Acid-Base Balance

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Introduction

- Acid-base balance is one of the most important of the body's homeostatic mechanisms
- Acid-base balance refers to regulation of hydrogen ion concentration in body fluids
- Precise regulation of pH at the cellular level is necessary for survival
- Slight pH changes have dramatic effects on cellular metabolism

Acids and Bases and Buffers

- Acids
  - Release H^+ into solution
- Bases
  - Remove H^+ from solution
- Acids and bases
  - Grouped as strong or weak

- Buffers: Resist changes in pH
  - When H^+ added, buffer removes it
  - When H^+ removed, buffer replaces it
- Types of buffer systems
  - Carbonic acid/bicarbonate
  - Protein
  - Phosphate

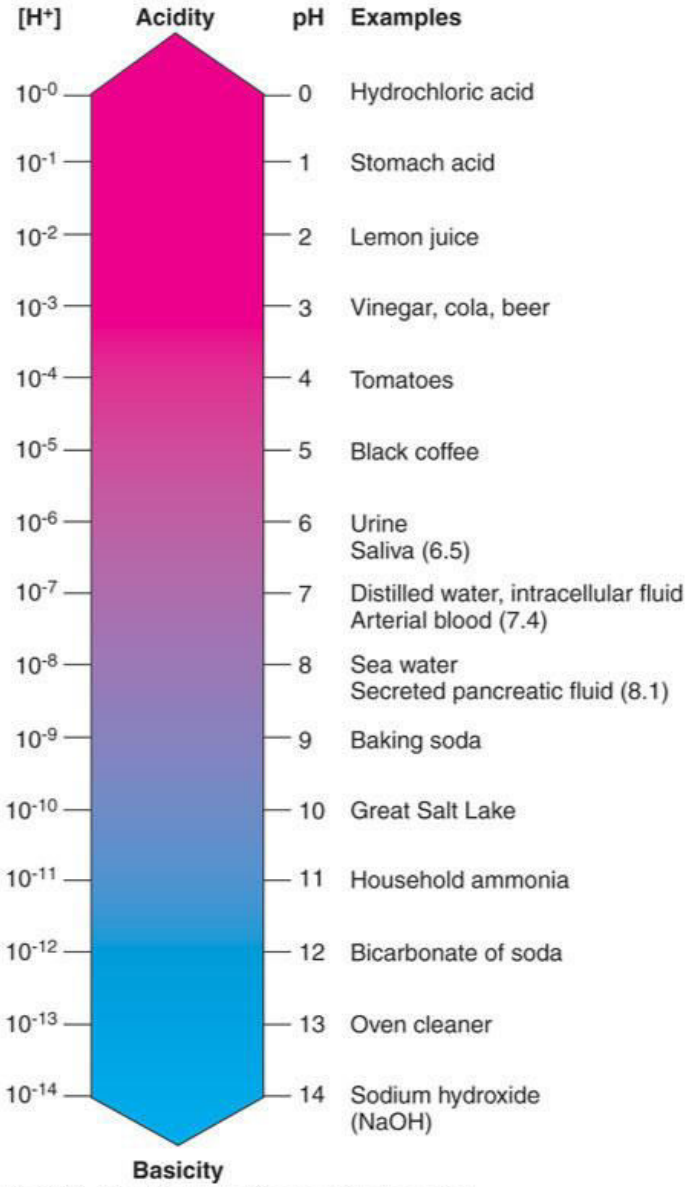
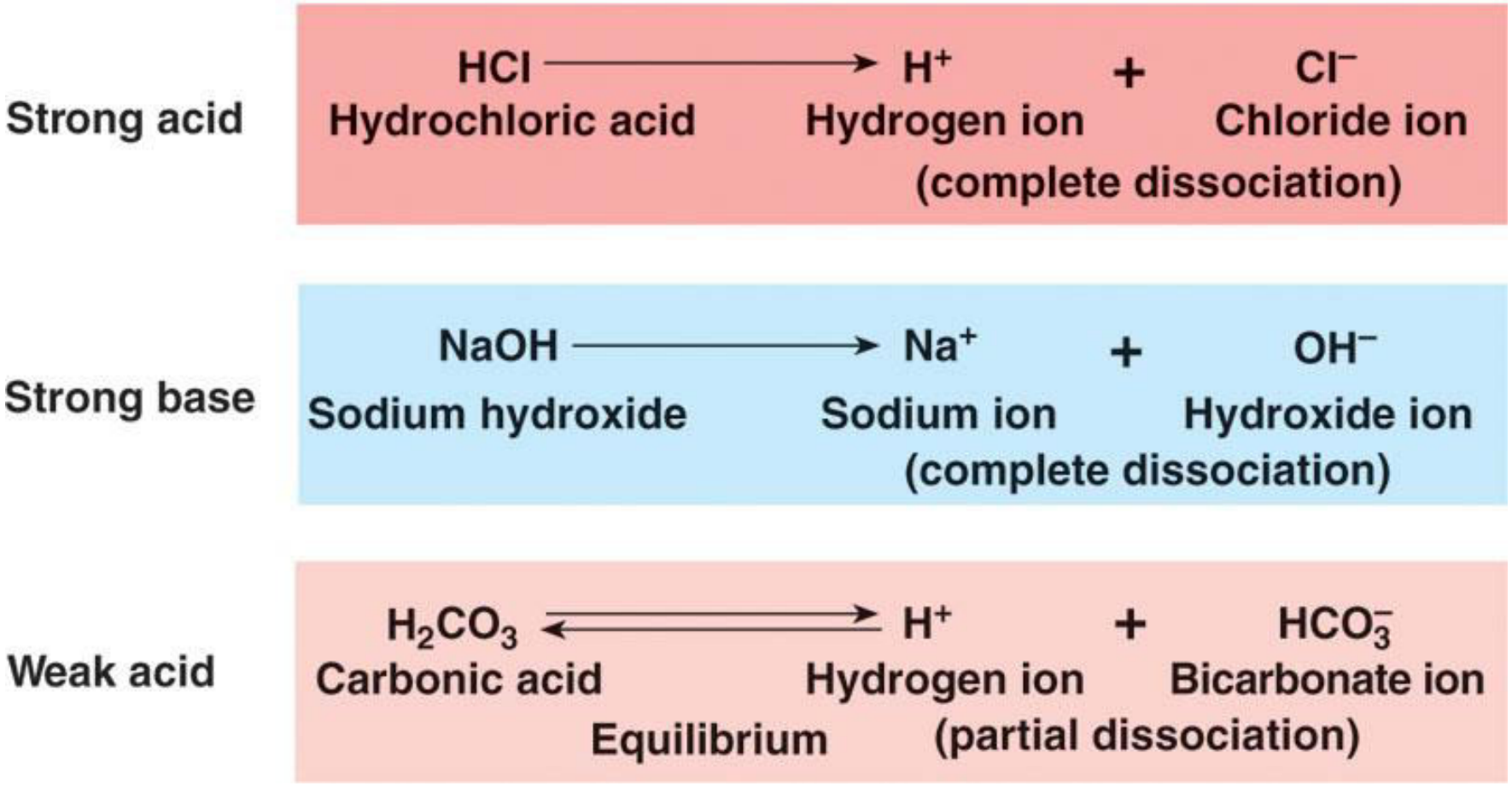


Fig. 30-1. **The pH range.** See text for discussion.

Comparison of Strong and Weak Acids



MECHANISMS THAT CONTROL pH OF BODY FLUIDS (cont.)

- Sources of pH-influencing elements
  - H+ ions are continually entering the body fluids from 5 major sources:
  1. Carbonic acid: formed by aerobic glucose metabolism
  2. Lactic acid: formed by anaerobic glucose metabolism
  3. Sulfuric acid: formed by oxidation of sulfur-containing amino acids
  4. Phosphoric acid: formed in the breakdown of phosphoproteins and ribonucleotides
  5. Acidic ketone bodies: formed in the breakdown of fats
     - Acetone
     - Acetoacetic acid
     - Beta-hydroxybutyric acid
  - Acid-forming minerals: chloride, sulfur, and phosphorus
  - Base forming minerals: potassium, calcium, sodium and magnesium

Regulation of Acid/Base Balance

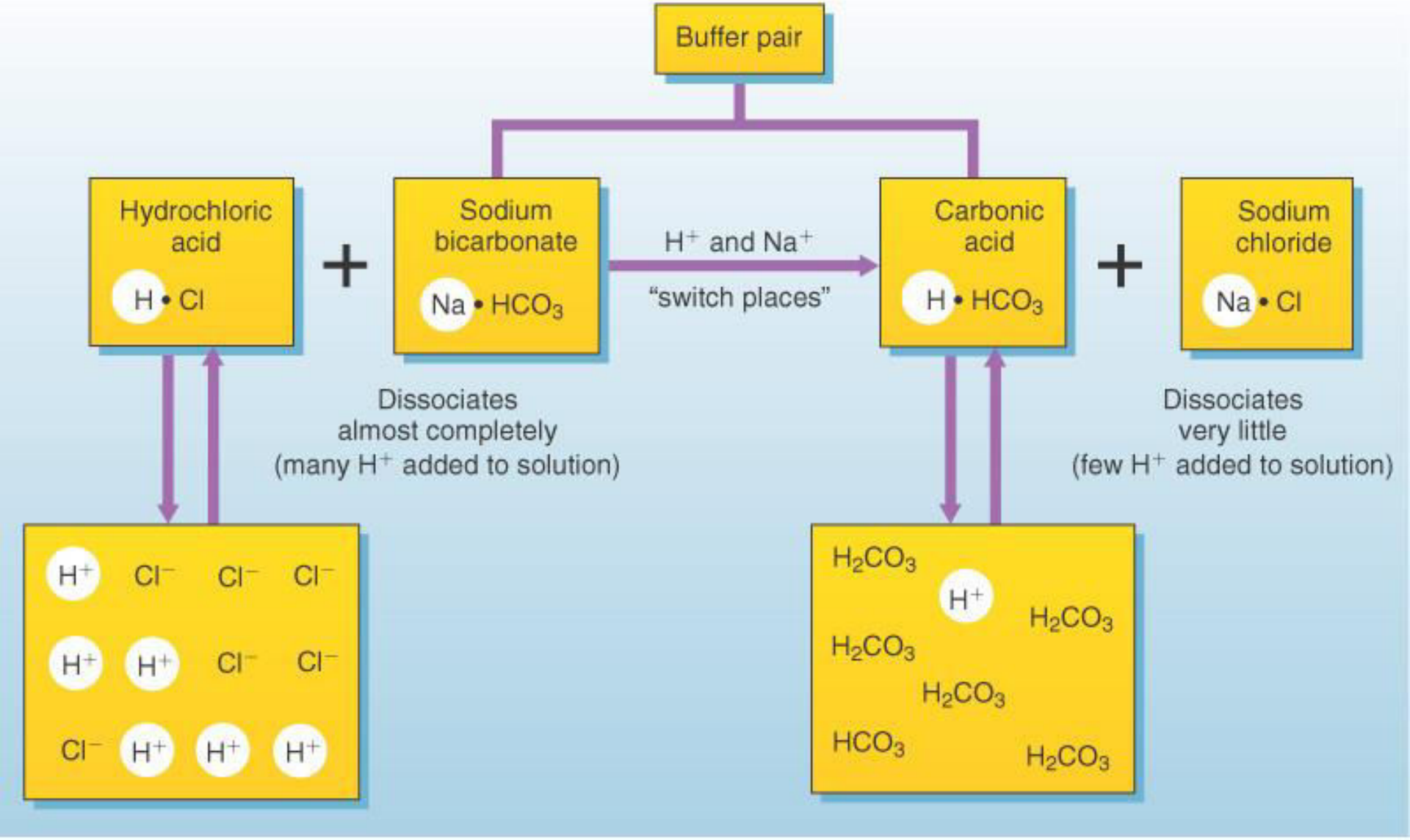
1. Buffers: if pH rises, buffers bind H^+; if pH falls, buffers release H^+
   - Protein buffer: Intracellular and plasma proteins absorb H^+. **Provide ¾ of buffering in body. E.g., hemoglobin.**
   - Bicarbonate buffering system: Important in plasma
   - Phosphate buffer system: important as an intracellular buffer
2. Respiratory center: if pH rises, respiratory rate decreases; if pH falls, respiratory rate increases
3. Kidneys: if pH rises, distal tubule decreases H^+ secretion into the urine and decreases HCO_3^- absorption into the blood (more H_2CO_3 will dissociate into H^+ and HCO_3^-); if pH falls, distal tubule increases H^+ secretion into the urine and increases HCO_3^- absorption into the blood

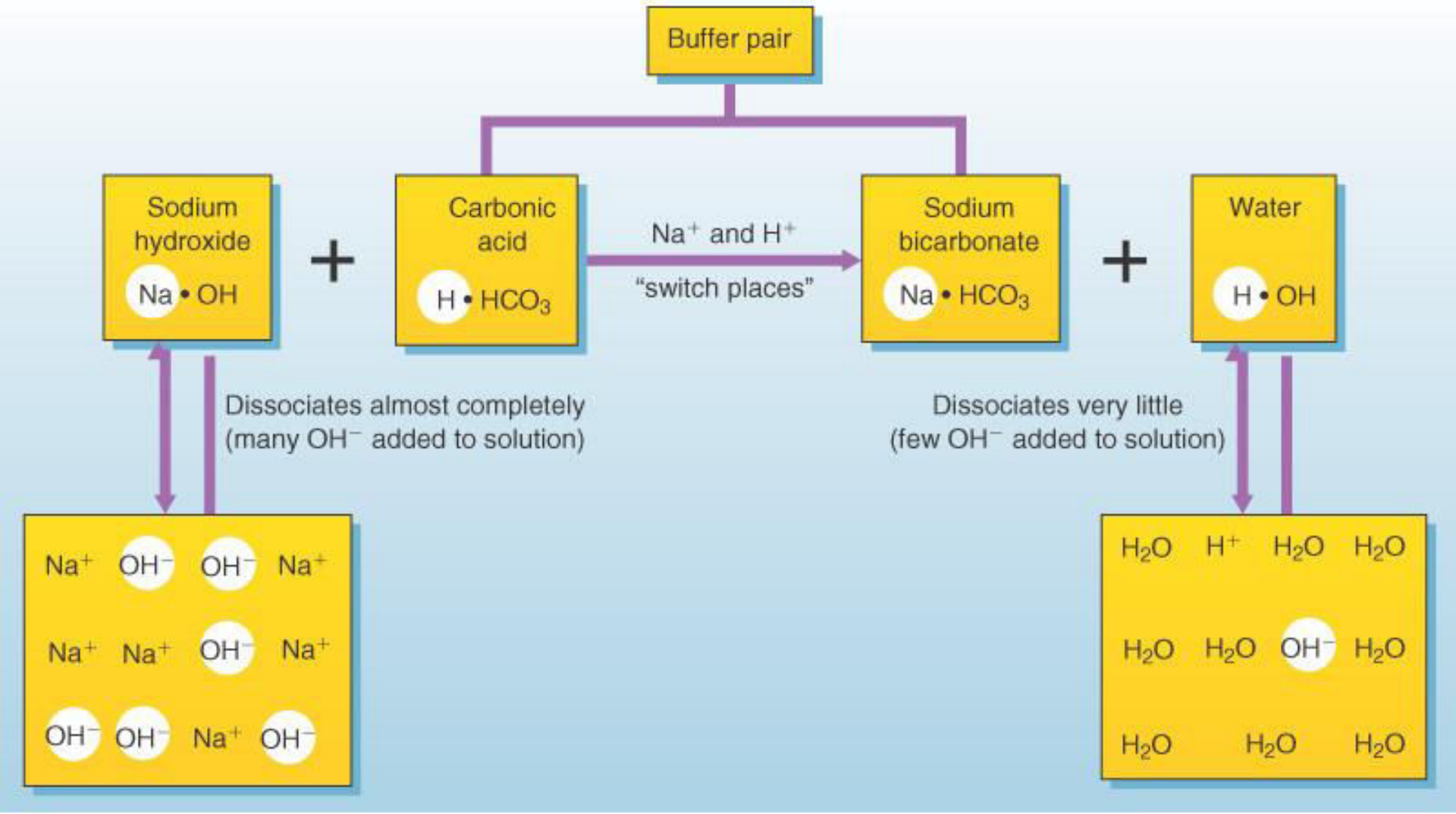
MECHANISMS THAT CONTROL pH OF BODY FLUIDS (cont.)

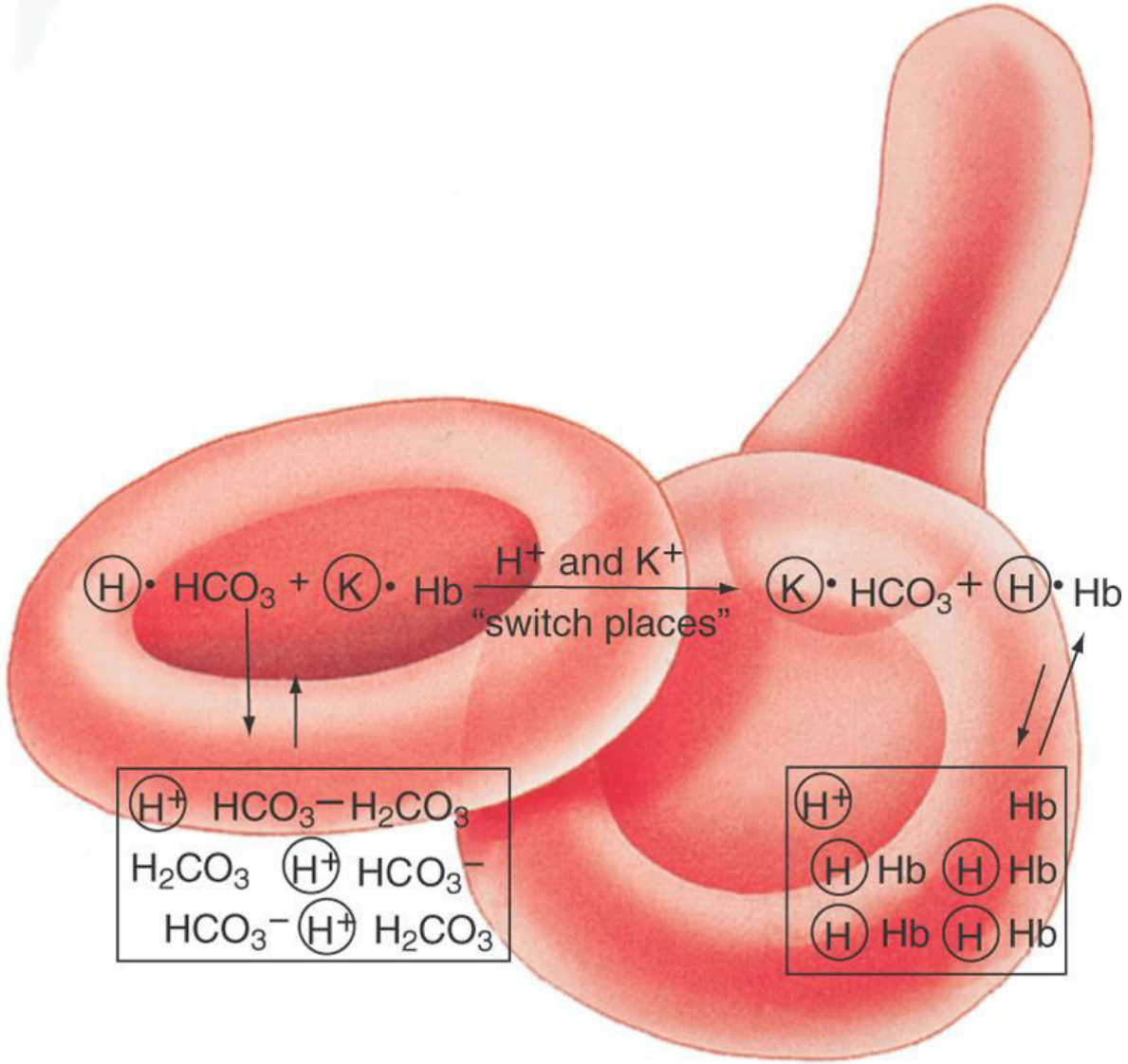
- Types of pH control mechanisms
  - Chemical: rapid-action buffers
    - Bicarbonate buffer system
    - Phosphate buffer system
    - Protein buffer system
  - Physiological: delayed-action buffers
    - Respiratory response
    - Renal response
  - Summary of pH homeostatic mechanisms
    - Buffers
    - Respiration
    - Kidney excretion of acids and bases
    - extremely effective, normally maintain blood pH within very narrow range of 7.36 to 7.40

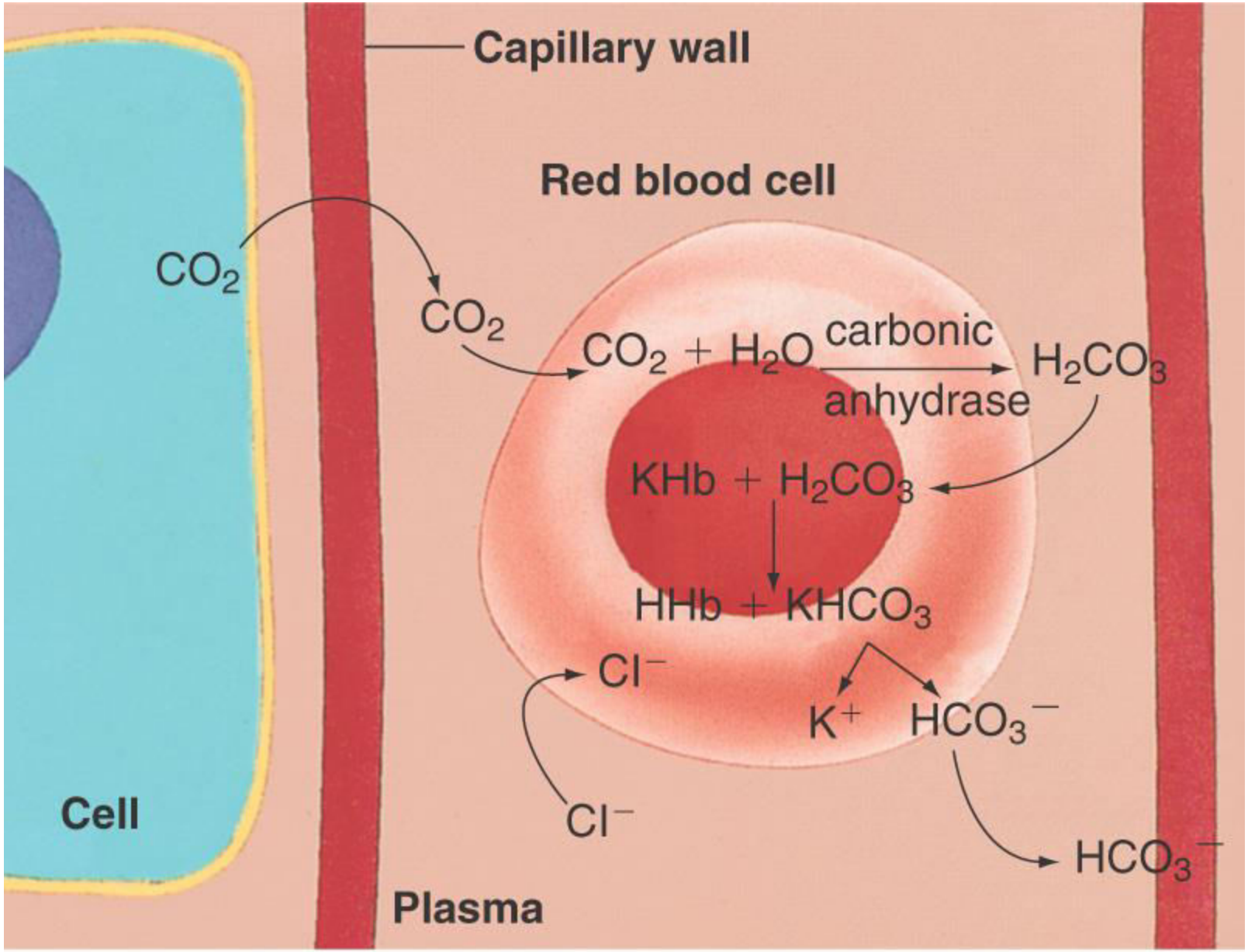
BUFFER MECHANISMS FOR CONTROLLING pH OF BODY FLUIDS

- Buffers
  - Substances that prevent a marked change in pH of a solution when an acid or base is added to it
  - Consist of a weak acid (or its acid salt) and a basic salt of that acid
  - Buffer pairs present in body fluids: mainly carbonic acid, proteins, hemoglobin, acid phosphate, and sodium and potassium salts of these weak acids









BUFFER MECHANISMS FOR CONTROLLING pH OF BODY FLUIDS (cont.)

- Buffer actions that prevent marked changes in pH of body fluids
  - The chloride shift lets carbonic acid be buffered in the red blood cell and then carried as bicarbonate in the plasma (Figure 30-6)
  - Nonvolatile acids, such as hydrochloric acid, lactic acid, and ketone bodies, are buffered mainly by sodium bicarbonate
  - Volatile acids, chiefly carbonic acid, are buffered mainly by potassium salts of hemoglobin and oxyhemoglobin
  - pH balance depends on a base-bicarbonate to carbonic acid buffer pair ratio of 20:1

Respiratory Mechanism of pH Control

- Explanation of mechanism
  - Amount of blood carbon dioxide directly relates to amount of carbonic acid and therefore to concentration of H^+
  - With increased respirations, less carbon dioxide remains in blood, hence less carbonic acid and fewer H^+; with decreased respirations, more carbon dioxide remains in blood, hence more carbonic acid and more H^+
  - Carbon dioxide levels and pH affect respiratory centers
    - Hypoventilation increases blood carbon dioxide levels
    - Hyperventilation decreases blood carbon dioxide levels

$$\mathrm{HCO_3^-} + \mathrm{H^+} \leftrightarrow \mathrm{H_2CO_3} \leftrightarrow \mathrm{CO_2} + \mathrm{H_2O}$$

RESPIRATORY MECHANISMS OF pH CONTROL (cont.)

- Principles that relate respirations to pH value
  - Acidosis $\rightarrow$ Hyperventilation

↓

Increases elimination of CO_2

↓

Decreases blood CO_2

↓

Decreases blood H_2CO_3

↓

Decreases blood H^+ (increases blood pH)

↓

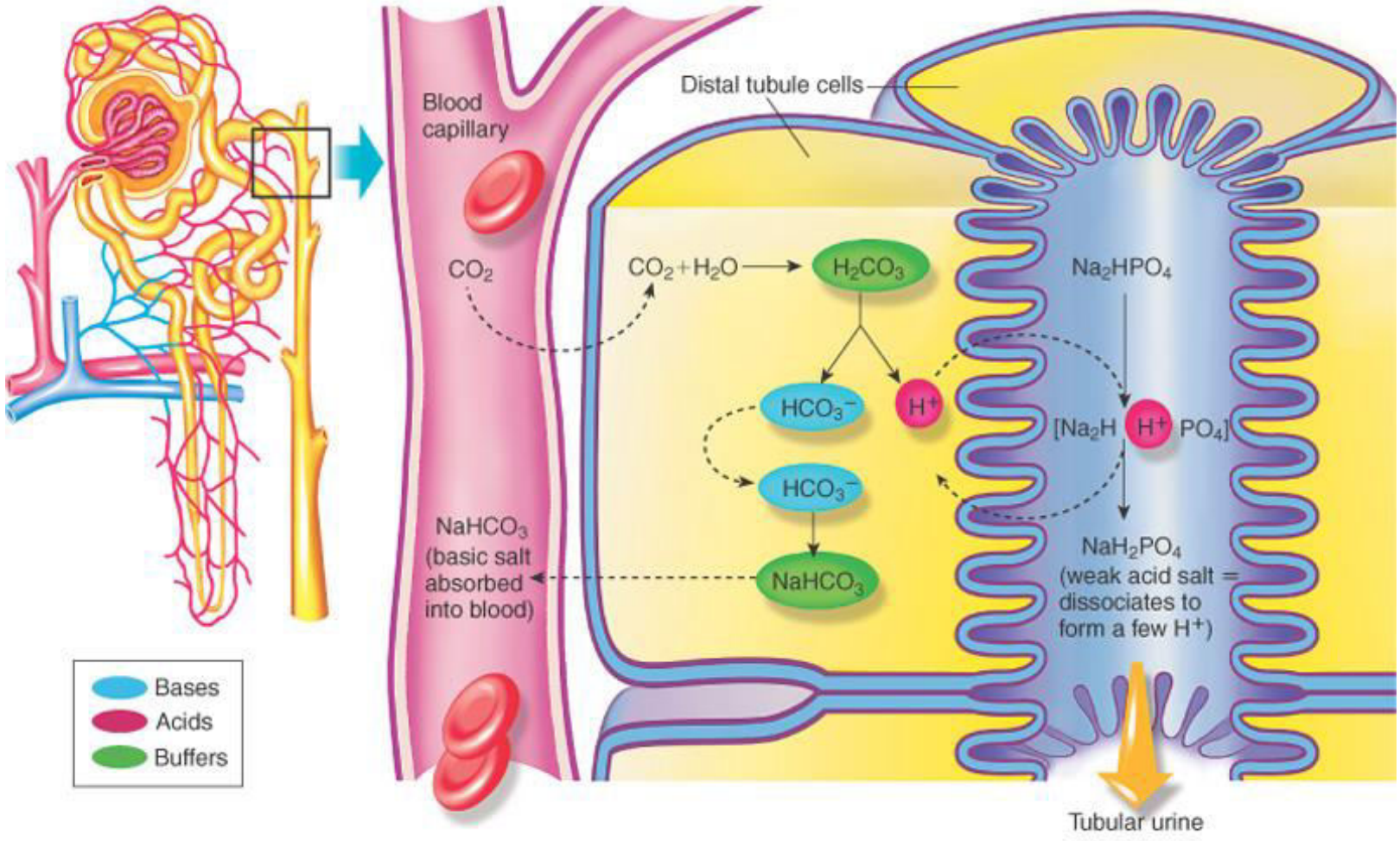
Tends to correct acidosis (restore normal pH)

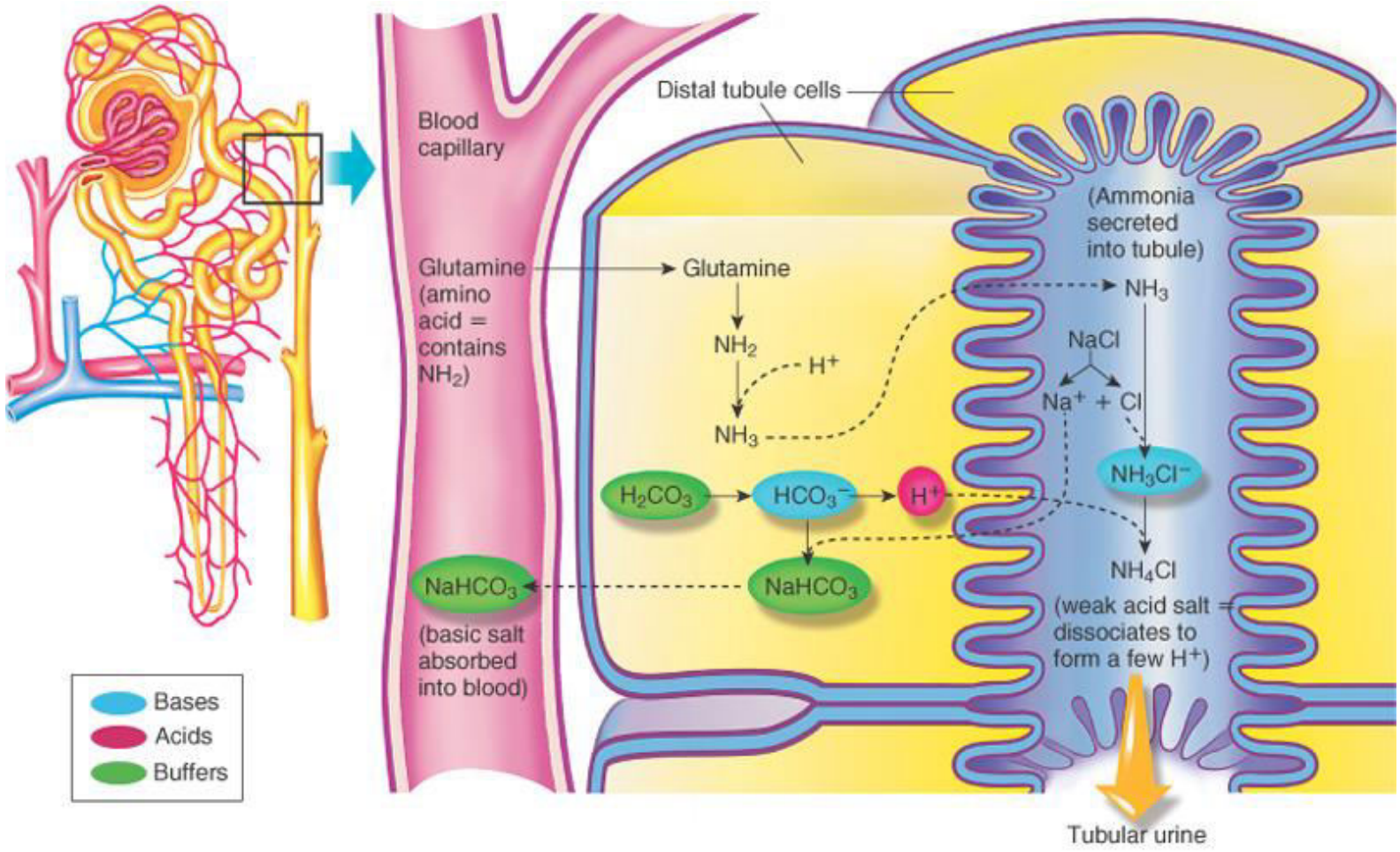
RESPIRATORY MECHANISMS of pH CONTROL (cont.)

- Principles that relate respirations to pH value (cont.)
  - Prolonged hyperventilation, by decreasing blood H^+ excessively, may produce alkalosis
  - Alkalosis causes hypoventilation, which tends to correct alkalosis by increasing blood CO_2 and therefore blood H_2CO_3 and H^+
  - Prolonged hypoventilation, by eliminating too little CO_2, causes an increase in blood H_2CO_3 and consequently in blood H^+, thereby possibly producing acidosis

General principles of Renal Regulation of Acid-Base Balance

- Secretion of H^+ into filtrate and reabsorption of HCO_3^- into ECF cause extracellular pH to increase
- Rate of H^+ secretion increases as body fluid pH decreases





URINARY MECHANISMS THAT CONTROL pH (cont.)

- Mechanisms that control urine pH
  - Secretion of H^+ into urine: when blood CO_2, H_2CO_3, and H^+ increase above normal, distal tubules secrete more H^+ into urine to displace basic ion (mainly sodium) from a urine salt and then reabsorb sodium into blood in exchange for the H^+ excreted
  - Secretion of NH_3: when blood H^+ concentration increases, distal tubules secrete more NH_3, which combines with the H^+ of urine to form ammonium ion, which displaces a basic ion (mainly sodium) from a salt; the basic ion is then reabsorbed back into blood in exchange for the ammonium ion excreted

Acidosis and Alkalosis

- **Acidosis**: pH body fluids below 7.35
  - Respiratory: Caused by inadequate ventilation- reduced elimination of CO_2, asthma, damage to respiratory center in brain, emphysema.
  - Metabolic: Results from all conditions other than respiratory that decrease pH- diarrhea, vomiting, ingesting overdose of aspirin, untreated diabetes mellitus, anaerobic respiration
- **Alkalosis**: pH body fluids above 7.45
  - Respiratory: Caused by hyperventilation, high altitude (reduced partial pressure of O_2
  - Metabolic: Results from all conditions other than respiratory that increase pH- severe vomiting, too much aldosterone, ingestion of substances like bicarbonate of soda