Lecture 3

Calculating the pH of an Acid or Base in Water

Definitions of Acids and Bases (p. 80)

Acid-base reactions are called proton transfer reactions. In a chemical reaction, H^+ is the symbol for a proton. So acid-base reactions are ones that involve the transfer of a proton (H^+) from one species to another.

Acid = proton (H^+) donor; simple acid = HA

Base = proton (H^+) acceptor; simple base = B

Acids and Bases in Water (p. 80)

General Acid Reaction in Water (K_a reaction):

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

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

General Base Reaction in Water (K_b reaction):

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

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

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

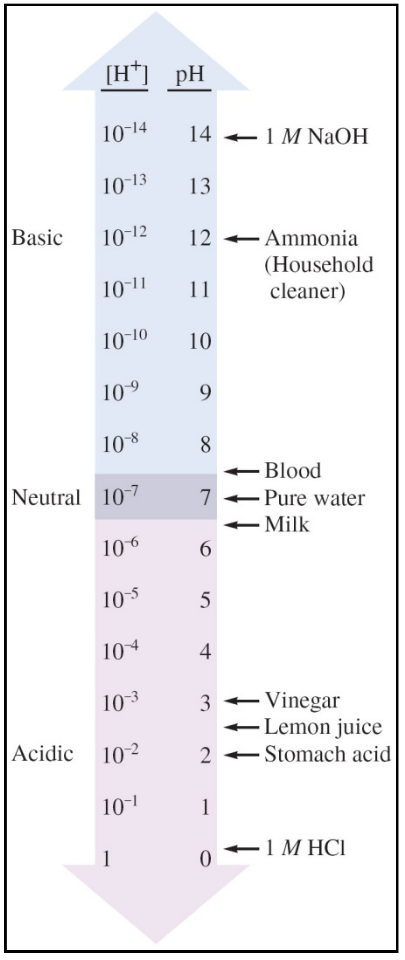
$H_2O(l) \leftrightarrow H^+(aq) + OH^-(aq)$

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

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

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

$pH + pOH = 14.00$



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

$pH + pOH = 14.00$

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

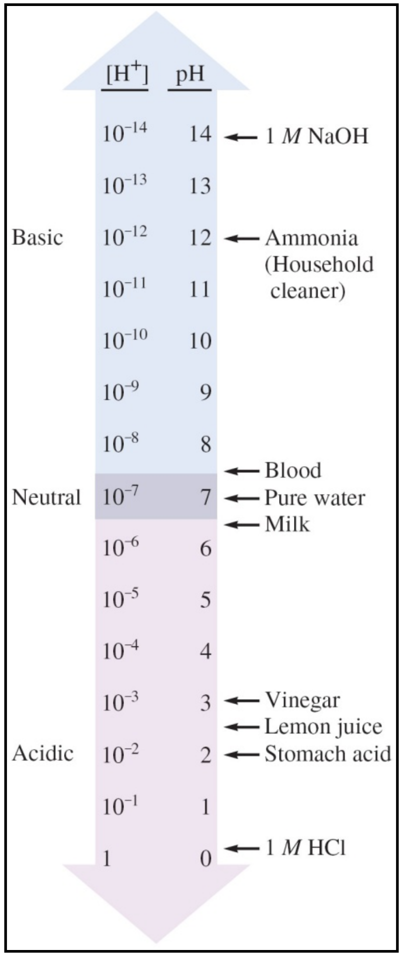

Figure 14.6: The pH Scale and pH Values of Some Common Substances – p. 84

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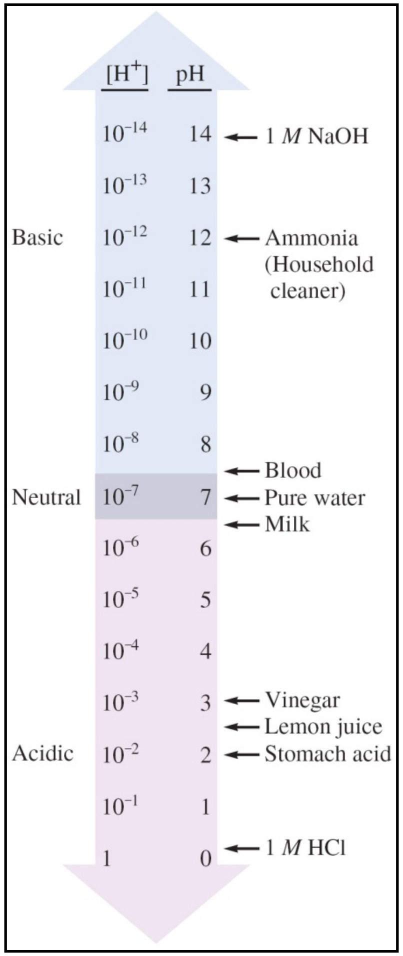


Bases add OH^- to water.
A basic solution has:
large $[OH^-]$, so small $[H^+]$
low pOH, so high pH

Calculating pH of Acids or Bases (p. 88)

A. Calculate the pH of 0.10 *M* HCl.

B. Calculate the pH of 0.10 *M* $HC_2H_3O_2$.

C. Calculate the pH of 0.10 *M* NH_3.

D. Calculate the pH of 0.10 *M* NaOH.

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:

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

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, $K_b = 1.7 \times 10^{-9}$:

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

Calculating pH of Acids or Bases (p. 88)

A. Calculate the pH of 0.10 *M* HCl.

HCl is a strong acid to memorize.

B. Calculate the pH of 0.10 *M* $HC_2H_3O_2$.

$HC_2H_3O_2$ is a weak acid ($K_a = 1.8 \times 10^{-5}$).

C. Calculate the pH of 0.10 *M* NH_3.

NH_3 is a weak base ($K_b = 1.8 \times 10^{-5}$).

D. Calculate the pH of 0.10 *M* NaOH.

NaOH is a strong base to memorize.

Calculating pH of Acids or Bases (p. 88)

$pH = -log[H^+]$

A. Calculate the pH of 0.10 *M* HCl.

HCl is a strong acid to memorize.

B. Calculate the pH of 0.10 *M* $HC_2H_3O_2$.

$HC_2H_3O_2$ is a weak acid ($K_a = 1.8 \times 10^{-5}$).

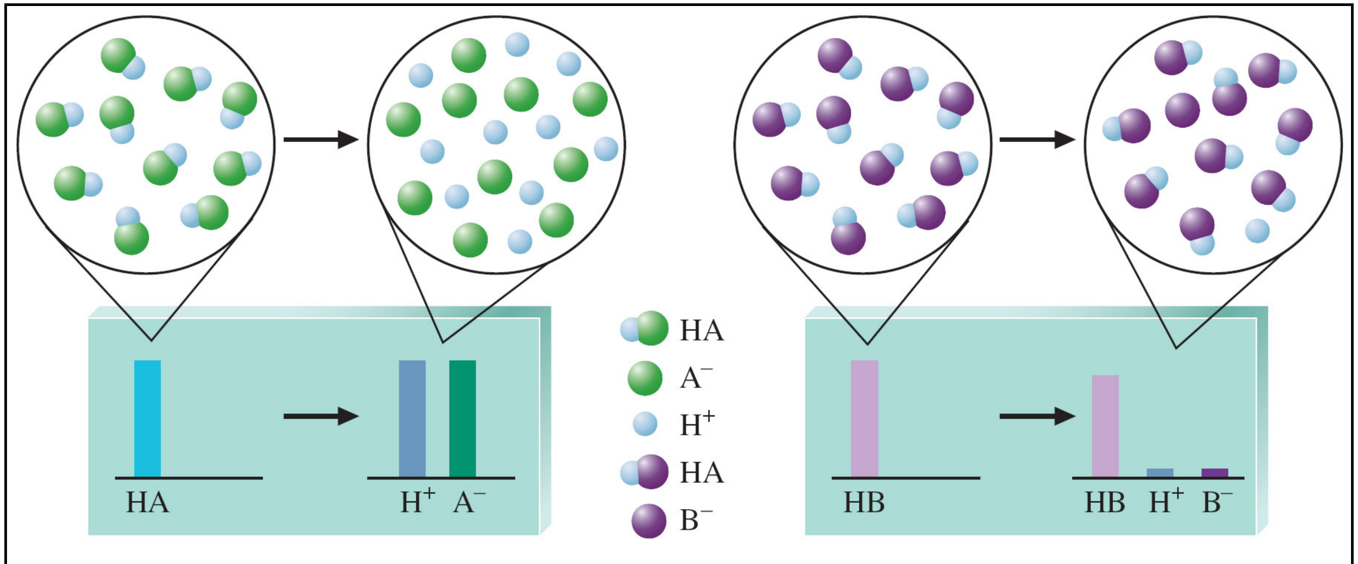
C. Calculate the pH of 0.10 *M* NH_3.

NH_3 is a weak base ($K_b = 1.8 \times 10^{-5}$).

D. Calculate the pH of 0.10 *M* NaOH.

NaOH is a strong base to memorize.

Figure 14.4: (a) Strong Acid HA Ionized in Water; (B) Weak Acid HB



(a) Strong acid (b) Weak acid

K_a reaction:

$HX(aq) + H_2O(l) \leftrightarrow H_3O^+(aq) + X^-(aq)$

or: $HX(aq) \leftrightarrow H^+(aq) + X^-(aq)$

Calculating pH of Acids or Bases

A. Calculate the pH of 0.10 *M* HCl. pH = 1.00

HCl is a strong acid to memorize.

B. Calculate the pH of 0.10 *M* $HC_2H_3O_2$. pH=2.87

$HC_2H_3O_2$ is a weak acid ($K_a = 1.8 \times 10^{-5}$).

C. Calculate the pH of 0.10 *M* NH_3. pH = 11.13

NH_3 is a weak base ($K_b = 1.8 \times 10^{-5}$).

D. Calculate the pH of 0.10 *M* NaOH. pH = 13.00

NaOH is a strong base to memorize.

Variation of a weak acid problem-p. 89

A 3.00 *M* weak acid (HX) solution is 20.% dissociated to reach equilibrium. What is the equilibrium concentration of HX in this solution?

% dissociation or % ionization

$$= \text{percent acid reacted} = \frac{x}{[\mathrm{HA}]_0} \times 100$$

Calculate the K_a value for HX.

Variation of a weak base problem (p. 89, #2)

The pH of s 1.0×10^{-3} *M* solution of pyrrolidine is 10.82. Calculate K_b for pyrrolidine (C_4H_9N).

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How solve?

Variation of a weak base problem (p. 89, #2)

The pH of s 1.0×10^{-3} *M* solution of pyrrolidine is 10.82. Calculate K_b for pyrrolidine (C_4H_9N).

How solve?

Set up ICE table using the K_b reaction for the weak base pyrrolidine. See p. 89.5 for solution.

Conjugate Acid-Base Pairs (p. 83)

Pairs of substances that only differ by a proton (H^+) in their formulas are called conjugate acid-base pairs.

Examples of acid-conjugate base pairs:

- HBr and Br^-
- $HC_2H_3O_2$ and $C_2H_3O_2^-$
- $HOCl$ and OCl^-

Examples of base-conjugate acid pairs:

- NH_3 and NH_4^+
- $HONH_2$ and $HONH_3^+$

Conjugate Acid-Base Pairs (p. 83)

-As the name indicates, one species in a conjugate acid-base pair behaves as an acid (H^+ donor), while the other species in the pair behaves as a base (H^+ acceptor).

-To determine how good an acid or base something is, you need to determine the K_a or K_b value.

-For all conjugate acid-base pairs:

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

-See p. 85 of Handouts packet for a derivation of this formula.

Using $K_a \times K_b = K_w = 1.0 \times 10^{-14}$ (p. 83)

For HNO_2, $K_a = 4.0 \times 10^{-4}$ and the conjugate base is NO_2^- . What type of base is NO_2^-?

Using K_a x K_b = K_w = 1.0 x 10^{-14} (p. 83)

For HNO_2, K_a = 4.0 x 10^{-4} and the conjugate base is NO_2^- . What type of base is NO_2^-? Need to calculate K_b for NO_2^-.

$NO_2^-(aq) + H_2O(l) \leftrightarrow HNO_2(aq) + OH^-(aq)$ K_b=?

Using $K_a \times K_b = K_w = 1.0 \times 10^{-14}$ (p. 83)

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

K_b for NO_2^- = K_w/K_a for HNO_2

Using K_a x K_b = K_w = 1.0 x 10^{-14} (p. 83)

For HNO_2, $K_a = 4.0 \times 10^{-4}$ and the conjugate base is NO_2^- . What type of base is NO_2^-?

$NO_2^-(aq) + H_2O(l) \leftrightarrow HNO_2(aq) + OH^-(aq)$ K_b=?

K_b for NO_2^- = K_w/K_a for HNO_2

$$K_b = \frac{1.0 \times 10^{-14}}{4.0 \times 10^{-4}} = 2.5 \times 10^{-11} \text{ (} NO_2^- \text{ is a weak base.)}$$

Using K_a x K_b = K_w = 1.0 x 10^{-14} (p. 83)

For HCl, $K_a \approx$ 1 x 10^6 and the conjugate base is Cl^-. What type of base is Cl^-?

Using $K_a \times K_b = K_w = 1.0 \times 10^{-14}$ (p. 83)

For HCl, $K_a \approx 1 \times 10^{6}$ and the conjugate base is Cl^-. What type of base is Cl^-? Need to calculate K_b for Cl^-.

Using $K_a \times K_b = K_w = 1.0 \times 10^{-14}$ (p. 83)

For HCl, $K_a \approx 1 \times 10^6$ and the conjugate base is Cl^-. What type of base is Cl^-? Need to calculate K_b for Cl^-. For conjugate acid-base pairs, $K_a \times K_b = K_w$.

Using $K_a \times K_b = K_w = 1.0 \times 10^{-14}$ (p. 83)

For HCl, $K_a \approx 1 \times 10^{6}$ and the conjugate base is Cl^-. What type of base is Cl^-?

K_b for Cl^- = K_w/K_a for HCl

$$K_b = \frac{1.0 \times 10^{-14}}{1 \times 10^{6}} = 1 \text{ x } 10^{-20} \text{ (a very tiny number)}$$

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$$K_b = \frac{1.0 \times 10^{-14}}{1 \times 10^{6}} = 1 \times 10^{-20} \text{ (a very tiny number)}$$

We call Cl^- a worthless base because $K_b << K_w = 1.0 \times 10^{-14}$.

Using $K_a \times K_b = K_w = 1.0 \times 10^{-14}$ (p. 83)

For NH_3, $K_b = 1.8 \times 10^{-5}$ and the conjugate acid is NH_4^+. What type of acid is NH_4^+?

Using $K_a \times K_b = K_w = 1.0 \times 10^{-14}$ (p. 83)

For NH_3, $K_b = 1.8 \times 10^{-5}$ and the conjugate acid is NH_4^+. What type of acid is NH_4^+? Need to calculate K_a for NH_4^+.

Using $K_a \times K_b = K_w = 1.0 \times 10^{-14}$ (p. 83)

For NH_3, $K_b = 1.8 \times 10^{-5}$ and the conjugate acid is NH_4^+ . What type of acid is NH_4^+? Need to calculate K_a for NH_4^+.

$NH_4^+(aq) \leftrightarrow NH_3(aq) + H^+(aq) \quad K_a = ?$

Using $K_a \times K_b = K_w = 1.0 \times 10^{-14}$ (p. 83)

For NH_3, $K_b = 1.8 \times 10^{-5}$ and the conjugate acid is NH_4^+. What type of acid is NH_4^+? Need to calculate K_a for NH_4^+.

$NH_4^+(aq) \leftrightarrow NH_3(aq) + H^+(aq) \quad K_a = ?$

$K_a \times K_b = K_w$, so K_a for $NH_4^+ = K_w/K_b$ for NH_3.

Using $K_a \times K_b = K_w = 1.0 \times 10^{-14}$ (p. 83)

For NH_3, $K_b = 1.8 \times 10^{-5}$ and the conjugate acid is NH_4^+. What type of acid is NH_4^+? Need to calculate K_a for NH_4^+.

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$$K_a = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} = 5.6 \times 10^{-10} \text{ (}NH_4^+\text{ is a weak acid.)}$$

Using K_a x K_b = K_w = 1.0 x 10^{-14} (p. 83)

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One of my favorite sayings with acid-base chemistry is that weak gives you weak, and strong gives you garbage. What does this saying refer to?

Using K_a x K_b = K_w = 1.0 x 10^{-14} (p. 83)

For NH_3, $K_b = 1.8 \times 10^{-5}$ and the conjugate acid is NH_4^+ . What type of acid is NH_4^+?

K_a for NH_4^+ = K_w/K_b for NH_3

$$K_a = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} = 5.6 \times 10^{-10} \quad (NH_4^+ \text{ is a weak acid.})$$

One of my favorite sayings with acid-base chemistry is that weak gives you weak, and strong gives you garbage. How about the stronger the acid, the weaker the conjugate base?

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

Consider the K_a and K_b values given on 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^+ .

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Lecture Question (p. 89, #1)

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% dissociation or % ionization

$$= \text{percent acid reacted} = \frac{\text{x}}{[\text{HA}]} \times 100$$

a. 0.60 b. 2.20 *M* c. 2.40 *M* d. 2.80 *M* e. 3.00 *M*

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