Acids & Bases

Three definitions

Arrhenius

Acids are substances that, when dissolved in water, increase the concentration of H^+ ions. Likewise, bases are substances that, when dissolved in water, increase the concentration of OH^- ions.

Bronsted-Lowry

An acid is a substance that can donate a proton to another substance while a base is a substance that can accept a proton.

Lewis

An acid is an electron pair acceptor while a base is an electron pair donor.

Arrhenius vs Bronsted-Lowry

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

$$HCl(g) + NH_3(l) \rightarrow NH_4^+(l) + Cl^-(g)$$

An acid and a base that differ only in the presence or absence of a proton are called a conjugate acid-base pair.

$$\underset{\text{acid}}{HNO_2(aq)} + \underset{\text{base}}{H_2O(l)} \rightleftharpoons \underset{\text{conjugate base}}{NO_2^-(aq)} + \underset{\text{conjugate acid}}{H_3O^+(aq)}$$

$$\underset{\text{base}}{NH_3(aq)} + \underset{\text{acid}}{H_2O(l)} \rightleftharpoons \underset{\text{conjugate acid}}{NH_4^+(aq)} + \underset{\text{conjugate base}}{OH^-(aq)}$$

Conjugate Acid & Base

Acid	*Base*
$HClO_4$	*?*
H_2S	*?*
PH_4^+	*?*
HCO_3^-	*?*

Base	*Acid*
CN^-	*?*
SO_4^-	*?*
H_2O	*?*
HCO_3^-	*?*

Autoionization of Water

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

$$K_{eq} = K_w = [H_3O^+][OH^-] = [H^+][OH^-]$$

$$K_w = 1.0x10^{-14}$$

In pure water

$$[H^+] = [OH^-] = 1.0x10^{-7}$$

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

In pure water

$$pH = 7$$

Strong Acids & Bases

Acid	*Name*
HCl	*hydrochloric*
HBr	*hydrobromic*
HI	*hydroiodic*
HNO_3	*nitric*
$HClO_3$	*chloric*
$HClO_4$	*perchloric*

$$HNO_3(aq) + H_2O(l) \rightarrow H_3O^+(aq) + NO_3^-(aq)$$

$$HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$$

Base	Name
$NaOH$	sodium hydroxide
KOH	potasium hydroxide
$Ca(OH)_2$	calcium hydroxide
Na_2O	sodium oxide
CaO	calcium oxide
H^-	hydride ion
N^{-3}	nitride ion

$$Ca(OH)_2(aq) \rightarrow Ca^{+2}(aq) + 2OH^-(aq)$$

$$CaO(s) + H_2O(l) \rightarrow Ca^{+2}(aq) + 2OH^-(aq)$$

$$N^{-3}(aq) + 3H_2O(l) \rightarrow NH_3(aq) + 3OH^-(aq)$$

Weak Acids

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

$$K_{eq} = K_a = \frac{[A^-][H^+]}{[HA]}$$

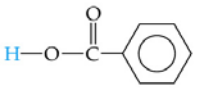
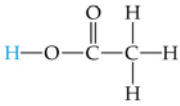
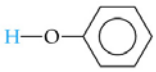
K_a = *acid dissociation constant*

pH determines K_a

or

K_a determines *pH*

TABLE 16.2 Some Weak Acids in Water at 25°C*

Acid	Structural Formula	Conjugate Base	Equilibrium Reaction	K_a
Hydrofluoric (HF)	H—F	F^-	$HF(aq) + H_2O(l) \Delta H_3O^+(aq) + F^-(aq)$	$6.8 * 10^{-4}$
Nitrous (HNO_2)	H—O—N=O	NO_2^-	$HNO_2(aq) + H_2O(l) \Delta H_3O^+(aq) + NO_2^-(aq)$	$4.5 * 10^{-4}$
Benzoic ($HC_7H_5O_2$)		$C_7H_5O_2^-$	$HC_7H_5O_2(aq) + H_2O(l) \Delta H_3O^+(aq) + C_7H_5O_2^-(aq)$	$6.3 * 10^{-5}$
Acetic ($HC_2H_3O_2$)		$C_2H_3O_2^-$	$HC_2H_3O_2(aq) + H_2O(l) \Delta H_3O^+(aq) + C_2H_3O_2^-(aq)$	$1.8 * 10^{-5}$
Hypochlorous (HClO)	H—O—Cl	ClO^-	$HClO(aq) + H_2O(l) \Delta H_3O^+(aq) + ClO^-(aq)$	$3.0 * 10^{-8}$
Hydrocyanic (HCN)	H—C≡N	CN^-	$HCN(aq) + H_2O(l) \Delta H_3O^+(aq) + CN^-(aq)$	$4.9 * 10^{-10}$
Phenol (HC_6H_5O)		$C_6H_5O^-$	$HC_6H_5O(aq) + H_2O(l) \Delta H_3O^+(aq) + C_6H_5O^-(aq)$	$1.3 * 10^{-10}$

*The proton that ionizes is shown in blue.

Calculating K_a from *pH*

a. Given that a 0.1 M solution of formic acid has a *pH* of 2.38, calculate K_a

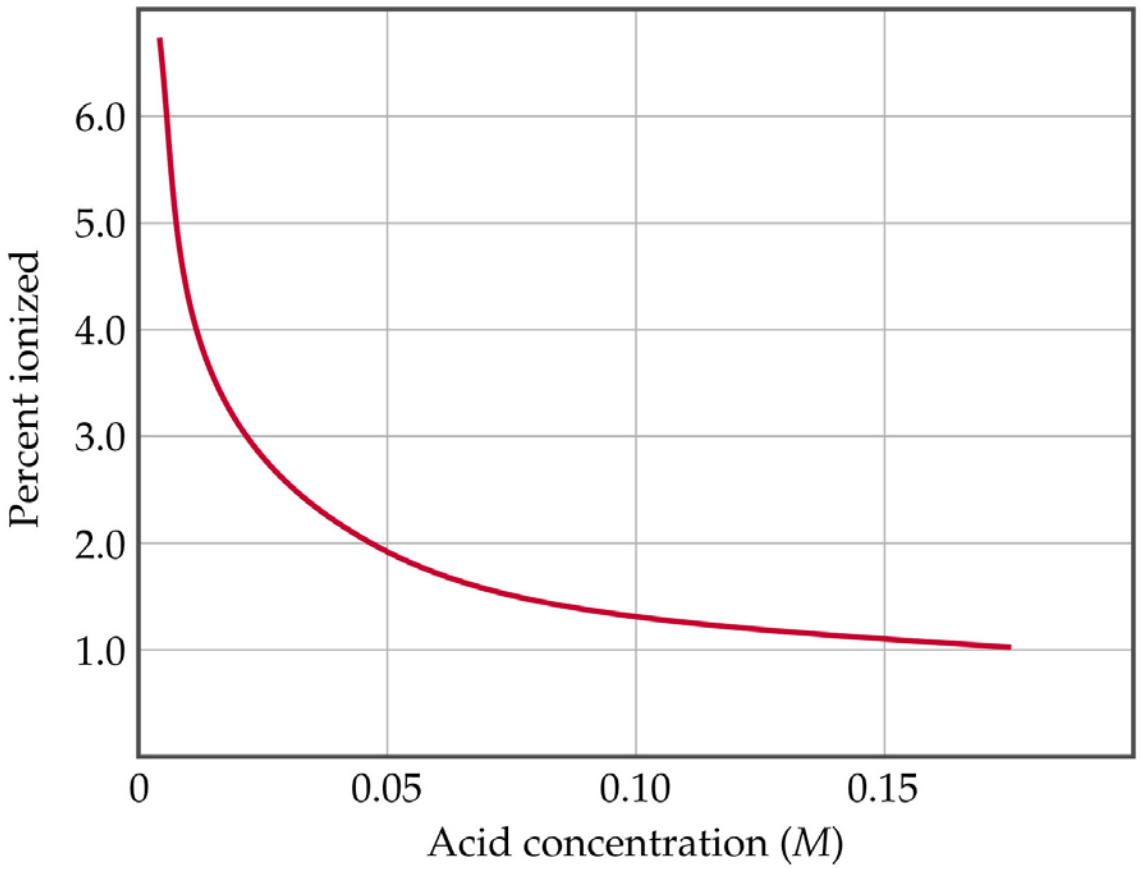
b. What % of the acid is dissociated?

Calculating *pH* from K_a

a. Given that the K_a for acetic acid is 1.8×10^{-5}, what is the *pH* of a 0.30M solution?

b. What % of the acid is dissociated?

Effect of Dilution on % Dissociation



Polyprotic Acids

More than one ionizablbe H atom

$$H_2SO_3(aq) \rightleftharpoons H^+(aq) + HSO_3^- \qquad K_{a1}=1.7x10^{-2}$$

$$HSO_3^-(aq) \rightleftharpoons H^+(aq) + SO_3^{2-}(aq) \qquad K_{a2}=6.4x10^{-8}$$

TABLE 16.3 Acid-Dissociation Constants of Some Common Polyprotic Acids

Name	Formula	K_{a1}	K_{a2}	K_{a3}
Ascorbic	$H_2C_6H_6O_6$	$8.0 * 10^{-5}$	$1.6 * 10^{-12}$	
Carbonic	H_2CO_3	$4.3 * 10^{-7}$	$5.6 * 10^{-11}$	
Citric	$H_3C_6H_5O_7$	$7.4 * 10^{-4}$	$1.7 * 10^{-5}$	$4.0 * 10^{-7}$
Oxalic	$H_2C_2O_4$	$5.9 * 10^{-2}$	$6.4 * 10^{-5}$	
Phosphoric	H_3PO_4	$7.5 * 10^{-3}$	$6.2 * 10^{-8}$	$4.2 * 10^{-13}$
Sulfurous	H_2SO_3	$1.7 * 10^{-2}$	$6.4 * 10^{-8}$	
Sulfuric	H_2SO_4	Large	$1.2 * 10^{-2}$	
Tartaric	$H_2C_4H_4O_6$	$1.0 * 10^{-3}$	$4.6 * 10^{-5}$	

The solubility of CO_2 in pure water 25^0C and 0.1 *atm* pressure is 0.0037 M.

$$CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$$

? pH

$$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq) \qquad K_{a1}=4.3x10^{-7}$$

$$HCO_3^-(aq) \rightleftharpoons H^+(aq) + CO_3^{2-}(aq) \qquad K_{a2}=5.6x10^{-11}$$

Predict whether the equilibrium is predominantly to the left or to the right

$$HSO_4^-(aq) + CO_3^{2-}(aq) \rightleftharpoons SO_4^{2-}(aq) + HCO_3^-(aq)$$

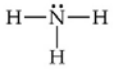
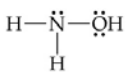
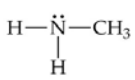
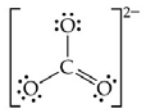
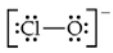
$$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons H_2PO_4^-(aq) + OH^-(aq)$$

$$NH_4^+(aq) + OH^-(aq) \rightleftharpoons NH_3(aq) + H_2O(l)$$

Weak Bases

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

TABLE 16.4 Some Weak Bases and Their Aqueous Solution Equilibria

Base	Lewis Structure	Conjugate Acid	Equilibrium Reaction	K_b
Ammonia (NH_3)		NH_4^+	$NH_3 + H_2O \Delta NH_4^+ + OH^-$	$1.8 * 10^{-5}$
Pyridine (C_5H_5N)		$C_5H_5NH^+$	$C_5H_5N + H_2O \Delta C_5H_5NH^+ + OH^-$	$1.7 * 10^{-9}$
Hydroxylamine (H_2NOH)		H_3NOH^+	$H_2NOH + H_2O \Delta H_3NOH^+ + OH^-$	$1.1 * 10^{-8}$
Methylamine (NH_2CH_3)		$NH_3CH_3^+$	$NH_2CH_3 + H_2O \Delta NH_3CH_3^+ + OH^-$	$4.4 * 10^{-4}$
Hydrosulfide ion (HS^-)		H_2S	$HS^- + H_2O \Delta H_2S + OH^-$	$1.8 * 10^{-7}$
Carbonate ion (CO_3^{2-})		HCO_3^-	$CO_3^{2-} + H_2O \Delta HCO_3^- + OH^-$	$1.8 * 10^{-4}$
Hypochlorite ion (ClO^-)		HClO	$ClO^- + H_2O \Delta HClO + OH^-$	$3.3 * 10^{-7}$

A solution is made by adding solid sodium hypochlorite *(NaClO)* to water to make a 2.0L solution. If the solution has a pH of 10.5, how many moles of *(NaClO*) were added to the water?

$$ClO^-(aq) + H_2O(aq) \rightleftharpoons ClOH(aq) + OH^-(aq)$$

$$K_{eq} = \frac{[HClO][OH^-]}{[ClO^-]} = 3.33x10^{-7}$$

The solubility of CO_2 in pure water at 25^0C and 0.1 *atm* pressure is 0.0037 M.

$$CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$$

? pH

$$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq) \qquad K_{a1}=4.3x10^{-7}$$

$$HCO_3^-(aq) \rightleftharpoons H^+(aq) + CO_3^{2-}(aq) \qquad K_{a2}=5.6x10^{-11}$$

Three Broad Classes of Acids

1. Binary Acids

   H atom + one other element; H-X

   HF, HCl, H_2O, H_2S, etc

2. Oxyacids

   One or more OH groups attached to a central atom. Often additional oxygen atoms will be attached to the central atom.

   $HOCl, HOClO, HOClO_2, HOClO_3, H_2SO_4, H_2SeO_3, etc$

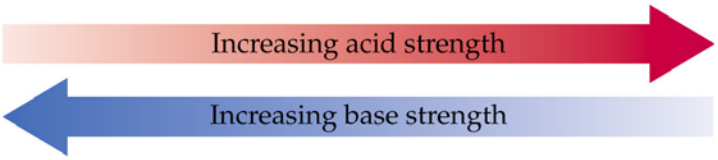
3. Carboxylic acids

   Contain the carboxyl group

	GROUP			
	4A	5A	6A	7A
Period 2	CH_4 No acid or base properties	NH_3 Weak base	H_2O ---	HF Weak acid
Period 3	SiH_4 No acid or base properties	PH_3 Weak base	H_2S Weak acid	HCl Strong acid

Increasing acid strength

Increasing base strength



Representative Questions

1. Make an aqueous solution of each of the following

NaCl, NH_4Cl, & NaClO

Which solution is acidic, basic or neutral?

2. Dissolve Na_2HPO_4 in water.

Is the solution acidic, basic or neutral?

3. An unknown salt is either *NaF, NaCl*, or *NaOCl*. A solution of 0.05 mol of salt in 0.50 L of H_2O has a pH=8.08.

Which salt is it?