11: Buffers

- What is a buffer?
- Calculating pH
  - Weak acids / bases
  - Equilibrium constants of acids / bases
  - Hendersen-Hasselbach Equation
- Buffer capacity
- Preparing buffers

What is a buffer?

- Solution that resists changes in pH when
  - Small amounts of acid or base are added
  - Dilution occurs

- Consists of either:
  - Weak acid / conjugate base pair

    OR
  - Weak base / conjugate acid pair

What is a Buffer?

- Two things to know about a buffer:
  - pH that buffer creates
  - Buffer capacity

Weak Acids and Bases

Acid: $HA + H_2O \rightleftharpoons H_3O^+_{(aq)} + A^-_{(aq)}$

Base: $B + H_2O \rightleftharpoons BH^+_{(aq)} + OH^-_{(aq)}$

Acid/Base Conjugate Pair

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

Conj. Base: **A^-**(aq) + $H_2O \rightleftharpoons$ **HA**(aq) + $OH^-(aq)$

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Base/Acid Conjugate Pair

Base: **B** + $H_2O \rightleftharpoons$ **BH^+**(aq) + $OH^-(aq)$

Conj. Acid: **BH^+** + $H_2O \rightleftharpoons H_3O^+(aq)$ + **B**(aq)

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Acid / Base Equilibrium Constants

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

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

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

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

Some Acid Constants

Name	Formula	K_a
Phosphoric acid	H_3PO_4	7.5×10^{-3}
Hydrofluoric acid	HF	7.2×10^{-4}
Nitrous acid	HNO_2	4.5×10^{-4}
Formic acid	HCO_2H	1.8×10^{-4}
Benzoic acid	$C_6H_5CO_2H$	6.3×10^{-5}
Acetic acid	CH_3CO_2H	1.8×10^{-5}
Propanoic acid	$CH_3CH_2CO_2H$	1.3×10^{-5}

The "p" function

$$pX = -\log(X)$$

so….

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

$$pK_a = -\log(K_a)$$

$$pK_b = -\log(K_b)$$

Example

$$H_3PO_4 + H_2O \rightleftharpoons H_3O^+(aq) + H_2PO_4^-(aq)$$

$$K_a = \frac{[H_3O^+][H_2PO_4^-]}{[H_3PO_4]} = 7.5 \times 10^{-3}$$

$$pK_a = -\log(7.5 \times 10^{-3}) = 2.12$$

Henderson-Hasselbalch Equation

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

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

Using p-functions, can derive:

$$pH = pK_a + \log\left(\frac{[A^-]}{[HA]}\right)$$

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Henderson-Hasselbalch Equation

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

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

Using p-functions, can derive:

$$pOH = pK_b + \log\left(\frac{[BH^+]}{[B]}\right)$$

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Buffer Capacity

- Definition: Moles of strong acid or base needed to change pH ±1 of 1 L of buffer
- For best buffer capacity, use conjugate pair with pK_a = pH ±1
- Larger [HA] and $[A^-]$ yields greater buffer capacity
- Most buffers are 0.01 to 0.10 M

Making a Buffer: Questions to Consider

- What pH do you want?
  - Conjugate pair with pK_a close to pH
- What volume is needed?
- How strong do you need to make buffer?
  - Buffering capacity
  - Concentration of acid / base
- Limitations on conjugate pair?
  - Availability
  - Expense
  - Incompatible with your system (i.e. toxic)?

How to Attain your pH?

- Method 1: Use Henderson-Hasselbalch to calculate exact amounts
- Method 2: Add amount of acid needed. Titrate with strong base (NaOH) and pH meter
- Method 3: Combination
  - Use Henderson-Hasselbalch to calculate
  - Add amount of acid needed
  - "Titrate" with conjugate base and pH meter

Today's Lab

- Make two buffers with pH = 5.0
  - Different buffering capacities
- Determine the buffering capacity
- Pre-lab question: Mass of sodium acetate to make 100 mL buffer at pH = 5.0, with 5.0 mL of 0.50 M acetic acid