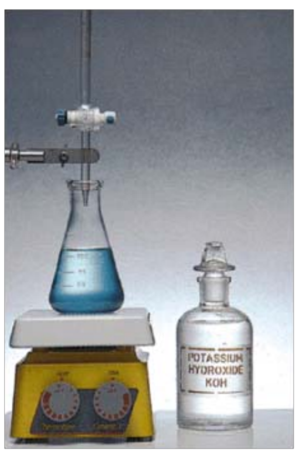
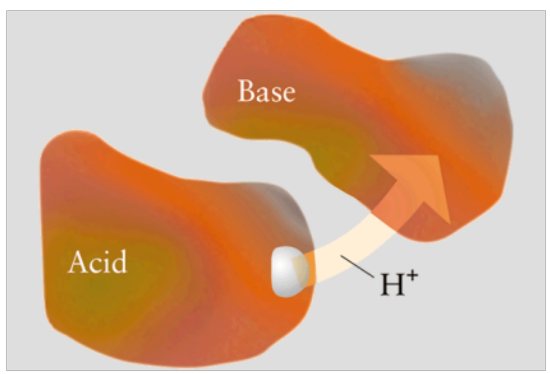
Acid-Base Reactions/ The pH concept.

Dr Richard Doyle
School of Chemistry
Trinity College Dublin.
rdoyle5@tcd.ie





Lecture Outline.

- 2 lectures dealing with some core chemistry :
  - acid/base reactions
  - the pH concept.
- These concepts will be studied in more detail during the main lecture course.
- Topics to be addressed:
  - What are acids and bases?
  - Can we provide a general definition of acid and base?
  - How can we quantify acidity and basicity?
  - Can we classify acid and base strength?
  - pH concept and pH scale.
  - Acid/base reactions: neutralization
  - How can we monitor an acid/base reaction in real time?
    - Acid/base titrations

Required Reading Material.

- Silberberg, Chemistry, 4th edition.
  - Chapter 18.
    - Acid/base equilibria. pp.766-813.
  - Chapter 19.
    - Ionic equilibria in aqueous systems. pp.814-862.

- Kotz, Treichel and Weaver, 7th edition.
  - Chapter 17&18, pp.760-859.

- Burrows et al. Chemistry^3 (OUP), 2009.Ch.6, pp.263-300.

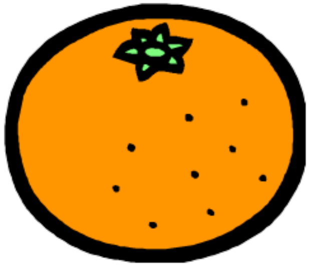
- Lecture notes available after course on School of Chemistry website located at:

http://www.tcd.ie/Chemistry/outreach/prelim/

Useful websites

- http://www.shodor.org/unchem/basic/ab/
- http://chemistry.about.com/od/acidsbases/
- http://www.chem.neu.edu/Courses/1221PAM/acidbase/index.htm
- http://dbhs.wvusd.k12.ca.us/webdocs/AcidBase/AcidBase.html
- http://www.sparknotes.com/chemistry/acidsbases/fundamentals/section1.html

Acids



- Have a sour taste.
  - Vinegar owes its taste to acetic acid.
  - Citrus fruits contain citric acid.

- React with certain metals to produce hydrogen gas.

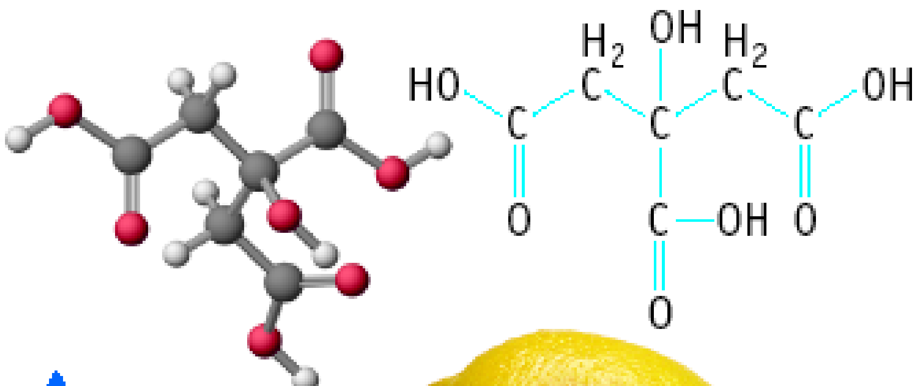
- React with carbonates and bicarbonates to produce carbon dioxide gas.
  - Yeast free Baking

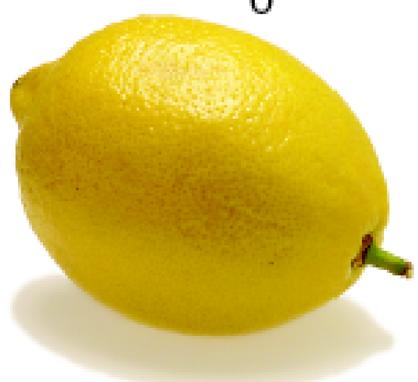
Bases

- Have a bitter taste.
  - Baking soda, dark unsweetened chocolate

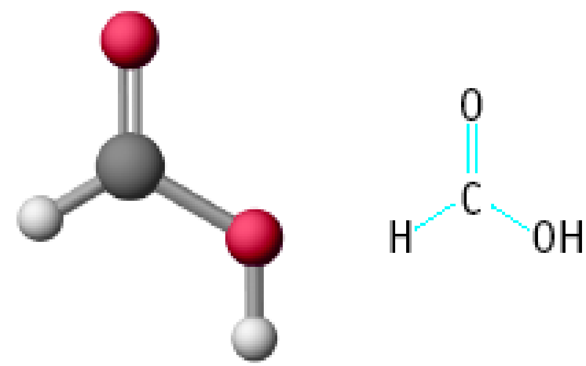
- Feel slippery. Many soaps contain bases.

Acid and Bases



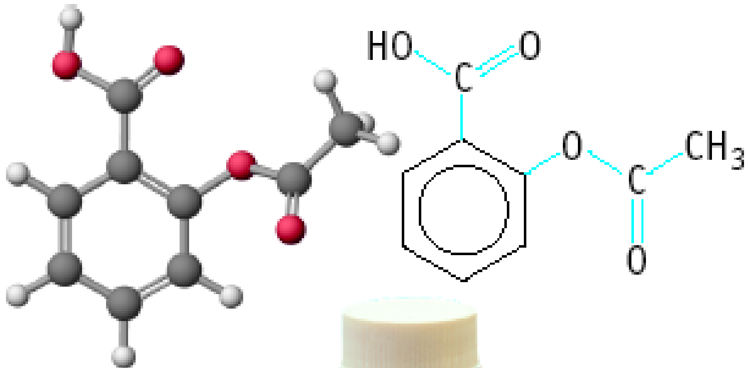


The tartness of lemons and oranges comes from the weak acid citric acid. The acid is found widely in nature and in many consumer products. *(Charles D. Winters)*

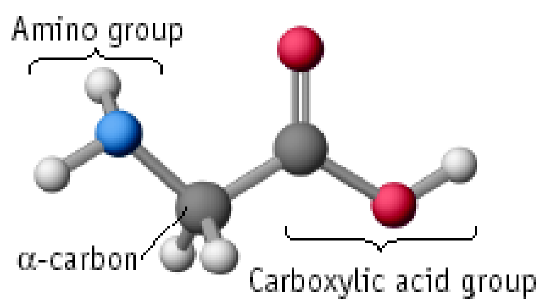


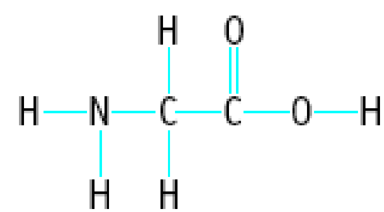
The sting of ants is due to the weak acid formic acid, HCO_2H. *(Gallo Images/@ CORBIS)*

Acid and Bases



Aspirin is a weak acid that has been used as an analgesic for over 100 years. *(Charles D. Winters)*

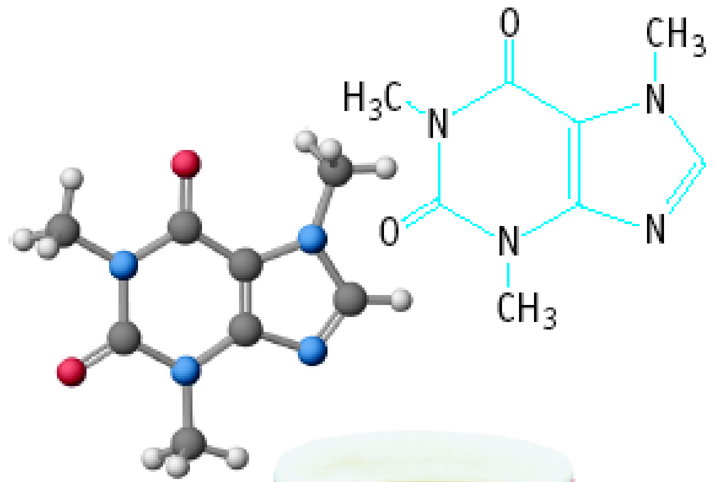




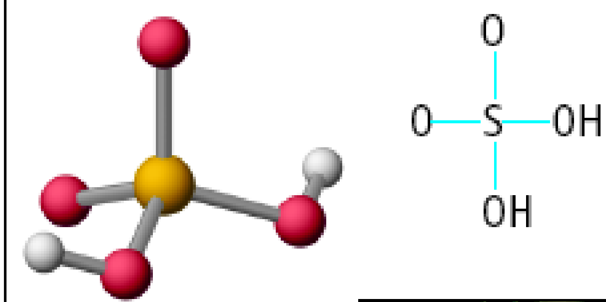
Glycine, $NH_2CH_2CO_2H$

Glycine is representative of the amino acids that are the basis of proteins. The $-CO_2H$ group is the acid portion of the molecule, and the $-NH_2$ group is the basic portion. *(Charles D. Winters)*

Acid and Bases



Caffeine is a well known stimulant and a weak base. *(Charles D. Winters)*



A sea slug excretes the strong acid sulfuric acid in self-defense. *(Sharksong/ M. Kazmers/Dembinski Photo Associates)*

Uses of Common Acids and Bases

18.1 Some Common Acids and Bases and Their Household Uses

Substance	Formula	Use
Acids		
Acetic acid (vinegar)	CH_3COOH (or $HC_2H_3O_2$)	Flavoring, preservative
Citric acid	$H_3C_6H_5O_7$	Flavoring
Phosphoric acid	H_3PO_4	Rust remover
Boric acid	$B(OH)_3$ (or H_3BO_3)	Mild antiseptic; insecticide
Aluminum salts	$NaAl(SO_4)_2 \cdot 12H_2O$	In baking powder, with sodium hydrogen carbonate
Hydrochloric acid (muriatic acid)	HCl	Brick and ceramic tile cleaner
Bases		
Sodium hydroxide (lye)	$NaOH$	Oven cleaner, unblocking plumbing
Ammonia	NH_3	Household cleaner
Sodium carbonate	Na_2CO_3	Water softener, grease remover
Sodium hydrogen carbonate	$NaHCO_3$	Fire extinguisher, rising agent in cake mixes (baking soda), mild antacid
Trisodium phosphate	Na_3PO_4	Cleaner for surfaces before painting or wallpapering

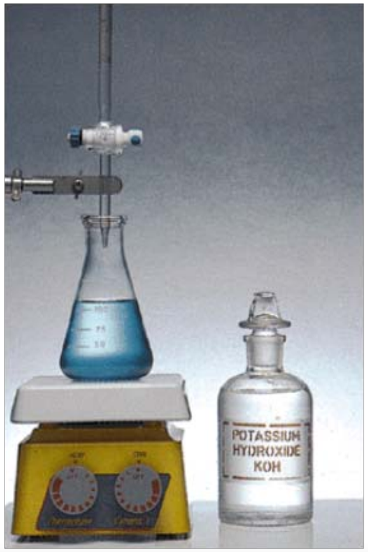
Arrhenius (or Classical) Acid-Base Definition

- *Acid* - a neutral substance that contains hydrogen and dissociates or ionises in water to yield protons (H^+)or hydronium ions (H_3O^+).
- *Base* - a neutral substance that contains the hydroxyl group and dissociates in water to yield hydroxide ions OH^-.
- *Neutralization* - the reaction of an H^+ (H_3O^+) ion from the acid and the OH^- ion from the base to form water, H_2O.
- These definitions although correct are limited in that they are not very general and do not give a comprehensive idea of what acidity and basicity entails.

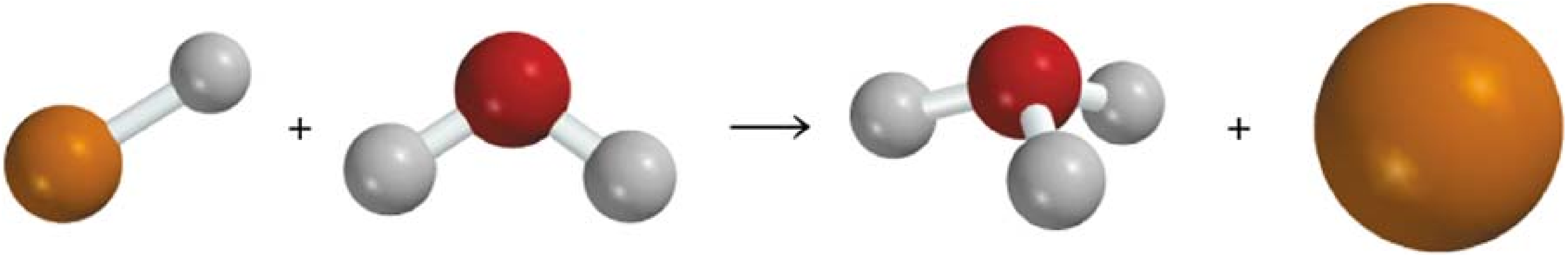
$$HCl \rightarrow H^+(aq) + Cl^-(aq)$$
$$NaOH \rightarrow Na^+(aq) + OH^-(aq)$$

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

acid base salt water

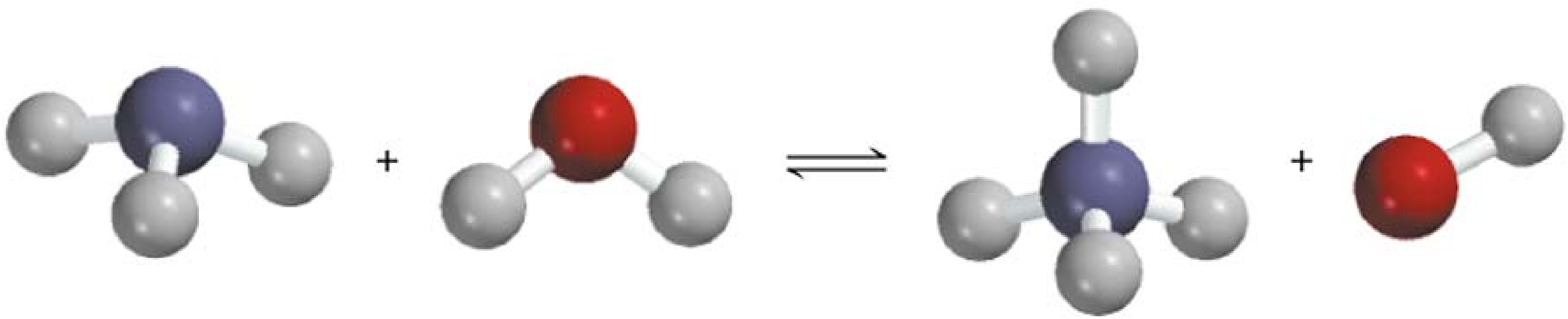


Arrhenius acid is a substance that produces H^+ (H_3O^+) in water



$$HCl + H_2O \longrightarrow H_3O^+ + Cl^-$$

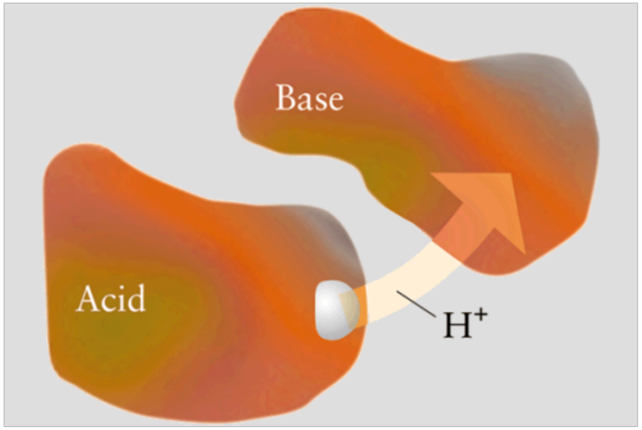
Arrhenius base is a substance that produces OH^- in water



$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

Acids and bases: Bronsted/Lowry definition.

- Bronsted/Lowry Acid (HA): An acid is a species which donates a proton
- Bronsted/Lowry Base (B): A base is a species which accepts a proton.
- A more general definition and refer to the reaction between an acid and a base but not necessarily in water.
- An acid must contain H in its formula;
  - HNO_3 and $H_2PO_4^-$
- A base must contain a lone pair of electrons to bind the H^+ ion;
  - NH_3, CO_3^{2-}, F^-, as well as OH^-.
- All Arrhenius acids/bases are Bronsted/Lowry acids/bases.



Bronsted/Lowry Perspective

Acid: Proton Donor

Base: Proton Acceptor

Acid-Base reaction is the exchange of a proton.

BL acid/base equilibria.

BL acid BL base

$$HA(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + A^-(aq)$$

Proton transfer

BL acid

$$B(aq) + H_2O(l) \rightleftharpoons HB^+(aq) + OH^-(aq)$$

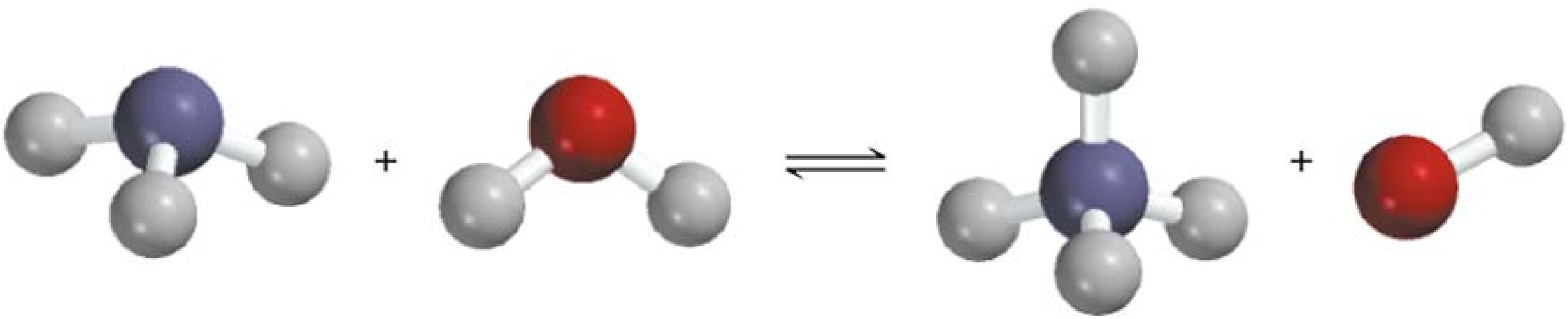
BL base

Water can function both as an acid and a base depending on the circumstances.

- Proton donation and acceptance are dynamic processes
  - proton transfer equilibrium is rapidly established in solution.
- The equilibrium reaction is described in terms of conjugate acid/base pairs.
- Conjugate base (CB) of a BL acid - the base which forms when the acid has donated a proton.
- Conjugate acid (CA) of a BL base - the acid which forms when the base has accepted a proton.
- A conjugate acid has one more proton than the base.
- A conjugate base has one less proton than the acid.
- If the acid of a conjugate acid/base pair is strong (good tendency to donate a proton) then the conjugate base will be weak (small tendency to accept a proton) and vice versa.

A Brønsted acid is a proton donor

A Brønsted base is a proton acceptor



$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

base	acid	acid	base
base	acid	conjugate acid	conjugate base

The Conjugate Pairs in Some Acid-Base Reactions

Conjugate Pair

Acid + Base ⇌ Base + Acid

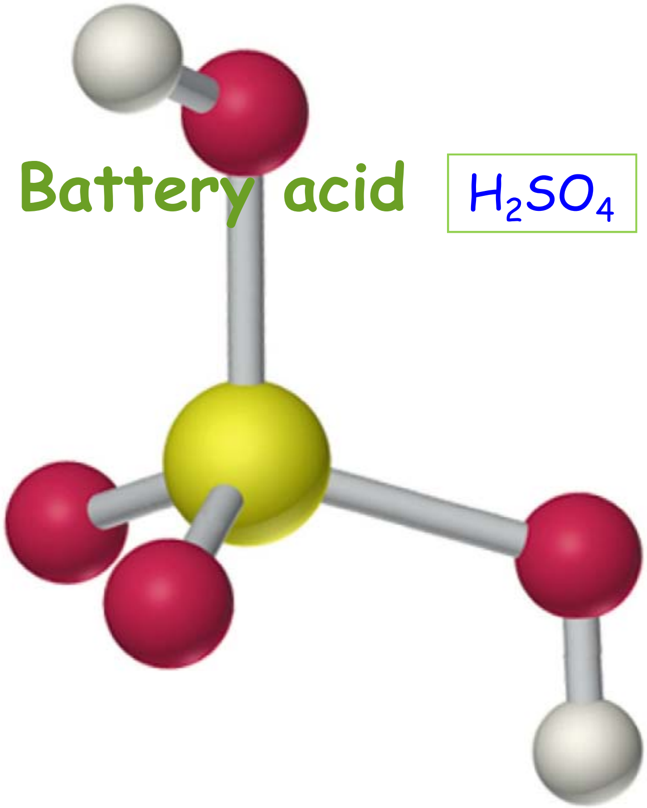
Conjugate Pair

Reaction 1	HF	+	H_2O	⇌	F^-	+	H_3O^+
Reaction 2	$HCOOH$	+	CN^-	⇌	$HCOO^-$	+	HCN
Reaction 3	NH_4^+	+	CO_3^{2-}	⇌	NH_3	+	HCO_3^-
Reaction 4	$H_2PO_4^-$	+	OH^-	⇌	HPO_4^{2-}	+	H_2O
Reaction 5	H_2SO_4	+	$N_2H_5^+$	⇌	HSO_4^-	+	$N_2H_6^{2+}$
Reaction 6	HPO_4^{2-}	+	SO_3^{2-}	⇌	PO_4^{3-}	+	HSO_3^-

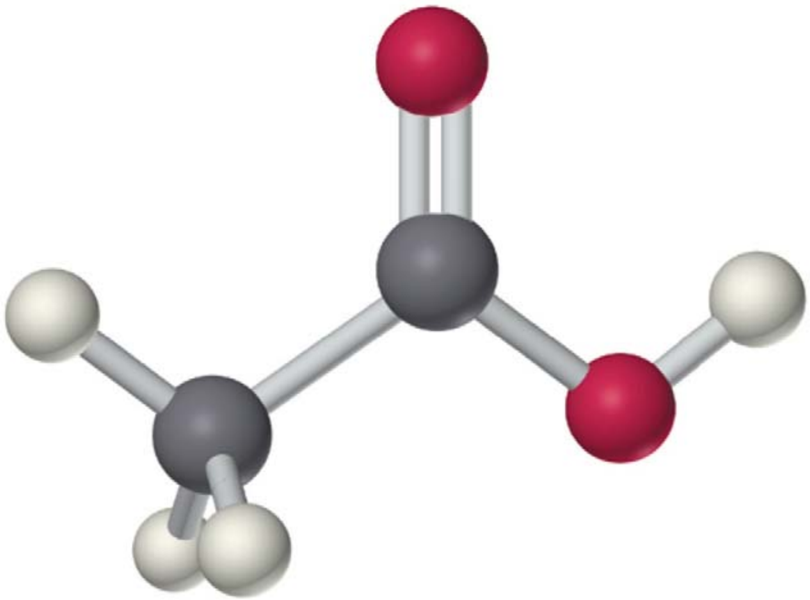
Quantifying acid/base strength.

- How can acid and base strength be quantified?
  - 'Strong' acids vs 'weak' acids
  - 'Strong' bases vs 'weak' bases
  - Key concept is extent or **degree of ionization/dissociation**.
  - Correlation exists between **acid/base strength**, **degree of ionization in solution** and extent to which solution exhibits **ionic conductivity**.

Battery acid H_2SO_4



Sulfuric acid



Acetic acid

Vinegar

CH_3COOH

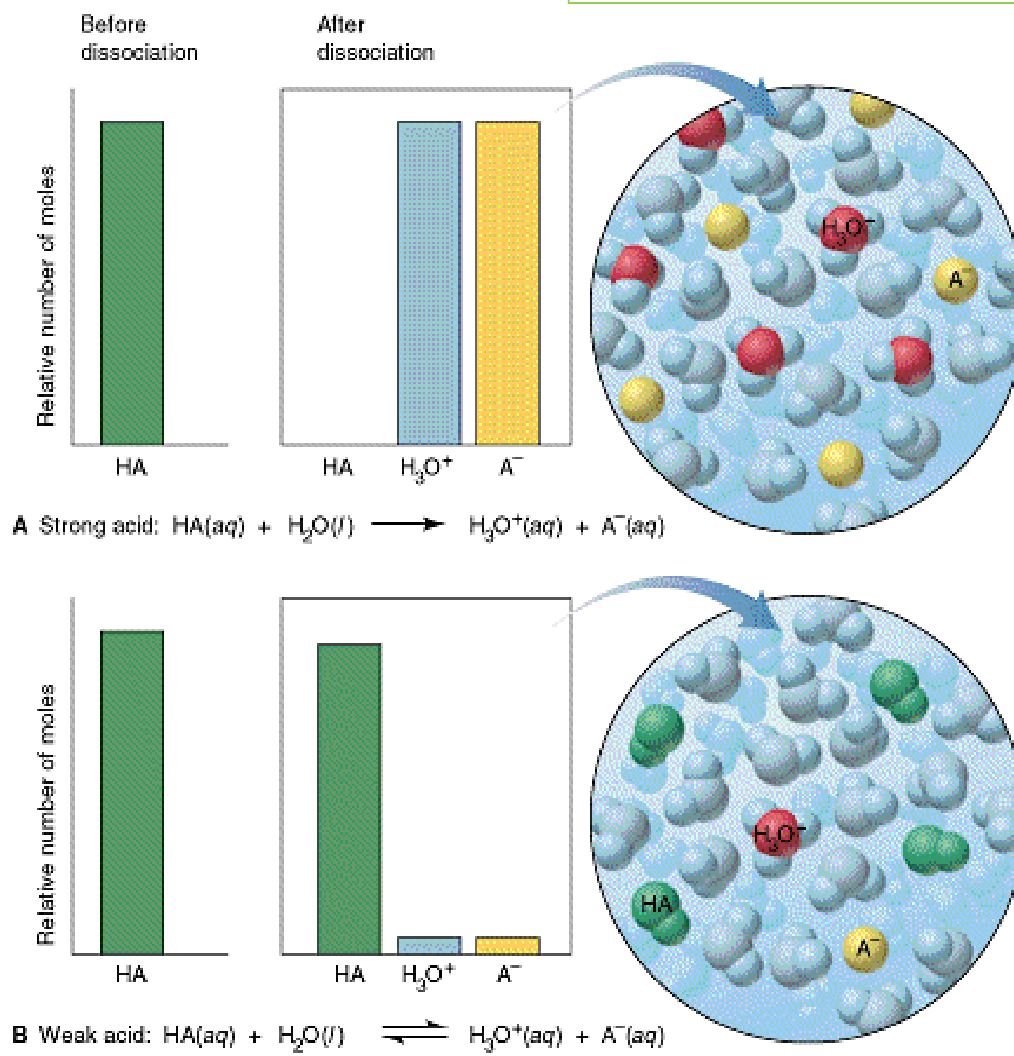
Strong and weak acids.

The Extent of Dissociation for Strong and Weak Acids

Complete ionization

Key concept : Acid/base strength quantified in terms of extent or degree of dissociation.

- A strong acid or base is fully ionized in solution
  - HCl
  - NaOH
- For a weak acid or base only a small fraction is ionized in solution
  - CH_3COOH,
  - NH_3



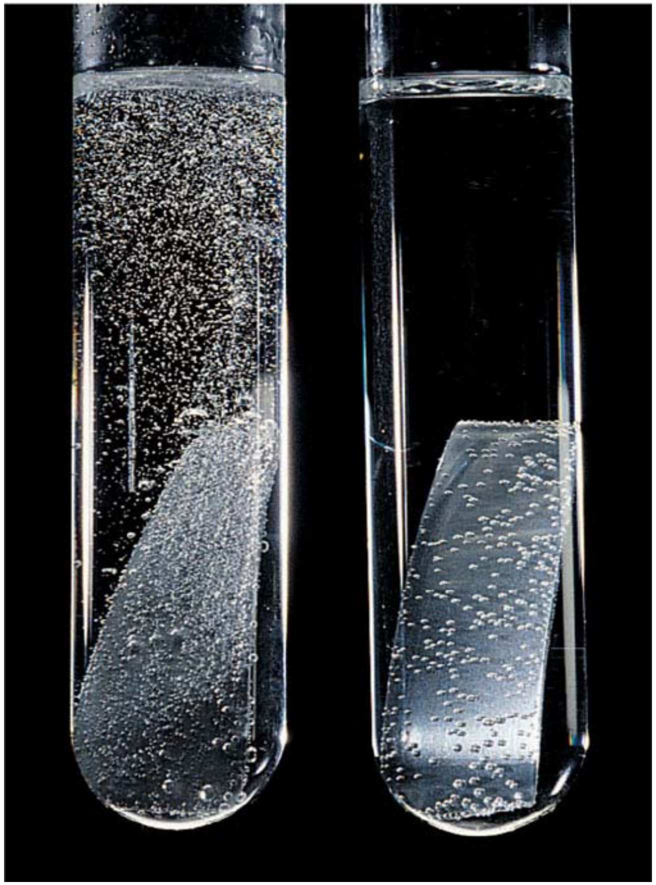
Partial ionization

Reactivity of strong and weak acids.

- Acids react with metals to produce hydrogen gas

1M HCl(*aq*)

Strong acid:
Extensive H_2 evolution

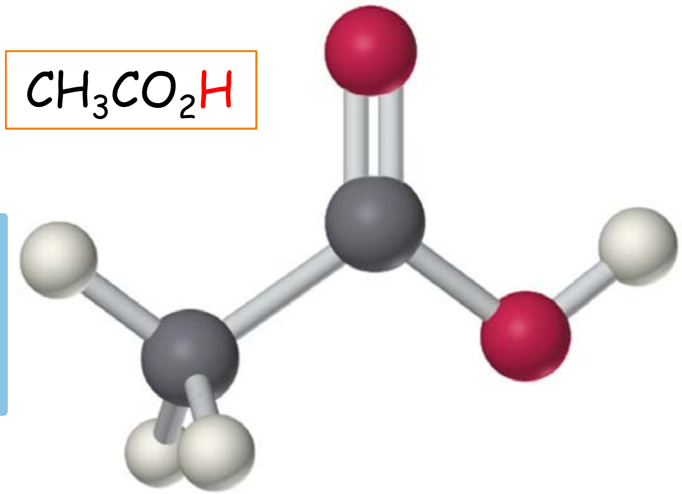


1M CH_3COOH(*aq*)

Weak acid:
H_2 evolution
Not very extensive

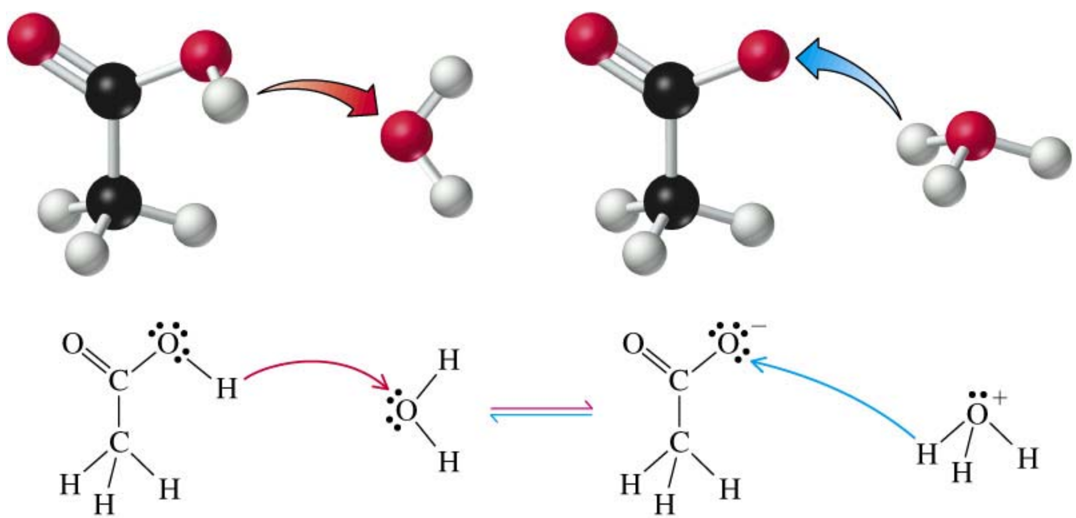
Weak acids.

CH_3CO_2H



Acetic acid

- Do not fully dissociate in solution.
- Only a small fraction becomes ionised



$$\underset{\text{acid(1)}}{HC_2H_3O_2} + \underset{\text{base(2)}}{H_2O} \rightleftharpoons \underset{\text{base(1)}}{C_2H_3O_2^-} + \underset{\text{acid(2)}}{H_3O^+}$$

Acids & Bases as Electrolytes

Strong Acids are strong electrolytes (100% dissociation)

$$HCl\ (aq) + H_2O\ (l) \longrightarrow H_3O^+\ (aq) + Cl^-\ (aq)$$

$$H_2SO_4\ (aq) + H_2O\ (l) \longrightarrow H_3O^+\ (aq) + HSO_4^-\ (aq)$$

Weak Acids are weak electrolytes (not fully dissociated)

$$HF\ (aq) + H_2O\ (l) \rightleftharpoons H_3O^+\ (aq) + F^-\ (aq)$$

$$H_2O\ (l) + H_2O\ (l) \rightleftharpoons H_3O^+\ (aq) + OH^-\ (aq)$$

Acids & Bases as Electrolytes

Strong Bases are strong electrolytes (100% dissociated)

$$NaOH\ (s) \xrightarrow{H_2O} Na^+\ (aq) + OH^-\ (aq)$$

$$KOH\ (s) \xrightarrow{H_2O} K^+\ (aq) + OH^-\ (aq)$$

Weak Bases are weak electrolytes (not fully dissociated)

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

$$NO_2^-\ (aq) + H_2O\ (l) \rightleftharpoons OH^-\ (aq) + HNO_2\ (aq)$$

Weak acids/bases.

- Quantifying the extent of dissociation of a weak acid or a weak base in aqueous solution:
  - the acid dissociation constant **K_a**

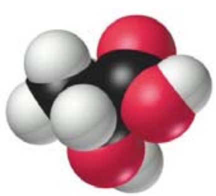
  or

  - the base dissociation constant **K_b**.
- Reflect acid or base strength
- Computed by determining the equilibrium concentrations of all relevant species in the solution.

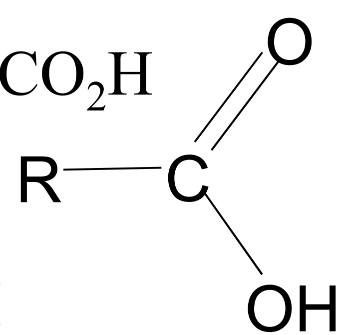
Weak Acids

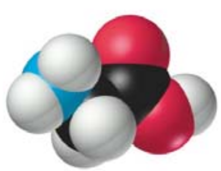
$$CH_3CO_2H_{(aq)} \rightleftarrows CH_3CO_2^- + H_3O^+$$

$$K_a = \frac{[CH_3CO_2^-][H_3O^+]}{[CH_3CO_2H]} = 1.8\text{x}10^{-5}$$



lactic acid $CH_3CH(OH)\,CO_2H$





glycine $H_2NCH_2CO_2H$

Mathematical interlude : the logarithm

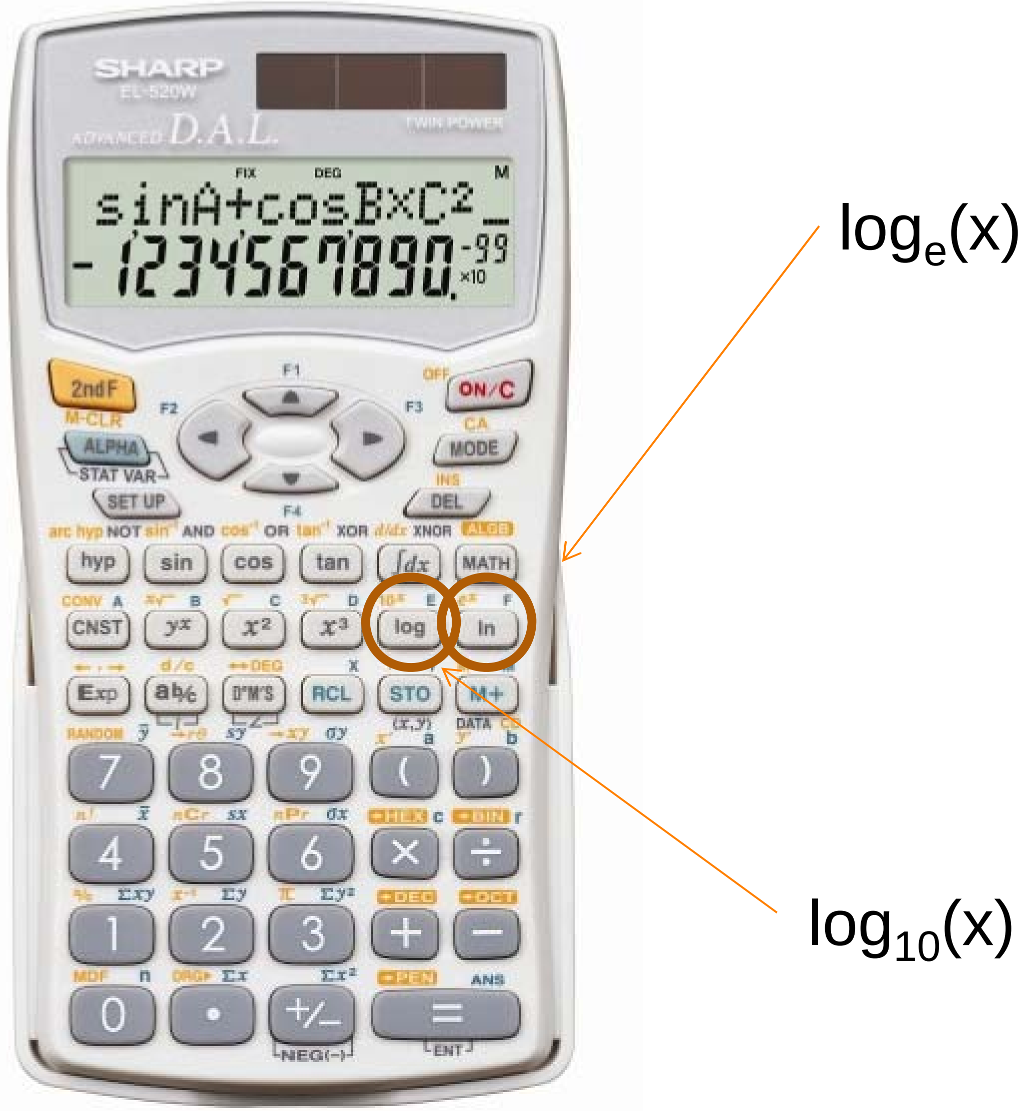
Useful Resources:
- Paul Monk, Maths for Chemistry, Oxford University Press, 2006.
- http://mathworld.wolfram.com/Logarithm.html

- The **logarithm** is a mathematical operation that is the inverse of exponentiation.
- If $x = b^n$ then $\log_b(x)=n$ where b is the base.
- If $10^x = y$ then $\log_{10}y = x$,
- Example: $10^2=10\times10=100$, then $\log_{10}(100)=2$.
- Logarithms are useful for making lengthy numerical operations easier to perform and for reducing large numbers to smaller ones.

Mathematical interlude : the logarithm

- The most widely used bases for logarithms are 10, the mathematical constant *e* ≈ 2.71828... and 2.
- When "log" is written without a base (*b* missing from log *b*), the intent can usually be determined from context:
  - natural logarithm (log*e*) in mathematical analysis
  - common logarithm (log10) in engineering and when logarithm tables are used to simplify hand calculations
  - binary logarithm (log2) in information theory and musical intervals .
- The notation "ln(x)" invariably means $\log_e(x)$, i.e., the natural logarithm of x, but the implied base for "log (x)" varies by discipline:
  - Mathematicians generally understand both "ln(x)" and "log(x)" to mean $\log_e(x)$ and write "$\log_{10}(x)$" when the base-10 logarithm of x is intended.
  - Engineers, biologists, and some others write only "ln(x)" or "$\log_e(x)$" when they mean the natural logarithm of x, and take "log (x)" to mean $\log_{10}(x)$ or, sometimes in the context of computing, $\log_2(x)$.

On most calculators, the LOG button is $\log_{10}(x)$ and LN is $\log_e(x)$.



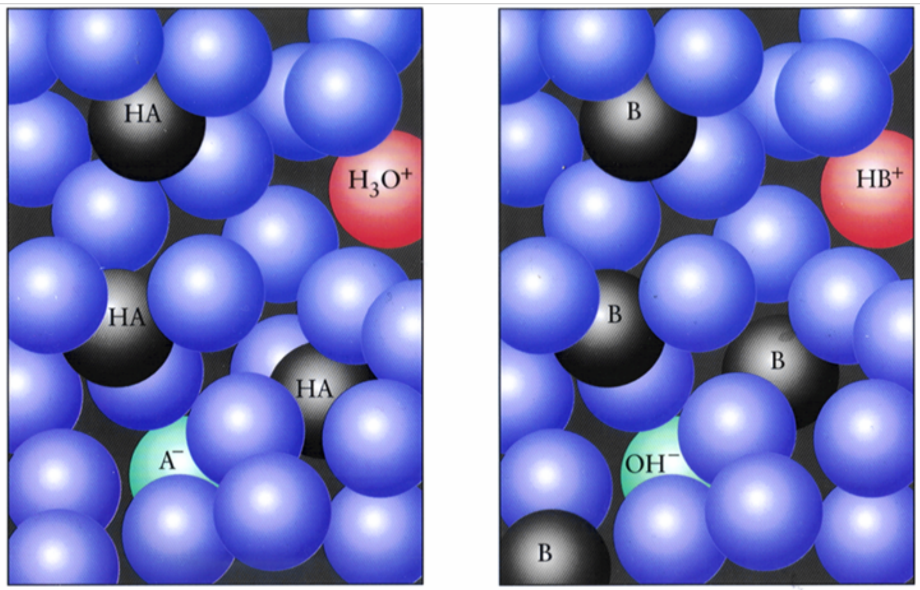
Logarithms are particularly useful when dealing with lengthy numerical operations as they reduce multiplication to addition, division to subtraction, exponentiation to multiplication, and roots to division.

Operations with numbers	Logarithmic identity
$a \, . b$	$\log\left(a.b\right) = \log(a) + \log(b)$
a/b	$\log\left(a/b\right) = \log(a) - \log(b)$
a^b	$\log\left(a^b\right) = b\log\left(a\right)$
$\sqrt[b]{a}$	$\log\left(\sqrt[b]{a}\right) = \log(a)/b$

Acid/base equilibria.

Recall: at equilibrium weak acids/bases only dissociate to a **small degree.**

Weak acid solution at equilibrium



Figures 3 and 4.14, page 520
Atkins/Jones: *Chemistry: Molecules, Matter, and Change*, **3e**

Weak base solution at equilibrium

How small is small?

Acid strength : the acid dissociation constant K_A.

- It is easy to quantify the strength of strong acids since they fully dissociate to ions in solution.
- For weak acids we quantify the idea of incomplete dissociation of a weak acid HA by noting that the dissociation reaction is an equilibrium process and introducing the acid dissociation constant K_A.

$$HA(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + A^-(aq)$$

Acid dissociation equilibrium

$$K_C = \frac{[H_3O^+][A^-]}{[HA][H_2O]}$$

$$K_A = K_C[H_2O] = \frac{[H_3O^+][A^-]}{[HA]}$$

Acid dissociation constant

- K_A is a measure of the acid strength.
- Large K_A implies considerable dissociation and the acid is strong.
- Small K_A low levels of dissociation, and the acid is weak.

The Relationship Between K_a and pK_a

K_A values vary over a wide range so it is best to use a log scale.

$$pK_A = -\log_{10} K_A$$

Note: When K_A is small pK_A is large and the acid does not dissociate in solution to a large extent. A change in 1 pK_A unit implies a 10 fold change in K_A value and hence acid strength.

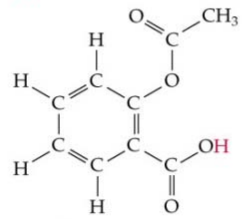
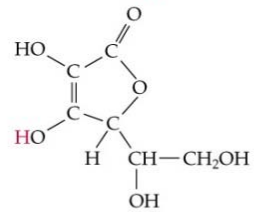
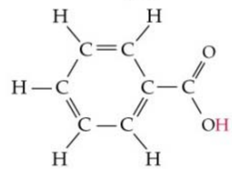
Acid Name (Formula)	K_A at 298 K	pK_A
Hydrogen sulfate ion (HSO_4^-)	1.02×10^{-2}	1.991
Nitrous acid (HNO_2)	7.1×10^{-4}	3.15
Acetic acid (CH_3COOH)	1.8×10^{-5}	4.74
Hypobromous acid (HBrO)	2.3×10^{-9}	8.64
Phenol (C_6H_5OH)	1.0×10^{-10}	10.00

$K_A \downarrow$

$pK_A \uparrow$

Acid dissociation constants.

TABLE 15.2 Acid–Dissociation Constants at 25°C

	Acid	Molecular Formula	Structural Formula*	K_a	pK_a†
Stronger acid	Hydrochloric	HCl	H—Cl	2×10^{6}	−6.3
	Nitrous	HNO_2	H—O—N=O	4.5×10^{-4}	3.35
	Hydrofluoric	HF	H—F	3.5×10^{-4}	3.46
	Acetylsalicylic (aspirin)	$C_9H_8O_4$		3.0×10^{-4}	3.52
	Formic	HCO_2H	H—C(=O)—O—H	1.8×10^{-4}	3.74
	Ascorbic (vitamin C)	$C_6H_8O_6$		8.0×10^{-5}	4.10
	Benzoic	$C_6H_5CO_2H$		6.5×10^{-5}	4.19
	Acetic	CH_3CO_2H	CH_3—C(=O)—O—H	1.8×10^{-5}	4.74
	Hypochlorous	$HOCl$	H—O—Cl	3.5×10^{-8}	7.46
Weaker acid	Hydrocyanic	HCN	H—C≡N	4.9×10^{-10}	9.31
	Methanol	CH_3OH	CH_3—O—H	2.9×10^{-16}	15.54

* The proton that is transferred to water when the acid dissociates is shown in color.　　†$pK_a = -\log K_a$.

Basicity Constant K_b.

$$B(aq) + H_2O\ (l) \rightleftharpoons BH^+\ (aq) + OH^-\ (aq)$$

$$K_C = \frac{[BH^+][OH^-]}{[B][H_2O]}$$

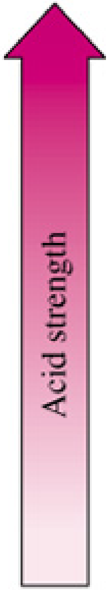
$$K_b = K_C[H_2O] = \frac{[BH^+][OH^-]}{[B]}$$

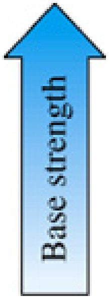
$$pK_b = -\log_{10} K_b$$

- Similarly, the proton accepting strength of a base is quantified in terms of the basicity constant K_b.
- The larger the value of K_b, the stronger the base.
- If K_b is large then pK_b will be small, and the stronger the base.

Ionization Constants of Weak Acids and Bases

	Ionization Equilibrium	Ionization Constant K	pK
Acid		K_a =	pK_a =
Iodic acid	$HIO_3 + H_2O \rightleftharpoons H_3O^+ + IO_3^-$	1.6×10^{-1}	0.80
Chlorous acid	$HClO_2 + H_2O \rightleftharpoons H_3O^+ + ClO_2^-$	1.1×10^{-2}	1.96
Chloroacetic acid	$HC_2H_2ClO_2 + H_2O \rightleftharpoons H_3O^+ + C_2H_2ClO_2^-$	1.4×10^{-3}	2.85
Nitrous acid	$HNO_2 + H_2O \rightleftharpoons H_3O^+ + NO_2^-$	7.2×10^{-4}	3.14
Hydrofluoric acid	$HF + H_2O \rightleftharpoons H_3O^+ + F^-$	6.6×10^{-4}	3.18
Formic acid	$HCHO_2 + H_2O \rightleftharpoons H_3O^+ + CHO_2^-$	1.8×10^{-4}	3.74
Benzoic acid	$HC_7H_5O_2 + H_2O \rightleftharpoons H_3O^+ + C_7H_5O_2^-$	6.3×10^{-5}	4.20
Hydrazoic acid	$HN_3 + H_2O \rightleftharpoons H_3O^+ + N_3^-$	1.9×10^{-5}	4.72
Acetic acid	$HC_2H_3O_2 + H_2O \rightleftharpoons H_3O^+ + C_2H_3O_2^-$	1.8×10^{-5}	4.74
Hypochlorous acid	$HOCl + H_2O \rightleftharpoons H_3O^+ + OCl^-$	2.9×10^{-8}	7.54
Hydrocyanic acid	$HCN + H_2O \rightleftharpoons H_3O^+ + CN^-$	6.2×10^{-10}	9.21
Phenol	$HOC_6H_5 + H_2O \rightleftharpoons H_3O^+ + C_6H_5O^-$	1.0×10^{-10}	10.00
Hydrogen peroxide	$H_2O_2 + H_2O \rightleftharpoons H_3O^+ + HO_2^-$	1.8×10^{-12}	11.74
Base		K_b =	pK_b =
Diethylamine	$(C_2H_5)_2NH + H_2O \rightleftharpoons (C_2H_5)_2NH_2^+ + OH^-$	6.9×10^{-4}	3.16
Ethylamine	$C_2H_5NH_2 + H_2O \rightleftharpoons C_2H_5NH_3^+ + OH^-$	4.3×10^{-4}	3.37
Ammonia	$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$	1.8×10^{-5}	4.74
Hydroxylamine	$HONH_2 + H_2O \rightleftharpoons HONH_3^+ + OH^-$	9.1×10^{-9}	8.04
Pyridine	$C_5H_5N + H_2O \rightleftharpoons C_5H_5NH^+ + OH^-$	1.5×10^{-9}	8.82
Aniline	$C_6H_5NH_2 + H_2O \rightleftharpoons C_6H_5NH_3^+ + OH^-$	7.4×10^{-10}	9.13

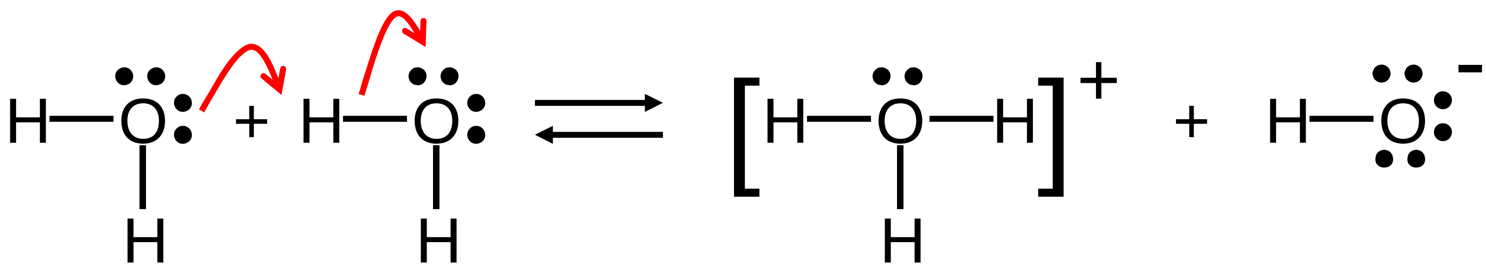




Acid-Base Properties of Water

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

autoionization of water



base

conjugate acid

$$H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$$

acid

conjugate base

Amphoteric
act as an acid or a base

The Ion Product of Water

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

$$K_c = \frac{[H^+][OH^-]}{[H_2O]}$$

$[H_2O]$ = constant

$$K_c[H_2O] = K_w = [H^+][OH^-]$$

The ***ion-product constant*** (K_w) is the product of the molar concentrations of H^+ and OH^- ions at a particular temperature.

At 25^0C

$$K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$$

	Solution Is
$[H^+] = [OH^-]$	neutral
$[H^+] > [OH^-]$	acidic
$[H^+] < [OH^-]$	basic

The pH concept.

- Quantitatively acidity or alkalinity is measured using the concentration of hydrated protons $[H_3O^+]$ present in a solution.

- The $[H_3O^+]$ varies in magnitude over quite a large range in aqueous solution, typically from 1 M to 10^{-14} M.

- To make the numbers meaningful $[H_3O^+]$ is expressed in terms of a logarithmic scale called the pH scale.

$$pH = -\log_{10}\left[H_3O^+\right]$$
$$\left[H_3O^+\right] = 10^{-pH}$$

- The higher the $[H_3O^+]$, the more acidic the solution and the lower is the solution pH.

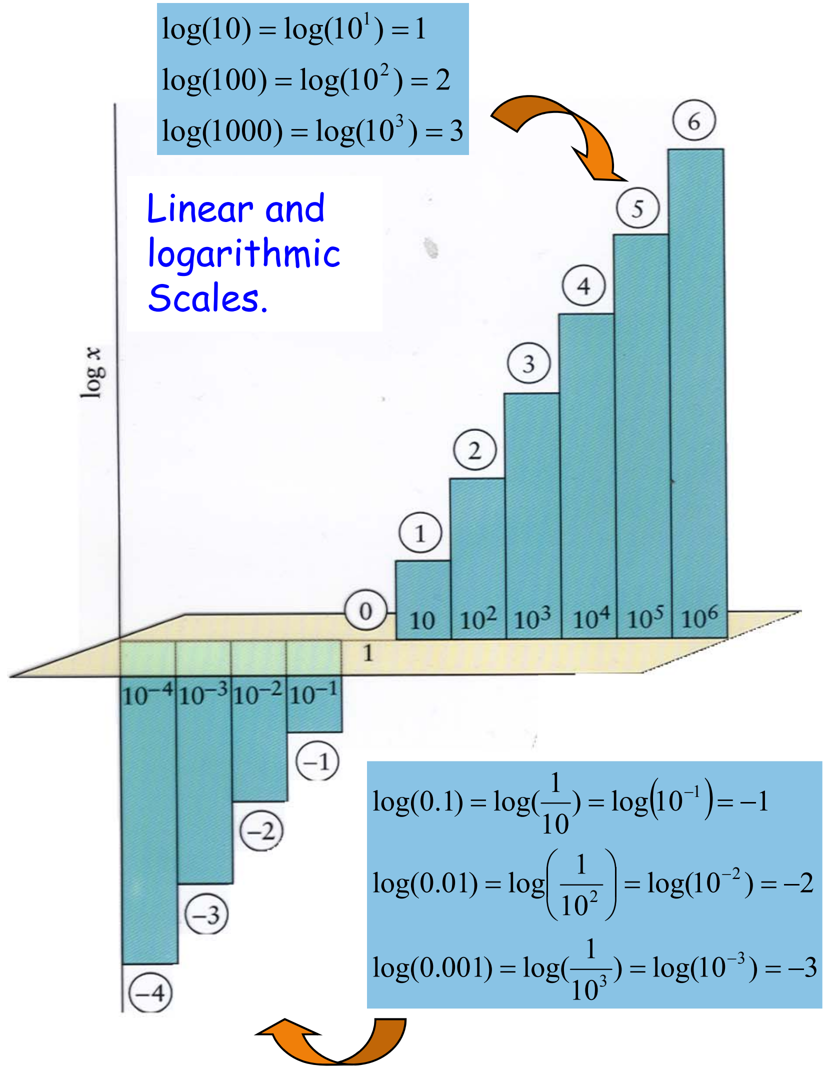
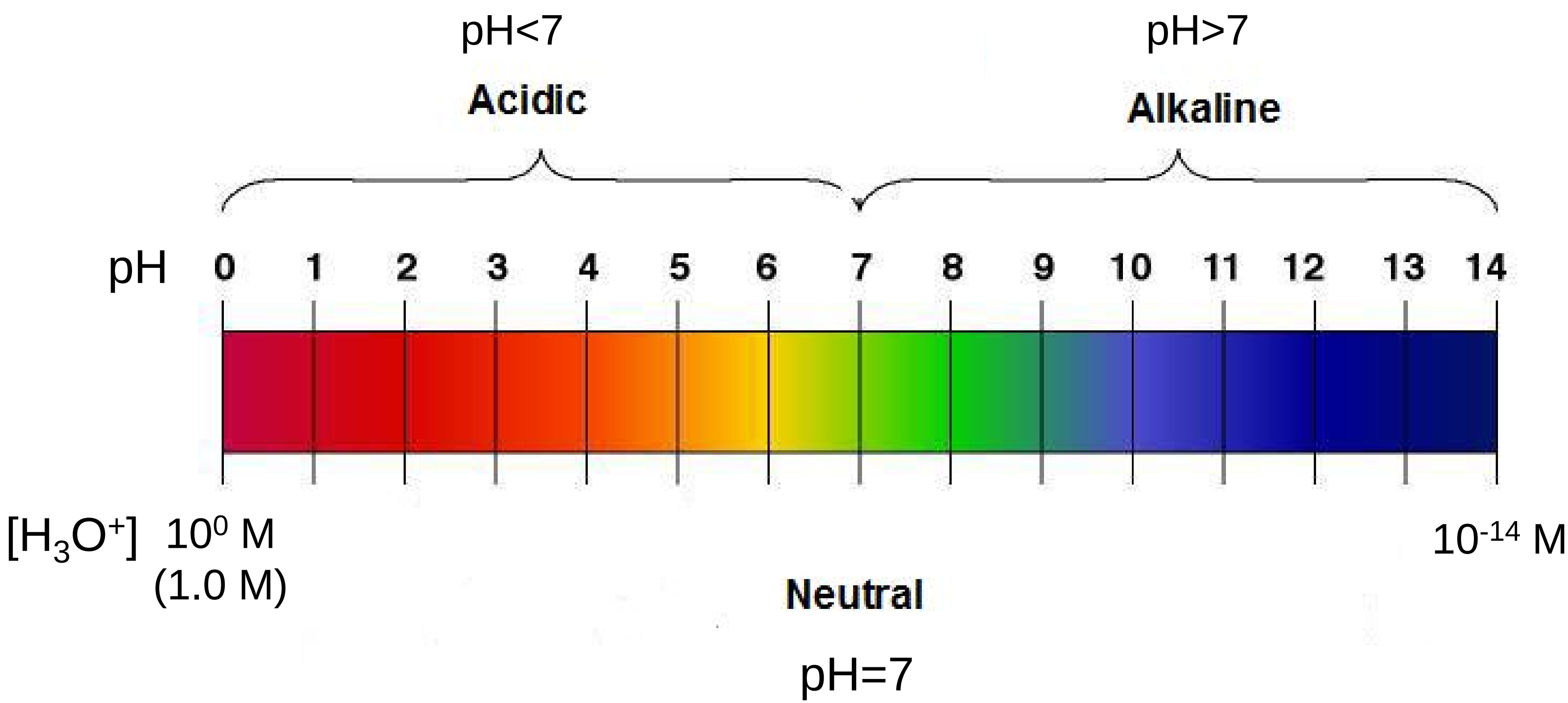


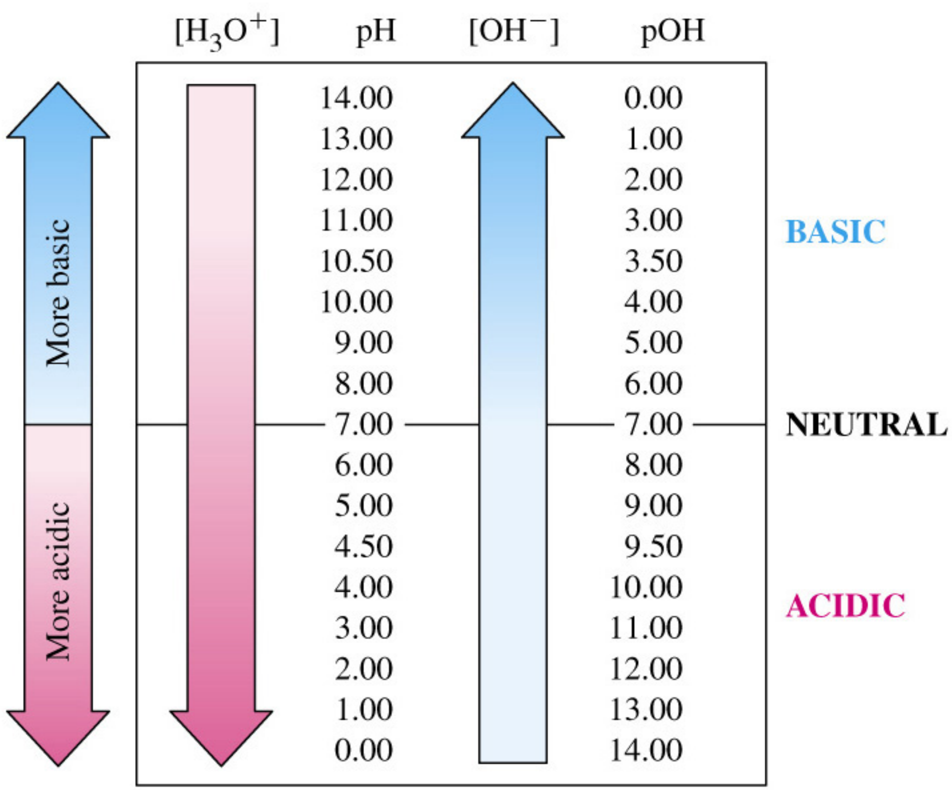
Figure 14.8, page 515
Atkins/Jones: *Chemistry: Molecules, Matter, and Change*.

The pH Scale



A pH change of 1 unit implies a 10 fold change in [H_3O^+]

pH & pOH Scales.

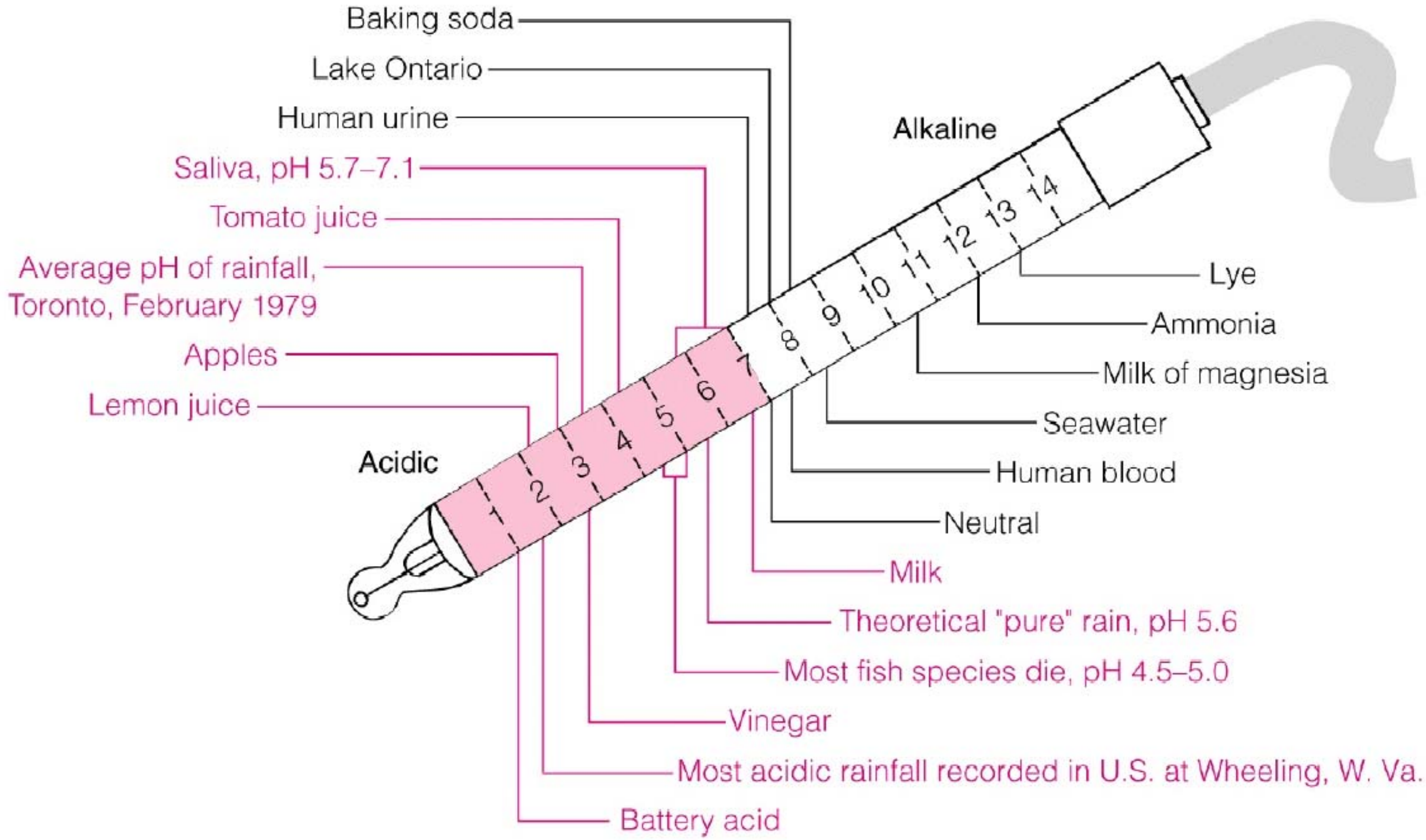


$pOH = -\log[OH^-]$

$pH = -\log[H_3O^+]$

$pH + pOH = pK_w = 14$

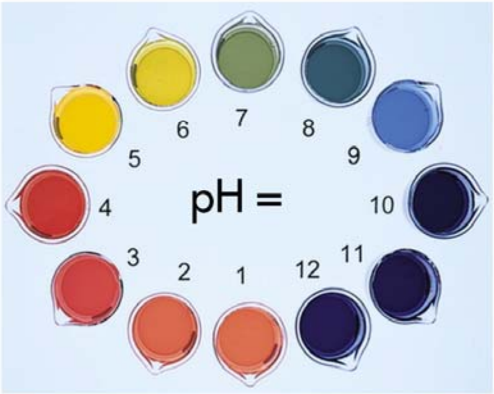
Typical pH values.



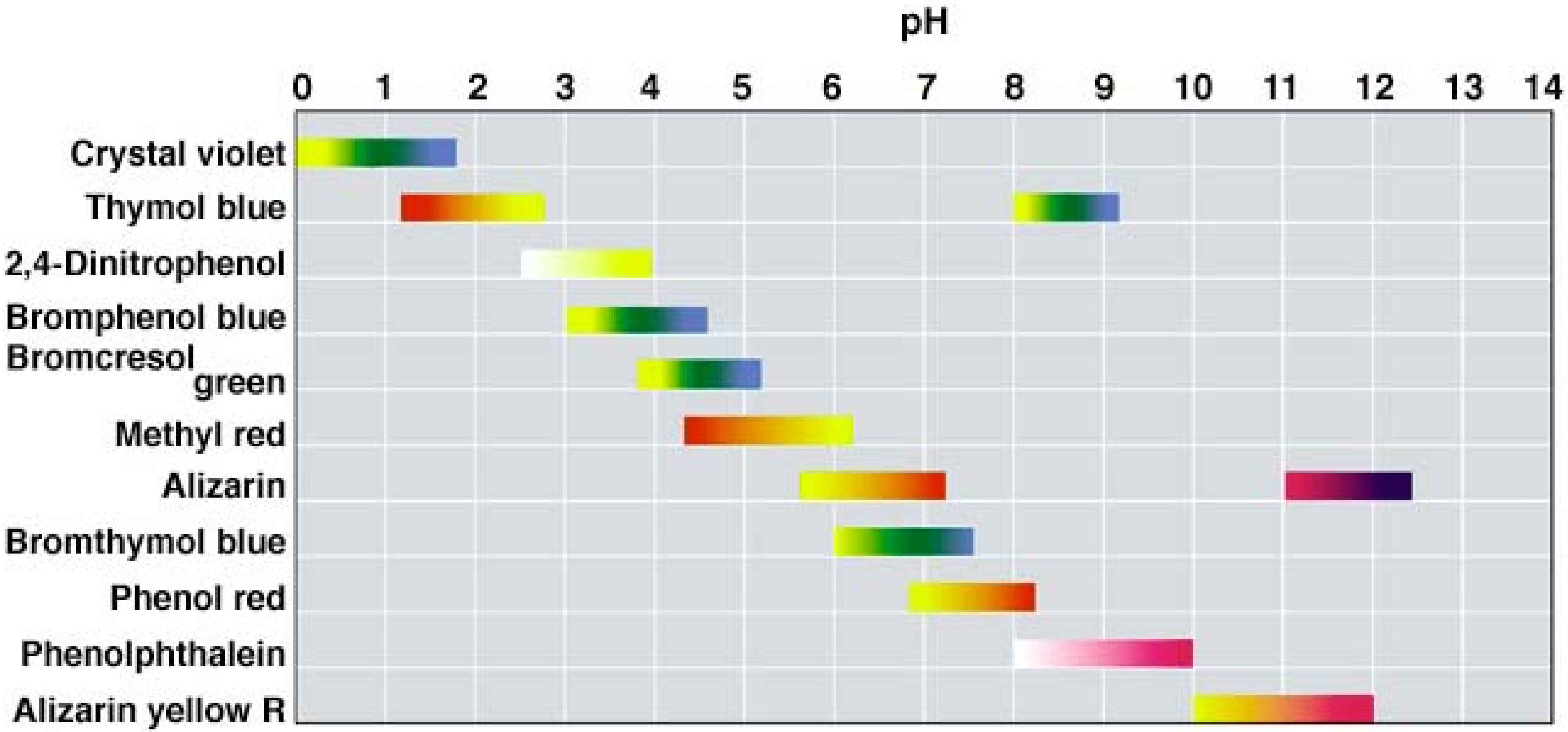
Measuring pH: Indicators, a visual estimation.

$$HIn(aq) + H_2O \rightarrow H_3O^+(aq) + In^-$$

- Indictors are weak acids which change colour over a specific pH range when they donate protons.
- Used in acid/base titrations.
- Universal indicator used for pH measurements over a larger range.
  - Mixture of pH indicators
  - Different colours from red to purple

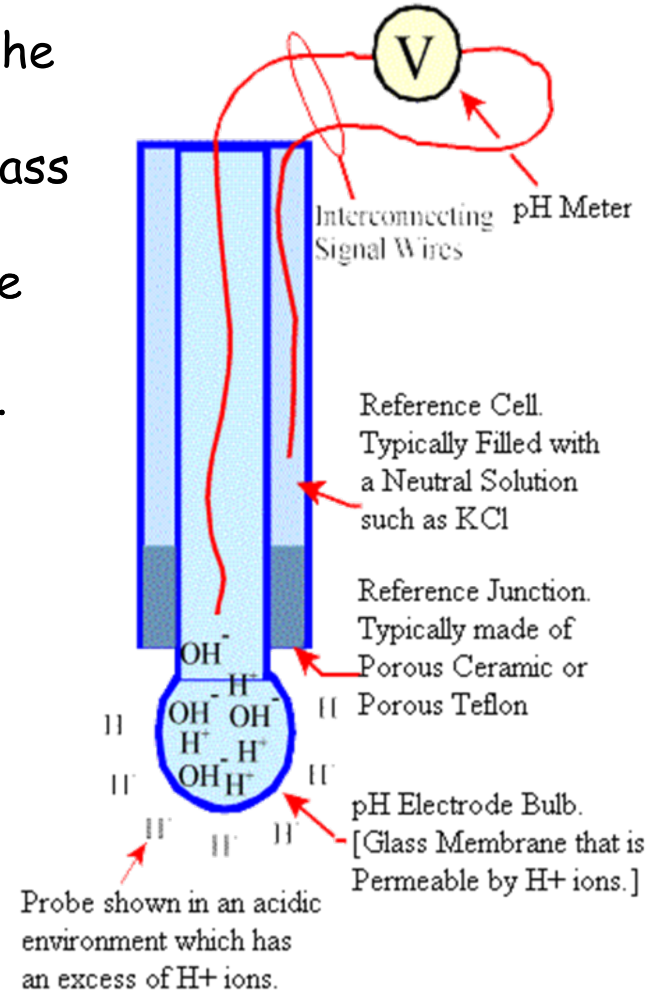


Colors and Approximate pH Range of Some Common Acid-Base Indicators



Measuring pH: The pH meter.

- The pH meter is a voltmeter connected to a chemical sensor probe which is sensitive to the concentration of H_3O^+.
- Measures the electrical potential across a glass membrane in the probe.
- The measured potential is proportional to the logarithm of $[H_3O^+]$
- A digital read out of the solution pH is given.



Summary. pH – A Measure of Acidity

$$pH = -\log [H^+]$$

Solution Is		**At 25^{0}C**	
neutral	$[H^+] = [OH^-]$	$[H^+] = 1 \times 10^{-7}$	$pH = 7$
acidic	$[H^+] > [OH^-]$	$[H^+] > 1 \times 10^{-7}$	$pH < 7$
basic	$[H^+] < [OH^-]$	$[H^+] < 1 \times 10^{-7}$	$pH > 7$

$pH \uparrow$ $\quad$ $[H^+] \downarrow$

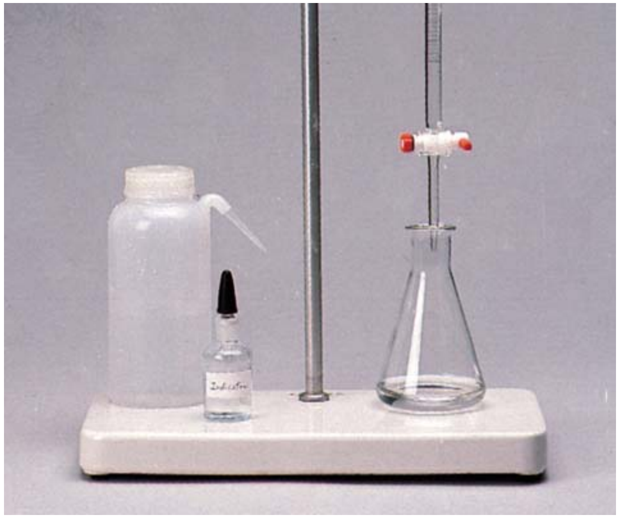
Titrations

In a ***titration*** a solution of accurately known concentration is added gradually added to another solution of unknown concentration until the chemical reaction between the two solutions is complete.

$$HA + MOH \rightarrow MA + H_2O$$

Equivalence point - the point at which the reaction is complete

Indicator – substance that changes color at (or near) the equivalence point



Slowly add base to unknown acid UNTIL The indicator changes color (pink)

Strong Acid-Strong Base Titrations

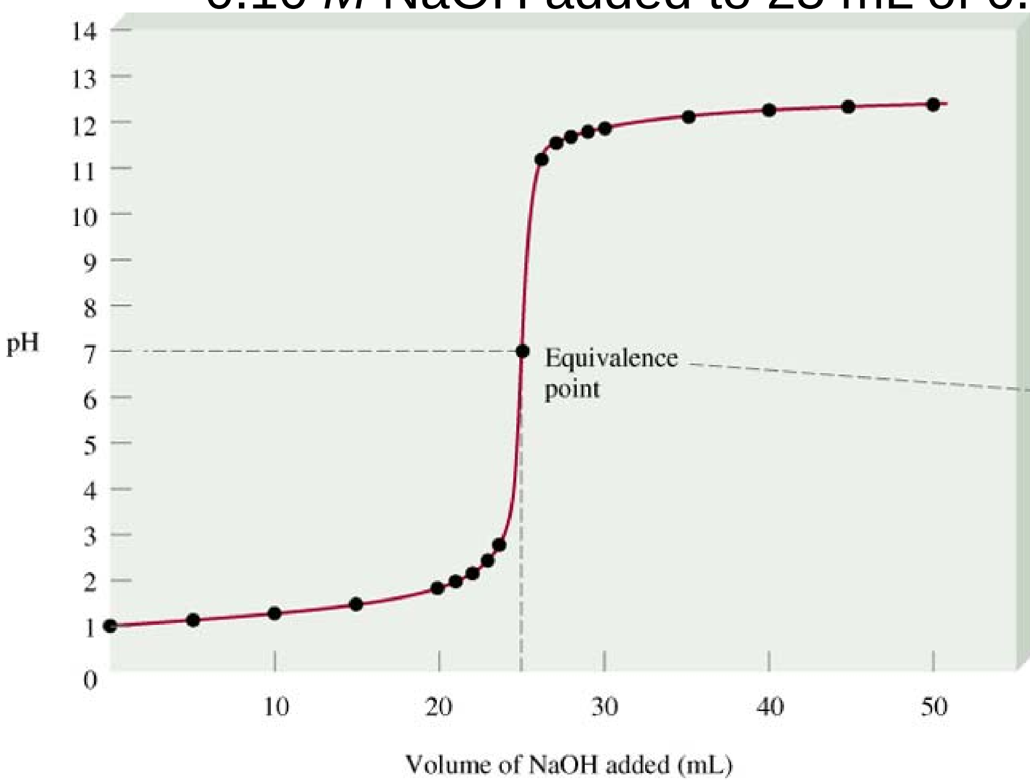
$NaOH\ (aq) + HCl\ (aq) \longrightarrow H_2O\ (l) + NaCl\ (aq)$

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

Equivalence point

Amount of acid = Amount of base

0.10 *M* NaOH added to 25 mL of 0.10 *M* HCl



Volume NaOH added (mL)	pH
0.0	1.00
5.0	1.18
10.0	1.37
15.0	1.60
20.0	1.95
22.0	2.20
24.0	2.69
25.0	7.00
26.0	11.29
28.0	11.75
30.0	11.96
35.0	12.22
40.0	12.36
45.0	12.46
50.0	12.52

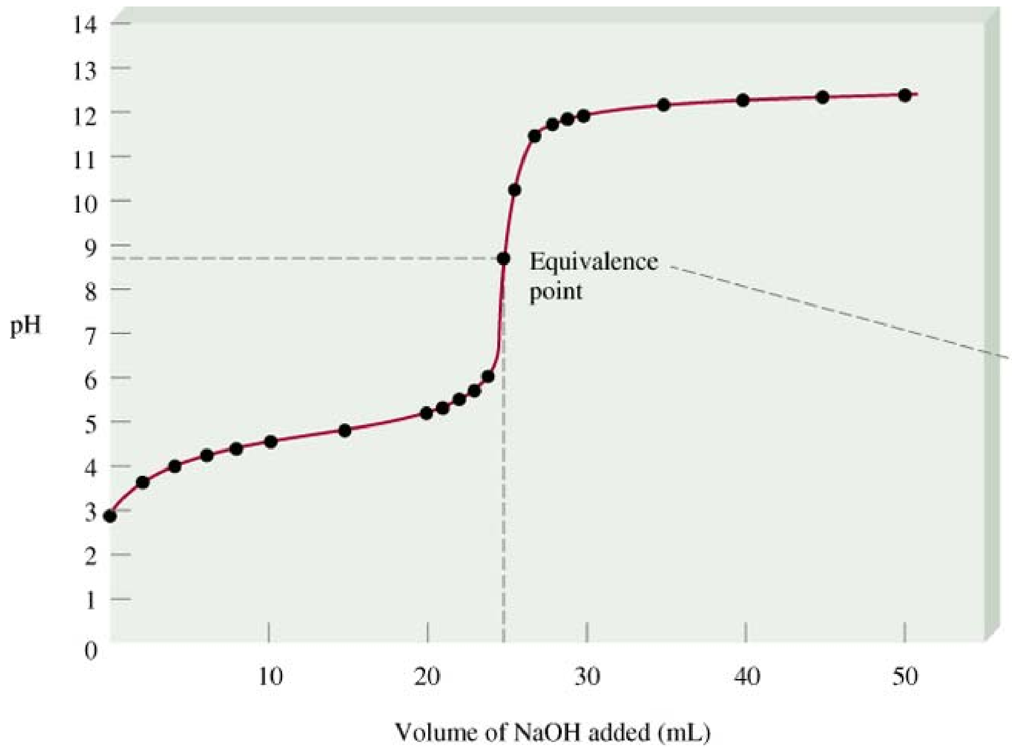
Weak Acid-Strong Base Titrations

CH_3COOH (*aq*) + NaOH (*aq*) $\longrightarrow$ CH_3COONa (*aq*) + H_2O (*l*)

CH_3COOH (*aq*) + OH^- (*aq*) $\longrightarrow$ CH_3COO^- (*aq*) + H2O (*l*)

At equivalence point (pH > 7):

CH_3COO^- (*aq*) + H_2O (*l*) $\rightleftharpoons$ OH^- (*aq*) + CH_3COOH (*aq*)



Volume NaOH added (mL)	pH
0.0	2.87
5.0	4.14
10.0	4.57
15.0	4.92
20.0	5.35
22.0	5.61
24.0	6.12
25.0	8.72
26.0	10.29
28.0	11.75
30.0	11.96
35.0	12.22
40.0	12.36
45.0	12.46
50.0	12.52

Concluding Comments

- Acid/base reactions represent an example of a fundamental class of chemical reactions.
- The process involves the transfer of a hydrated proton from a donor species (the acid) to an acceptor species (the base).
- The degree of proton transfer can be quantified and enables a distinction between strong and weak acids/bases to be made.
- The degree of acidity or alkalinity of a solution may be quantified in terms of the logarithmic pH scale. Acidic solutions have a low pH and basic solutions have a high pH.
- The solution pH can be measured via use of indicators or via use of pH meter.
- An acid/base reaction is termed a neutralization reaction and can be monitored by measuring the pH during the reaction.