CHEM 115
Acids, Bases and Intro to pH

Lecture 10
Prof. Sevian

Agenda
- Schedule modification for Monday lab as a result of yesterday's snow day
- Acids and bases
- pH scale
- Weak vs. strong acids and bases
- Neutralization reactions

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Grouping Reactions

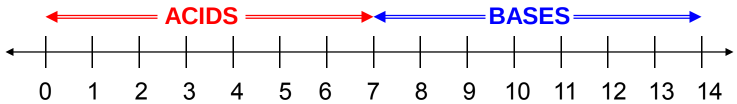
- Exchange rxns: no oxidation number change
  - Precipitation rxns
  - Acid-base rxns
    - Acid + Base → Salt + Water
    - Gas-forming rxns
- Redox rxns: oxidation numbers change
  - Single replacement (*e.g.*, many electrochemistry reactions)
  - Formation of compound from elements (*e.g.*, synthesis of sulfuric acid anhydride)
  - Decomposition of compound into elements (*e.g.*, producing pure metals from metal ores)
  - Combustion
- Other rxns that are neither exchange nor redox, but oxidation numbers do not change
  - Acid anhydride rxns with water
    - SO_3 (*g*) + H_2O (*l*) → H_2SO_4 (*aq*)
  - Some decomposition rxns
    - $MgCO_3$ (*s*) → MgO (*s*) + CO_2 (*g*)

The trouble with mixing up classifying rxns based on patterns (e.g., exchange, synthesis, decomposition) or based on an underlying theoretical model (e.g., redox)

Acid-Base Rxns

Macroscopic View

- **pH scale is used to identify acids and bases, and indicate their level of strength**



- **A chemical "indicator" can also indicate the pH** (indicator compound undergoes chemical transformation based on pH of solution, different configurations of indicator compound are different colors)
- **Reaction between an acid and a base produces a solution with pH somewhere in between**
- **Resulting solution tastes salty (do not do this in lab)**
- **Some examples**
  - Acids, bases, and what happens when you mix them?

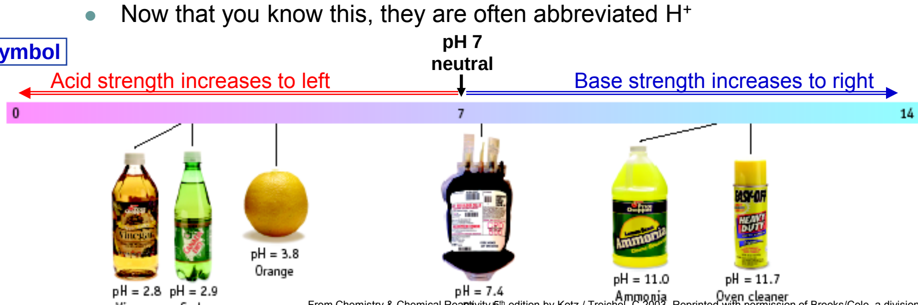
What is the pH scale?

Macro Provides information about whether a material (aqueous solution) is acid or base, and how strong it is

Particle Actually measures hydronium ion (H^+ or H_3O^+) concentration

- Hydrogen ions (H^+) do not actually exist in solution
- Instead, H^+ ions attach to water molecules and form H_3O^+ ions
- H_3O^+ ions are called <u>hydronium</u> ions
- Now that you know this, they are often abbreviated H^+

Symbol



Macroscopic View

Acids vs. Bases

Acids
- Taste sour
- Sharp odor
- Corrosive
- Most foods are acidic
- Solution conducts electricity

Bases
- Taste bitter
- Feel slippery
- Caustic
- Most cleaners are basic
- Solution conducts electricity

When acid and base solutions are mixed in stoichiometrically equal quantities, the pH moves toward being neutral, and the resulting solution tastes salty. Reaction is called NEUTRALIZATION.

$$\text{Acid} + \text{Base} \rightarrow \text{Salt} + \text{Water}$$

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Particle Level View

Acids vs. Bases

Acids
- When a chemical that is an acid is added to water, it increases the H^+ concentration in the solution
- Registers less than 7 on pH scale because $[H^+]$ is greater than neutral water, which is 1.0×10^{-7} *mol/L*

Bases
- When a chemical that is a base is added to water, it increases the OH^- concentration in the solution
- Registers more than 7 on pH scale because $[OH^-]$ is greater than neutral water, which is 1.0×10^{-7} *mol/L*

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Why is Water So Special?

Water itself breaks into ions:

$$H_2O \rightarrow H^+ + OH^-$$ ☆

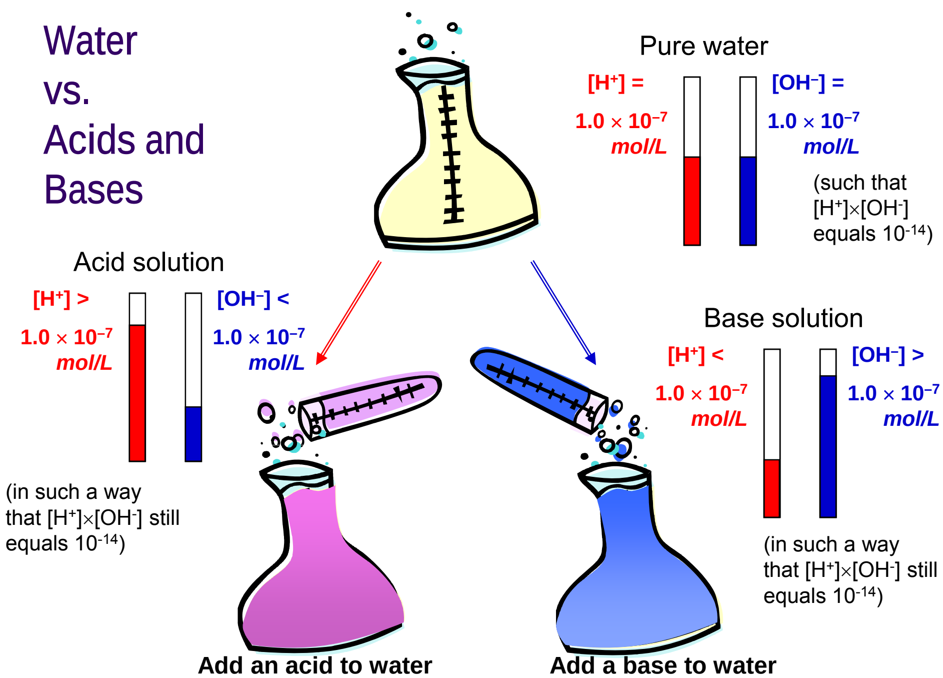
In a sample of pure water, equal quantities of these ions are present:

$$[H^+] = [OH^-] = 1.0 \times 10^{-7} \text{ mol/L}$$

But when you add a solute that is an acid or base to water, the balance changes.

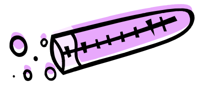
☆ Note: H^+ doesn't actually exist by itself. The ion is only found attached to an H_2O molecule to form H_3O^+.

Water vs. Acids and Bases



Symbolic Representation

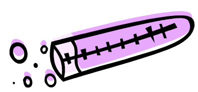
How Can You Recognize an Acid?



Sometimes true → Always true

- Name of chemical is "--- acid"
  - Hydrochloric acid: **HCl**
  - Sulfuric acid: $\mathbf{H_2SO_4}$
  - Nitrous acid: $\mathbf{HNO_2}$
  - But there are acids that aren't named acid
- Chemical formula has a "releasable" H^+ ion in it
  - All the above
  - Substances containing carboxy groups such as acetic acid, $\mathbf{CH_3COOH}$, and benzoic acid, $\mathbf{C_6H_5CH_3COOH}$
  - But acid anhydrides also form acidic solutions
- When the chemical is added to water, it forms a compound that is able to break apart into an H^+ ion and something else

Strong vs. Weak Acids



- Strong acids are strong electrolytes (ionize or dissociate entirely)
  - Only a few common acids are strong

    $\mathbf{HCl, HBr, HI, HNO_3, H_2SO_4, HClO_4}$ (*you already memorized these*)
  - A few other less common acids are strong (you do not need to memorize these)

    e.g., $\mathbf{HClO_3, HBrO_3}$ and some others
- Weak acids are weak electrolytes (remain mostly un-dissociated)
  - It is safe to assume that all other acids are weak

    Most common weak acids:

    $\mathbf{HF, HNO_2, HClO_2, HSO_3, CH_3COOH}$

Another Way to Form Acids

Acid anhydrides

- Nonmetal oxides
- When dissolved in water, react with water to form acid solution
- No change in oxidation number* of the nonmetal
- Examples:

$SO_3 + H_2O \rightarrow H_2SO_4$

$SO_2 + H_2O \rightarrow H_2SO_3$

$N_2O_5 + H_2O \rightarrow 2\ HNO_3$

$P_2O_5 + 3\ H_2O \rightarrow 2\ H_3PO_4$

*We will study oxidation numbers soon…

Clicker question #1

Which of these is not an acid?

(A) HCl

(B) H_2SO_3

(C) H_2SO_4

(D) CH_3COOH

(E) CH_3OH

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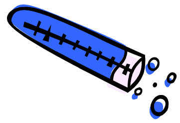
Symbolic Representation

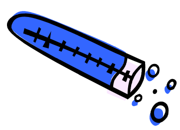
How Can You Recognize a Base?



- Chemical formula contains hydroxide ion (OH^-)
  - Sodium hydroxide: **NaOH**
  - Calcium hydroxide: $\mathbf{Ca(OH)_2}$
  - Aluminum hydroxide: $\mathbf{Al(OH)_3}$
  - Beware chemical formulas that look like they contain hydroxide ion. Organic alcohol group (-OH) is same atoms, but doesn't ionize to form $\mathbf{OH^-}$ ions.

    methanol $\mathbf{CH_3OH}$, ethanol $\mathbf{CH_3CH_2OH}$, phenol $\mathbf{C_6H_5OH}$
- Substance reacts with water to form hydroxide ions
  - Ammonia: $\mathbf{NH_3 + H_2O \rightarrow NH_4^+ + OH^-}$
  - Other amines (chemicals with $-NH_2$ functional group)

Strong vs. Weak Bases



- Strong bases are strong electrolytes (ionize or dissociate entirely)
  - All bases containing the hydroxide ion (OH^-) are strong

    Most common strong bases:

    $\mathbf{NaOH, KOH, LiOH, Ca(OH)_2, Mg(OH)_2}$
- Weak bases are weak electrolytes (remain mostly un-dissociated)
  - Bases that do not contain the hydroxide ion (OH^-) are weak

    Most common weak bases:

    $\mathbf{NH_3, CH_3NH_2, C_6H_5NH_2}$
- Organic alcohols are not bases
  - Organic molecules that contain an alcohol functional group (-OH) do not ionize to form hydroxide ions
  - You can tell if it an organic alcohol because it will be made of all non-metals (usually C, H, and O)

Clicker question #2

Which of these is <u>not</u> a base?

(A) NaOH

(B) CH_3OH

(C) $Ca(OH)_2$

(D) NH_3

(E) $C_6H_5NH_2$

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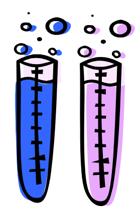
What does pH mean?



- Tells you the hydronium ion concentration (H^+ ion)
- Concentration symbol is […], so hydronium ion concentration is abbreviated as $[H^+]$
- Concentration is measured in molarity, which is moles of solute per liter of solution, or *mol/L*, or *M*
- Concentration of H^+ ions in pure water at 25°C is $[H^+]$ = 0.00000010 mol/L, or 1.0×10^{-7} *M*
- Too difficult to work with such small numbers, invent pH scale
- pH defined to equal $-\log [H^+]$

Review of Powers of 10 Math

- All numbers can be written as powers of 10. Most important to remember where the decimal point is. (Key: is it a big or small number? If big then exponent is positive. If small, then exponent is negative.)

$10{,}000 = 10^4$

$100 = 10^2$

$10 = 10^1$

$1 = 10^0$

$0.1 = 10^{-1}$

$0.001 = 10^{-3}$

$0.000001 = 10^{-6}$

- When multiplying two powers of 10, add the exponents. When dividing, subtract the exponents.

$10^5 \times 10^{-2} = 10^{5+(-2)} = 10^3$

$10^{-3} / 10^1 = 10^{(-3)-1} = 10^{-4}$

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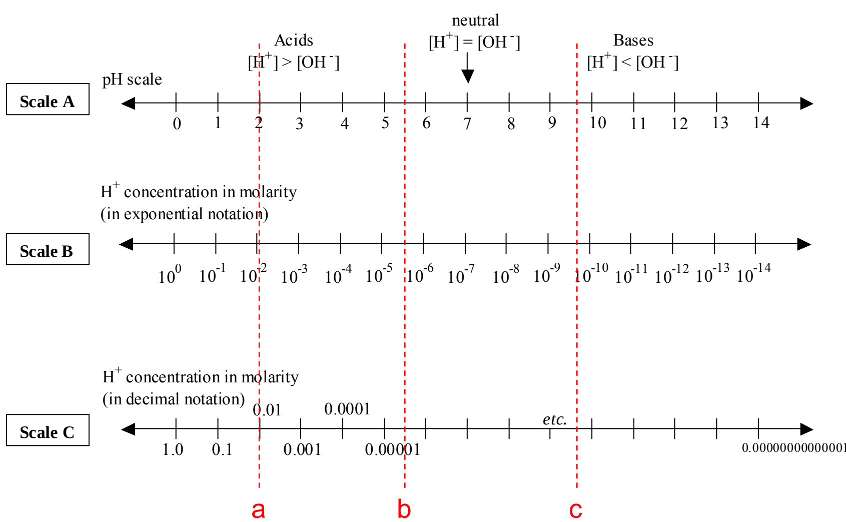
What does pH mean mathematically?

pH scale is a logarithmic scale



from Sevian et al, *Active Chemistry* (2006)

The pH scale, mathematically

- The logarithm (base 10) of a number is just the exponent of the power of 10 when you express the number as a power of 10

  $\log 100 = \log 10^{2} = 2$

  $\log 0.00001 = \log 10^{-5} = -5$

- Numbers that are not integer powers of 10 can still be represented as powers of 10

  $45.6 = 4.56 \times 10^{1} = 10^{1.659}$ therefore, $\log 45.6 = 1.659$

  $0.000000821 = 8.21 \times 10^{-7} = 10^{-6.086}$ therefore,

  $\log 0.000000821 = -6.086$

  (Note: sig figs of logarithms are only counted after the decimal point, because the integer comes from the exponent of 10)

- How to do this on your calculator

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The pH scale, mathematically

- pH values range from 1 to 14
- $pH = -\log [H^{+}]$
- Examples

  $[H^{+}] = 0.00010$ *M*, therefore pH = -log(0.0001) = 4.00

  $[H^{+}] = 0.00000050$ *M*, therefore pH = -log(0.00000050) = 6.30

  You try it:

  $[H^{+}] = 0.0025$ *M*, therefore pH = ?

- If you know the pH, you can get $[H^{+}]$

  $[H^{+}]$ = antilog(-pH) or 10^{-pH}

  pH = 4.00, therefore $[H^{+}]$ = antilog(-4.00) = $10^{-4} = 0.00010$ *M*

  pH = 8.20, therefore $[H^{+}]$ = antilog(-8.20) = $10^{-8.2} = 6.3 \times 10^{-9}$ *M*

  You try it:

  pH = 2.30, therefore $[H^{+}]$ = ?

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Clicker question #3

Which of these has the lowest pH value?

(A) $[H^+] = 1.0 \times 10^{-6}\ M$

(B) $[H^+] = 5.0 \times 10^{-5}\ M$

(C) $[H^+] = 2.0 \times 10^{-4}\ M$

(D) $[H^+] = 0.003\ M$

(E) $[H^+] = 0.000001\ M$

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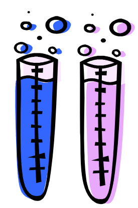
What happens to pH when you mix acid and base solutions? Neutralization rxn



Acid + Base → Salt + Water

$(H^+)(\text{anion}^-) + (\text{cation}^+)(OH^-) \rightarrow (\text{cation}^+)(\text{anion}^-) + (H^+)(OH^-)$

This reaction occurs if the Base contains OH^- (in other words, only strong bases)

Strong acid + Strong base (strong acid ionizes nearly completely):

$HCl + NaOH \rightarrow NaCl + H_2O$

$H_2SO_4 + KOH \rightarrow KHSO_4 + H_2O$

Weak acid + Strong base (weak acid is mostly present as whole molecule):

$HF + NaOH \rightarrow NaF + H_2O$

$CH_3COOH + KOH \rightarrow KCH_3COO + H_2O$

When a metal carbonate reacts with an acid: two-step process

1. $MgCO_3\ (s) + 2\ HCl\ (aq) \rightarrow MgCl_2\ (aq) + H_2CO_3\ (aq)$
   (exchange rxn)

2. $H_2CO_3\ (aq) \rightarrow H_2O\ (l) + CO_2\ (g)$
   (carbonic acid is unstable)

Sum/overall reaction:

$$MgCO_3\ (s) + 2\ HCl\ (aq) \rightarrow MgCl_2\ (aq) + H_2O\ (l) + CO_2\ (g)$$

Net ionic equation:

$$MgCO_3\ (s) + 2\ H^+\ (aq) \rightarrow Mg^{2+}\ (aq) + H_2O\ (l) + CO_2\ (g)$$

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Net Ionic Equations of Weak vs. Strong Acid + Strong Base Reactions Differ

Strong acid examples (acid ionizes nearly completely):

$$HCl + NaOH \rightarrow NaCl + H_2O$$

$$H^+\ (aq) + \cancel{Cl^-\ (aq)} + \cancel{Na^+\ (aq)} + OH^-\ (aq) \rightarrow \cancel{Na^+\ (aq)} + \cancel{Cl^-\ (aq)} + H_2O\ (l)$$

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

$$H_2SO_4 + KOH \rightarrow KHSO_4 + H_2O$$

$$H^+\ (aq) + \cancel{HSO_4^-\ (aq)} + \cancel{K^+\ (aq)} + OH^-\ (aq) \rightarrow \cancel{K^+\ (aq)} + \cancel{HSO_4^-\ (aq)} + H_2O\ (l)$$

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

Notice that only the first H^+ in the H_2SO_4 reacted

- Only the first H^+ (in H_2SO_4) is highly acidic, resulting in a complete ionization to form H^+ and HSO_4^-.
- The second H^+ is only weakly acidic. That is, HSO_4^- remains mostly intact and does not ionize to any considerable extent.
- This means that if HSO_4^- were a reactant, then it would remain that way on the product side.

Net Ionic Equations of Weak vs. Strong Acid + Strong Base Reactions Differ

Weak acid examples (acid is mostly present as whole molecule):

$HF + NaOH \rightarrow NaF + H_2O$

$HF\ (aq) + Na^+\ (aq) + OH^-\ (aq) \rightarrow Na^+\ (aq) + F^-\ (aq) + H_2O\ (l)$

Net ionic equation: $HF\ (aq) + OH^-\ (aq) \rightarrow F^-\ (aq) + H_2O\ (l)$

$CH_3COOH + KOH \rightarrow KCH_3COO + H_2O$

$CH_3COOH\ (aq) + K^+\ (aq) + OH^-\ (aq) \rightarrow K^+\ (aq) + CH_3COO^-\ (aq) + H_2O\ (l)$

Net ionic equation: $CH_3COOH\ (aq) + OH^-\ (aq) \rightarrow CH_3COO^-\ (aq) + H_2O\ (l)$

The difference between strong and weak acid-base reactions:
Strong acid present as ions, so it cancels out of net ionic equation.
Weak acid present as molecules, so doesn't cancel out of net ionic equation.

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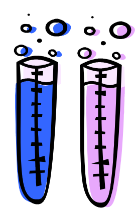
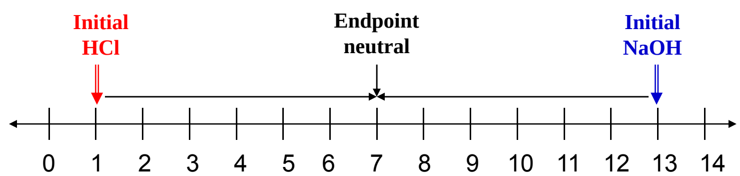
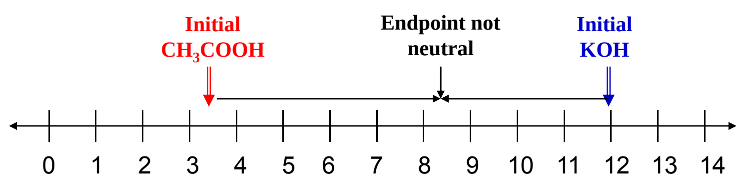
Neutralization: What happens to pH?
It approaches neutral pH



Ex 1: $\mathbf{HCl + NaOH \rightarrow NaCl + H_2O}$ (strong acid + strong base)
(equal concentrations of **HCl** and **NaOH** mixed in equal molar quantities)



Ex 2: $\mathbf{CH_3COOH + KOH \rightarrow KCH_3COO + H_2O}$ (weak acid + strong base)
(equal concentrations of $\mathbf{CH_3COOH}$ and **KOH** mixed in equal molar quantities)



What we have learned today

- Water is neutral because it has equal parts H^+ and OH^-
  - pH is 7
  - $[H^+] = [OH^-]$
- Acids are aqueous solutions which the solute has caused to have $[H^+] > [OH^-]$
  - pH is below 7, and the further below 7, the stronger the acid
  - How you write the acid in net ionic reactions depends on whether acid is strong or weak
    - Strong acids are strong electrolytes (they break apart entirely into ions when in aqueous solution)
    - Weak acids are weak electrolytes (they mostly remain molecules)
- Bases are aqueous solutions which the solute has caused to have $[OH^-] > [H^+]$
  - pH is above 7, and the further above 7, the stronger the base
  - Solutes that are bases have OH^- groups that can break off as ions
- pH is a measure of acidity, or H^+ concentration, and is mathematically derived as $pH = -\log [H^+]$

What we have learned today (cont'd)

- More on net ionic equations
  - Only ions that are aqueous can be spectator ions
  - If a molecule (e.g., CH_3COOH) or an ion (e.g., HSO_4^-) does not dissociate very much, then it is expressed in a net ionic equation in its un-dissociated form, and does not form ions that could be spectators

    Example: The reaction
    $CH_3COOH\ (aq) + NaOH\ (aq) \rightarrow NaCH_3COO\ (aq) + H_2O\ (l)$

    Has the net ionic equation:
    $CH_3COOH\ (aq) + OH^-\ (aq) \rightarrow CH_3COO^-\ (aq) + H_2O\ (l)$

    Not:
    $H^+\ (aq) + OH^-\ (aq) \rightarrow H_2O\ (l)$

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