

# Acid–Base Balance

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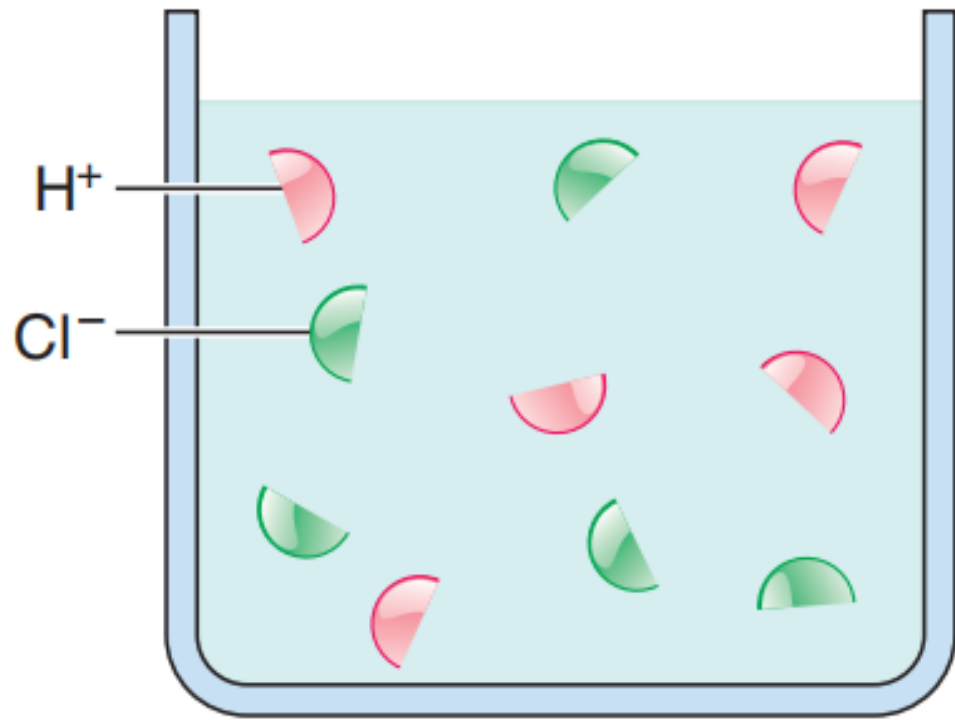
# Definitions

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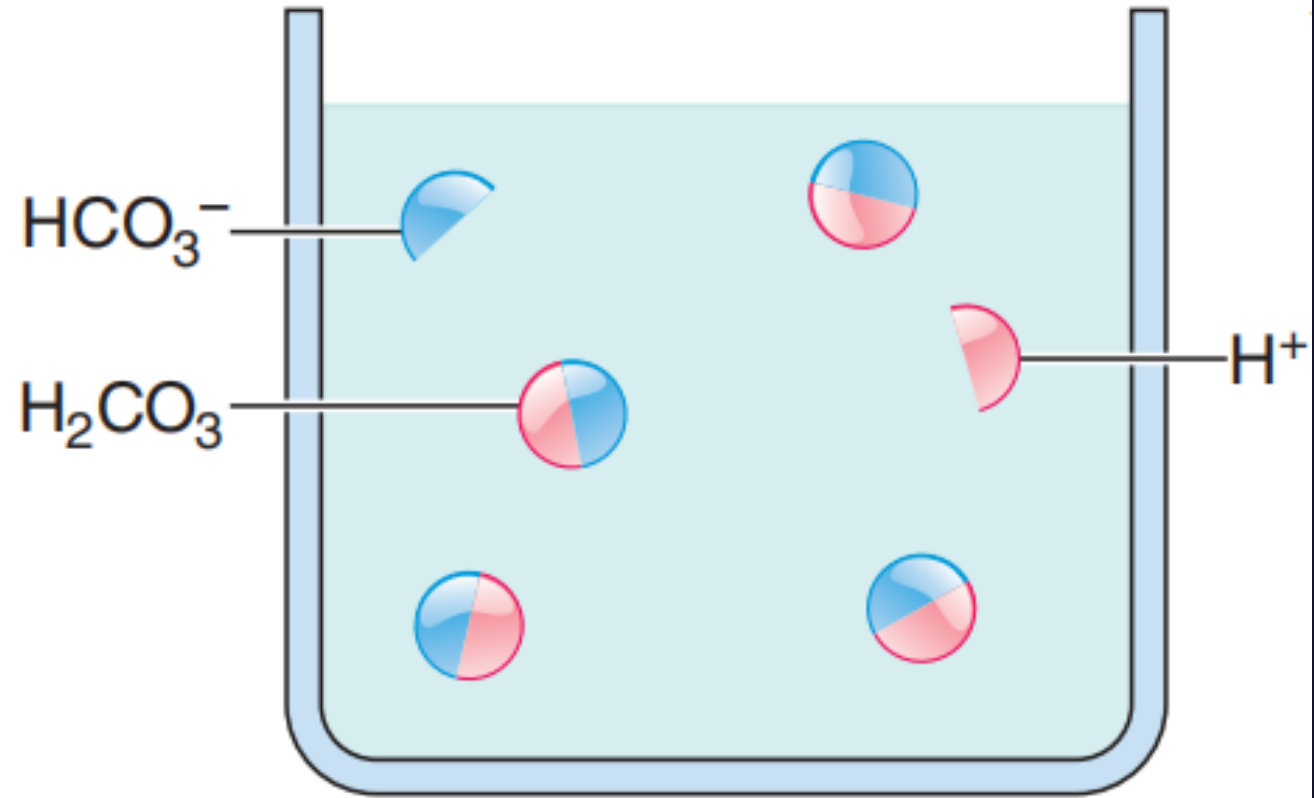
- The term acid–base balance refers to: the **precise regulation of free (unbound) hydrogen ion ( $H^+$ ) concentration** in the body fluids.

# Definitions

- **Acids:** are a special group of hydrogen-containing substances that dissociate, or separate, when in solution to liberate **free H<sup>+</sup> and anions**.
- A **strong acid** has a **greater tendency to dissociate** in solution than a weak acid does.
- With a **weaker acid**, only a **portion** of the molecules **dissociates** in solution into H<sup>+</sup> and anions. The **remaining** acid molecules remain **intact**.



**(a)** Strong acid ( $HCl$ )



**(b)** Weak acid ( $H_2CO_3$ )



- Dissociation constant (K)

# Definitions

- A **base** is a substance that can **combine with a free  $H^+$**  and thus **remove it from solution**.
- A **strong base** can bind  $H^+$  more readily than a weak base can.

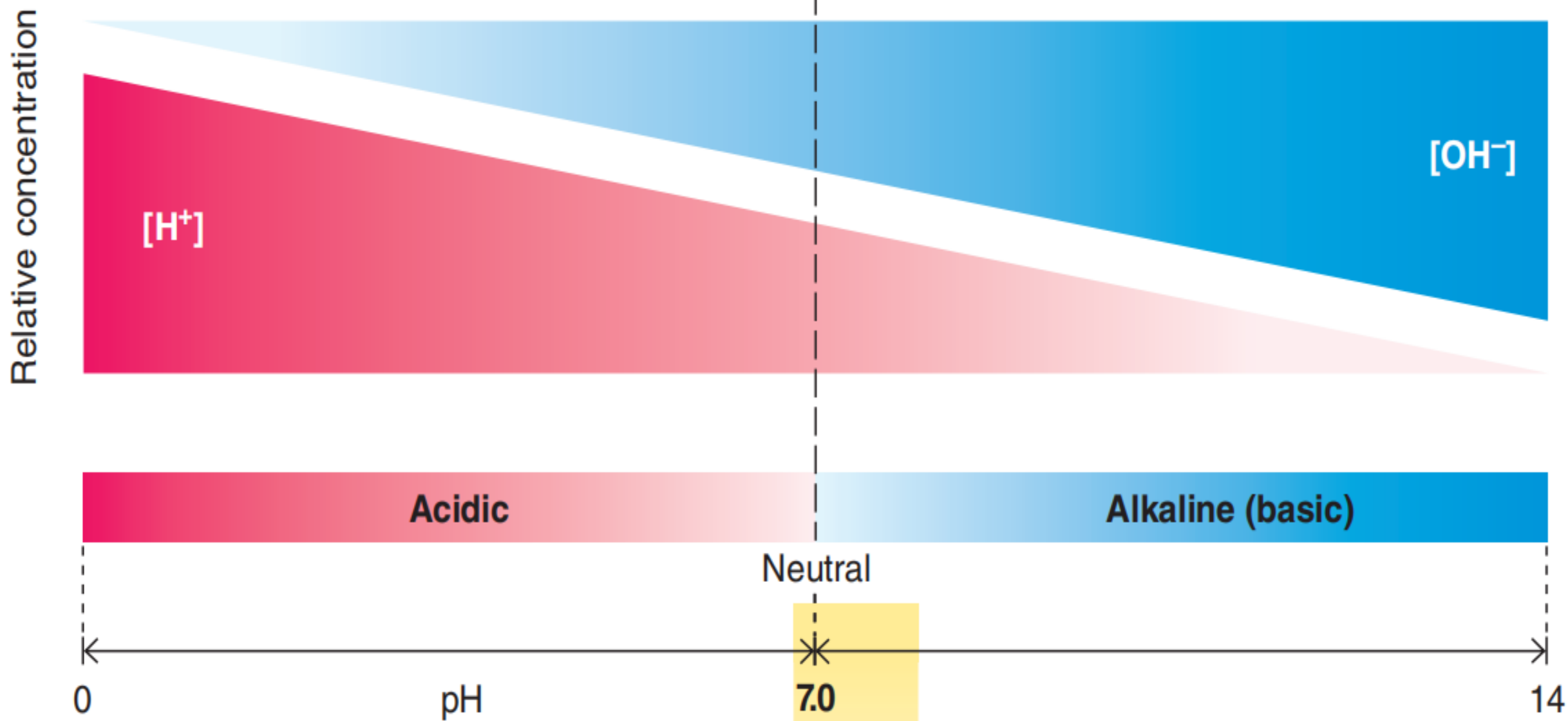
**pH**

# pH

- The pH designation is used to express  $[H^+]$ .
- The  $[H^+]$  in the ECF is normally  $0.00000004 = 4 \times 10^{-8}$  equivalents per liter, about 3 million times less than the  $[Na^+]$  in the ECF.
- The concept of pH was developed to express the low value of  $[H^+]$  more conveniently.
- Specifically, pH equals the logarithm (log) to the base 10 of the reciprocal of  $[H^+]$ .
- $pH = \log 1/[H^+] = -\log [H^+]$

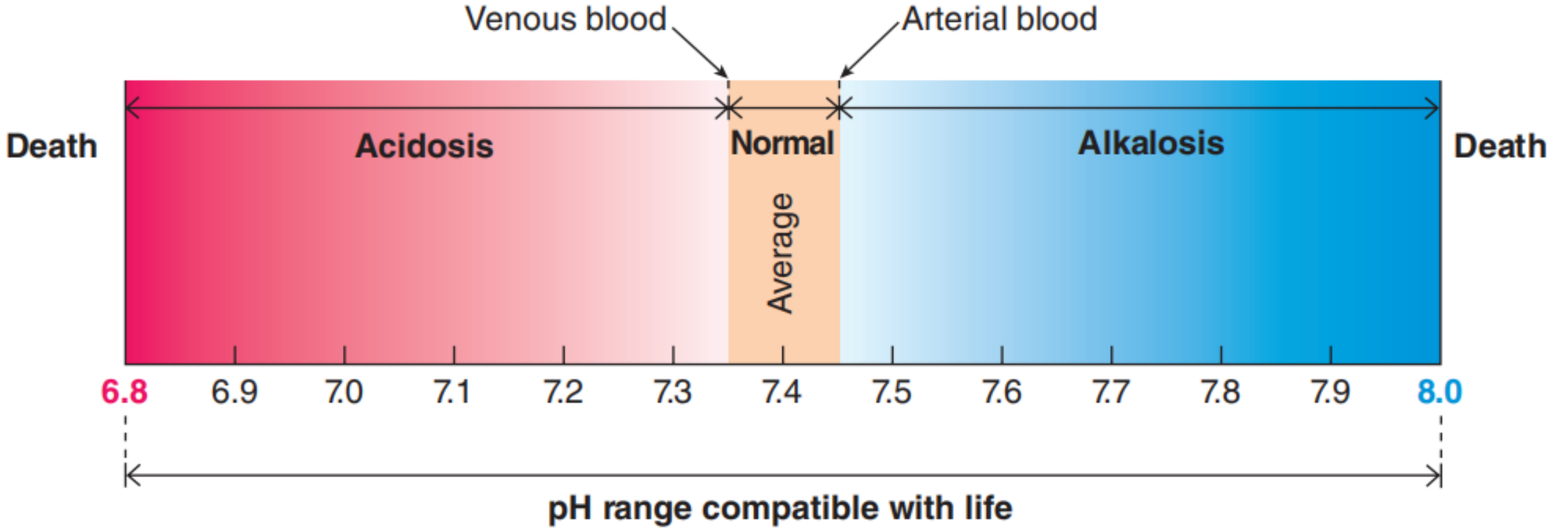
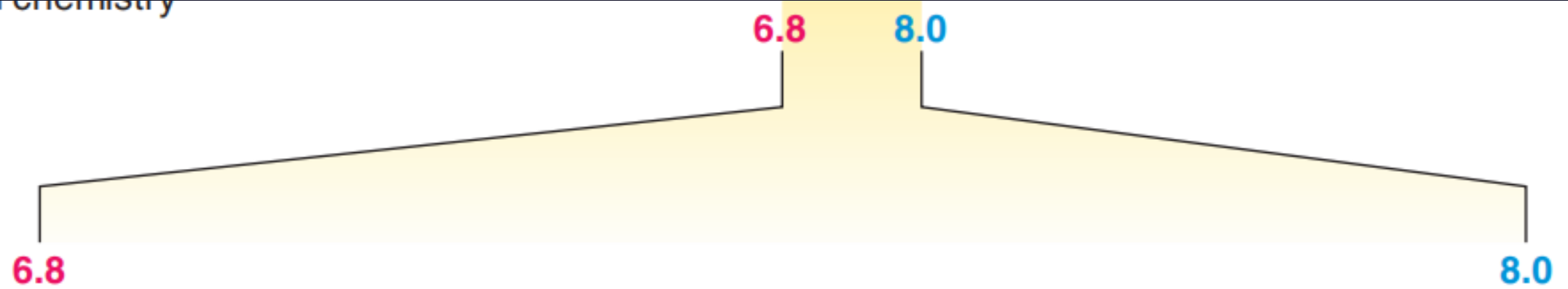
# pH

- The pH of **pure H<sub>2</sub>O** is **7.0**, which is considered chemically **neutral**.
- Solutions having a **pH less than 7.0** contain a **higher [H<sup>+</sup>]** than pure H<sub>2</sub>O and are considered **acidic**.
- Solutions having a **pH value greater than 7.0** have a **lower [H<sup>+</sup>]** than pure H<sub>2</sub>O and are considered **basic, or alkaline**.



(a) In chemistry

(a) In chemistry



(b) In the body

# Acidosis and Alkalosis in the Body

# Acidosis and Alkalosis in the Body

- The pH of **arterial blood** is normally **7.45** and the pH of **venous blood** is **7.35**, for an average blood pH of 7.4.
- The **pH of venous blood is slightly lower** (more acidic) than that of arterial blood because  $H^+$  is generated by the formation of  $H_2CO_3$  from  $CO_2$  picked up at the tissue capillaries.
- **Acidosis** exists whenever blood pH falls **below 7.35**.
- **Alkalosis** occurs when blood pH is **above 7.45**.

# Acidosis and Alkalosis in the Body

- **Acidosis** exists whenever blood pH falls **below 7.35**.
- **Alkalosis** occurs when blood pH is **above 7.45**.
- An arterial pH of **less than 6.8 or greater than 8.0** is **not compatible with life**.
- Fluctuations in  $[H^+]$  alter nerve, enzyme, and  $K^+$  activity.

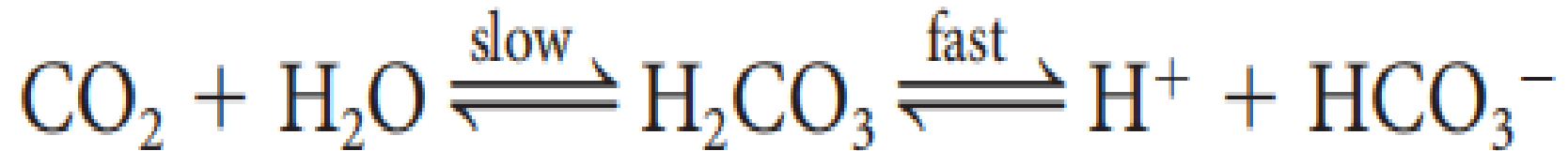
# Sources of H<sup>+</sup> in the Body

# Sources of $H^+$ in the Body

- **Most  $H^+$**  in the body fluids is generated **internally** from metabolic activities.

# Sources of H<sup>+</sup> in the Body

- 1. Carbonic acid formation:



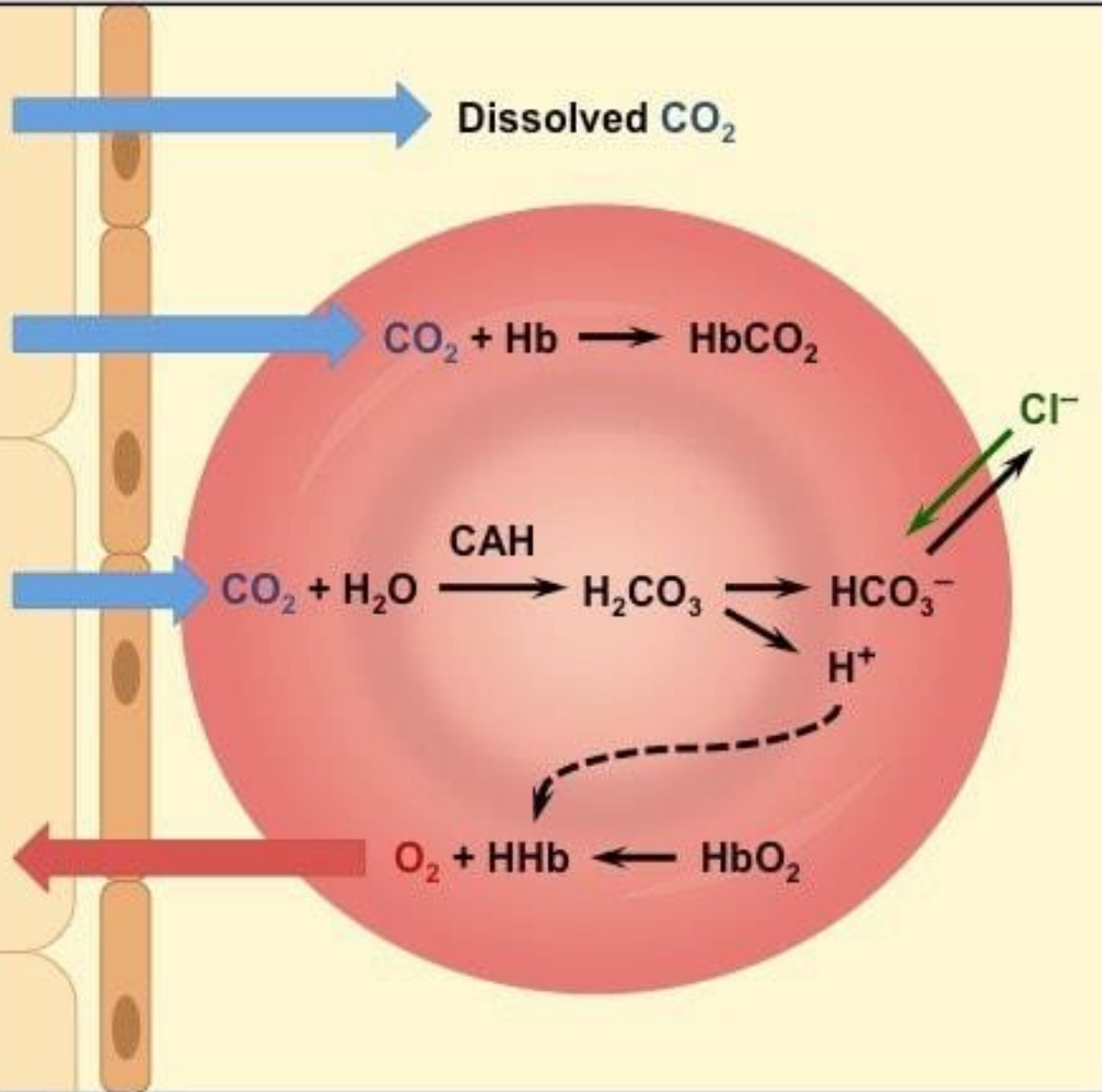
- by **enzyme carbonic anhydrase**



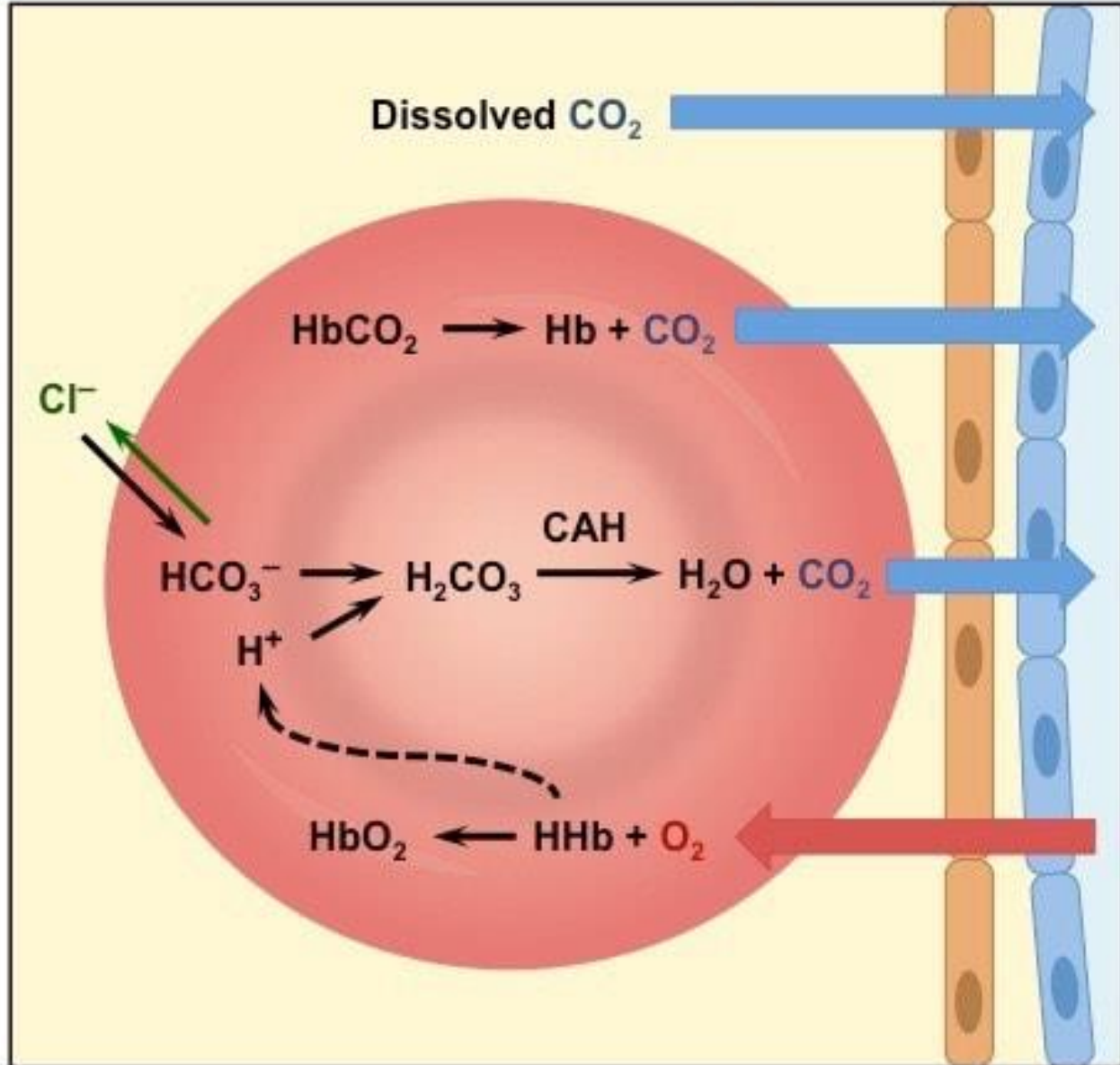
# Sources of $H^+$ in the Body

- These reactions are **reversible** because they can proceed in either direction, **depending on the concentrations** of the substances involved.

## GAS EXCHANGE AT RESPIRING TISSUES



## GAS EXCHANGE AT LUNGS (ALVEOLI)



# Sources of H<sup>+</sup> in the Body

- 2. Inorganic acids produced during breakdown of nutrients.
- 3. Organic acids resulting from intermediary metabolism.
- For example, **fatty acids** are produced during fat metabolism, and muscles produce lactic acid (**lactate**) during heavy exercise. These acids partially dissociate to yield free H<sup>+</sup>.

# Lines of Defense Against Changes in $[H^+]$

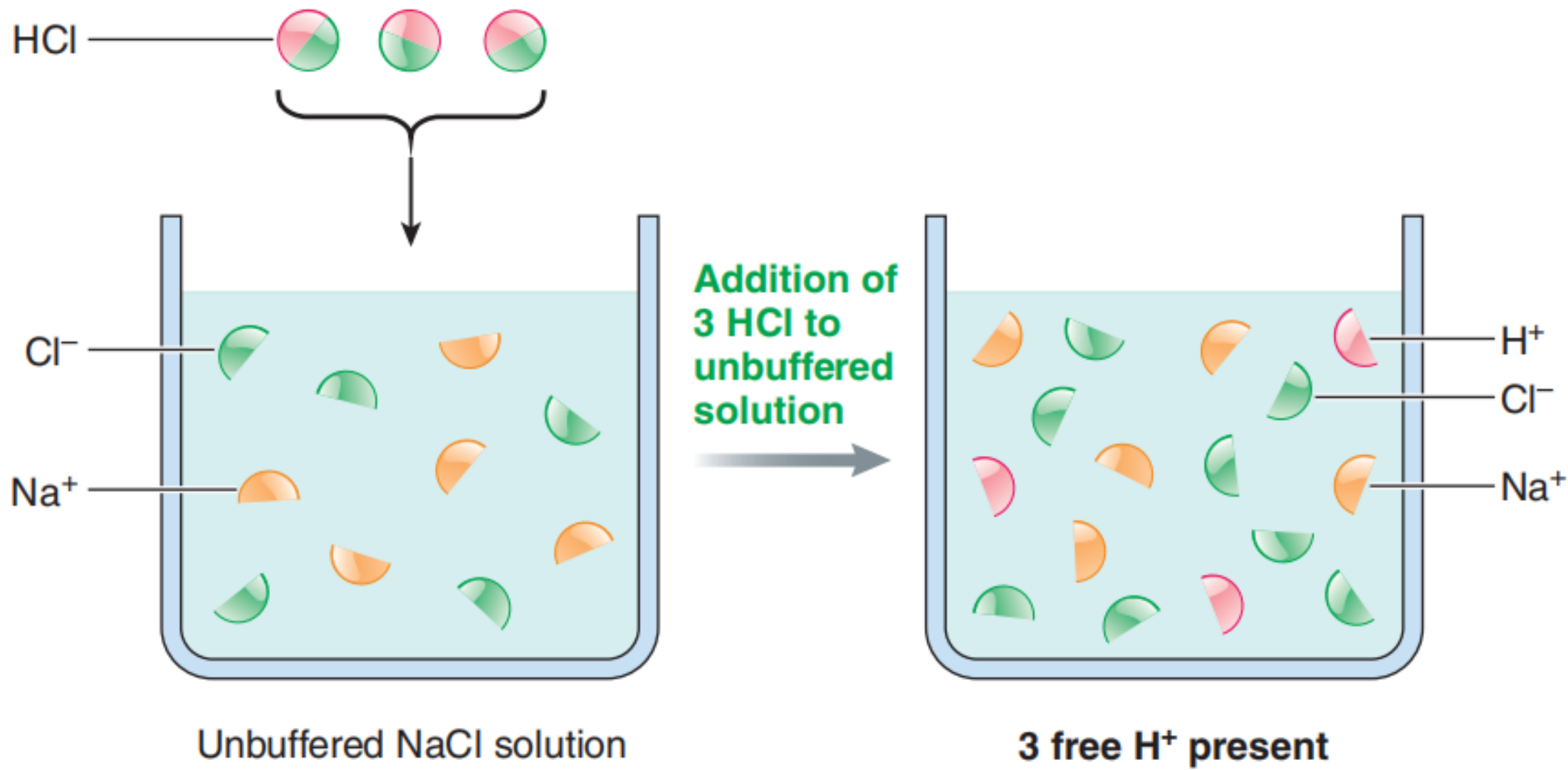
# Lines of Defense Against Changes in $[H^+]$

- Three lines of defense against changes in  $[H^+]$  operate to maintain  $[H^+]$  of body fluids at a nearly constant level despite unregulated input:
  - (1) the chemical buffer systems.
  - (2) the respiratory mechanism of pH control.
  - (3) the renal mechanism of pH control.

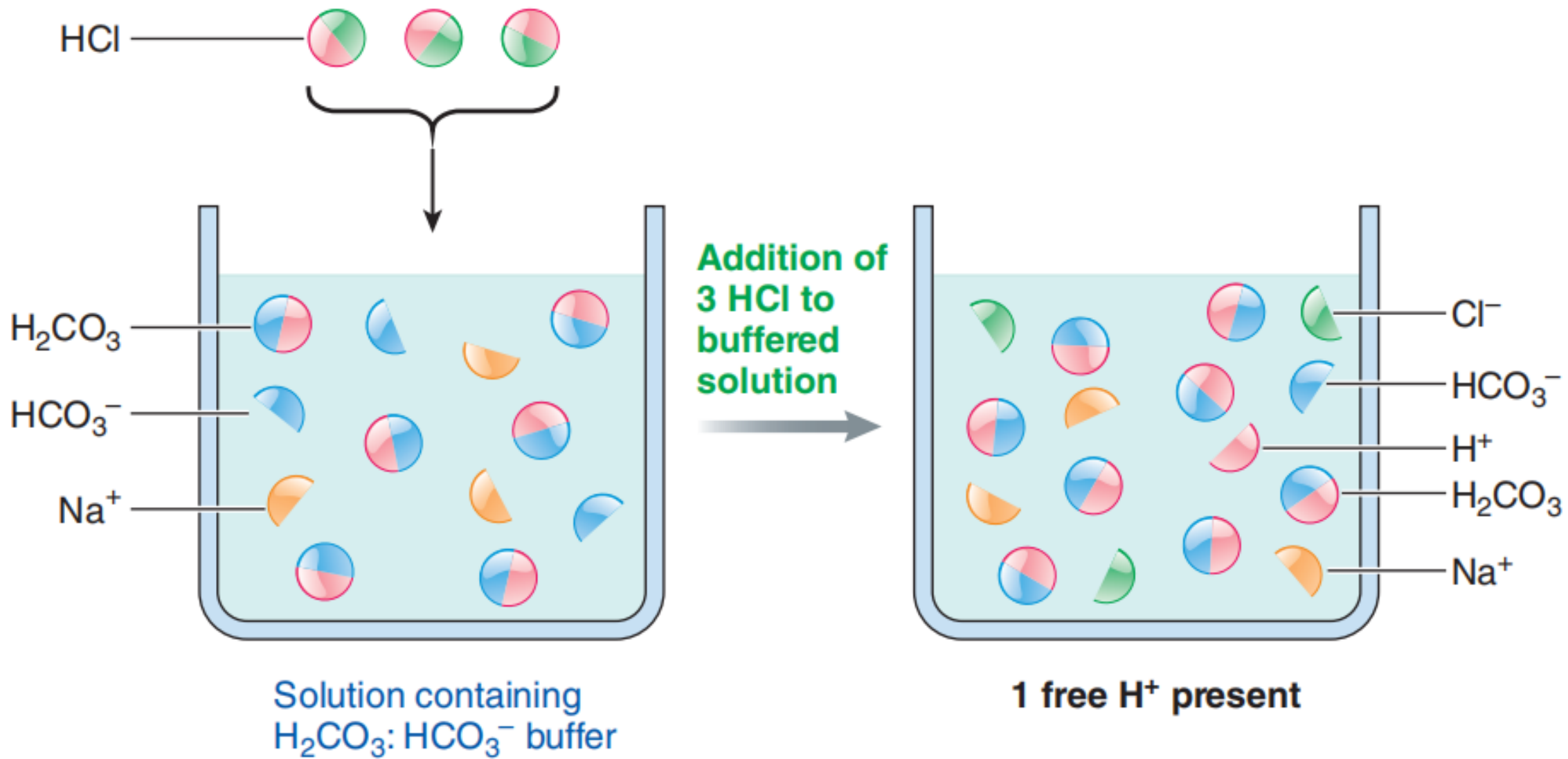
# Chemical buffer systems

- A chemical buffer system is a **mixture in a solution of two chemical compounds** that **minimize pH changes** when either an acid or a base is added to or removed from the solution.
- An important example of such a buffer system is the carbonic acid–bicarbonate ( $\text{H}_2\text{CO}_3 : \text{HCO}_3^-$ ) buffer pair, which is involved in the following reversible reaction:





(a) Addition of HCl to an unbuffered solution



**(b)** Addition of HCl to a buffered solution

# Chemical buffer systems

- The body has four buffer systems:
  - (1) the  $\text{H}_2\text{CO}_3:\text{HCO}_3^-$  buffer system.
  - (2) the protein buffer system.
  - (3) the hemoglobin buffer system.
  - (4) the phosphate buffer system.

# Chemical buffer systems

- Because  $[\text{HCO}_3^-]$  is regulated by the kidneys and  $[\text{CO}_2]$  by the lungs, the pH of the plasma can be shifted up and down by kidney and lung influences.

$$\text{pH} \propto \frac{[\text{HCO}_3^-] \text{ controlled by kidney function}}{[\text{CO}_2] \text{ controlled by respiratory function}}$$

# Chemical buffer systems

Buffer System	Major Functions
<b>H<sub>2</sub>CO<sub>3</sub>:HCO<sub>3</sub><sup>-</sup> buffer system</b>	Primary ECF buffer against noncarbonic acid changes
<b>Protein buffer system</b>	Primary ICF buffer; also buffers ECF
<b>Hemoglobin buffer system</b>	Primary buffer against carbonic acid changes
<b>Phosphate buffer system</b>	Important urinary buffer; also buffers ICF

# Chemical buffer systems

- All chemical buffer systems act **immediately**, within **fractions of a second**.
- Accordingly, the buffer systems are the **first line of defense** against changes in  $[H^+]$  because they are **the first mechanism to respond**.

# Respiratory mechanism of pH control

- The respiratory system **regulates  $[H^+]$**  by controlling the rate of  **$CO_2$  removal**.
- (through its ability to **alter pulmonary ventilation** and consequently to alter excretion of  $H^+$  -generating  $CO_2$ ).

# Respiratory mechanism of pH control

- The level of **respiratory activity** is governed in part by **arterial  $[H^+]$** .
  1. Increase in arterial  $[H^+]$  → increase pulmonary ventilation (rate and depth of breathing increase).
  2. Arterial  $[H^+]$  falls → pulmonary ventilation is reflexly reduced (slower and shallower breathing).

# Respiratory mechanism of pH control

- The respiratory system serves as the **second line of defense** against changes in  $[H^+]$ .

# Renal mechanism of pH control

- The kidneys control the pH of body fluids by adjusting three interrelated factors:
  - (1)  $H^+$  excretion
  - (2)  $HCO_3^-$  excretion
  - (3) ammonia ( $NH_3$ ) secretion

# Renal mechanism of pH control

- All of the filtered  $H^+$  is excreted because the kidney tubules are not able to reabsorb  $H^+$  , but most excreted  $H^+$  enters the urine via secretion.

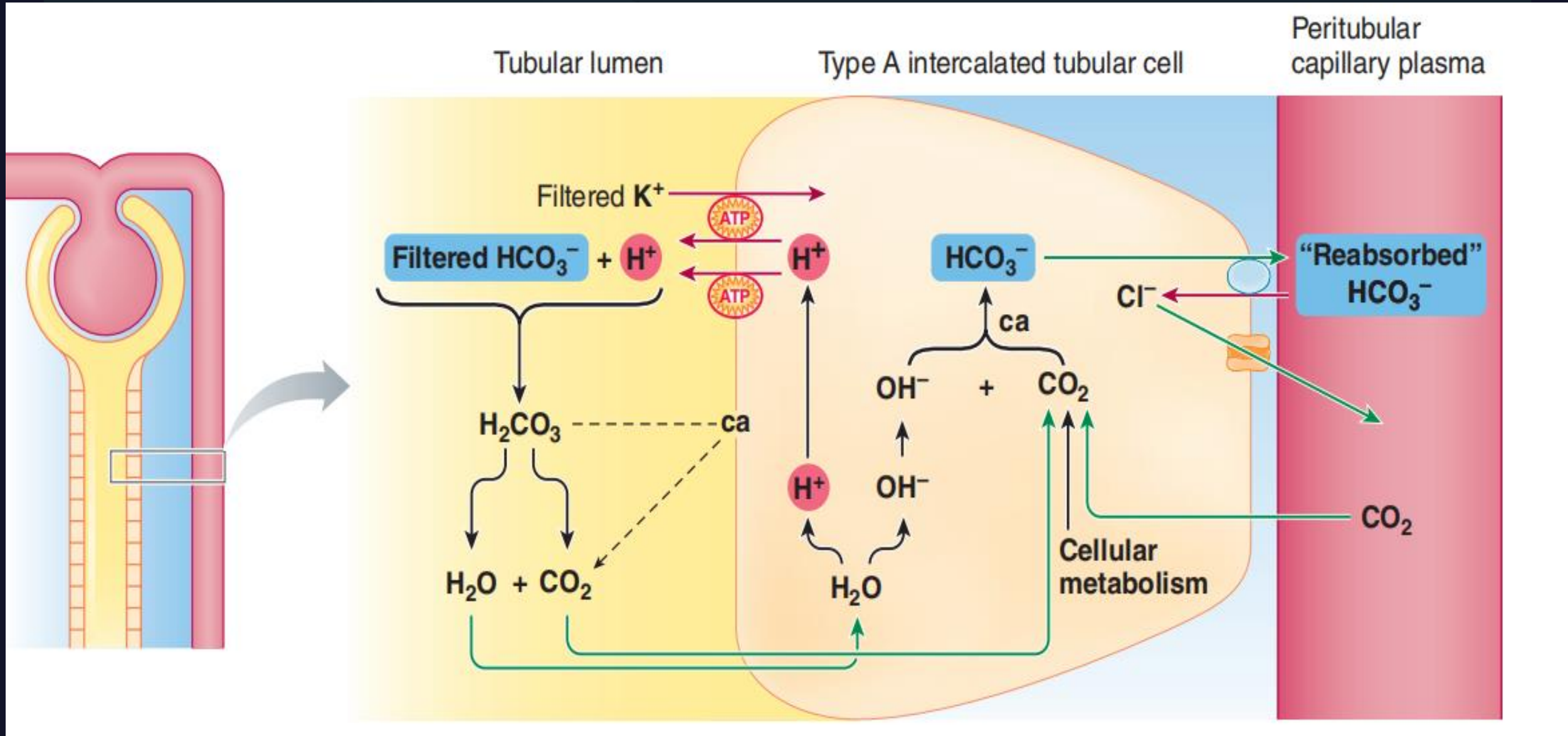
# Renal mechanism of pH control

- Mechanism of Renal H<sup>+</sup> Secretion in the Proximal Tubule:
  1. H<sup>+</sup> ATPase pumps
  2. Na<sup>+</sup> -H<sup>+</sup> antiporters

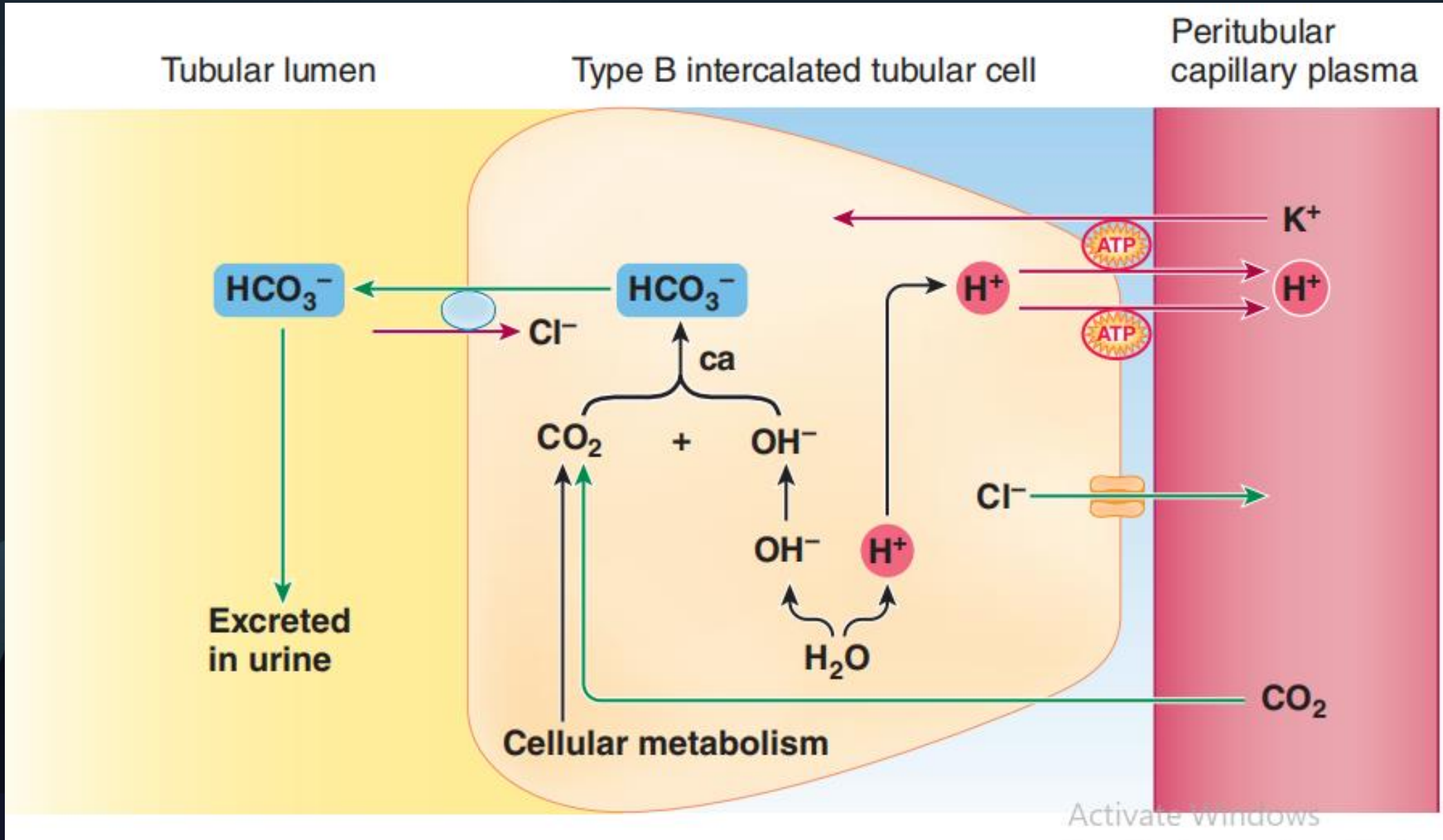
# Renal mechanism of pH control

- Mechanism of Renal  $H^+$  Secretion in the **Distal and Collecting Tubules:**
- Type A & B intercalated cells

# Type A intercalated cell



# Type B intercalated cell



# Renal mechanism of pH control

- The **kidneys require hours to days** to compensate for changes in body-fluid pH, compared to the immediate responses of the buffer systems and the few minutes of delay before the respiratory system responds.

Disorder	pH	H <sup>+</sup>	HCO <sub>3</sub> <sup>-</sup>	CO <sub>2</sub>
Normal	7.35-7.45	40 × 10 <sup>-9</sup> mol/L	24-28 mEq/L	35-45 mmHg
Respiratory acidosis	↓	↑	↑	↑
Respiratory alkalosis	↑	↓	↓	↓
Metabolic acidosis	↓	↑	↓	↓
Metabolic alkalosis	↑	↓	↑	↑



**Thank You**