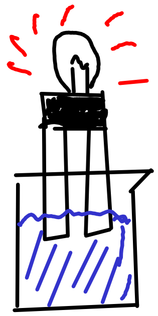
Ionic theory experiment



Simple conductivity tester: The stronger the electrolyte, the brighter the light.

SOME PURE COMPOUNDS (MOLECULAR AND IONIC)

DISTILLED WATER

NO LIGHT. PURE WATER IS NONCONDUCTING

SOLID SODIUM CHLORIDE

Contains ions, but these ions are unable to move. Since they can't move, they can't carry a current. NO LIGHT.

SOLID SUCROSE $C_{12}H_{22}O_{11}$

No light. Like water, sucrose is made of neutral molecules. It will not conduct an appreciable current.

MOLECULAR AND IONIC SOLUTIONS

SODIUM CHLORIDE + WATER

Bright light. In solution, sodium chloride breaks apart into its component ions. These free ions can carry a current. We say that sodium chloride is a STRONG ELECTROLYTE.

SUCROSE + WATER

No light. Sucrose molecules do not break apart in water to form ions. Sucrose is a NONELECTROLYTE.

ACIDS

PURE (GLACIAL) ACETIC ACID

No light. Pure acetic acid is a nonconductor, so it must be a molecular substance (like water).

ACETIC ACID + WATER

Light turns on, but is dimmer than the NaCl solution. We conclude that acetic acid is probably a WEAK ELECTROLYTE.

2M ACETIC ACID (AQUEOUS)

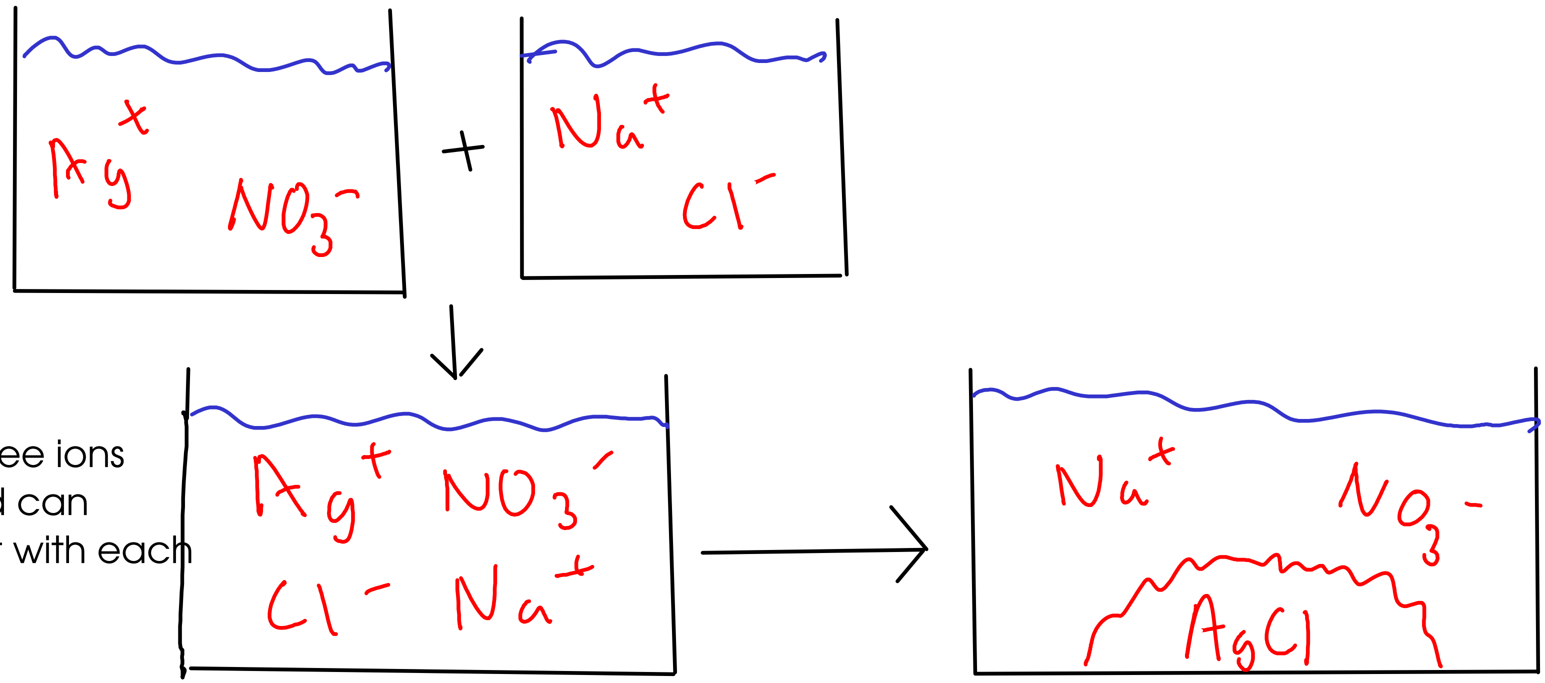
Lights, but is dim (compated to the hydrochloric acid solution). Acetic acid is a WEAK ELECTROLYTE.

2M HYDROCHLORIC ACID (AQUEOUS)

Brighter light than the acetic acid solution. Hydrochloric acid is likely a STRONG ELECTROLYTE. In any case, it is a stronger elecrolyte than acetic acid.

- What good is ionic theory?
  - provides an easy-to-understand MECHANISM for certain kinds of chemical reactions.
    - "Exchange" reactions. (a.k.a "double replacement" reactions)

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

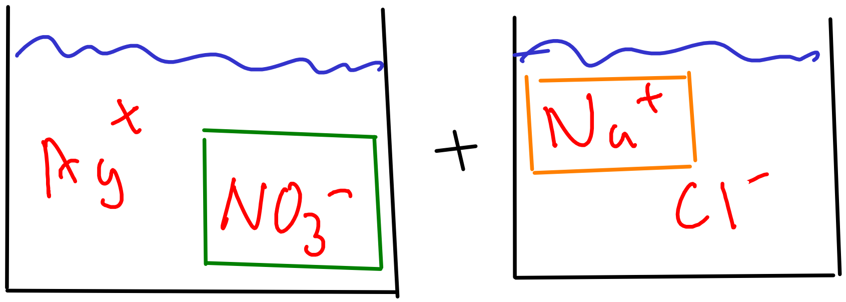


These free ions mix and can interact with each other!

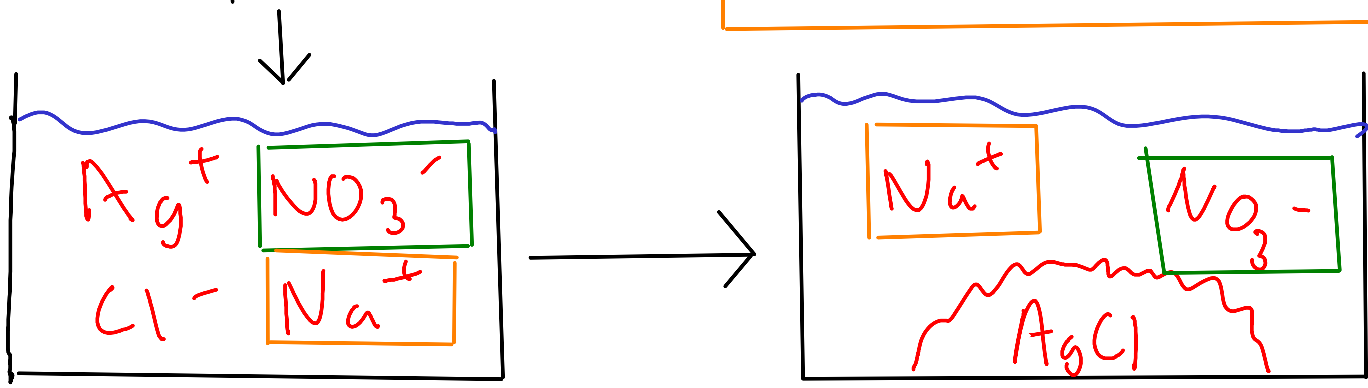
"ion soup"!

Insoluble AgCl falls out of solution as it is formed - "precipitation"

Looking a bit more closely...



The nitrate and sodium ions do not really participate in this reaction. They start and end in exactly the same state. We call them "SPECTATOR IONS".



$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$ "Molecular equation"

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$ "Net ionic equation"

(The net ionic equation shows only ions and substances that change during the course of the reaction!)

- The net ionic equation tells us that any source of aqueous silver and chloride ions will exhibit this same chemistry, not just silver nitrate and sodium chloride!

A bit more about molecular, ionic, and net ionic equations

- molecular equations: Represent all substances (even ionic substances) as if they were molecules. Include spectator ions, and do not show charges on ions. Traditional chemical equations.

- ionic equations: Show all free ions - including spectators - in a chemical reaction. Molecules and WEAK electrolytes are shown as molecules. STRONG electrolytes (like HCl) are shown as ions. Ions that are part of undissolved ionic compounds are shown as molecules.

- NET ionic equation: An ionic equation that leaves out spectator ions. Intended to show only things that actually change in a reaction.

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

$$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \rightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq) \; *$$

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$

* You can get from the complete ionic equation to the net ionic equation by crossing out the spectator ions on both sides.

"Undissolved ionic compounds":

How can I tell if an ionic compound dissolves in water?

- consult experimental data: "solubility rules"!

A few of the "rules"...

- Compounds that contain a Group IA cation (or ammonium) are soluble
- Nitrates and acetates are soluble
- Carbonates, phosphates, and hydroxides tend to be insoluble

See p 129 9th edition

... or see the web site for a solubility chart.

$Fe(OH)_3$ (s)

#8 - hydroxides generally insoiluble, except Group IA, ammonium, calcium strontium, barium

Conclusion: iron(III) hydroxide is insoluble.

$Ca(C_2H_3O_2)_2$ (aq)

#2 - acetates are soluble, no common exceptions.

Conclusion: calcium acetate is soluble.

AgI (s)

#3 - Iodides usually dissolve, exceptions are silver, mercury, lead

Conclusion: silver(I) iodide is INSOLUBLE

Exchange Chemistry

- Three kinds of exchange chemistry.

1. PRECIPITATION

2. ACID/BASE or NEUTRALIZATION

3. GAS FORMATION (formation of unstable molecules)

   SOME (but not all) reactions that form gases are examples of exchange chemistry.

Just because you mix together two ionic compounds does NOT mean that a reaction will occur. You need a DRIVING FORCE for a reaction.

PRECIPITATION REACTIONS

- driving force is the formation of an insoluble ionic compound.

$$3MgCl_2(aq) + 2Na_3PO_4(aq) \rightarrow 6NaCl(aq) + Mg_3(PO_4)_2(s)$$

ions: Mg^{2+} Cl^- Na^+ PO_4^{3-}

Potential Products:

$NaCl$

$Mg_3(PO_4)_2$

The formation of INSOLUBLE magnesium phosphate drives this reaction!

Mg^{2+} PO_4^{3-}

Mg^{2+} PO_4^{3-}

Mg^{2+}

When you're trying to complete a precipitation reaction:

(1) Write the IONS that form when the reactants are dissolved.

(2) Make NEW compounds by pairing up cations with anions. Don't forget that the positive and negative charges must balance each other out!

(3) Use the solubility rules to determine the PHASE of each new compound - solid or aqueous.

(4) Balance the overall equation.

$MgCl_2(aq) + NaC_2H_3O_2(aq) \rightarrow$ NO REACTION!*

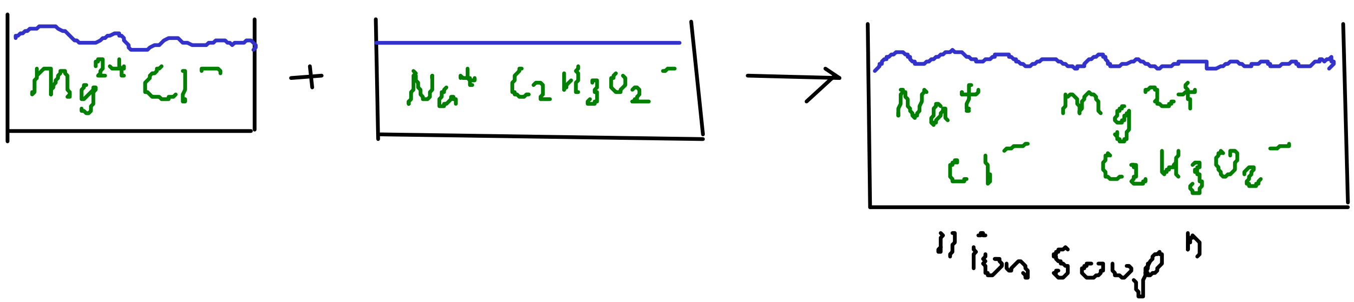
ions: Mg^{2+} Cl^- Na^+ $C_2H_3O_2^-$

"exchange"

$Mg(C_2H_3O_2)_2$ ... dissolves in water (Rule #2, p129)

$NaCl$ ... dissolves in water (Rule #1, p129)

So, no solid forms here. All possible combinations of these four ions result in compounds that dissolve readily in water.



NO CHANGE, therefore NO DRIVING FORCE, and NO REACTION

* We will learn about other driving forces than the formation of solid, but these driving forces do not apply to this reaction

ACID/BASE REACTIONS (also called NEUTRALIZATION REACTIONS)

- There are several stable molecules that may be formed in double replacement reactions, but the most common is WATER!

- Double replacement reactions that form water are also called "neutralizations"

$$HA + BOH \rightarrow H_2O + BA$$

HA: acid
BOH: base
H_2O: "HOH"
BA: salt (ionic compound)

$$H^+ \; A^- \qquad B^+ \; OH^-$$

* To make water (H_2O), you need a source of hydrogen ion (H^+) and hydroxide ion (OH^-)

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

This is the NET IONIC EQUATION for many neutralizations

... assumes you're reacting STRONG acid with STRONG base!

ACIDS

- compounds that release hydrogen ion (H^+), when dissolved in water.

Properties of acids:

- Corrosive: React with most metals to give off hydrogen gas
- Cause chemical burns on contact
- Taste sour (like citrus - citric acid!)
- Changes litmus indicator to RED

BASES

- Substances that release hydroxide ion (OH^-) when dissolved in water

Properties of bases:

- Caustic: Attack and dissolve organic matter (think lye, which is NaOH)
- Cause skin/eye damage on contact
- Taste bitter
- changes litmus indicator to BLUE

Due to the dissolving action of base on your skin, bases will feel "slippery". The base ITSELF is not particularly slippery, but what's left of your skin IS!

ACID/BASE or NEUTRALIZATION reactions continued

- the driving force of these reactions is the formation of water molecules.

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

From the acid (H^+) — From the base (OH^-)

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$$

ions: H^+ SO_4^{2-} Na^+ OH^-

Potential products: H_2O, Na_2SO_4

- How can this reaction be detected?
  - pH detector (indicator paper, etc.)
  - do the products have similar chemical properties to the reactants?
  - release of heat!

... formation of water is usually accompanied by a release of heat

GAS FORMATION / OTHER MOLECULES

- There are a few other molecules that can be made with exchange-type chemistry.
- Most of these molecules are unstable and can break apart to form gases.

- Formation of a weak acid:
    - The formation of ANY weak acid in an exchange-type reaction can be a driving force.
    - Some weak acids are unstable and can break apart into gas molecules.

$$H_2CO_3(aq) \longrightarrow H_2O(l) + \boxed{CO_2(g)}$$

Gas bubbles can leave solution!

... but how would you form carbonic acid in an exchange-type reaction?

acid + carbonate CO_3^{2-}

OR

acid + bicarbonate HCO_3^-

$$H_2SO_4(aq) + 2NaHCO_3(aq) \rightarrow 2\boxed{H_2CO_3(aq)} + Na_2SO_4(aq)$$

H^+ SO_4^{2-} Na^+ HCO_3^-

$$H_2SO_4(aq) + 2NaHCO_3(aq) \rightarrow Na_2SO_4(aq) + 2H_2CO_3(aq)$$

H^+ SO_4^{2-} Na^+ HCO_3^-

... but when we mix sulfuric acid and sodium bicarbonate, we observe BUBBLES. We need to write an equation that agrees with our observations. We know that carbonic acid decomposes, so we go ahead and put that into our equation.

$$H_2CO_3(aq) \longrightarrow H_2O(l) + CO_2(g)$$

$$H_2SO_4(aq) + 2NaHCO_3(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) + 2CO_2(g)$$

Other molecules of interest:

H_2SO_3 : sulfurous acid - React an ACID with a SULFITE

$$H_2SO_3(aq) \rightarrow H_2O(l) + SO_2(g)$$

H_2S : hydrogen sulfide (gas) - React an ACID with a SULFIDE

$$H_2SO_4(aq) + Na_2S(aq) \rightarrow Na_2SO_4(aq) + H_2S(g)$$

A few more exchange examples:

* Transition metals DO NOT change their charge in exchange reactions!

$CaCl_2(aq) + 2AgNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + 2\underline{\underline{AgCl}}(s)$ ✓

Ca^{2+} Cl^- Ag^+ NO_3^-

PRECIPITATION of AgCl drives this reaction!

$H_3PO_4(aq) + 3NaOH(aq) \rightarrow 3\underline{\underline{H_2O}}(l) + Na_3PO_4(aq)$ ✓

H^+ PO_4^{3-} Na^+ OH^-

Driving force is formation of WATER. This is a neutralization reaction, detectable by heat.

$KCl(aq) + NaNO_3(aq) \rightarrow$ ~~$KNO_3(aq) + NaCl(aq)$~~ NO REACTION

K^+ Cl^- Na^+ NO_3^-

Both "products" are water-soluble ionic compounds - present in water as FREE IONS. This is the same state they were in before being mixed. Therefore, we conclude that there is no reaction here. NO DRIVING FORCE!

$H_2SO_4(aq) + Na_2CO_3(aq) \rightarrow$