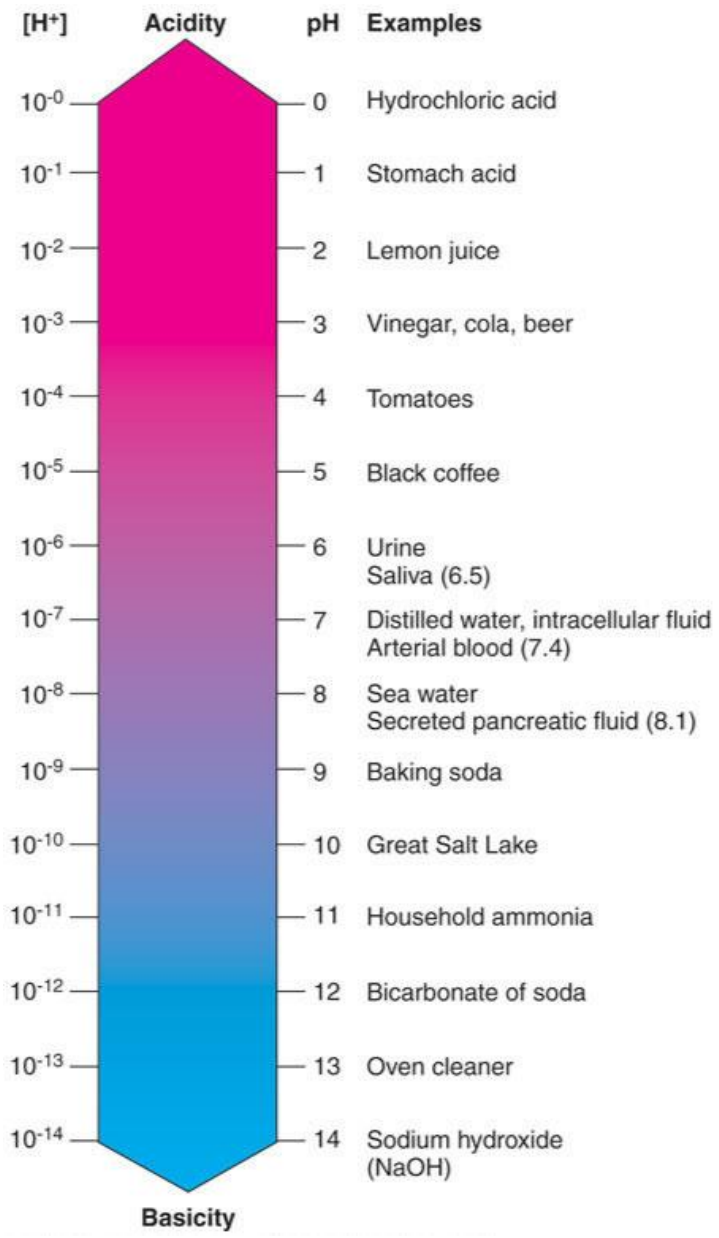
Acid-Base Balance

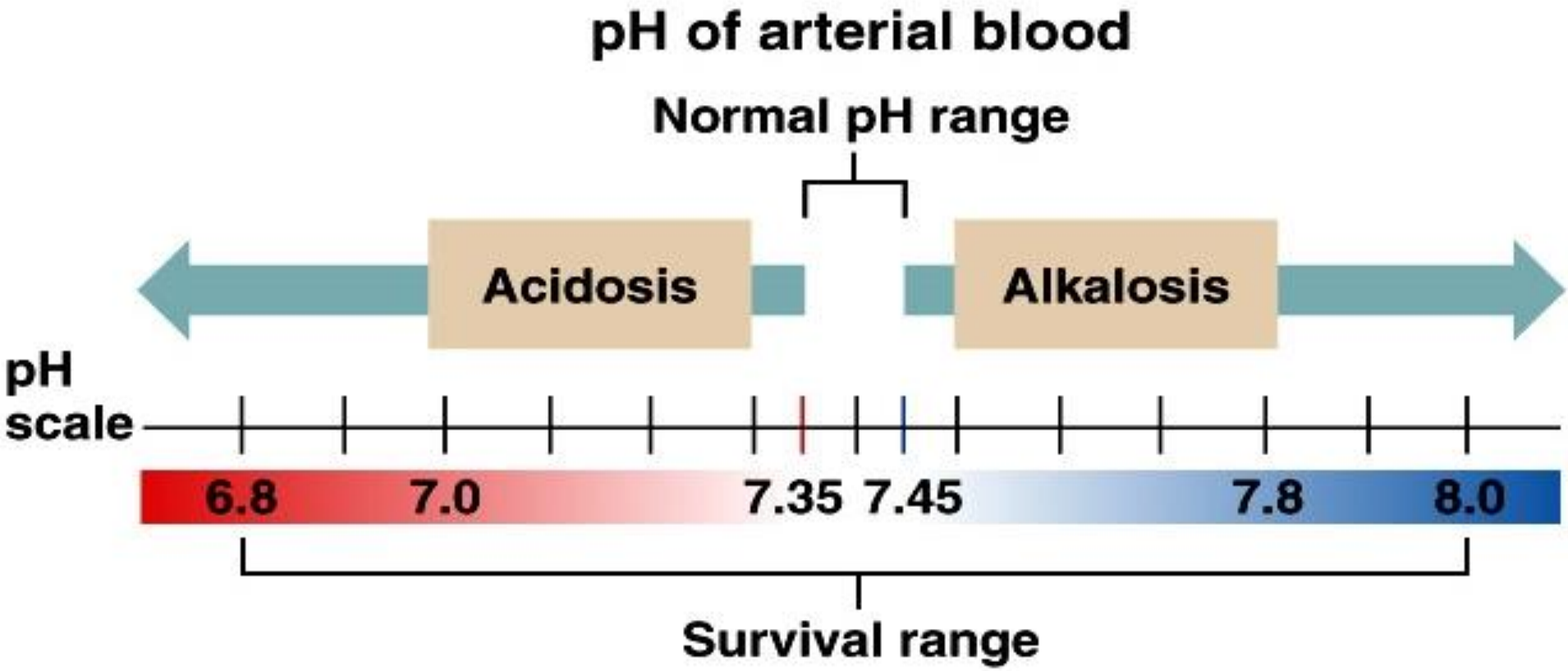
Introduction

- Acid-base balance is one of the most important of the body's homeostatic mechanisms
- Acid-base balance refers to regulation of hydrogen ion (H^+) 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

Mechanisms That Control pH of Body Fluids

- Review of pH concept
  - pH indicates degree of acidity or alkalinity of a solution - range is from 0 - 14
  - If $[H^+]$ is high, solution is acidic; pH < 7
  - If $[H^+]$ is low, solution is basic or alkaline ; pH > 7
  - Acidosis describes arterial blood pH of less than 7.35
  - Alkalosis describes arterial blood pH greater than 7.45


[H+]
Acidity
pH
Examples
10-0
0
Hydrochloric acid
10-1
1
Stomach acid
10-2
2
Lemon juice
10-3
3
Vinegar, cola, beer
10-4
4
Tomatoes
10-5
5
Black coffee
10-6
6
Urine
Saliva (6.5)
10-7
7
Distilled water, intracellular fluid
Arterial blood (7.4)
10-8
8
Sea water
Secreted pancreatic fluid (8.1)
10-9
9
Baking soda
10-10
10
Great Salt Lake
10-11
11
Household ammonia
10-12
12
Bicarbonate of soda
10-13
13
Oven cleaner
10-14
14
Sodium hydroxide
(NaOH)
Basicity


pH of arterial blood
Normal pH range
Acidosis
Alkalosis
pH scale
6.8
7.0
7.35
7.45
7.8
8.0
Survival range

Small changes in pH can produce major disturbances

- Most enzymes function only with narrow pH ranges
- Acid-base balance can also affect electrolytes (Na^+, K^+, Cl^-)
- Can also affect hormones

The body produces more acids than bases

- Acids take in with foods
- Acids produced by metabolism of lipids and proteins
- Cellular metabolism produces CO_2
- $CO_2 + H_20 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3$

Mechanisms That Control pH of Body Fluids

- 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 control mechanisms
    - Buffers
    - Respiration
    - Kidney excretion of acids and bases

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
  - Buffer pairs present in body fluids: mainly carbonic acid, proteins, hemoglobin, acid phosphate, and sodium and potassium salts of these weak acids

Buffer systems

- Take up H+ or release H+ as conditions change
  - Buffer pairs – weak acid and a base
  - Exchange a strong acid or base for a weak one
  - Results in a much smaller pH change
- Types of buffer systems
  - Bicarbonate buffers
  - Phosphate buffers
  - Protein buffers

Bicarbonate buffer

- Sodium Bicarbonate ($NaHCO_3$) and carbonic acid (H_2CO_3)
- Maintain a 20:1 ratio : HCO_3^- : H_2CO_3

$$HCl + NaHCO_3 \leftrightarrow H_2CO_3 + NaCl$$

$$NaOH + H_2CO_3 \leftrightarrow NaHCO_3 + H_2O$$

Phosphate buffer

- Major intracellular buffer
- $H^+ + HPO_4^{2-} \leftrightarrow H_2PO4^-$
- $OH^- + H_2PO_4^- \leftrightarrow H_2O + H_2PO_4^{2-}$

Protein Buffers

- Includes hemoglobin, work in blood and ISF
- Carboxyl group gives up H^+
- Amino Group accepts H^+
- Side chains that can buffer H^+ are present on 27 amino acids

2. Respiratory mechanisms

- Respiratory mechanism – limited to adjustments of CO_2.
  - With every exhalation CO_2 and H_2O leaves the body
  - Hypoventilation causes respiratory acidosis, and hyperventilation cause respiratory alkalosis
  - Respiratory control centers “sense” and regulate RR and depth
  - Changes in respiratory rate and depth also can partially correct metabolic disturbances

Respiratory Mechanisms of pH Control

- Explanation of respiratory mechanisms
  - Amount of blood carbon dioxide (CO_2) directly relates to the amount of carbonic acid and therefore to the concentration of H^+
  - With increased respirations, less CO_2 remains in blood, hence less carbonic acid and fewer H^+; with decreased respirations, more CO_2 remains in blood, hence more carbonic acid and more H^+
- Respirations adjustment to counter pH imbalance of arterial blood

Respiratory Mechanisms of pH Control

- Principles that relate respirations to pH value
  - 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

3. Kidney excretion

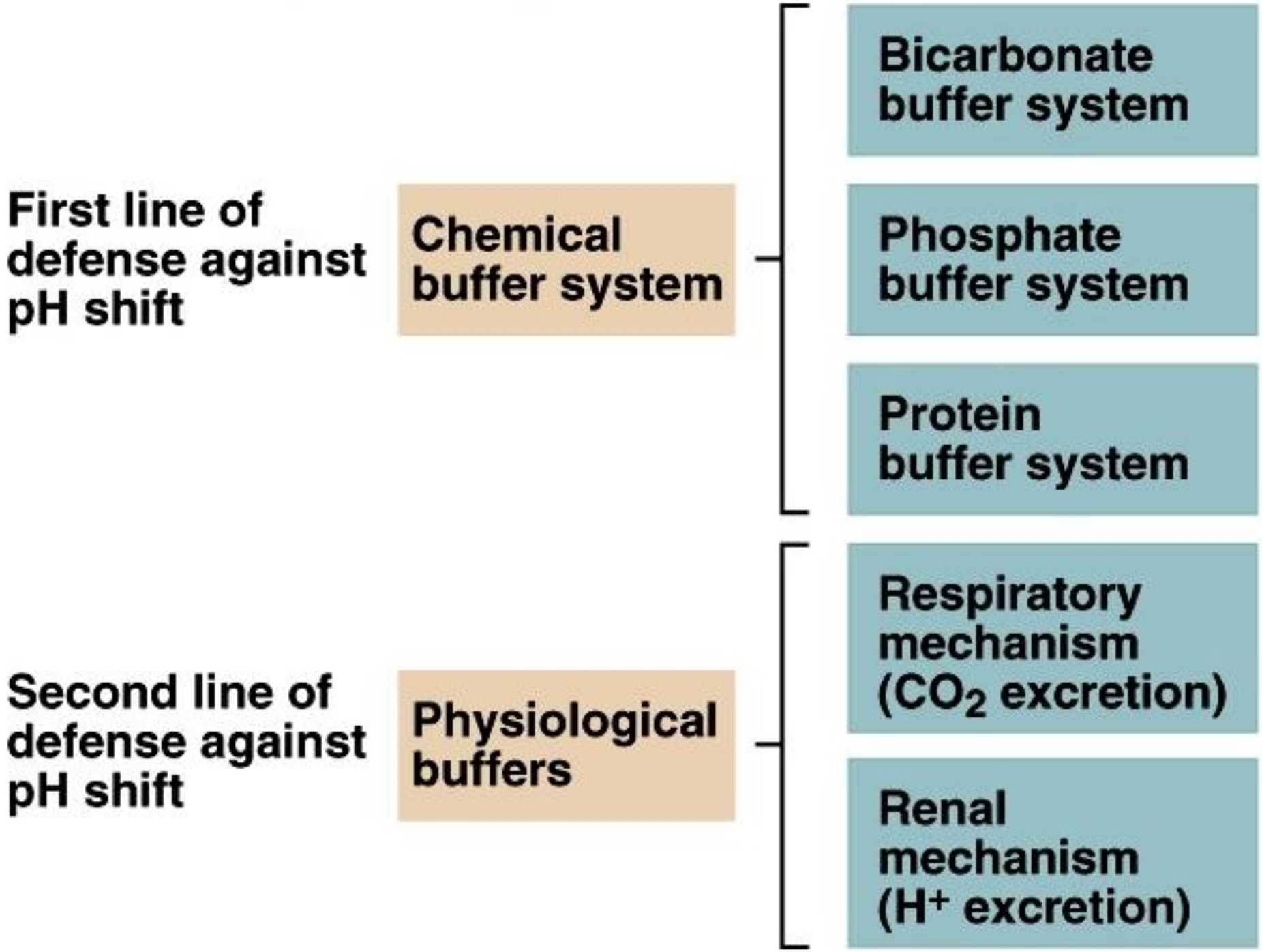
- Urinary mechanism - greatest capacity to adjust pH changes
- Slow to begin but long-lasting
  - The kidneys are the most effective regulators of blood pH
  - Eliminates much larger amounts of acid than the lungs, and if necessary can excrete excess base which the lungs cannot do
  - Renal Failure – acid base control fails

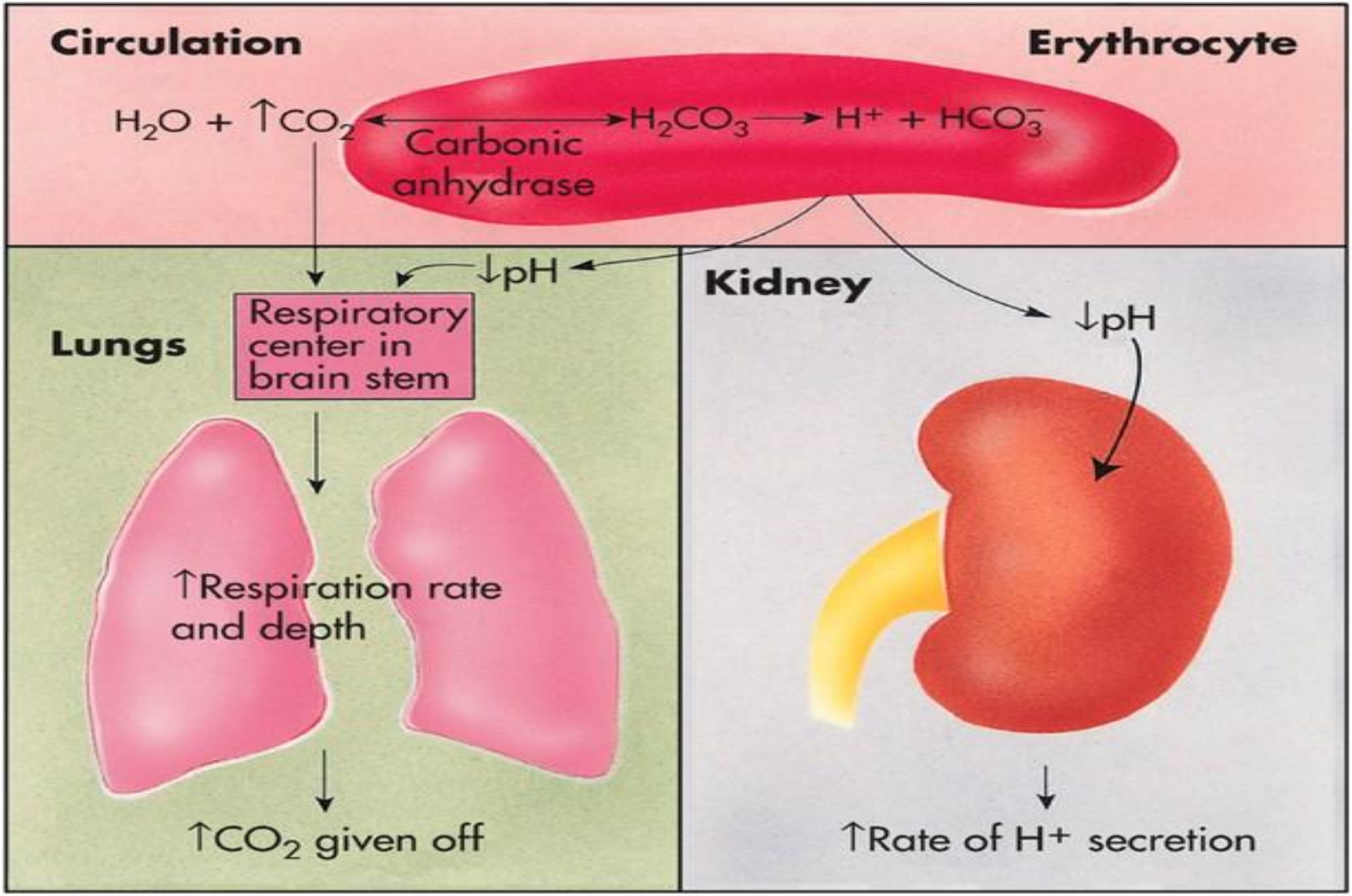
Urinary Mechanisms That Control pH

- General principles concerning urinary mechanisms
  - play vital role in acid-base balance because kidneys can eliminate more H^+ from the body while reabsorbing more base when pH lowers
- Mechanisms that control urine pH
  - Secretion of H^+ into urine: when blood CO_2, H_2CO_3, and H^+ increase above normal
  - Secretion of NH_3: when blood H^+ concentration increases, distal tubules secrete more NH_3

Rates of correction

- Buffers function almost instantaneously
- Respiratory mechanisms take several minutes to hours
- Renal mechanisms may take several hours to days
- Evaluation of the role of buffers in pH control: cannot maintain normal pH without adequate functioning of the respiratory and urinary pH control mechanisms


First line of defense against pH shift
Chemical buffer system
Bicarbonate buffer system
Phosphate buffer system
Protein buffer system
Second line of defense against pH shift
Physiological buffers
Respiratory mechanism (CO_2 excretion)
Renal mechanism (H^+ excretion)



From Thibodeau GA, Patton KT: *Anatomy & physiology*, ed 5, St Louis, 2003, Mosby.

Acid Base Disturbances

- Metabolic Acidosis – to little bicarbonate
  - Acidosis – may be related to kidney disease, uncontrolled diabetes mellitus, excessive diarrhea, vomiting or use of diuretics
    - Increased H^+ stimulate respiratory centers and RR increases
    - Effects/symptoms of acidosis – depresses CNS, confusion, coma, and perhaps death

Acid Base Disturbances

- Metabolic
  - Ketoacidosis
    - Occurs in diabetic patients (and those on the Atkin's diet) when fats and proteins are used for energy instead of glucose
    - The use of fats without some glucose is inefficient and ketones accumulate in the blood making it acid

Acid Base Disturbances

- Metabolic Alkalosis - to much bicarbonate
  - Alkalosis – rare but can occur with ingestion of too many antacids, vomiting of stomach contents only
    - Effects/symptoms – affects the PNS, irritability, muscle spasms, convulsions

Acid Base Disturbances

- Respiratory Disturbances
  - Acidosis – to much carbonic acid
    - Seen in pneumonia and emphysema which retains CO2 in blood
    - Also seen in drug abuse and decreased breathing
  - Alkalosis – to little carbonic acid
    - Seen in hyperventilation

Language of Medicine – Ch. 30

- Bicarbonate loading
- Emesis
- Hyperkalemia
- Lactic acidosis
- Metabolic acidosis
- Metabolic alkalosis
- Pernicious vomiting
- Respiratory acidosis
- Respiratory alkalosis