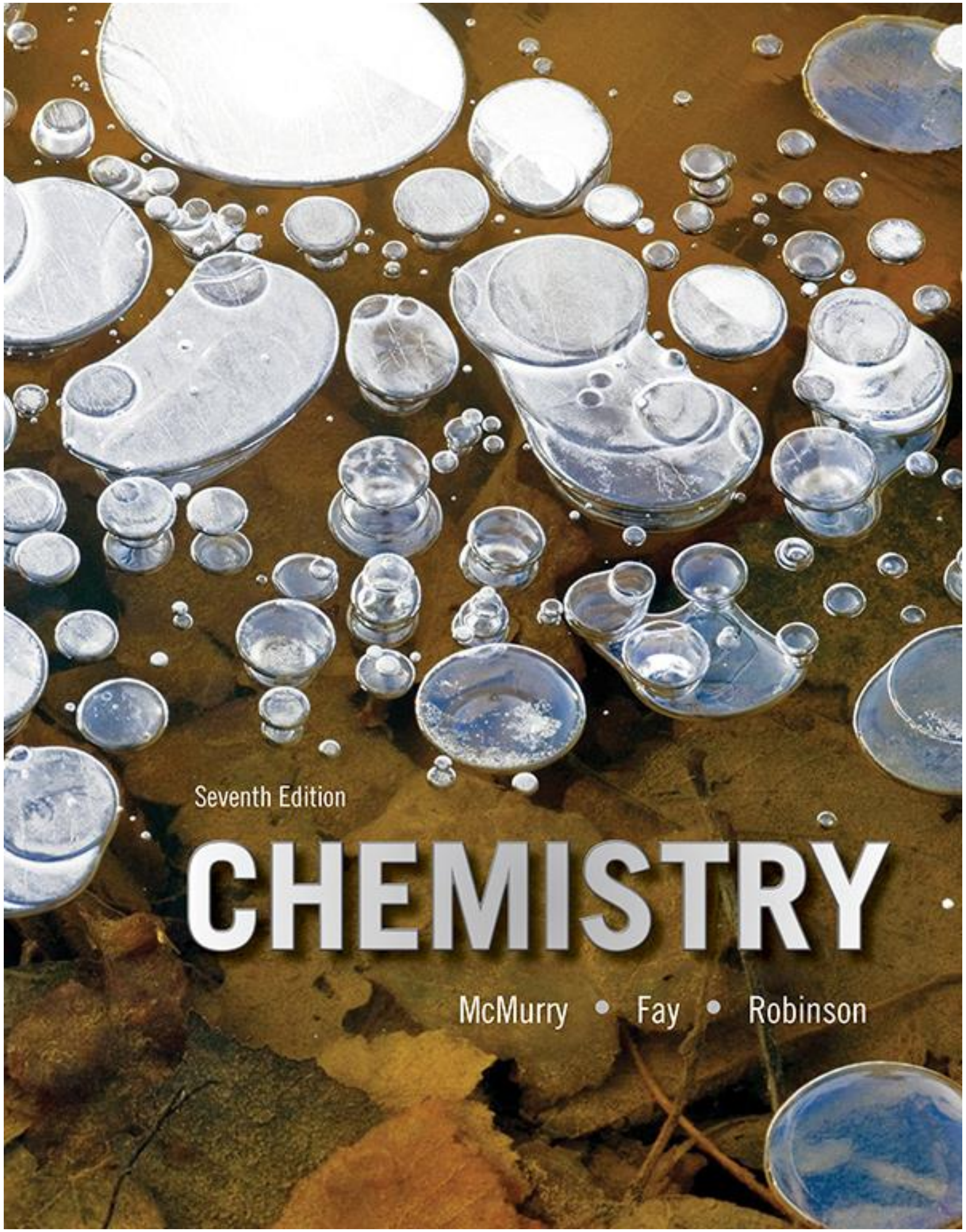


Lecture Presentation

Chapter 15 Aqueous Equilibria: Acids and Bases

HW: 15.1, 15.2, 15.5, 15.11, 15.15, 15.16, 15.17, 15.19, 15.20, 15.23, 15.24, 15.25

John E. McMurry
Robert C. Fay

Acid-Base Concepts: The Brønsted-Lowry Theory

Arrhenius Acid: dissociates in water to produce hydrogen ions, H^+

$$HA(aq) \rightleftharpoons H^+(aq) + A^-(aq)$$

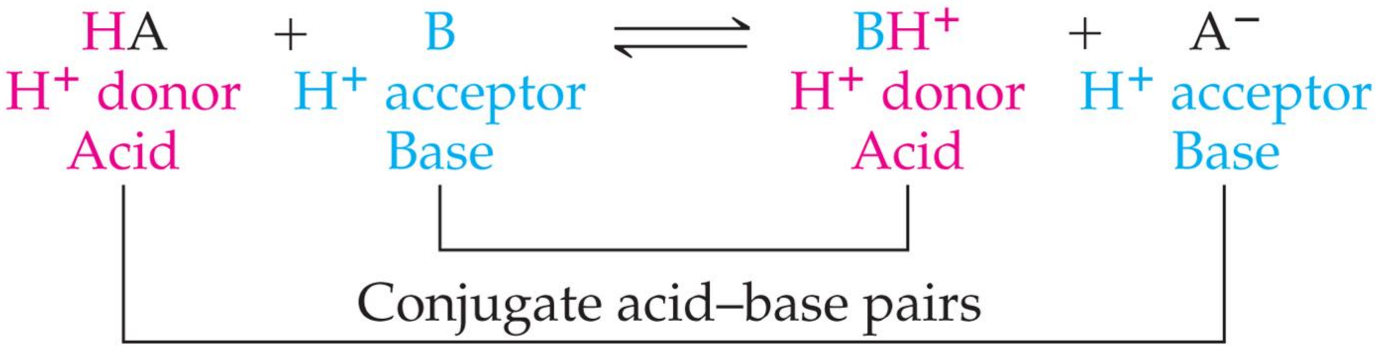
Arrhenius Base: dissociates in water to produce hydroxide ions, OH^-

$$MOH(aq) \rightleftharpoons M^+(aq) + OH^-(aq)$$

Acid-Base Concepts: The Brønsted-Lowry Theory

Brønsted-Lowry Acid: can transfer hydrogen ions, H^+. In other words, a proton donor

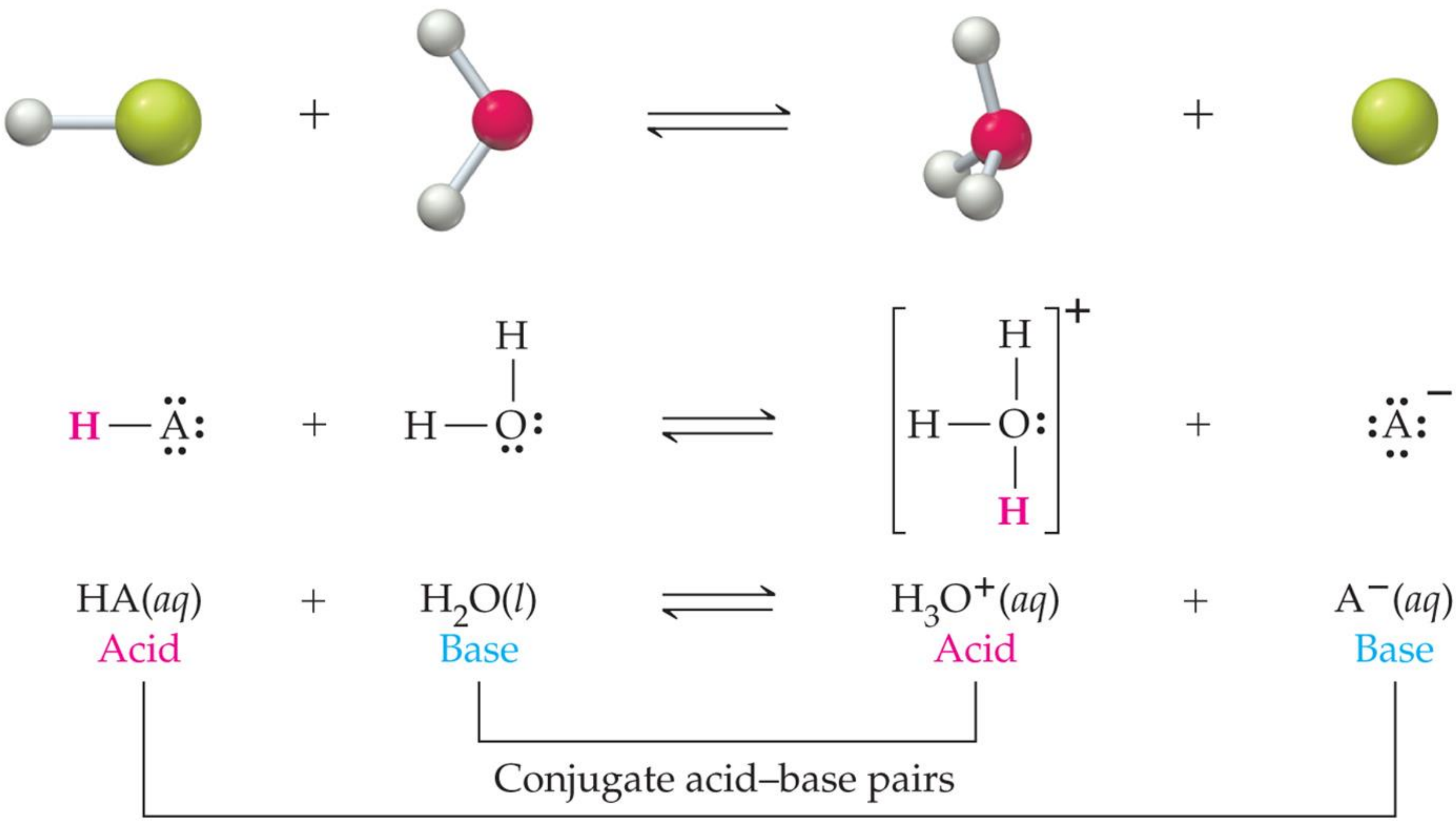
Brønsted-Lowry Base: can accept hydrogen ions, H^+. In other words, a proton acceptor



Conjugate Acid-Base Pairs: Chemical species whose formulas differ only by one hydrogen ion, H^+

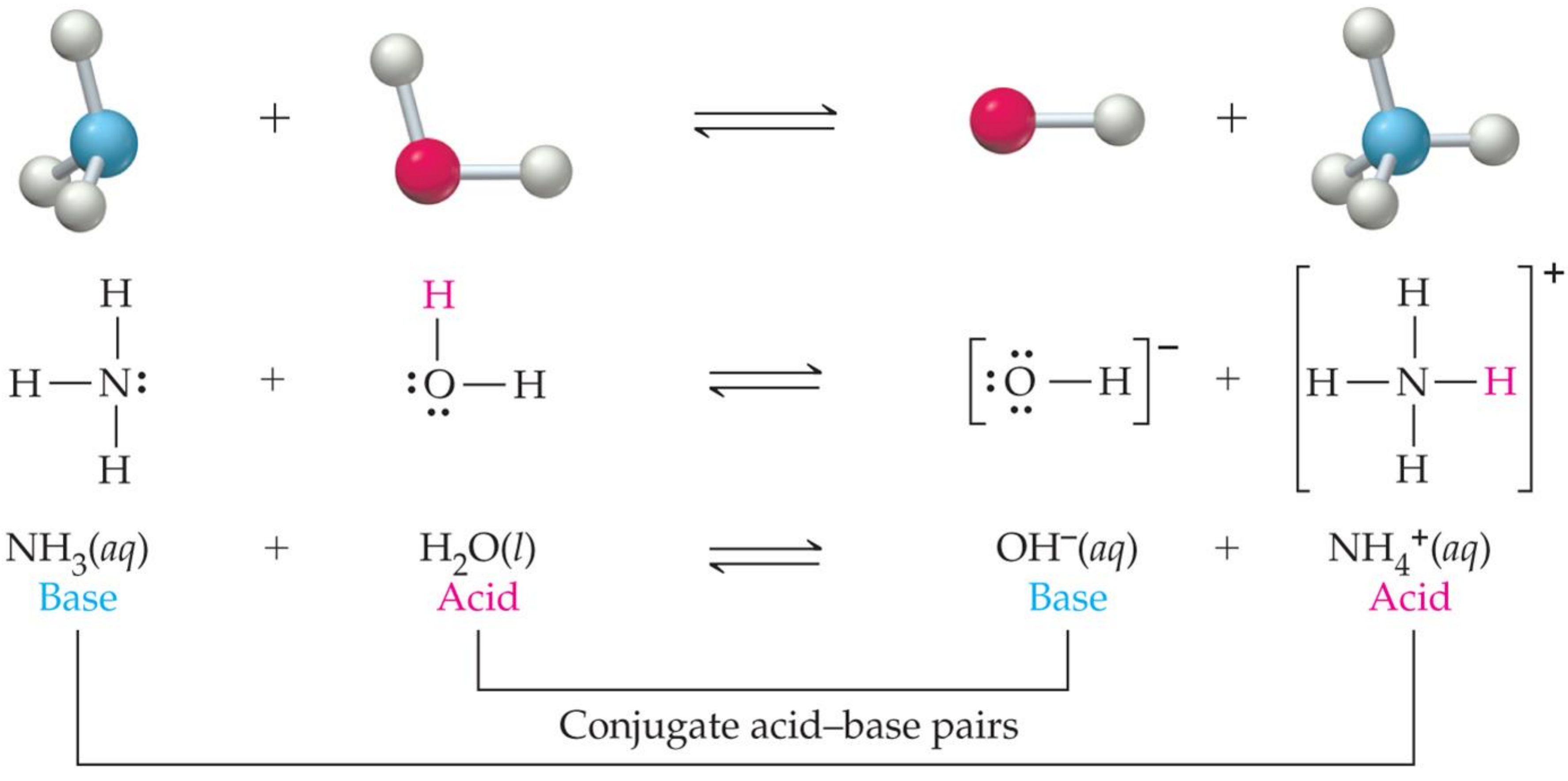
Acid-Base Concepts: The Brønsted-Lowry Theory (proton donor / acceptor)

Acid-Dissociation Equilibrium



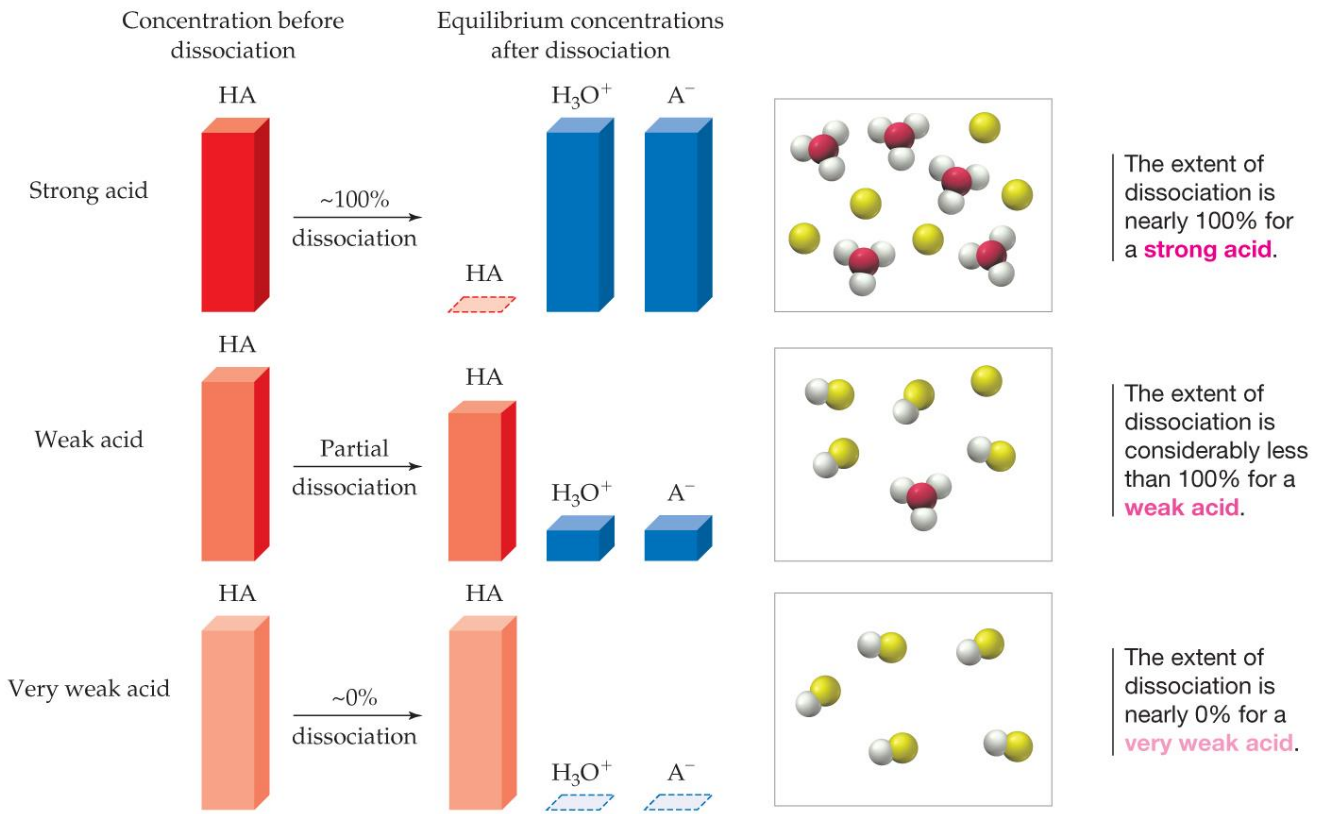
Acid-Base Concepts: The Brønsted-Lowry Theory (proton donor / acceptor)

Base-Dissociation Equilibrium



Acid Strength and Base Strength

Weak Acid: An acid that is only partially dissociated in water and is thus a weak electrolyte



Acid Strength and Base Strength

Should know strong & weak acids circled.

TABLE 15.1 Relative Strengths of Conjugate Acid–Base Pairs

	Acid, HA		Base, A^-		
Stronger acid	$HClO_4$	**Strong acids:** 100% dissociated in aqueous solution.	ClO_4^-	**Very weak bases:** Negligible tendency to be protonated in aqueous solution.	Weaker base
	HCl		Cl^-		
	H_2SO_4		HSO_4^-		
	HNO_3		NO_3^-		
	H_3O^+		H_2O		
	HSO_4^-	**Weak acids:** Exist in solution as a mixture of HA, A^-, and H_3O^+.	SO_4^{2-}	**Weak bases:** Moderate tendency to be protonated in aqueous solution.	
	H_3PO_4		$H_2PO_4^-$		
	HNO_2		NO_2^-		
	HF		F^-		
	CH_3CO_2H		$CH_3CO_2^-$		
	H_2CO_3		HCO_3^-		
	H_2S		HS^-		
	NH_4^+		NH_3		
	HCN		CN^-		
	HCO_3^-		CO_3^{2-}		
	H_2O		OH^-		
	NH_3	**Very weak acids:** Negligible tendency to dissociate.	NH_2^-	**Strong bases:** 100% protonated in aqueous solution.	
	OH^-		O^{2-}		
Weaker acid	H_2		H^-		Stronger base

HW 15.1: Acid-Base Concepts: Arrhenius & Brønsted-Lowry Theory (conjugate acid/base)

Given the following equation of acid/base dissociation. Give the Acid/Conjugate Base, Base/Conjugate Acid pairs.

a. $H\ NO_3 + H_2O \rightarrow NO_3^- + H_3O^+$

Acid ___________ Conjugate Base __________
Base ___________ Conjugate Acid ____________

b. $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$

Base _____________ Conjugate Acid ___________
Acid ______________ Conjugate Base __________

c. $H\ NO_3 + NaOH \rightarrow Na\ NO_3 + H_2O$

Acid __________ Conjugate Base _________
Base __________ Conjugate Acid ___________

Do this HW by emailing the answer in the text of your email instead of taking a photo of your answer on paper.

HW 15.1: Acid-Base Concepts: Arrhenius & Brønsted-Lowry Theory (conjugate acid/base)

Given the following equation of acid/base dissociation. Give the Acid/Conjugate Base, Base/Conjugate Acid pairs.

$H NO_3 + H_2O \rightarrow NO_3^- + H_3O^+$

Acid $H NO_3$ Conjugate Base NO_3^-
Base H_2O Conjugate Acid H_3O^+

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

Base NH_3 Conjugate Acid NH_4^+
Acid H_2O Conjugate Base OH^-

$H NO_3 + NaOH \rightarrow Na NO_3 + H_2O$

Acid $H NO_3$ Conjugate Base NO_3^-
Base $NaOH$ Conjugate Acid H_2O

Do this HW by emailing the answer in the text of your email instead of taking a photo of your answer on paper.

Hydrated Protons and Hydronium Ions

$$HA(aq) \rightleftharpoons H^+(aq) + A^-(aq)$$

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

same

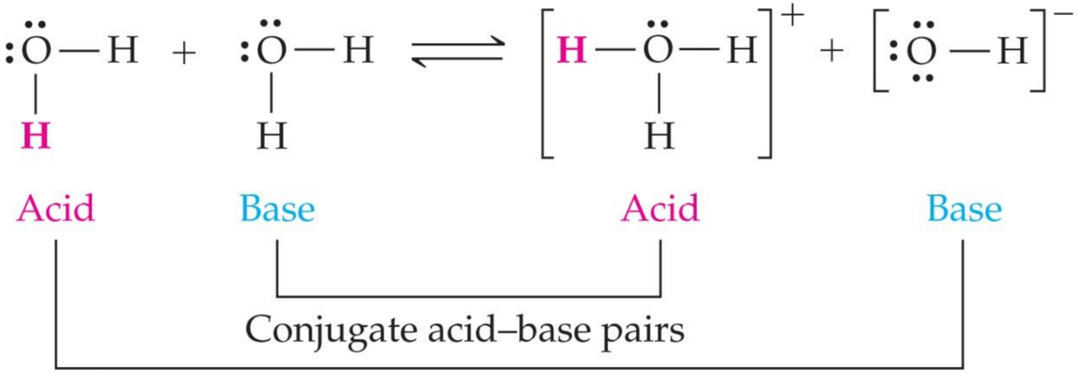
Due to high reactivity of the hydrogen ion, it is actually hydrated by one or more water molecules.

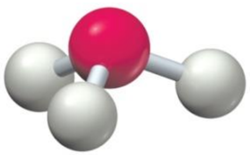
$$[H(H_2O)_n]^+ \begin{cases} n = 1 & H_3O^+ \\ n = 2 & H_5O_2^+ \\ n = 3 & H_7O_3^+ \\ n = 4 & H_9O_4^+ \end{cases}$$

For our purposes, H^+ is equivalent to H_3O^+.

Dissociation of Water

K_w equilibrium is present for water with acid or base added.





The hydronium ion, H_3O^+

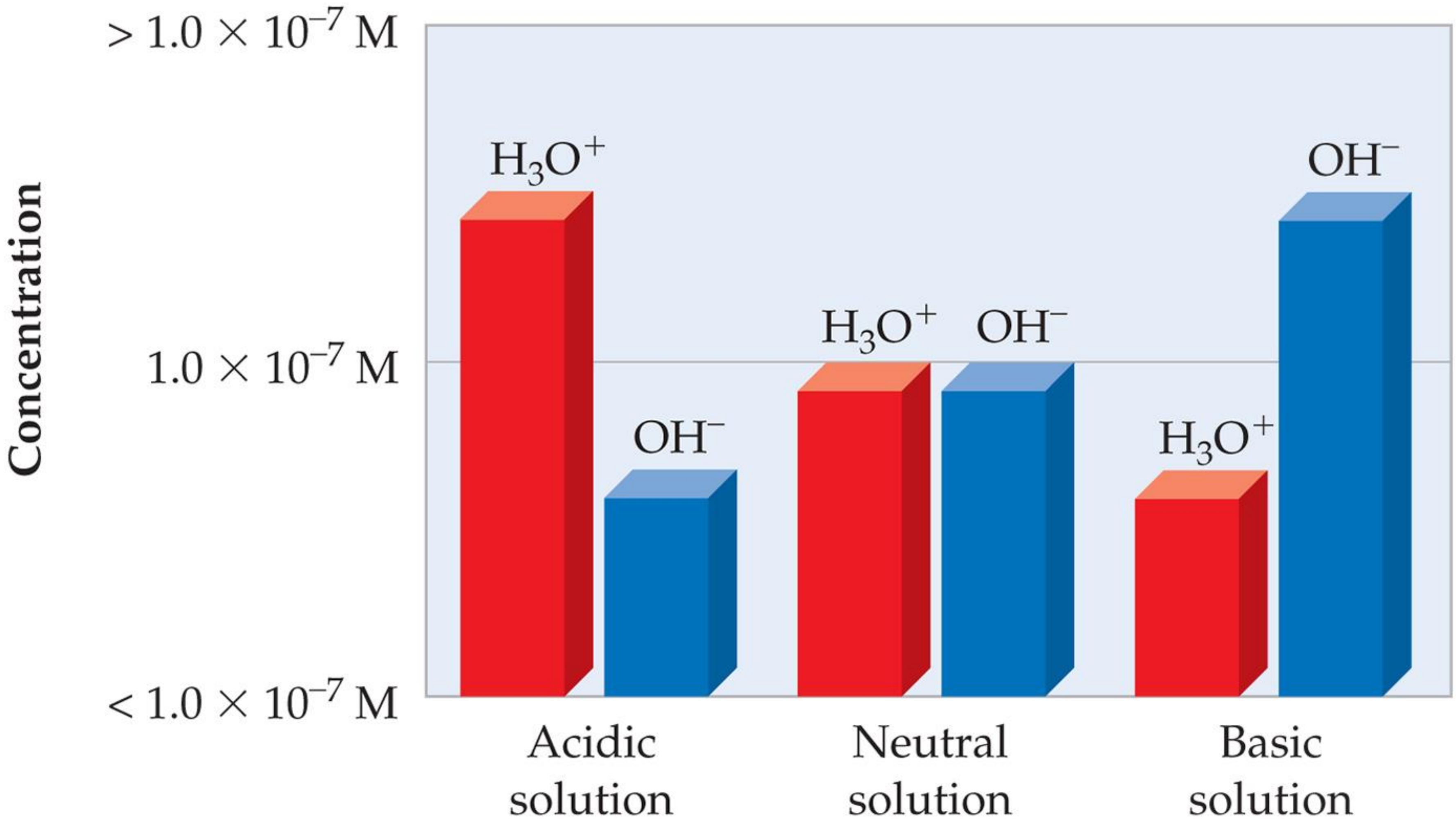
Dissociation of Water: $2\ H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

Ion-Product Constant for Water: $K_w = [H_3O^+][OH^-]$

at 25 ºC: $[H_3O^+] = [OH^-] = 1.0 \times 10^{-7}\ M$

$K_w = (1.0 \times 10^{-7})(1.0 \times 10^{-7}) = \mathbf{1.0 \times 10^{-14}}$

Dissociation of Water



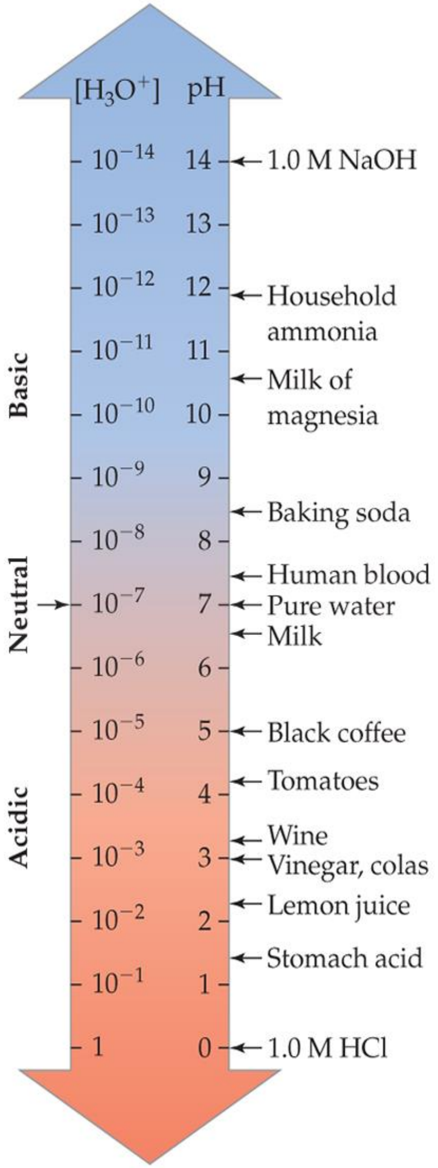
Dissociation of Water

Acidic: $[H_3O^+] > [OH^-]$

Neutral: $[H_3O^+] = [OH^-]$

Basic: $[H_3O^+] < [OH^-]$

The pH Scale



$pH = -\log[H_3O^+]$ $[H_3O^+] = 10^{-pH}$

antilog

Acidic: $pH < 7$

Neutral: $pH = 7$

Basic: $pH > 7$

Dissociation of Water

$$K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$$

$$[H_3O^+] = \frac{1.0 \times 10^{-14}}{[OH^-]} \qquad [OH^-] = \frac{1.0 \times 10^{-14}}{[H_3O^+]}$$

p(anything) = -log (anything)

$pK_w = pH + pOH = 14$

$pH = 14 - pOH$

$pOH = 14 - pH$

The pH Scale

The hydronium ion concentration for lemon juice is approximately 0.0025 M. What is the pH when $[H_3O^+]$ = 0.0025 M?

2 significant figures

$$pH = -\log(0.0025) = 2.60$$

2 decimal places

The pH Scale

Calculate the pH of an aqueous ammonia solution that has an OH^- concentration of 0.0019 M.

$$[H_3O^+] = \frac{1.0 \times 10^{-14}}{[OH^{1-}]} = \frac{1.0 \times 10^{-14}}{0.0019} = 5.3 \times 10^{-12}\text{ M}$$

$$pH = -\log(5.3 \times 10^{-12}) = 11.28$$

OR pOH = - log (0.0019) = -(-2.72)

pKw = 14 = pH + pOH (14 has infinite sig fig)

14 = pH + 2.72

pH = 11.28

The pH Scale

Acid rain is a matter of serious concern because most species of fish die in waters having a pH lower than 4.5–5.0. Calculate $[H_3O^+]$ in a lake that has a pH of 4.5.

$$[H_3O^+] = 10^{-4.5} = 3 \times 10^{-5}\ M$$

$pH = 4.5 = -\log [H_3O^+]$

$-4.5 = \log [H_3O^+]$

$[H_3O^+] = \text{antilog}\ (-4.5)$

antilog = 10^x in most calculators

The pH Scale Equations

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

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

$$pK_w = -\log K_w$$

$$K_w = [H^+][OH^-] = 1 \times 10^{-14}$$

$$pK_w = pH + pOH = 14$$

HW 15.2: The pH Scale

(a) What is the pH of a solution of $[H^+] = 2.3 \times 10^{-2}$

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

(b) What is the pOH of a solution of [OH-] = 7.7×10^{-3}

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

End class 3/30 M
A sect, end class
3/31T sect C

(c) What is the pH of the solution in (b) above ?

$pH + pOH = 14$

(d) What is the $[H^+]$ of the solution in (c) above ?

$[H^+]$ = antilog (-pH)

Answer this HW by writing the text of the answer into your email instead of uploading photo.

HW 15.2: The pH Scale

(a) What is the pH of a solution of $[H^+] = 2.3 \times 10^{-2}$

$pH = -\log[H^+] = -\log(2.3 \times 10^{-2}) = -(-1.638) = 1.64$

(b) What is the pOH of a solution of [OH-] = 7.7×10^{-3}

$pOH = -\log[OH^-] = -\log(7.7 \times 10^{-3}) = -(-2.11) – 2.11$

(c) What is the pH of the solution in (b) above ?

$pH + pOH = 14$ $\quad pH + 2.11 = 14$ $\quad pH = 11.9$

(d) What is the $[H^+]$ of the solution in (c) above ?

$[H^+] = \text{antilog}(-pH) = \text{antilog}(-11.9) = 1.26 \times 10^{-12}$

Answer this HW by writing the text of the answer into your email instead of uploading photo.

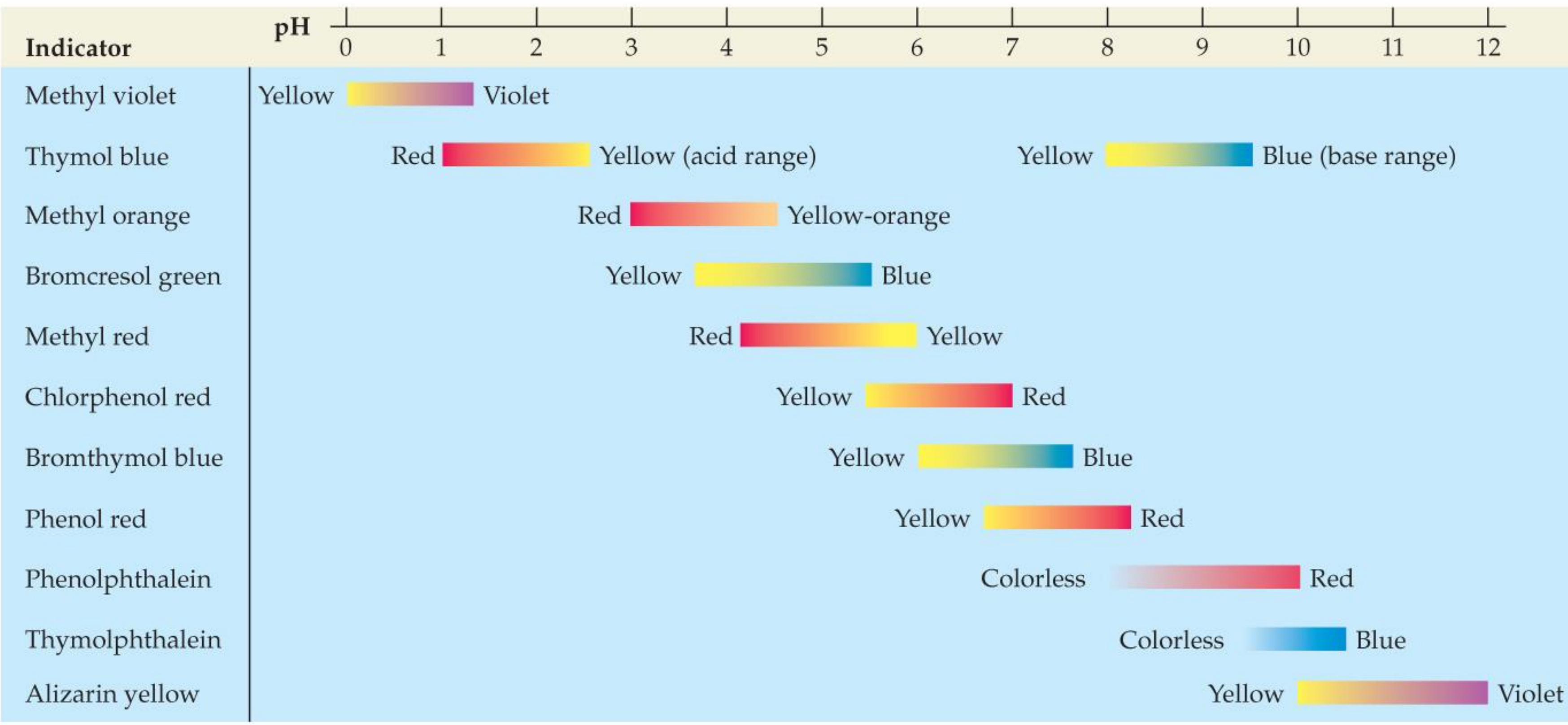
Measuring pH

Acid–Base Indicator: A substance that changes color in a specific pH range. Indicators exhibit pH-dependent color changes because they are weak acids and have different colors in their acid (HIn) and conjugate base (In^-) forms.

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

Color A Color B

Measuring pH



The pH in Solutions of Strong Acids and Strong Bases

Just use concentration of strong acid or base bc dissociates completely.

What is the pH of a 0.025 M solution of HNO_3?

$$HNO_3(aq) + H_2O(l) \xrightarrow{100\%} H_3O^+(aq) + NO_3^-(aq)$$

Since HNO_3 is a strong acid, $[H_3O^+] = [HNO_3]$.

$$pH = -\log([H_3O^+]) = -\log(0.025) = \boxed{1.60}$$

The pH in Solutions of Strong Acids and Strong Bases

Just use concentration of strong acid or base bc dissociates completely.

What is the pH of a 0.025 M solution of NaOH?

$$NaOH(aq) \longrightarrow Na^+(aq) + OH^-(aq)$$

Since NaOH is a strong base, $[OH^-] = [NaOH]$.

$$[H_3O^+] = \frac{1.0 \times 10^{-14}}{[OH^-]} = \frac{1.0 \times 10^{-14}}{0.025} = 4.0 \times 10^{-13} \text{ M}$$

$$pH = -\log([H_3O^+]) = -\log(4.0 \times 10^{-13}) = \boxed{12.40}$$

HW 15.3: The pH in Solutions of Strong Acids and Strong Bases

Just use concentration of strong acid or base bc dissociates completely.

a. What is the pH of a 0.025 M solution of HCl ?

b. What is the pH of a solution of 0.150 M solution of $NaOH$?

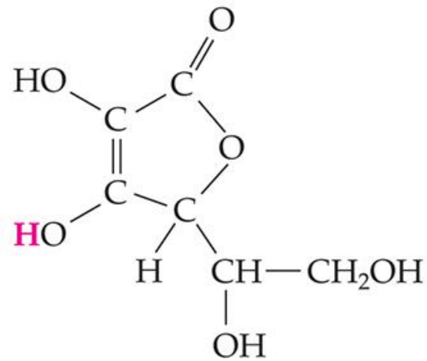
Answer this HW by writing the text of the answer into your email instead of uploading photo.

Equilibria in Solutions of Weak Acids

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

Acid-Dissociation Constant: $K_a = \dfrac{[H_3O^+][A^-]}{[HA]}$

For Weak Acids and Weak Bases –
MUST USE K_a / K_b

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
	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
	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 red.

† $pK_a = -\log K_a$.

Equilibria in Solutions of Weak Acids

The pH of 0.250 M HF is 2.036. What are the values of K_a and pK_a for hydrofluoric acid?

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

0.250		≈0	0
$-x$		$+x$	$+x$
$0.250 - x$		x	x

$$x = [H_3O^+] = 10^{-2.036} = 0.00920 \text{ M}$$

Equilibria in Solutions of Weak Acids

$$K_a = \frac{[H_3O^+][F^-]}{[HF]}$$

$$[F^-] = [H_3O^+] = 0.00920 \text{ M}$$

$$[HF] = 0.250 - x = 0.250 - 0.00920 = 0.241 \text{ M}$$

$$K_a = \frac{[H_3O^+][F^-]}{[HF]} = \frac{(0.00920)(0.00920)}{0.241} = \boxed{3.51 \times 10^{-4}}$$

$$pK_a = -\log(K_a) = -\log(3.51 \times 10^{-4}) = \boxed{3.455}$$

HW 15.4: Calculating Equilibrium Concentrations of Weak Acids

Calculate the pH of a 0.10 M HCN solution. At 25 °C, $K_a = 4.9 \times 10^{-10}$.

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

$$K_a = \frac{[H_3O^+][CN^-]}{[HCN]}$$

Polyprotic Acids – omit section 15.11

$$H_2CO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HCO_3^-(aq)$$

$$K_{a1} = \frac{[H_3O^+]\,[HCO_3^-]}{[H_2CO_3]} = 4.3 \times 10^{-7}$$

$$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CO_3^{2-}(aq)$$

$$K_{a2} = \frac{[H_3O^+]\,[CO_3^{2-}]}{[HCO_3^-]} = 5.6 \times 10^{-11}$$

Equilibria in Solutions of Weak Bases

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

Base Acid Acid Base

Base-Dissociation Constant: $K_b = \dfrac{[BH^+][OH^-]}{[B]}$

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

$$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$$

End 4/1 Wed A sect

END QUIZ 7

QUIZ 7 ENDS HERE

Equilibria in Solutions of Weak Bases

TABLE 15.4 K_b Values for Some Weak Bases and K_a Values for Their Conjugate Acids at 25 °C

Base	Formula, B	K_b	Conjugate Acid, BH^+	K_a
Ammonia	NH_3	1.8×10^{-5}	NH_4^+	5.6×10^{-10}
Aniline	$C_6H_5NH_2$	4.3×10^{-10}	$C_6H_5NH_3^+$	2.3×10^{-5}
Dimethylamine	$(CH_3)_2NH$	5.4×10^{-4}	$(CH_3)_2NH_2^+$	1.9×10^{-11}
Hydrazine	N_2H_4	8.9×10^{-7}	$N_2H_5^+$	1.1×10^{-8}
Hydroxylamine	NH_2OH	9.1×10^{-9}	NH_3OH^+	1.1×10^{-6}
Methylamine	CH_3NH_2	3.7×10^{-4}	$CH_3NH_3^+$	2.7×10^{-11}

Equilibria in Solutions of Weak Bases

Calculate the pH of a 0.40 M NH_3 solution. At 25 °C, $K_b = 1.8 \times 10^{-5}$.

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

0.40		0	≈0
$-x$		$+x$	$+x$
$0.40 - x$		x	x

$$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$$

Equilibria in Solutions of Weak Bases

$$1.8 \times 10^{-5} = \frac{(x)(x)}{(0.40 - x)} \approx \frac{x^2}{0.40}$$

End 4/1 Wed,
C section

$$x = [OH^-] = 0.0027 \text{ M}$$

$$[H_3O^+] = \frac{1.0 \times 10^{-14}}{0.0027} = 3.7 \times 10^{-12} \text{ M}$$

$$\text{pH} = -\log([H_3O^+]) = -\log(3.7 \times 10^{-12}) = \boxed{11.43}$$