Lecture 4

Salts, Polyprotic Acids, Oxides

Lecture Room for Next Week

There is a conference in Noyes Lab next week, so we have been kicked out of 100 Noyes Lab for the 1 pm lecture. The room for lecture next week is 144 Loomis.

Figure 14.6: The pH Scale and pH Values of Some Common Substances (p. 84)

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

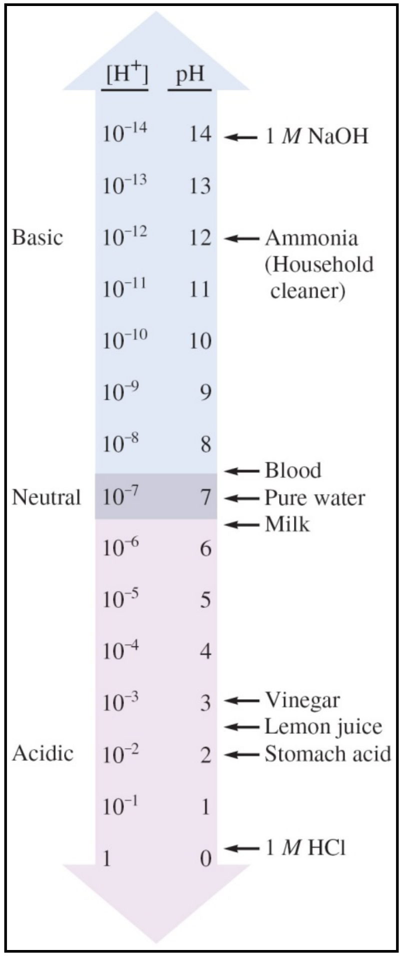
$K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$

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

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

$pH + pOH = 14.00$

Acids add H^+ to water.
An acidic solution has:
large $[H^+]$, so small $[OH^-]$
low pH, so high pOH



Bases add OH^- to water.
A basic solution has:
large $[OH^-]$, so small $[H^+]$
low pOH, so high pH

Values for K_b for Some Common Weak Bases (p. 81)

Table 14.3 ▶ Values of K_b for Some Common Weak Bases

Name	Formula	Conjugate Acid	K_b
Ammonia	NH_3	NH_4^+	1.8×10^{-5}
Methylamine	CH_3NH_2	$CH_3NH_3^+$	4.38×10^{-4}
Ethylamine	$C_2H_5NH_2$	$C_2H_5NH_3^+$	5.6×10^{-4}
Aniline	$C_6H_5NH_2$	$C_6H_5NH_3^+$	3.8×10^{-10}
Pyridine	C_5H_5N	$C_5H_5NH^+$	1.7×10^{-9}

Example K_b reaction for C_5H_5N, $K_b = 1.7 \times 10^{-9}$:

$$C_5H_5N(aq) + H_2O(l) \leftrightarrow OH^-(aq) + C_5H_5NH^+(aq)$$

Values for K_a for Some Common Monoprotic Acids (p. 81)

Table 14.2 ▶ Values of K_a for Some Common Monoprotic Acids

Formula	Name	Value of K_a*
HSO_4^-	Hydrogen sulfate ion	1.2×10^{-2}
$HClO_2$	Chlorous acid	1.2×10^{-2}
$HC_2H_2ClO_2$	Monochloracetic acid	1.35×10^{-3}
HF	Hydrofluoric acid	7.2×10^{-4}
HNO_2	Nitrous acid	4.0×10^{-4}
$HC_2H_3O_2$	Acetic acid	1.8×10^{-5}
$[Al(H_2O)_6]^{3+}$	Hydrated aluminum(III) ion	1.4×10^{-5}
HOCl	Hypochlorous acid	3.5×10^{-8}
HCN	Hydrocyanic acid	6.2×10^{-10}
NH_4^+	Ammonium ion	5.6×10^{-10}
HOC_6H_5	Phenol	1.6×10^{-10}

↑ Increasing acid strength

Example K_a reaction for HNO_2, $K_a = 4.0 \times 10^{-4}$:

$$HNO_2(aq) + H_2O(l) \leftrightarrow H_3O^+(aq) + NO_2^-(aq)$$

or:

$$HNO_2(aq) \leftrightarrow H^+(aq) + NO_2^-(aq)$$

Calculating the pH of Salt Solutions (p. 92)

Calculate the pH of the following solutions:

A. 0.20 M NaF

B. 0.15 M NH_4NO_3

C. 0.78 M $CaCl_2$

Given:

K_a for HF = 7.2×10^{-4}

K_b for NH_3 = 1.8×10^{-5}

pH of Salt Solutions – pH of Conjugate Acids and Conjugate Bases

Conjugate acid-base pairs: pairs of substances that only differ by a proton (H^+) in their formulas, e.g., HCl and Cl^- or NH_4^+ and NH_3.

For all conjugate acid-base pairs:

$K_a \times K_b = K_w$ (At 25^{o}C, $K_w = 1.0 \times 10^{-14}$)

Acids and Conjugate Bases (p. 84)

K_a	Acid	Conjugate Base	K_b
~10^{-3}	HF		
~10^{-5}	$HC_2H_3O_2$		
~10^{-11}	HOI		

For all conjugate acid-base pairs, $K_a \times K_b = K_w = 1.0 \times 10^{-14}$. Use it to fill in the table.

Bases and Conjugate Acids (p. 84)

K_b	Base	Conjugate Acid	K_a
~10^{-5}	NH_3		
~10^{-8}	$HONH_2$		
~10^{-10}	$C_6H_5NH_2$		

For all conjugate acid-base pairs, $K_a \times K_b = K_w = 1.0 \times 10^{-14}$. Use it to fill in the table.

Acids and Conjugate Bases

K_a	Acid	Conjugate Base	$K_b = K_w/K_a$ $K_b = 10^{-14}/K_a$
$\sim 10^{-3}$	HF	F^-	$\sim 10^{-11}$
$\sim 10^{-5}$	$HC_2H_3O_2$	$C_2H_3O_2^-$	$\sim 10^{-9}$
$\sim 10^{-11}$	HOI	OI^-	$\sim 10^{-3}$

The conjugate base of a weak acid is a weak base.
The weaker the acid, the stronger the conjugate base.

Values for K_a for Some Common Monoprotic Acids (p. 81)

Table 14.2 ▶ Values of K_a for Some Common Monoprotic Acids

Formula	Name	Value of K_a*
HSO_4^-	Hydrogen sulfate ion	1.2×10^{-2}
$HClO_2$	Chlorous acid	1.2×10^{-2}
$HC_2H_2ClO_2$	Monochloracetic acid	1.35×10^{-3}
HF	Hydrofluoric acid	7.2×10^{-4}
HNO_2	Nitrous acid	4.0×10^{-4}
$HC_2H_3O_2$	Acetic acid	1.8×10^{-5}
$[Al(H_2O)_6]^{3+}$	Hydrated aluminum(III) ion	1.4×10^{-5}
HOCl	Hypochlorous acid	3.5×10^{-8}
HCN	Hydrocyanic acid	6.2×10^{-10}
NH_4^+	Ammonium ion	5.6×10^{-10}
HOC_6H_5	Phenol	1.6×10^{-10}

↑ Increasing acid strength

Example K_a reaction for HNO_2, $K_a = 4.0 \times 10^{-4}$:

$$HNO_2(aq) + H_2O(l) \leftrightarrow H_3O^+(aq) + NO_2^-(aq)$$

or:

$$HNO_2(aq) \leftrightarrow H^+(aq) + NO_2^-(aq)$$

Bases and Conjugate Acids

K_b	Base	Conjugate Acid	$K_a = K_w/K_b$ $K_a = 10^{-14}/K_b$
$\sim 10^{-5}$	NH_3	NH_4^+	$\sim 10^{-9}$
$\sim 10^{-8}$	$HONH_2$	$HONH_3^+$	$\sim 10^{-6}$
$\sim 10^{-10}$	$C_6H_5NH_2$	$C_6H_5NH_3^+$	$\sim 10^{-4}$

The conjugate acid of a weak base is a weak acid.
The weaker the base, the stronger the conjugate acid.

Values for K_b for Some Common Weak Bases (p. 81)

Table 14.3 ▶ Values of K_b for Some Common Weak Bases

Name	Formula	Conjugate Acid	K_b
Ammonia	NH_3	NH_4^+	1.8×10^{-5}
Methylamine	CH_3NH_2	$CH_3NH_3^+$	4.38×10^{-4}
Ethylamine	$C_2H_5NH_2$	$C_2H_5NH_3^+$	5.6×10^{-4}
Aniline	$C_6H_5NH_2$	$C_6H_5NH_3^+$	3.8×10^{-10}
Pyridine	C_5H_5N	$C_5H_5NH^+$	1.7×10^{-9}

Example K_b reaction for C_5H_5N, $K_b = 1.7 \times 10^{-9}$:

$$C_5H_5N(aq) + H_2O(l) \leftrightarrow OH^-(aq) + C_5H_5NH^+(aq)$$

Lecture Question (p. 94a)

Consider the following solutions:

0.20 M NaF, 0.15 M NH_4NO_3, 0.78 M $CaCl_2$

Place these solutions in order of increasing pH.

a. NaF < NH_4NO_3 < $CaCl_2$

b. NaF < $CaCl_2$ < NH_4NO_3

c. NH_4NO_3 < $CaCl_2$ < NaF

d. NH_4NO_3 < NaF < $CaCl_2$

e. $CaCl_2$ < NaF < NH_4NO_3

Hint: Weak gives you weak and strong gives you garbage.

Lecture Question

Consider the following solutions:

0.20 M NaF, 0.15 M NH_4NO_3, 0.78 M $CaCl_2$

Place these solutions in order of increasing pH.

a. NaF < NH_4NO_3 < $CaCl_2$

b. NaF < $CaCl_2$ < NH_4NO_3

c. NH_4NO_3 < $CaCl_2$ < NaF

acidic neutral basic

d. NH_4NO_3 < NaF < $CaCl_2$

e. $CaCl_2$ < NaF < NH_4NO_3

Hint: Weak gives you weak and strong gives you garbage.

Question (p. 94a)

Are the following salts acidic, basic, or neutral?

$NH_4C_2H_3O_2$

$HONH_3OI$

$C_6H_5NH_3F$

Values for K_b for Some Common Weak Bases (p. 81)

Table 14.3 ▶ Values of K_b for Some Common Weak Bases

Name	Formula	Conjugate Acid	K_b
Ammonia	NH_3	NH_4^+	1.8×10^{-5}
Methylamine	CH_3NH_2	$CH_3NH_3^+$	4.38×10^{-4}
Ethylamine	$C_2H_5NH_2$	$C_2H_5NH_3^+$	5.6×10^{-4}
Aniline	$C_6H_5NH_2$	$C_6H_5NH_3^+$	3.8×10^{-10}
Pyridine	C_5H_5N	$C_5H_5NH^+$	1.7×10^{-9}

Example K_b reaction for C_5H_5N, $K_b = 1.7 \times 10^{-9}$:

$$C_5H_5N(aq) \quad + \quad H_2O(l) \leftrightarrow \quad OH^-(aq) \quad + \quad C_5H_5NH^+(aq)$$

From Appendix A5.3, $HONH_2$ has $K_b = 1.1 \times 10^{-8}$.

Values for K_a for Some Common Monoprotic Acids (p. 81)

Table 14.2 ▶ Values of K_a for Some Common Monoprotic Acids

Formula	Name	Value of K_a*
HSO_4^-	Hydrogen sulfate ion	1.2×10^{-2}
$HClO_2$	Chlorous acid	1.2×10^{-2}
$HC_2H_2ClO_2$	Monochloracetic acid	1.35×10^{-3}
HF	Hydrofluoric acid	7.2×10^{-4}
HNO_2	Nitrous acid	4.0×10^{-4}
$HC_2H_3O_2$	Acetic acid	1.8×10^{-5}
$[Al(H_2O)_6]^{3+}$	Hydrated aluminum(III) ion	1.4×10^{-5}
$HOCl$	Hypochlorous acid	3.5×10^{-8}
HCN	Hydrocyanic acid	6.2×10^{-10}
NH_4^+	Ammonium ion	5.6×10^{-10}
HOC_6H_5	Phenol	1.6×10^{-10}

↑ Increasing acid strength

Example K_a reaction for HNO_2, $K_a = 4.0 \times 10^{-4}$:

$$HNO_2(aq) + H_2O(l) \leftrightarrow H_3O^+(aq) + NO_2^-(aq)$$

or: $$HNO_2(aq) \leftrightarrow H^+(aq) + NO_2^-(aq)$$

From Appendix A5.2, HOI has $K_b = 2 \times 10^{-11}$.

Question

Are the following salts acidic, basic, or neutral?

$NH_4C_2H_3O_2 \rightarrow NH_4^+ + C_2H_3O_2^-$

wk acid + wk base

$HONH_3OI \rightarrow HONH_3^+ + OI^-$

wk acid + wk base

$C_6H_5NH_3F \rightarrow C_6H_5NH_3^+ + F^-$

wk acid + wk base

Qualitative Prediction of pH for Solutions of Salts for Which Both Cation and Anion Have Acidic or Basic Properties

Table 14.5 ▶ Qualitative Prediction of pH for Solutions of Salts for Which Both Cation and Anion Have Acidic or Basic Properties

$K_a > K_b$	pH < 7 (acidic)
$K_b > K_a$	pH > 7 (basic)
$K_a = K_b$	pH $= 7$ (neutral)

Question

Are the following salts acidic, basic, or neutral?

$NH_4C_2H_3O_2 \rightarrow NH_4^+ + C_2H_3O_2^-$

wk acid + wk base

$HONH_3OI \rightarrow HONH_3^+ + OI^-$

wk acid + wk base

$C_6H_5NH_3F \rightarrow C_6H_5NH_3^+ + F^-$

wk acid + wk base

Bases and Conjugate Acids

K_b	Base	Conjugate Acid	$K_a = K_w/K_b$ $K_a = 10^{-14}/K_b$
$\sim 10^{-5}$	NH_3	NH_4^+	$\sim 10^{-9}$
$\sim 10^{-8}$	$HONH_2$	$HONH_3^+$	$\sim 10^{-6}$
$\sim 10^{-10}$	$C_6H_5NH_2$	$C_6H_5NH_3^+$	$\sim 10^{-4}$

The conjugate acid of a weak base is a weak acid.
The weaker the base, the stronger the conjugate acid.

Acids and Conjugate Bases

K_a	Acid	Conjugate Base	$K_b = K_w/K_a$ $K_b = 10^{-14}/K_a$
$\sim10^{-3}$	HF	F^-	$\sim10^{-11}$
$\sim10^{-5}$	$HC_2H_3O_2$	$C_2H_3O_2^-$	$\sim10^{-9}$
$\sim10^{-11}$	HOI	OI^-	$\sim10^{-3}$

The conjugate base of a weak acid is a weak base.
The weaker the acid, the stronger the conjugate base.

Question (p. 94a)

Are the following salts acidic, basic, or neutral?

$NH_4C_2H_3O_2 \rightarrow NH_4^+ + C_2H_3O_2^-$ pH=7.0 (K_a=K_b)

$K_a \sim 10^{-10}$ $K_b \sim 10^{-10}$

$HONH_3OI \rightarrow HONH_3^+ + OI^-$ pH>7.0 (K_b>K_a)

$K_a \sim 10^{-6}$ $K_b \sim 10^{-3}$

$C_6H_5NH_3F \rightarrow C_6H_5NH_3^+ + F^-$ pH<7.0 (K_a>K_b)

$K_a \sim 10^{-4}$ $K_b \sim 10^{-11}$

Calculating the pH of Salt Solutions (p. 92)

Calculate the pH of the following solutions:

A. 0.20 M NaF

B. 0.15 M NH_4NO_3

C. 0.78 M $CaCl_2$

Given:

K_a for HF = 7.2×10^{-4}

K_b for NH_3 = 1.8×10^{-5}

Lecture Question on Conjugate Acids and Conjugate Bases-p. 87.5

Consider the K_a and K_b values given at the bottom of p. 87.5. Which of the following statements is false?

a. The pH of a 1.0 *M* NaCl solution will be 7.00.

b. CN^- is a weak base.

c. $C_6H_5NH_3^+$ is a weak acid.

d. A 1.0 *M* solution of NO_2^- will have a higher pH than a 1.0 *M* solution of CN^-.

e. A 1.0 *M* solution of $C_6H_5NH_3^+$ will have a lower pH than a 1.0 *M* solution of NH_4^+ .

Lecture Question on Conjugate Acids and Conjugate Bases

Consider the K_a and K_b values given on the board. Which of the following statements is false?

a. The pH of a 1.0 *M* NaCl solution will be 7.00.

b. CN^- is a weak base.

c. $C_6H_5NH_3^+$ is a weak acid.

d. A 1.0 *M* solution of NO_2^- will have a higher pH than a 1.0 *M* solution of CN^-.

e. A 1.0 *M* solution of $C_6H_5NH_3^+$ will have a lower pH than a 1.0 *M* solution of NH_4^+ .

Stepwise Dissociation Constants for Several Common Polyprotic Acids

Table 14.4 ▶ Stepwise Dissociation Constants for Several Common Polyprotic Acids

Name	Formula	K_{a_1}	K_{a_2}	K_{a_3}
Phosphoric acid	H_3PO_4	7.5×10^{-3}	6.2×10^{-8}	4.8×10^{-13}
Arsenic acid	H_3AsO_4	5×10^{-3}	8×10^{-8}	6×10^{-10}
Carbonic acid	H_2CO_3	4.3×10^{-7}	5.6×10^{-11}	
Sulfuric acid	H_2SO_4	Large	1.2×10^{-2}	
Sulfurous acid	H_2SO_3	1.5×10^{-2}	1.0×10^{-7}	
Hydrosulfuric acid*	H_2S	1.0×10^{-7}	$\sim 10^{-19}$	
Oxalic acid	$H_2C_2O_4$	6.5×10^{-2}	6.1×10^{-5}	
Ascorbic acid (vitamin C)	$H_2C_6H_6O_6$	7.9×10^{-5}	1.6×10^{-12}	

Lecture Question (p. 94a)

Consider a 0.10 M H_2SO_4 solution. What is the correct ordering of species present in this solution from largest to smallest concentration?

a. $H^+ > HSO_4^- > SO_4^{2-}$

b. $HSO_4^- > SO_4^{2-} > H^+$

c. $H^+ > SO_4^{2-} > HSO_4^-$

d. $HSO_4^- > H^+ > SO_4^{2-}$

e. $SO_4^{2-} > H^+ > HSO_4^-$

Lecture Question

Consider a 0.10 M H_2SO_4 solution. What is the correct ordering of species present in this solution from largest to smallest concentration?

a. $H^+ > HSO_4^- > SO_4^{2-}$

b. $HSO_4^- > SO_4^{2-} > H^+$

c. $H^+ > SO_4^{2-} > HSO_4^-$

d. $HSO_4^- > H^+ > SO_4^{2-}$

e. $SO_4^{2-} > H^+ > HSO_4^-$