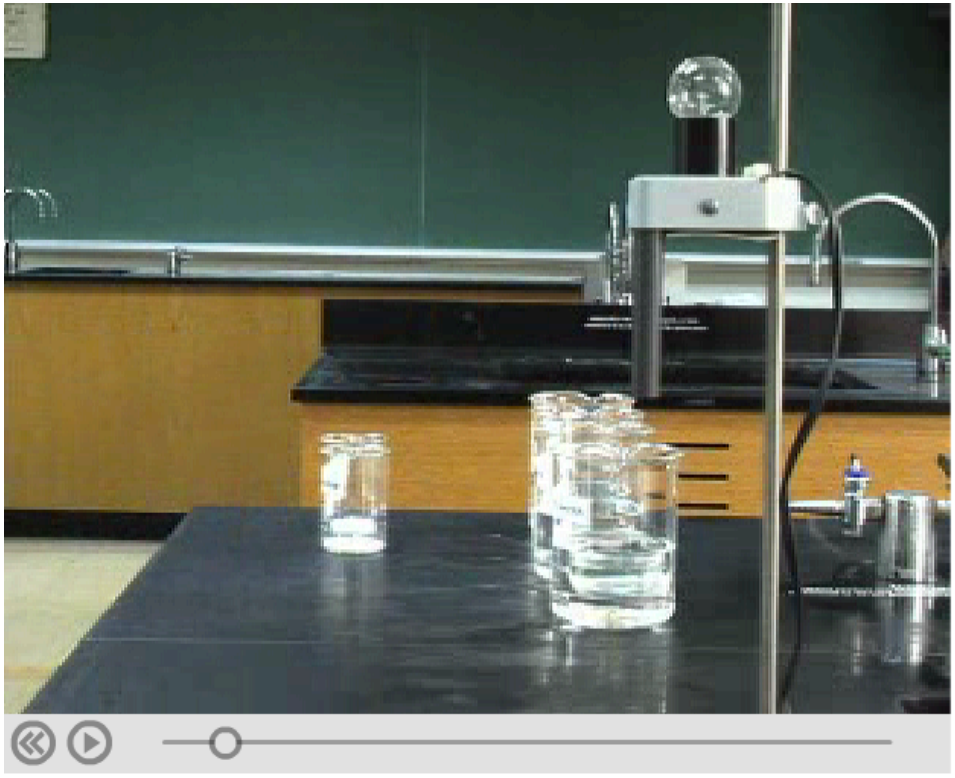
Solution Test Apparatus for Electrolytes (Ions)



strong *weak* *non-*

Conductivity depends on the amount of ions in solution

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:*

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

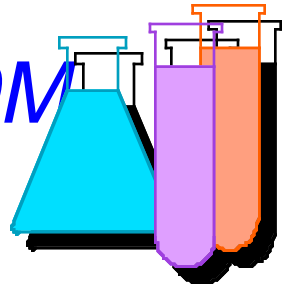
0.10M

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

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:*
- $CaCl_{2\,(s)} + H_2O_{(l)} \longrightarrow CaCl_{2(aq)}$ ——— *0.10M*

$$Ca^{2+}_{(aq)} + 2\ Cl^{-}_{(aq)}$$

0.10M *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*

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

$$0.1000M \qquad\qquad 0.09987M \rightleftharpoons 0.00013M$$

Acetic Acid ($HC_2H_3O_2$)

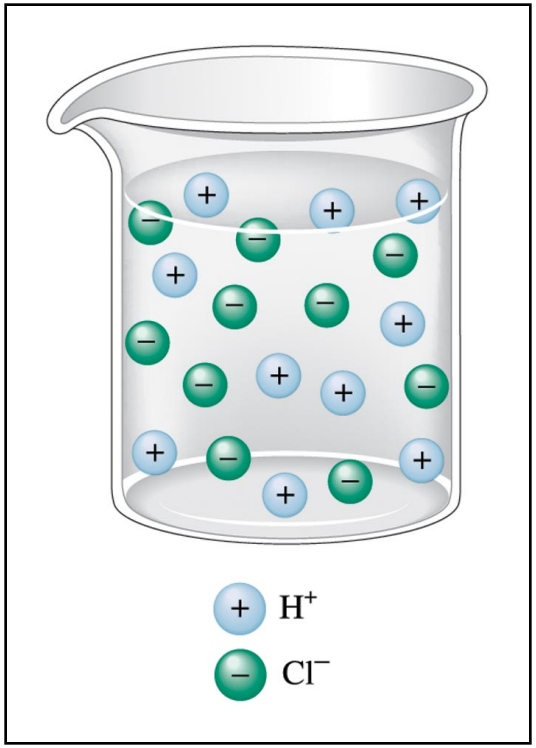
NOT *Completely Ionized*

Example of equilibrium

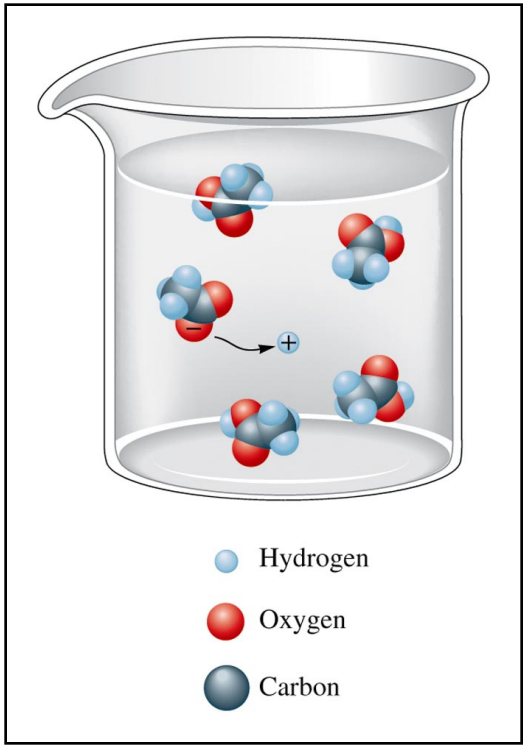
Conductivity

Which of these solutions will have highest conductivity?

A	B	C
0.1 M $KCl_{(aq)}$	0.2 M $HCl_{(aq)}$	0.3 M $HC_2H_3O_{2(aq)}$



HCl
Completely
Ionized



Acetic Acid
($HC_2H_3O_2$)

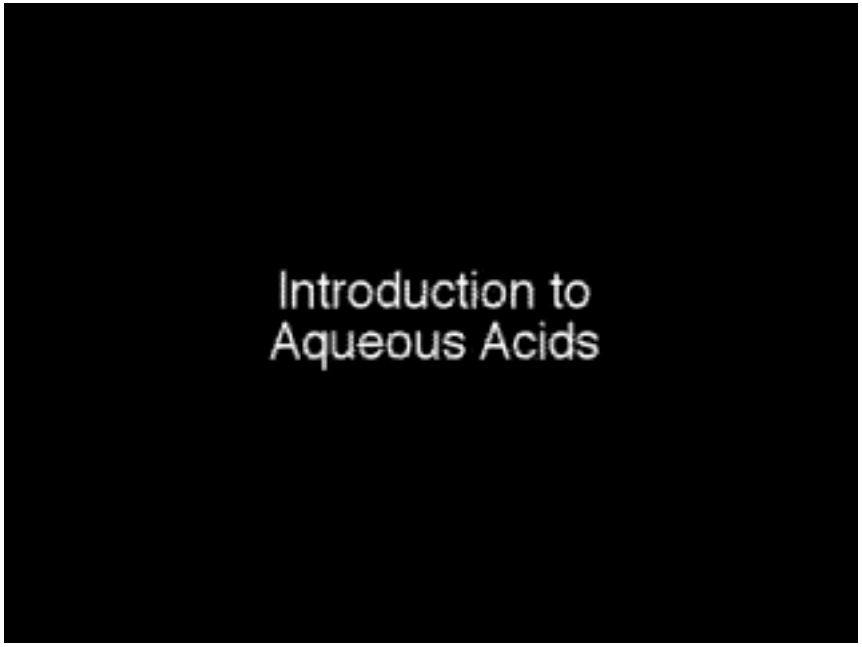
Conductivity

Which of these solutions will have highest conductivity?

A	B	C
0.1 M $HCl_{(aq)}$	0.1 M $CaCl_{2\,(aq)}$	0.2 M $HC_2H_3O_{2(aq)}$

Aqueous Acids

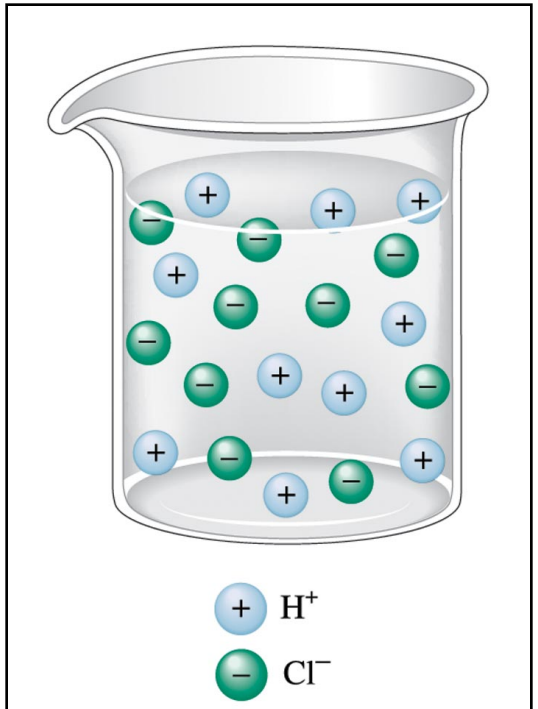
- *Any compound that provides a proton can be considered an acid. Strong acids are sulfuric acid, nitric acid, perchloric acid, HI, HBr and HCl.*

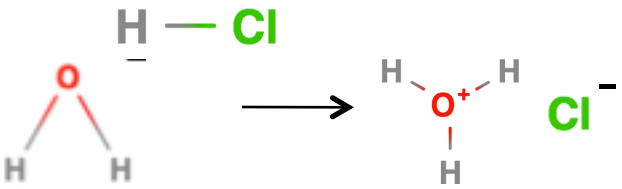


Electrolytes

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

strong

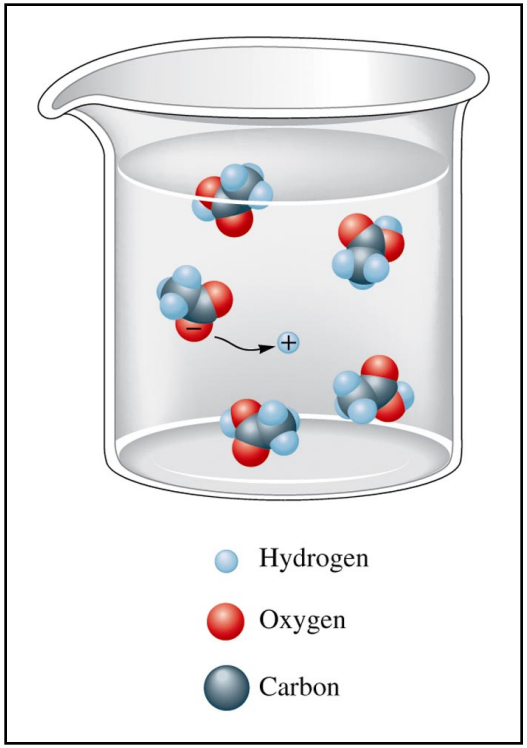


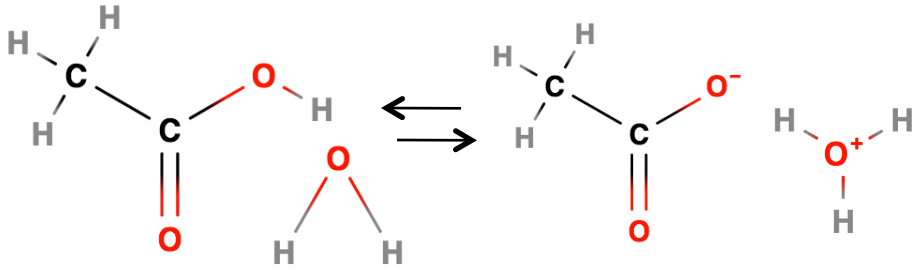


HCl

Completely Ionized

weak





Acetic Acid $(HC_2H_3O_2)$

NOT *Completely Ionized*

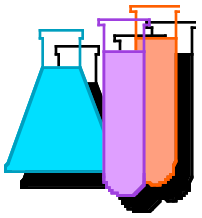
Example of equilibrium

Aqueous Bases

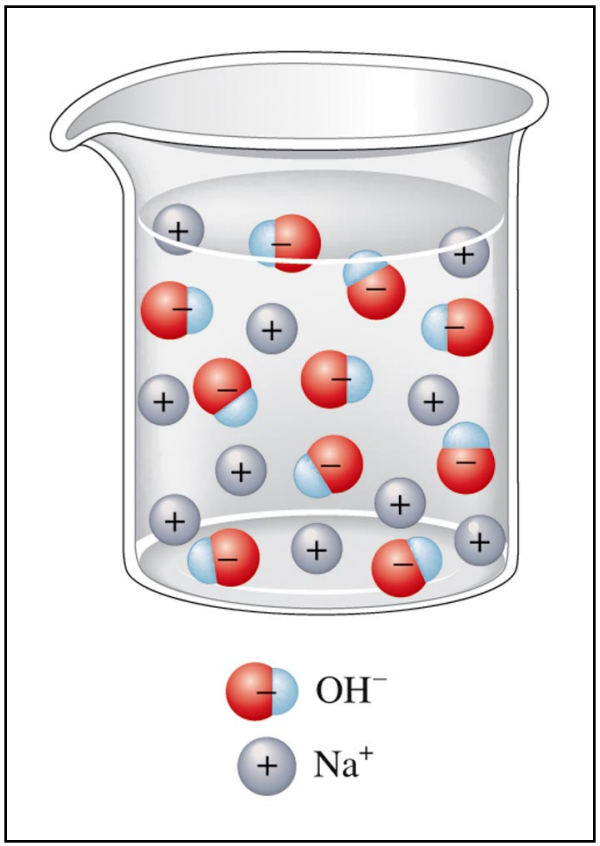
- *Any compound that accepts a proton is a base.*
- *The common bases are group IA & IIA metal hydroxide compounds. They are strong bases, dissociating completely in water.*
- *An example of a weak base is ammonia.*

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

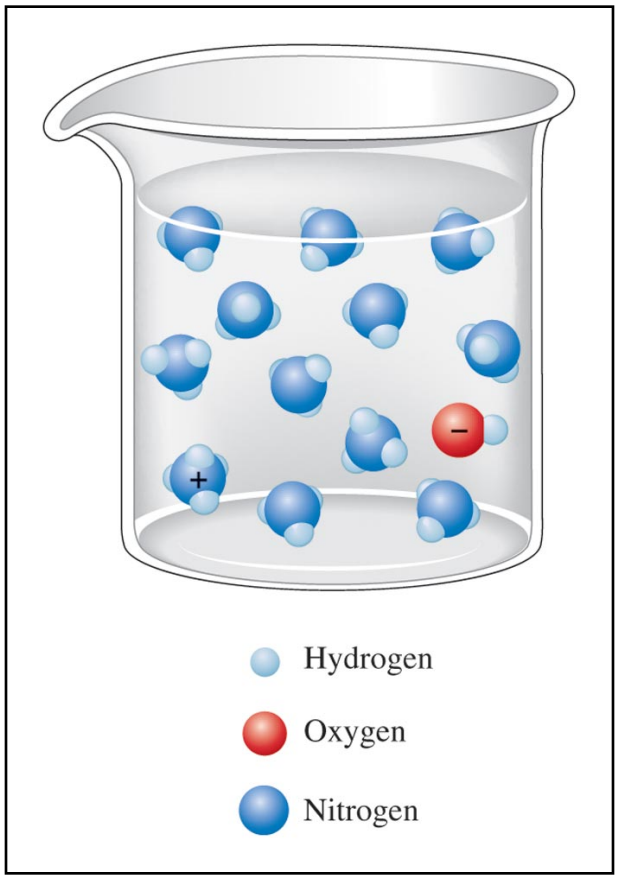
Consider that aqueous ammonia is in equilibrium with ammonium hydroxide. The names have often been used interchangeably.



strong



weak



An Aqueous Solution of Sodium Hydroxide

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

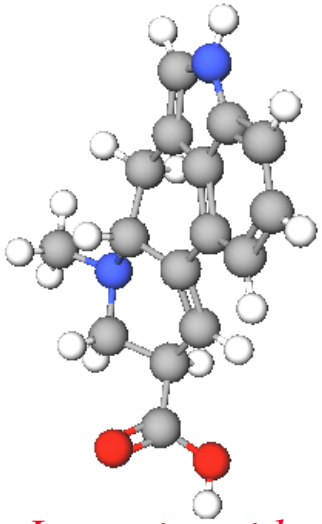
Completely Ionized

An Aqueous Solution of Ammonia

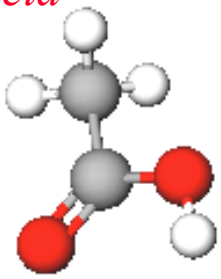
$$NH_{3\,(aq)} \rightleftarrows NH_4^+{}_{(aq)} + OH^-_{(aq)}$$

NOT *Completely Ionized*

Example of equilibrium



Lysergic acid



Acetic acid

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 $HC_2H_3O_2$)

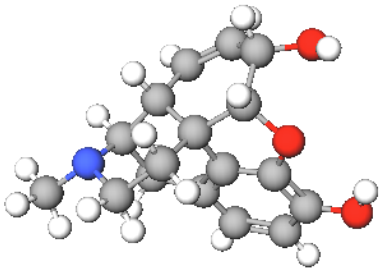
Bases

Strong

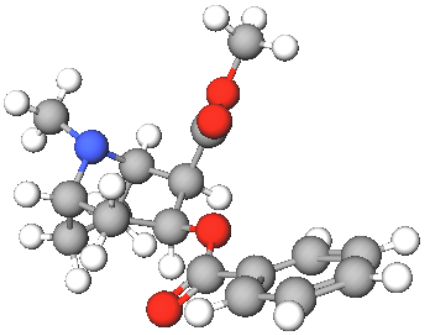
Sodium hydroxide, NaOH
Potassium hydroxide, KOH
Calcium hydroxide, $Ca(OH)_2$
Strontium hydroxide, $Sr(OH)_2$
Barium hydroxide, $Ba(OH)_2$

Weak

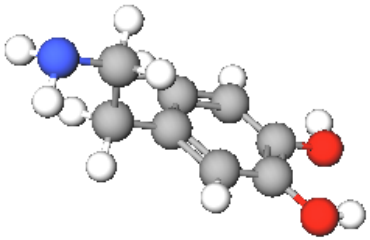
Ammonia, NH_3



Morphine



Cocaine



Dopamine

QUESTION

All of the following are weak acids *except*:

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

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

20 drops of 0.10M H_2SO_4 is added to 20 drops of a 0.10M aqueous solution of $Ba(OH)_2$. The reaction is monitored using a conductivity tester.

Predict the correct statement(s).

I) Both H_2SO_4 and $Ba(OH)_2$ are strong electrolytes.

II) This is a neutralization reaction.

III) This is a precipitation reaction.

IV) The light bulb will glow at the neutralization point.

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.

$$H_2SO_{4\,(aq)} + Ba(OH)_{2\,(aq)} \longrightarrow BaSO_{4\,(s)} + 2\,H_2O_{\,(l)}$$

A) II

B) I and II

C) I, II and III

D) I, II, III and IV

QUESTION

An antacid contains $Al(OH)_3$. It produces $AlCl_{3\,(aq)}$ on neutralization of stomach acid. How many moles of Cl^- ions are in 100.0 mL of 0.010 M $AlCl_3$ produced in the neutralization?

$$3\ HCl_{(aq)} + Al(OH)_{3\,(aq)} \longrightarrow AlCl_{3\,(aq)} + 3\ H_2O_{(l)}$$

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)

QUESTION

How many moles of Cl^- ions are in 100.0 mL of 0.010 M $AlCl_3$ produced in the neutralization?

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

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

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

$AlCl_{3\,(aq)}$ dissociates into 3 moles of Cl^-.

QUESTION

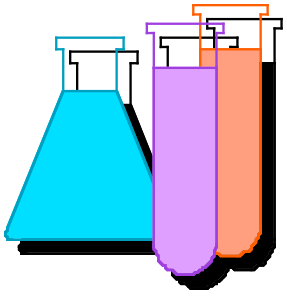
moles (Reactant) → moles (Product)

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

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

(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



(Chem 120 Prep)

QUESTION & ANSWER

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 a 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. $2PO_4^{3-} + 3Fe^{2+} \rightarrow Fe_3(PO_4)_2\ (s)$

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6. Most sulfide (S^{2-}), carbonate (CO_3^{2-}), chromate (CrO_4^{2-}), and phosphate (PO_4^{3-}) salts are only slightly soluble.

(Chem 120 Prep)

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:*

$$\underline{1}\ ?Na_2SO_{4(aq)} + \underline{2}\ ?AgNO_{3(aq)} \rightleftharpoons \underline{1}\ ?Ag_2SO_{4(s)} + \underline{2}\ ?NaNO_{3(aq)}$$

(Chem 120 Prep)

Aqueous Reactions: Precipitation

Net Ionic Equations

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

0.1M 0.2M

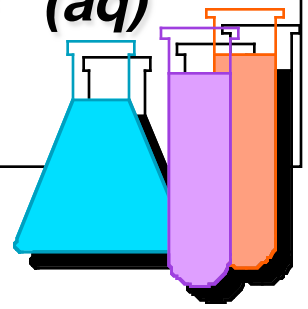
Ionic Reaction (Reactants):

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

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

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

0.2M 0.1M 0.2M 0.2M



(Chem 120 Prep)

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):

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

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

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

0.2M *0.2M* *solid*

(Chem 120 Prep)

Aqueous Reactions: Precipitation

Net Ionic Equations

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

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 form?

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

= 0.10 mol/L 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

Answer

$\underline{1}\ Na_2SO_{4(aq)} + \underline{2}\ Ag(NO_3)_{3(aq)} \longrightarrow \underline{1}\ Ag_2SO_{4\,(s)} + \underline{2}\ NaNO_{3(aq)}$

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

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

QUESTION & Answer

Which of the following salts is soluble 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.

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QUESTION & ANSWER

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C. $3Na^+ + PO_4^{3-} + Fe^{2+} + 2NO_3^- \rightarrow Fe_3(PO_4)_2\ (s) + 6\ Na^+ + 6\ NO_3^-$

D. $2PO_4^{3-} + 3Fe^{2+} \rightarrow Fe_3(PO_4)_2\ (s)$

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