

Chemistry 20

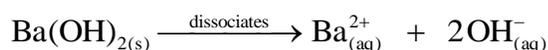
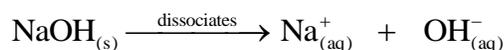
Lesson 25 – Theories of Acids and Bases

I. Arrhenius conceptual definitions of acids and bases

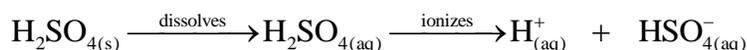
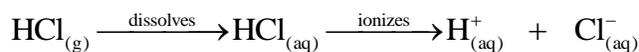
In Lesson 24 we found that acids, bases, neutral ionic and neutral molecular compounds have distinct chemical properties and from these properties we were able to define these compounds in operational terms. An **operational definition** is based on the **observable** properties of how something behaves. A **conceptual definition** is a definition based on **concepts and theories to explain** the observed properties.

As we saw in Lesson 20, soluble ionic compounds dissolve to form electrolytic solutions while molecular compounds dissolve to form non-electrolytic solutions. In addition, some hydrogen compounds formed strong electrolytes while others form weak electrolytes. In an effort to explain the properties of the different solutions a Swedish chemist, Svante Arrhenius (1859-1927), proposed a radical theory. In the year 1887, Arrhenius hypothesised that particles of a substance, when dissolving, separate from each other and disperse into solution. Non-electrolytes (i.e. molecular compounds) disperse electrically neutral particles, while ionic compounds **dissociate** into ions to form electrolytic solutions.

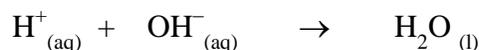
Arrhenius eventually extended his theory to explain some of the properties of acids and bases. According to Arrhenius, **bases** are ionic hydroxide compounds that dissociate to form hydroxide ions (OH^-) in water.



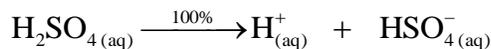
Acidic compounds, however, required a different explanation. Acidic solutions are electrolytes, but as pure substances most are molecular compounds. Molecules are not able to dissociate into ions, so where were the ions coming from? This unique behaviour required an explanation other than dissociation. According to Arrhenius, acids separate into individual molecules and then **ionize** into positive hydrogen ions and negative ions.



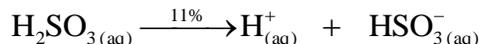
While dissociation is a physical process, **ionization** involves a **chemical reaction** with water to form ions. According to Arrhenius, an **acid** is a substance which yields H^+ ions on ionization with water. While Arrhenius did not provide an explanation for how ionization happens, his theory proved to be very useful. One useful aspect is that it explains the process whereby acids and bases will **neutralize** one another:



An additional feature of the Arrhenius theory of acids is that different acids ionize to different degrees. Some acids ionize 100% and are therefore strongly electrolytic. These acids are referred to as **strong acids**. In the Relative Strengths of Acids and Bases table on pages 8 and 9 of your Data Booklet, the acids above and including the greyed-out hydronium ion are strong acids. For example, sulphuric acid is a strong acid



The acids below the hydronium ion are **weak acids**. Weak acids ionize less than 100%. For example, sulphurous acid is a weak acid



In other words, the majority of the hydrogen sulfite molecules remain as neutral molecules in water. Only 11% of them react to form hydrogen ions. This explains why weak acids form weak electrolytes – there are not enough ions present to conduct electricity efficiently. (Note that in Chemistry 20 you are not expected to know how to calculate the % ionization ... something to look forward to in Chemistry 30.)

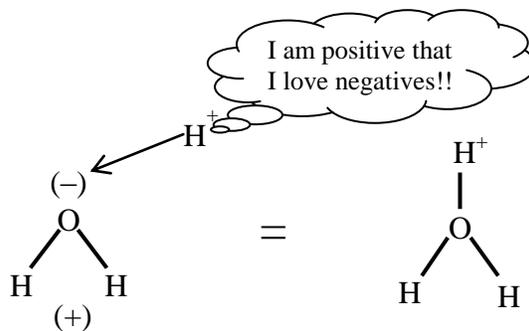
Since hydrogen ions are protons, acids containing a single hydrogen are referred to as **monoprotic** (one proton) acids and acids containing more than one hydrogen are referred to as **polyprotic** (many protons) acids.

II. Modified Arrhenius Theory

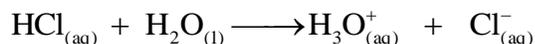
Unfortunately, there were several problems with Arrhenius acid/base theory. The first problem was that many substances show acid and base properties that cannot be explained by the Arrhenius acid/base theory. For example:

- ⇒ One would expect that a hydrogen compound like ammonia (NH_3) would have acidic properties when dissolved in water. But ammonia forms a **basic** solution in water. How did the hydroxide ion originate from this molecule?
- ⇒ Carbon dioxide (CO_2) should form a neutral molecular solution. However, it turns out to be **acidic**. Where did the hydrogen ion come from?

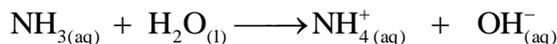
A second major problem arose when chemists attempted to detect the presence of hydrogen ions in solution. The technique used was a type of **spectroscopy**. In spectroscopy, molecules have a characteristic set of light wavelengths that they either absorb or emit. Spectroscopic analysis of acidic solutions revealed that hydrogen ions did not exist in solution. What did exist however, was a hydronium ion (H_3O^+). Hydrogen ions are too strongly charged to exist alone – they are strongly attracted to the negative ends of a water molecules. Thus, when acids ionize, they are reacting with water to form hydronium ions. The positive hydrogen ions attach themselves to the negative pole of a water molecule to form the hydronium (H_3O^+) ion.



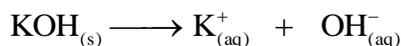
The original Arrhenius theory of an **acid** was **modified** from a substance that increases the H^+ concentration to a substance that reacts with water to **increase the H_3O^+ concentration**.



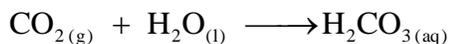
Likewise, the modified Arrhenius theory of a **base** is a substance that either reacts with water or dissociates in water to increase the OH^- concentration. For ammonia, which was discussed above, the molecules react with water to form ammonium ions and hydroxide ions.



For an ionic substance like potassium hydroxide, simple dissociation occurs.



Finally, why does carbon dioxide result in an acidic solution? The acidic properties of carbon dioxide result from two reactions with water. The first reaction forms the acid molecule, and the second is a weak ionization reaction to form hydronium ions.



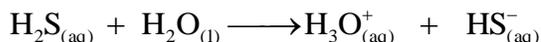
III. Ionization reaction equations

The rules for writing proper dissociation equations were discussed at length in Lessons 20 and 23. For ionization reactions, there are several additional rules:

- ⇒ An ionization reaction involves a reaction with water.
- ⇒ The hydrogen compound is written as aqueous prior to ionization.
- ⇒ Strong acids are written in their completely ionised form. For example:



- ⇒ For polyprotic acids, only one hydrogen ion (H^+) reacts with water to form hydronium. For example:

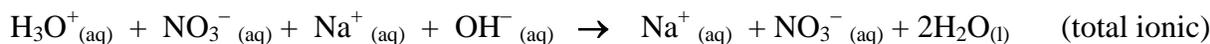


Example 1

Nitric acid neutralizes a sodium hydroxide solution. Write the non-ionic, total ionic and net ionic equations for this reaction.



Since nitric acid is a strong acid it ionises 100 % into hydronium and nitrate ions. Therefore, we write it in its ionised form.

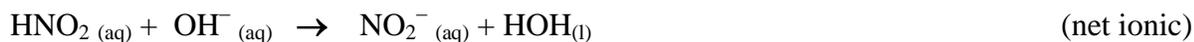
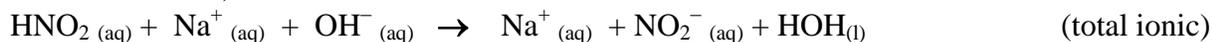


Example 2

Nitrous acid is neutralized by a sodium hydroxide solution. Write the non-ionic, total ionic and net ionic equations for this reaction.



Since nitrous acid is a weak acid and ionises to a very small degree, it reacts from its molecular form. Therefore, it is written in its molecular form.



IV. Assignment

1. Compare and contrast a *weak* acid and a *dilute* acid.
2. Compare and contrast a *strong* acid and a *concentrated* acid.
3. Write dissociation/ionization equations for the following compounds and state whether the compound will form an acidic, basic or neutral solution and whether the solution formed is a strong, weak or non-electrolyte.
 - a. sodium carbonate
 - b. propanoic acid
 - c. Rb_2S
 - d. $\text{Al}(\text{OH})_3$
 - e. KHSO_4
 - f. CO_2
 - g. $\text{H}_2\text{Cr}_2\text{O}_7$

- h. NaNO_3
- i. $\text{C}_2\text{H}_5\text{OH}$
- j. NH_3
- k. H_2SO_3
- l. FrOH
- m. HI
- n. $\text{Fe}(\text{H}_2\text{PO}_4)_3$
- o. HCOOH
- p. H_3BO_3
- q. $\text{C}_{12}\text{H}_{22}\text{O}_{11}$

4. The following list consists of a number of statements which can be applied to the Arrhenius theory, the modified Arrhenius theory, both theories or neither theory. Identify each statement as follows: statements that apply only to the Arrhenius theory (A), those that apply only to the Modified Arrhenius theory (MA), statements that apply to both theories (B), and statements that apply to neither (N) theory.
- a. A neutral solution has equal concentrations of $\text{H}^+_{(\text{aq})}$ and $\text{OH}^-_{(\text{aq})}$.
 - b. An acid contains $\text{H}_3\text{O}^+_{(\text{aq})}$ in solution.
 - c. A base dissociates to produce free $\text{OH}^-_{(\text{aq})}$ in solution.
 - d. $\text{NH}_3_{(\text{aq})}$ produces a basic solution.
 - e. The theory(ies) cannot predict whether $\text{H}_2\text{PO}_4^-_{(\text{aq})}$ will act as an acid or as a base.
 - f. Neutralization occurs when $\text{H}^+_{(\text{aq})} + \text{OH}^-_{(\text{aq})} \rightarrow \text{H}_2\text{O}_{(\text{l})}$
 - g. The theory(ies) involve(s) the creation of a hydronium ion.

- h. Basic solutions are formed when substances react with water to produce hydroxide ions.
 - i. Water has no reactive role to play in the formation of acidic and basic solutions.
 - j. The theory(ies) can only predict the basic behaviour of substances containing the hydroxide ion.
 - k. This theory can explain the acid or base behaviours of more substances than the other theory.
 - l. The theory(ies) need(s) revision to improve the ability to predict new results.
5. For the following reactions, write the non-ionic, total ionic and net ionic reaction equations.
- a. Excess hydrochloric acid in gastric fluid may be neutralized by a magnesium hydroxide suspension.

 - b. Chloric acid is neutralized by a potassium hydroxide solution.

 - c. Iron pipes are strongly attacked and corroded by hydrochloric acid.

 - d. Hydrocyanic acid can be used to neutralize a barium hydroxide solution.