# Buffer in solutions

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# Objective

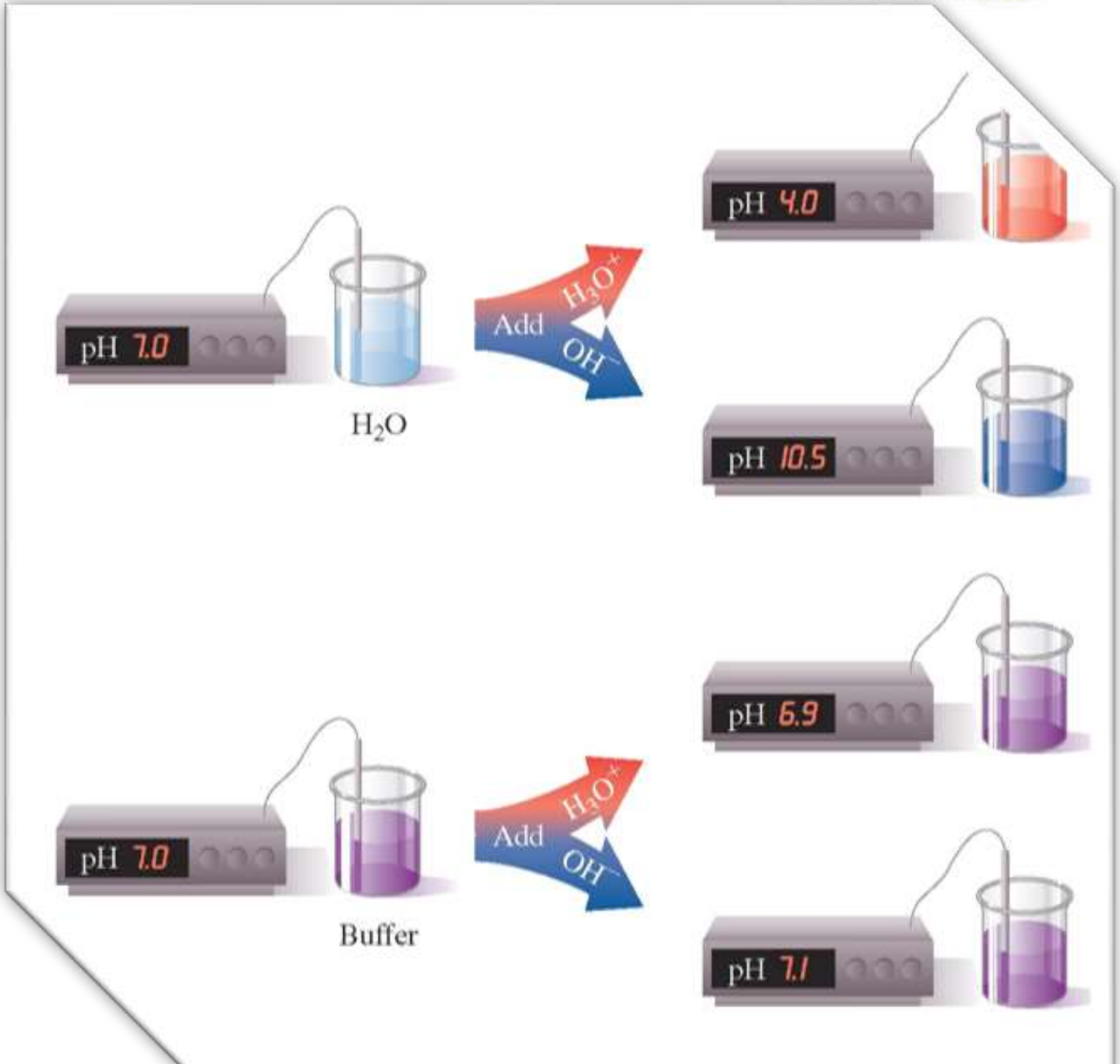
- **LEARNING GOAL: Describe the role of buffers in maintaining the pH of a solution in body fluids.**

- The pH of water and most solutions changes drastically when a small amount of acid or base is added.
- However, when an acid or base is added to a *buffer solution*, there is little change in pH.
- **A buffer solution** maintains pH by neutralizing small amounts of added acid or base.

- For example, blood contains buffers that maintain a consistent pH of about 7.4 .
- If the pH of the blood goes slightly above or below 7.4, changes in oxygen levels and metabolic processes can be drastic enough to cause death.
- Even though we obtain acids and bases from foods and cellular reactions, the buffers in the body absorb those compounds so effectively that the pH of the blood remains essentially unchanged **(see Figure 1)**

**FIGURE 1 ▶**

**Adding an acid or a base to water changes the pH drastically, but a buffer resists pH change when small amounts of acid or base are added**



- In a buffer, an **acid** must be present to react with any $OH^-$ that is added, and a base must be available to react with any added $H_3O^+$.
- However, that acid and base must not neutralize each other,
- Therefore, a combination of an acid-base conjugate pair is used to prepare a buffer.
- Most buffer solutions consist of nearly equal concentrations of a ***weak acid and a salt containing its conjugate base.***

- Buffers may also contain a weak base and a salt containing its conjugate acid.

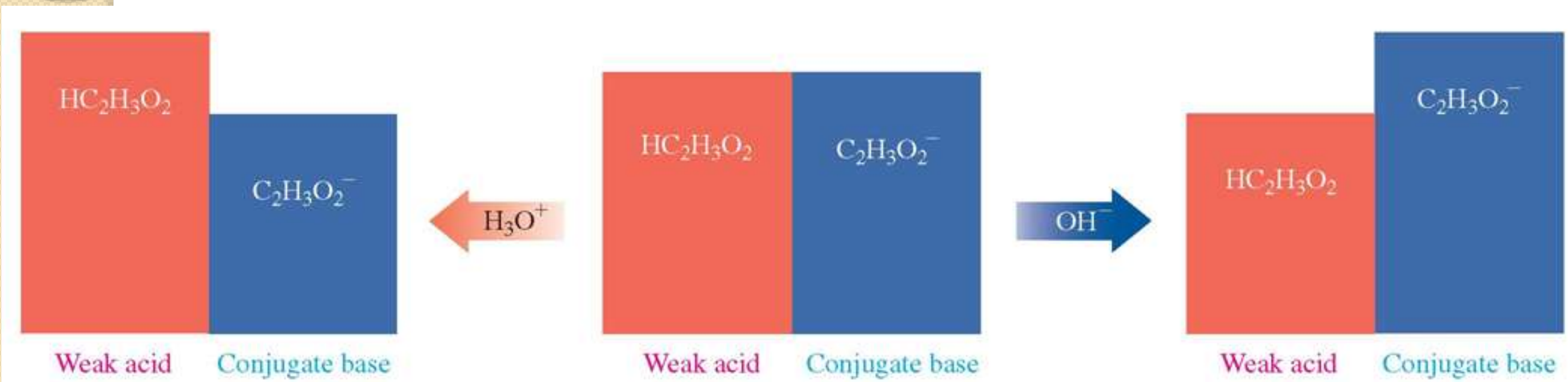



**FIGURE :2 ▶** The buffer described here consists of about equal concentrations of ace tic acid ($HC_2H_3O_2$) and its conjugate base, acetate ion ($C_2H_3O_2$). Adding $H_3O^+$ to the buffer reacts with $C_2H_3O_2$, whereas adding OH" neutralizes $HC_2H_3O_2$. The pH of the solution is maintained as long as the added amounts of acid or base are small compared to the concentrations of the buffer components

# Question

- How does this acetic acid-acetate ion buffer maintain pH ?
- For example, a typical buffer can be made from the weak acid, acetic acid ($HC_2H_3O_2$), and its salt, sodium acetate ($NaC_2H_3O_2$).
- As a weak acid, acetic acid ionizes slightly in water to form $H_3O^+$ and a small amount of $C_2H_3O_2^-$.
- The addition of its salt provides a much larger concentration of the acetate ion ($C_2H_3O_2^-$), which is necessary for its buffering capability.

$$HC_2H_3O_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + C_2H_3O_2^-(aq)$$

Large amount — Large amount

- We can now describe how this buffer solution maintains the $[H_3O^+]$.
- When a small amount of acid is added, it combines with the acetate ion, $C_2H_3O_2$-, causing the equilibrium to shift in the direction of $HC_2H_3O_2$. There will be a slight decrease in $[C_2H_3O_2$-$]$ and a slight increase in $[HC_2H_3O_2]$; thus both $[H_3O^+]$ and pH are maintained.

$$HC_2H_3O_2(aq) + H_2O(l) \longleftarrow H_3O^+(aq) + C_2H_3O_2^-(aq)$$

Equilibrium shifts in the direction of the reactants

- If a small amount of base is added to this buffer solution, it is neutralized by the acetic acid, $HC_2H_3O_2$.
- The equilibrium shifts in the direction of the products, water and $[C_2H_3O_2^-]$ .
- The $[HC_2H_3O_2]$ decreases slightly and the $[C_2H_3O_2^-]$ increases slightly, but again the $[H_3O^+]$ and the pH of the solution are maintained **(see Figure 2).**

$$HC_2H_3O_2(aq) + OH^-(aq) \longrightarrow H_2O(l) + C_2H_3O_2^-(aq)$$

Equilibrium shifts in the direction of the products

## **Sample problem 1** : indicate whether each of the following would make a buffer solution:

- **a.** HCl, a strong acid, and NaCl
- **b.** H3$PO_4$, a weak acid
- **c.** HF ,a weak acid ,and NaF
- **SOLUTION**
- **a.** No. A buffer requires a weak acid and a salt containing its conjugate base.
- **b.** No. A weak acid is part of a buffer, but the salt containing the conjugate base of the weak acid is also needed.
- **c.** Yes. This mixture would be a buffer since it contains a weak acid and a salt containing its conjugate base.

# STUDY CHECK 2

- In a buffer made from the weak acid $HCHO_2$ and its salt, $KCHO_2$, when $H_3O^+$ is added, is neutralized by :
- **(1)** the salt,
- **(2)** $H_2O$,
- **(3)** OH-, or
- **(4)** the acid?

# Buffers in the Body :

- The arterial blood has a normal pH of 7.35 to 7.45.
- If changes in $H_3O^+$ lower the pH **below 6.8** or raise it above 8.0, cells cannot function properly and death may result.
- In our cells, $CO_2$ is continually produced as an end product of cellular metabolism.
- Some $CO_2$ is carried to the lungs for elimination, and the rest dissolves in body fluids such as plasma and saliva, forming carbonic acid.
- As a weak acid, carbonic acid ionizes to give bicarbonate, $HCO_3^-$ and $H_3O^+$.
- More of the anion $HCO_3^-$ is supplied by the kidneys to give an important buffer system in the body fluid:
- the $H_2CO_3/HCO_3^-$ buffer.

$$CO_2(g) + H_2O(l) \rightleftarrows H_2CO_3(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + HCO_3^-(aq)$$

- Excess $H_3O^+$ entering the body fluids reacts with the $HCO_3^-$ and excess **$OH^-$** reacts with the carbonic acid.

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

Equilibrium shifts in the direction of the reactants

$$H_2CO_3(aq) + OH^-(aq) \longrightarrow H_2O(l) + HCO_3^-(aq)$$

Equilibrium shifts in the direction of the products

- In the body, the concentration of carbonic acid is closely associated with the partial pressure of $CO_2$.
- **Table I** : lists the normal values for arterial blood.
- If the $CO_2$ level increases, it produces more $H_2CO_3$ and more $H_3O^+$, lowering the pH.
- This condition is called **acidosis**. (Difficulty with ventilation or gas diffusion can lead to respiratory acidosis, which can happen in emphysema or when the medulla of the brain is affected by an accident or depressive drugs).

# TABLE 1: Normal Values for Blood Buffer in Arterial Blood

| | |
|---|---|
| $P_{CO_2}$ | 40 mmHg |
| $H_2CO_3$ | 2.4 mmoles/L of plasma |
| $HCO_3^-$ | 24 mmoles/L of plasma |
| pH | 7.35 to 7.45 |

- A decrease in the $CO_2$ level leads to a high blood pH, a condition called **alkalosis.** Excitement, trauma, or a high temperature may cause a person to hyperventilate, which expels large amounts of $CO_2$. As the partial pressure of $CO_2$ in the blood falls below normal, $H_2CO_3$ forms $CO_2$ and $H_2O$, decreasing the $[H_3O^+]$ and raising the pH.
- The kidneys also regulate $H_3O^+$ and $HCO_3^-$ components, but more slowly than the adjustment made by the lungs through ventilation.

# TABLE 2: Acidosis and Alkalosis: Symptoms, Causes, and Treatments

| | |
|---|---|
| **Respiratory Acidosis: $CO_2\uparrow$ pH$\downarrow$** | |
| Symptoms: | Failure to ventilate, suppression of breathing, disorientation, weakness, coma |
| Causes: | Lung disease blocking gas diffusion (e.g., emphysema, pneumonia, bronchitis, asthma); depression of respiratory center by drugs, cardiopulmonary arrest, stroke, poliomyelitis, or nervous system disorders |
| Treatment: | Correction of disorder, infusion of bicarbonate |
| **Metabolic Acidosis: $H^+\uparrow$ pH$\downarrow$** | |
| Symptoms: | Increased ventilation, fatigue, confusion |
| Causes: | Renal disease, including hepatitis and cirrhosis; increased acid production in diabetes mellitus, hyperthyroidism, alcoholism, and starvation; loss of alkali in diarrhea; acid retention in renal failure |
| Treatment: | Sodium bicarbonate given orally, dialysis for renal failure, insulin treatment for diabetic ketosis |
| **Respiratory Alkalosis: $CO_2\downarrow$ pH$\uparrow$** | |
| Symptoms: | Increased rate and depth of breathing, numbness, light-headedness, tetany |
| Causes: | Hyperventilation because of anxiety, hysteria, fever, exercise; reaction to drugs such as salicylate, quinine, and antihistamines; conditions causing hypoxia (e.g., pneumonia, pulmonary edema, heart disease) |
| Treatment: | Elimination of anxiety-producing state, rebreathing into a paper bag |
| **Metabolic Alkalosis: $H^+\downarrow$ pH$\uparrow$** | |
| Symptoms: | Depressed breathing, apathy, confusion |
| Causes: | Vomiting, diseases of the adrenal glands, ingestion of excess alkali |
| Treatment: | Infusion of saline solution, treatment of underlying diseases |

# Questions H.W :

1. Which of the following represents a buffer system? Explain.

**a.** NaOH and NaCl **b.** $H_2CO_3$ and $NaHCO_3$

**c.** HF and KF **d.** KC1 and NaCl

2. Which of the following represents a buffer system? Explain.

**a.** $H_3PO_3$ **b.** $NaNO_3$

**c.** $HC_2H_3O_2$ and $NaC_2H_3O_2$ **d.** HC1 and NaOH.

- **3. Consider the buffer system of hydrofluoric acid, HF, and its salt, NaF.**

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

- **a.** The purpose of this buffer system is to:
- **1.** maintain [HF] **2.** maintain [$F^-$]
  **3.** maintain pH

- **b.** The salt of the weak acid is needed to:

1. provide the conjugate base
2. neutralize added $H_3O^+$
3. provide the conjugate acid

- **c.** If OH" is added, it is neutralized by:
  **1.** the salt **2.** $H_2O$ **3.** $H_3O^+$
- **d.** When $H_3O^+$ is added, the equilibrium shifts in the direction of the:

**1.** Reactants **2.** Products **3.** does not change

- **4.Consider the buffer system of nitrous acid, $HNO_2$, and its salt, $NaNO_2^-$**

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

**a.** The purpose of this buffer system is to:

**1.** maintain $[HNO_2]$ **2.** maintain $[NO_2^-]$ **3.** maintain pH

**b.** The weak acid is needed to:

1. provide the conjugate base
2. neutralize added OH"
3. provide the conjugate acid

**c.** If $H_3O^+$ is added, it is neutralized by:

**1.** the salt **2.** $H_2O$ **3.** $OH^-$

**d.** When OH" is added, the equilibrium shifts in the direction of the:

**1.** reactants **2.** Products **3.** does not change

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