Acid-base Balance

Acids and Bases

Acids release H^+ and are therefore proton donors

$$\mathbf{HCl \rightarrow H^+ + Cl^-}$$

Bases are proton acceptors, some release OH^-

$$\mathbf{NaOH \rightarrow Na^+ + OH^-}$$

$$HCO_3^- + H^+ \rightarrow \mathbf{H_2CO_3}$$

Strong acid- has high tendency to dissociate

Weak acid- has a low tendency to dissociate

Strong alkali- high tendency to remove H+ from solution

Weak alkali- low tendency to remove H+ from solution

pH

$pH = \log 1/ [H^+]$

WATER

$H_2 0 \longrightarrow H^+ + OH^-$

$[H^+] = 10^{-7}$ mol/l

$pH = \log 1/ [10^{-7}]$

So pH of pure water = 7 **Neutral pH**

Acid-Base Concentration (pH)

- Acidic solutions have higher H^+ concentration and therefore a lower pH
- Alkaline solutions have lower H^+ concentration and therefore a higher pH
- Neutral solutions have equal H^+ to that of pure water

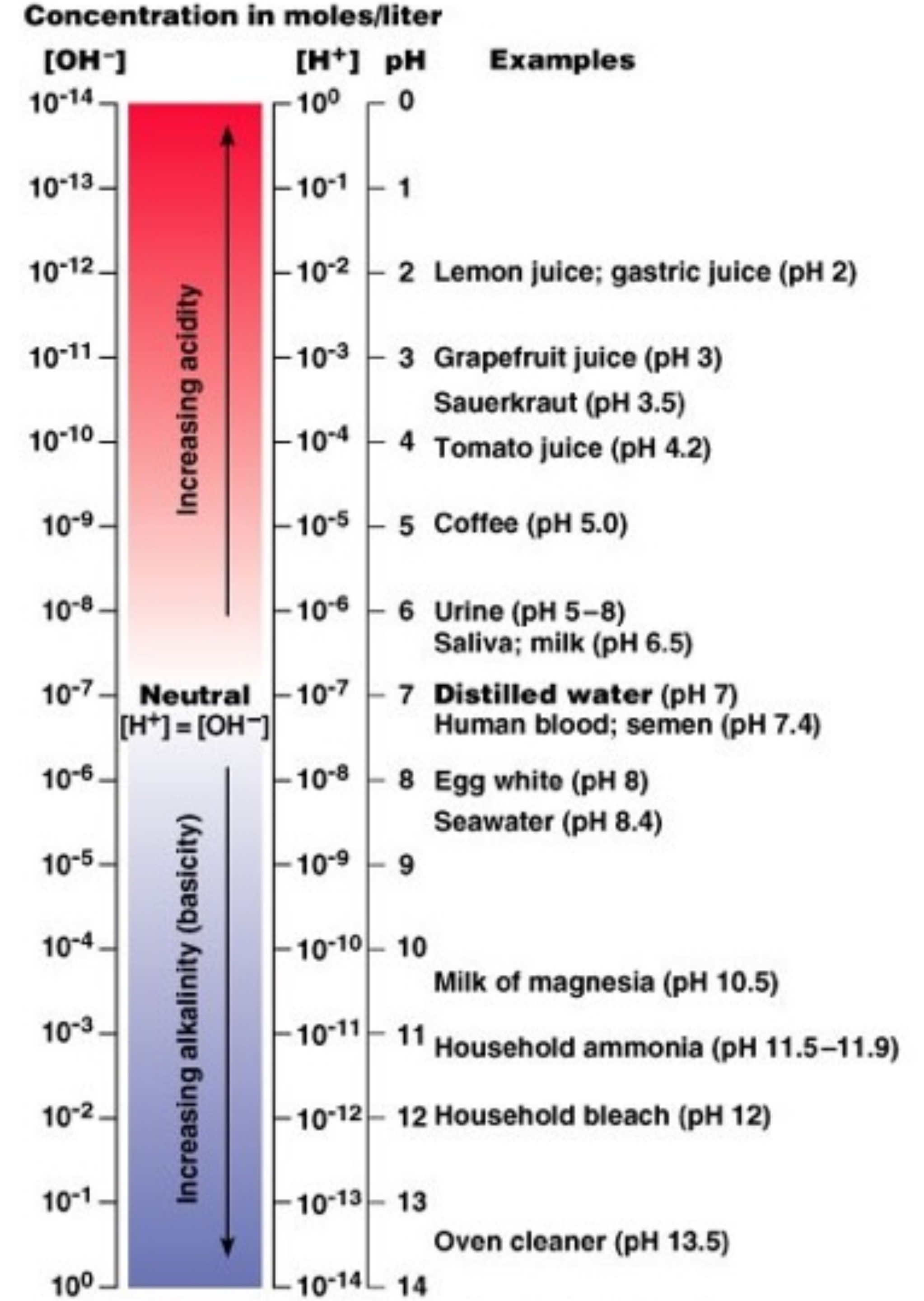

Concentration in moles/liter
[OH⁻]
[H⁺]
pH
Examples
10^-14 10^0 0
10^-13 10^-1 1
10^-12 10^-2 2 Lemon juice; gastric juice (pH 2)
10^-11 10^-3 3 Grapefruit juice (pH 3)
Sauerkraut (pH 3.5)
10^-10 10^-4 4 Tomato juice (pH 4.2)
10^-9 10^-5 5 Coffee (pH 5.0)
10^-8 10^-6 6 Urine (pH 5–8)
Saliva; milk (pH 6.5)
10^-7 10^-7 7 Distilled water (pH 7)
Human blood; semen (pH 7.4)
10^-6 10^-8 8 Egg white (pH 8)
Seawater (pH 8.4)
10^-5 10^-9 9
10^-4 10^-10 10
Milk of magnesia (pH 10.5)
10^-3 10^-11 11 Household ammonia (pH 11.5–11.9)
10^-2 10^-12 12 Household bleach (pH 12)
10^-1 10^-13 13
Oven cleaner (pH 13.5)
10^0 10^-14 14
Increasing acidity
Neutral
[H⁺] = [OH⁻]
Increasing alkalinity (basicity)

Figure 2.12

pH control

- The pH of the ECF remains between 7.35 and 7.45
  - If plasma levels fall below 7.35 (acidemia), acidosis results
  - If plasma levels rise above 7.45 (alkalemia), alkalosis results
  - Alteration outside these boundaries affects all body systems
    - Can result in coma, cardiac failure, and circulatory collapse

Significance of pH

- Chemical reactions sensitive to it
- Enzyme activity
- Cell membrane integrity
- Neural excitability
  - Fall in pH- coma
  - Rise in pH- fits
- Muscular contractility

Protein Denuaturation

- Reversible unfolding of proteins due to drops in pH and/or increased temperature

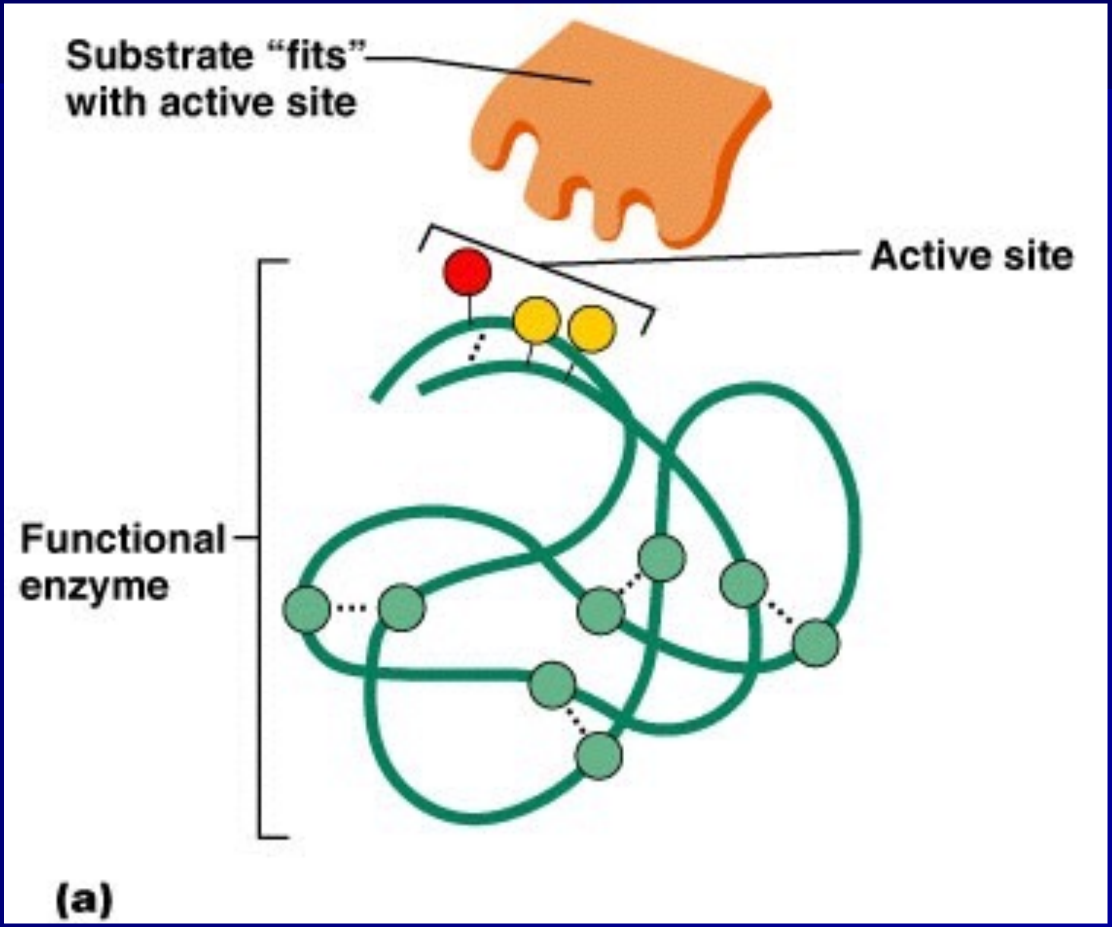


Figure 2.18a

Protein Denuaturation

- Irreversibly denatured proteins cannot refold and are formed by extreme pH or temperature changes

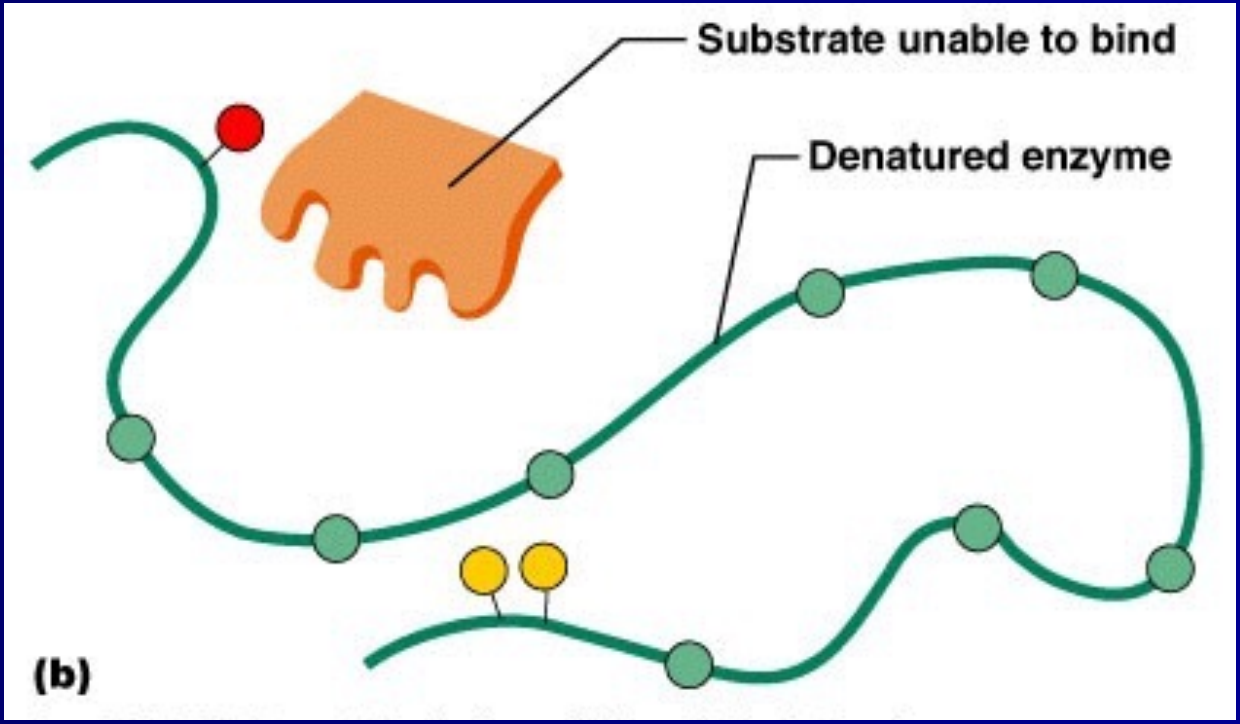


Figure 2.18b

Normal pH

- Plasma- 7.40 +/- 0.05
- If <7.1 or >7.6 – DEATH

- NB intracellular pH is lower than plasma pH
- Plasma pH is relatively easy to measure

Types of acids in the body

- Body is effectively an ‘ Acid producer’
- Volatile acid
  - Can leave solution and enter the atmosphere (e.g. carbonic acid)
  - $H^+ + HCO_3^- \leftrightarrow H_2CO_3 \leftrightarrow \mathbf{CO_2} + H_2O$
- Non-volatile acids
  - Acids that do not leave solution (e.g. sulfuric and phosphoric acids)
  - NH_4^+

Other sources of acid

- Exercise- lactic acid
- Diet
- Drugs
- Disease processes
  - Loss of alkali eg diarrhoea
  - Impaired removel- renal ds
  - Diabetes mellitus

Common Acids

- Carbonic acid is most important factor affecting pH of ECF
  - CO_2 reacts with water to form carbonic acid
  - Inverse relationship between pH and concentration of CO_2
- Sulfuric acid and phosphoric acid
  - Generated during catabolism of amino acids
- Organic acids
  - Metabolic byproducts such as lactic acid, ketone bodies

Sources of alkali

- Diet
- Loss of acid- vomiting
- Drugs

Buffers

- Systems that resist abrupt and large swings in the pH of body fluids
- Types:
  - Chemical buffers
  - Physiological buffers

Body buffering systems

- **I Chemical buffers**
  - Protein buffer system
    - Intra-cellular & plasma proteins
    - Hemoglobin buffer system
      - H^+ are buffered by hemoglobin
  - Bicarbonate
  - Minor buffering system
    - Phosphate

Body buffering systems

- **II Physiological buffers**
  - Respiratory system
  - Renal system

In general, HA <=> $H^+ + A^-$,

$$Ka = \frac{[H^+][A^-]}{[HA]} \quad \text{and} \quad pH = pKa + \log_{10}\frac{[A^-]}{[HA]}$$

This is the Henderson-Hasselbach equation.

Protein Buffers

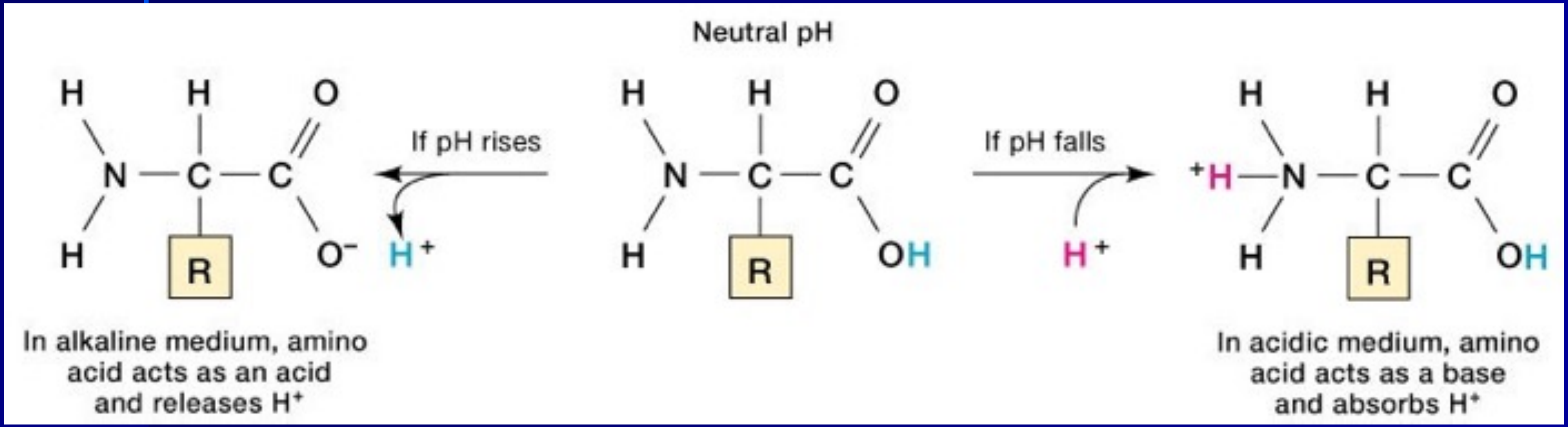


Figure 27.8

Protein buffer system

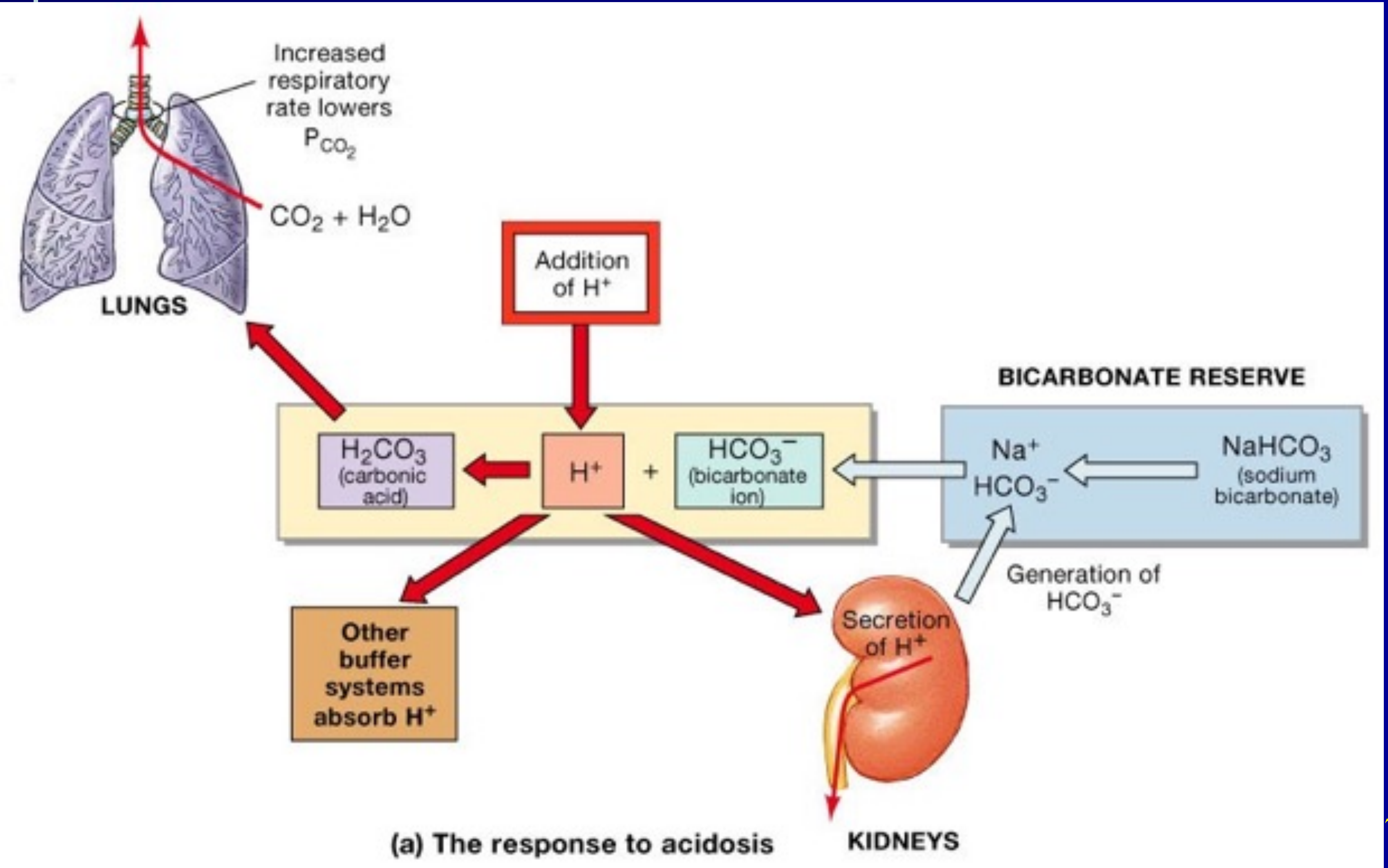
- If pH climbs, the carboxyl group of amino acid acts as a weak acid
- If the pH drops, the amino group acts as a weak base
- Hemoglobin buffer system
  - Prevents pH changes when P_{CO2} is rising or falling

- Haemoglobin
  - As a protein
  - Imidazole group of the Histidine residues
    - Can accept or release H^+
    - Each Hb has 38 Histidine residues
  - More effective than the plasma proteins

Carbonic Acid-Bicarbonate Buffering System

- Carbonic acid-bicarbonate buffer system
  - $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
- pK is 6.10
- $pH = 6.10 + \text{Log}[HCO_3^-] / [H_2CO_3]$

Carbonic Acid-Bicarbonate Buffer in the Regulation of pH



(a) The response to acidosis

7.11a

Carbonic Acid-Bicarbonate Buffer in the Regulation of pH

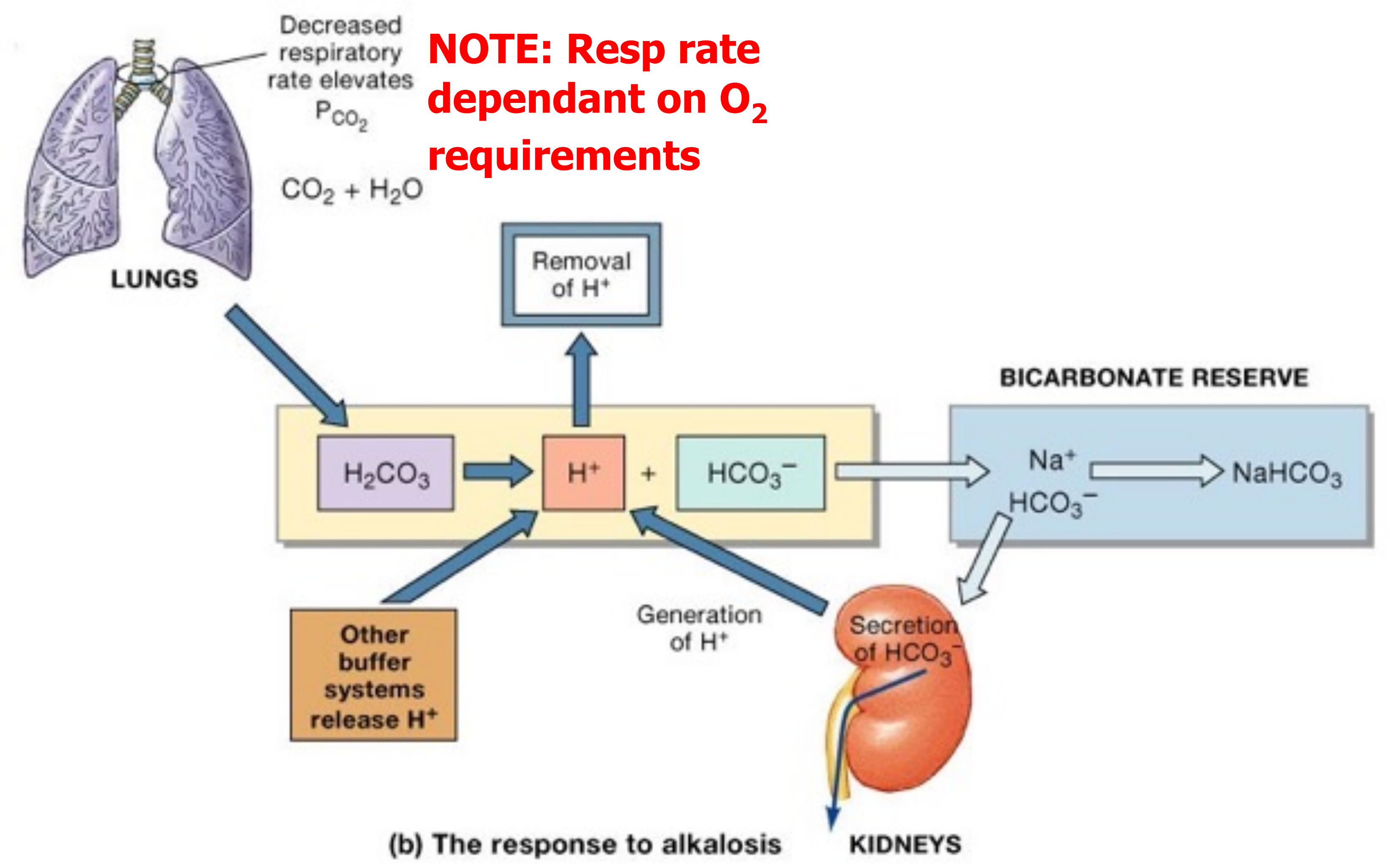


Figure 27.11b

The Carbonic Acid-Bicarbonate Buffer System

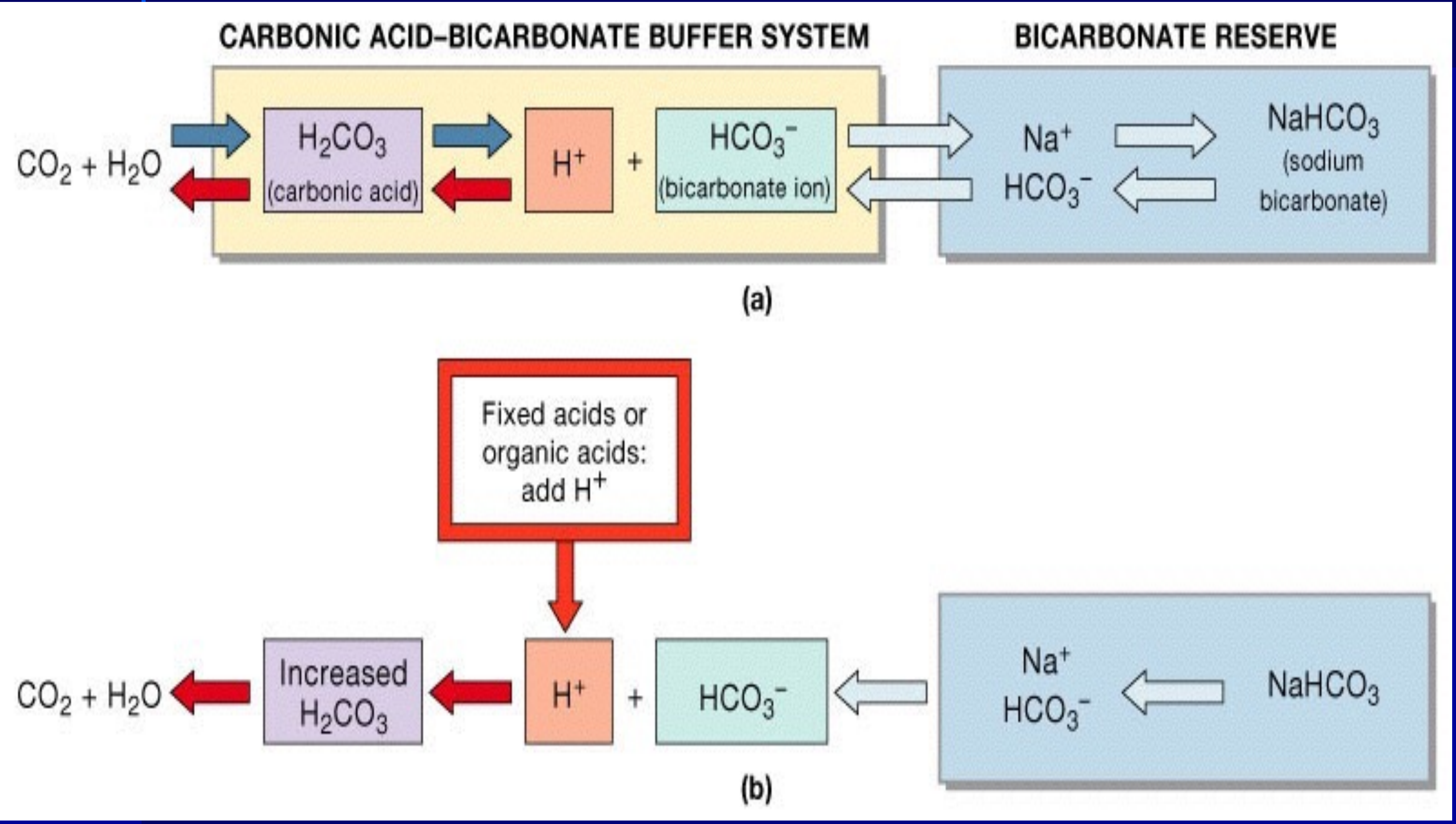
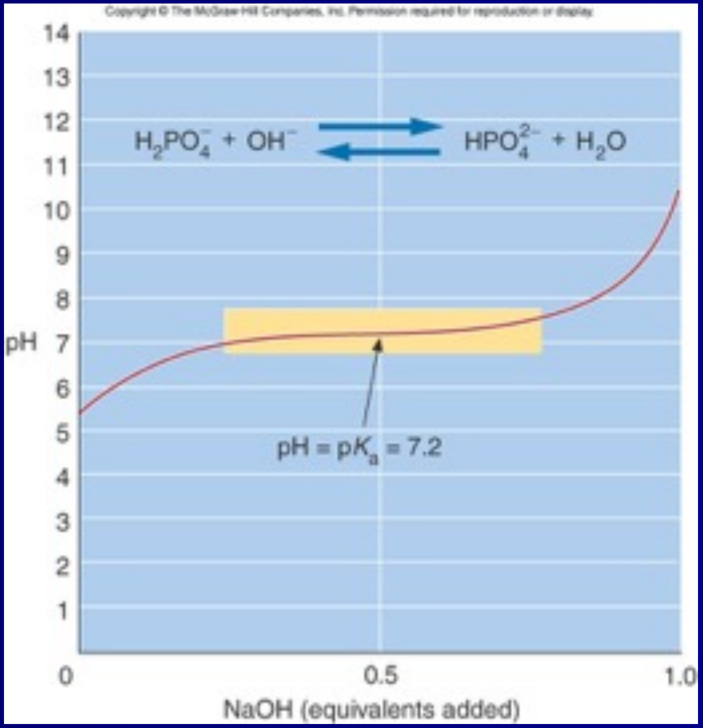


Figure 27.9a, b

Phosphate buffer-intracelluar

$H_2PO_4^- \leftrightarrow HPO_4^{2-} + H^+$

$H_2PO_4^- + OH^- \leftrightarrow HPO_4^{2-} + H_2O$



Figu
Syst ds

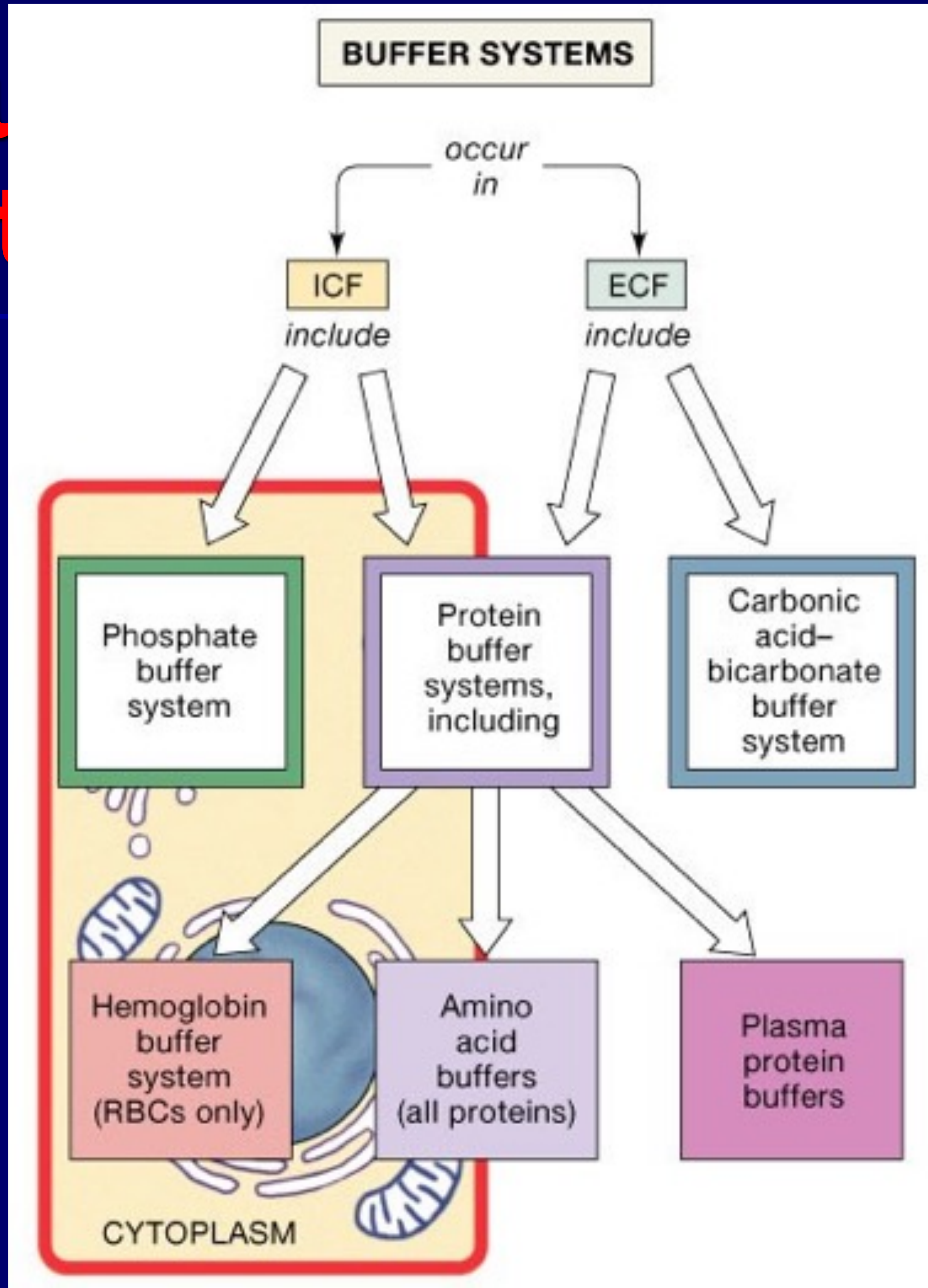


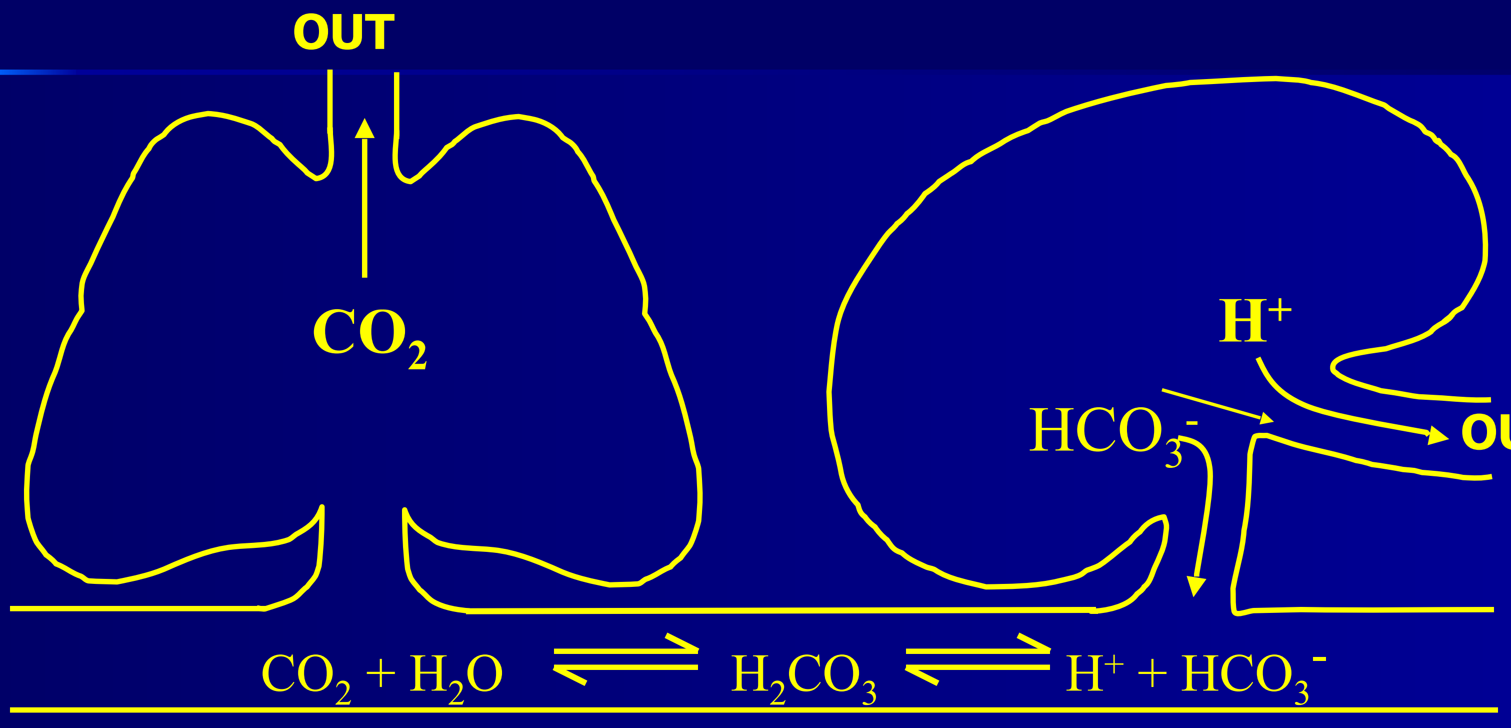
Figure 27.7

Physiological buffers

- Respiratory system
- Renal system

Maintenance of acid-base balance

- Lungs help regulate pH through carbonic acid - bicarbonate buffer system
  - Changing respiratory rates changes P_{CO2}
    - Respiratory compensation
- Kidneys help regulate pH through renal compensation


OUT
CO2
H+
HCO3-
OUT
CO2 + H2O ⇌ H2CO3 ⇌ H+ + HCO3-

Respiratory system

$$H^+ + HCO_3^- \leftrightarrow H_2CO_3 \leftrightarrow H_2O + CO_2$$ blown out

- Effect of respiration on pH
  - Rise in ventilation fall in CO_2
  - Fall in ventilation – rise in CO_2
- Effect of pH on ventilation
  - Ventilation rate is proportional to the amount of H^+
  - Fall in pH- rise in ventilation

Renal processes

- H^+ excretion
- HCO_3^- reabsorption
- NH_4^+ excretion

Renal pH Regulation

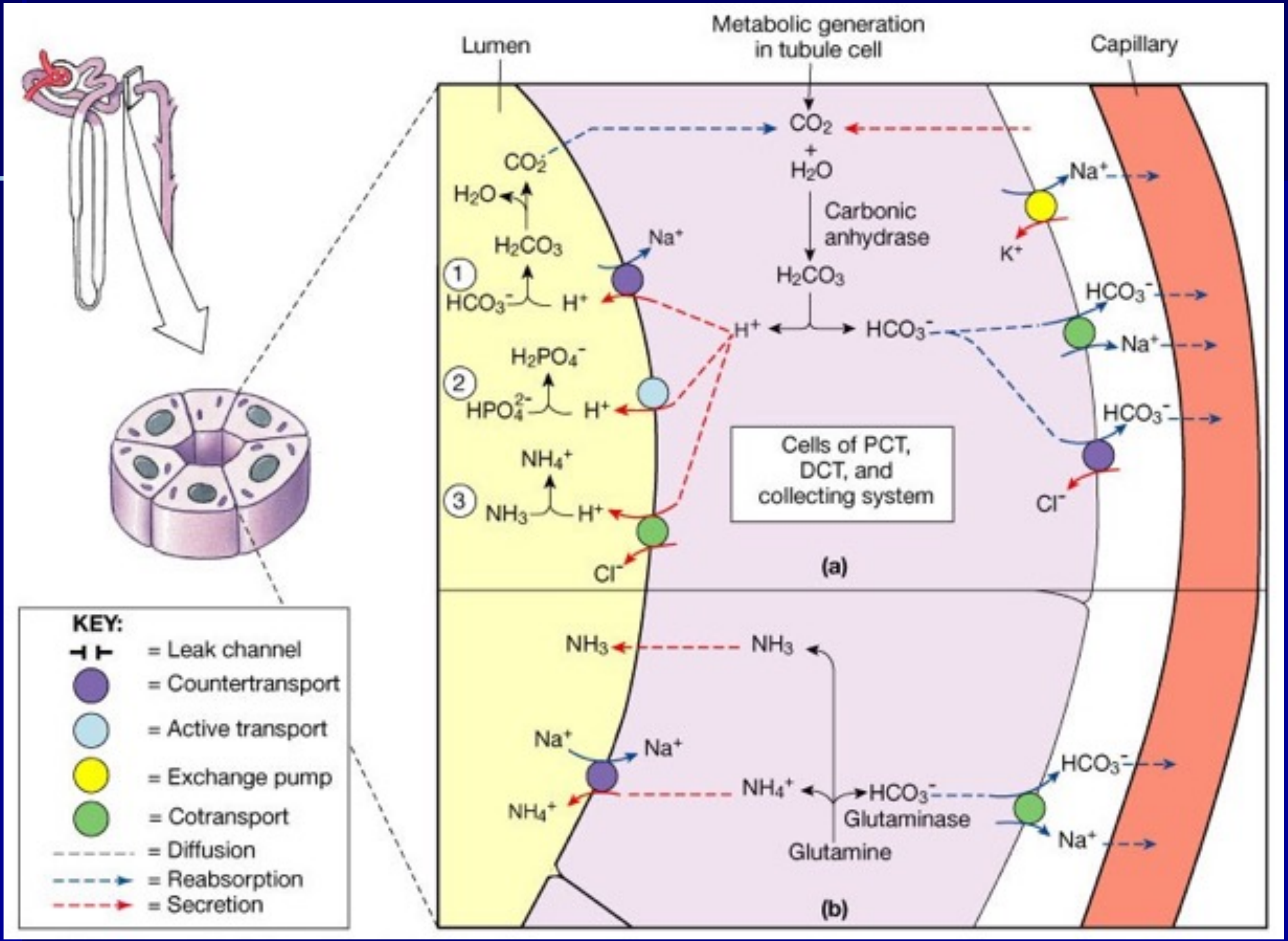
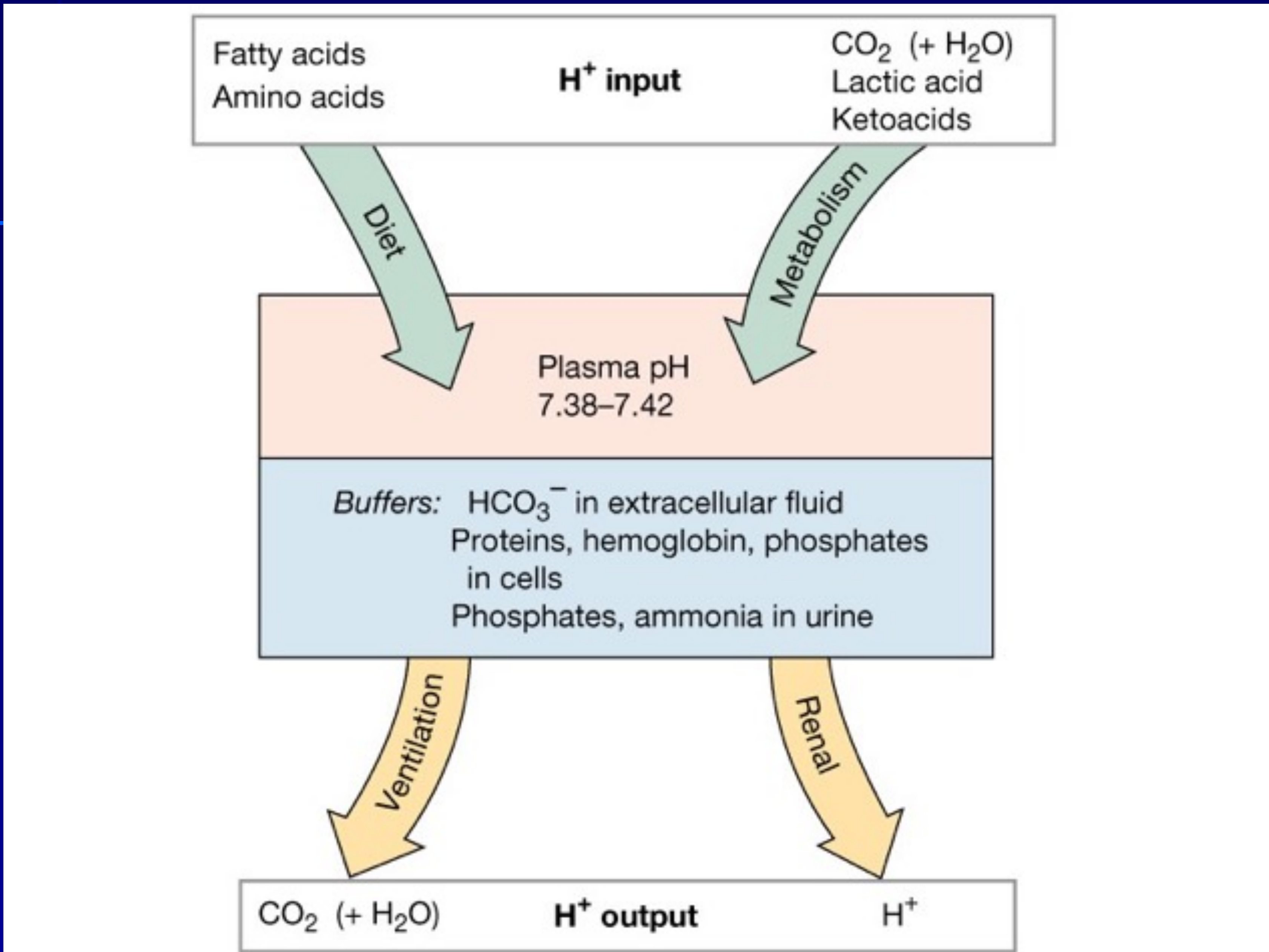
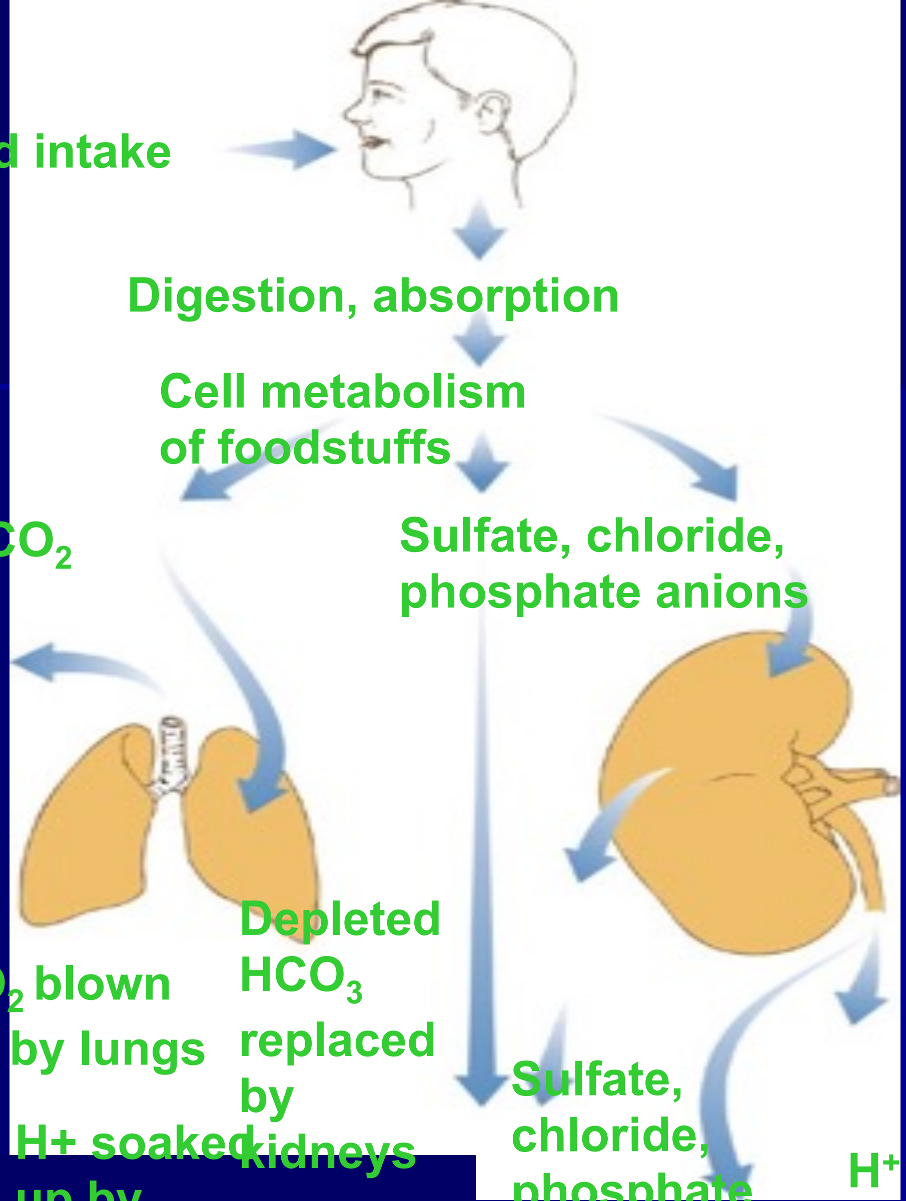


Figure 27.10a, b

- Isohydric principle

  All buffer mechanisms work on the same ‘H^+ pool’. NOT in isolation

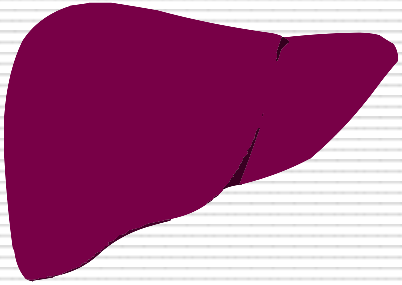

Fatty acids
Amino acids
H+ input
CO2 (+ H2O)
Lactic acid
Ketoacids
Diet
Metabolism
Plasma pH
7.38–7.42
Buffers: HCO3− in extracellular fluid
Proteins, hemoglobin, phosphates in cells
Phosphates, ammonia in urine
Ventilation
Renal
CO2 (+ H2O)
H+ output
H+


Food intake
Digestion, absorption
Cell metabolism of foodstuffs
CO_2
Sulfate, chloride, phosphate anions
CO_2 blown off by lungs
Depleted HCO_3 replaced by kidneys
H+ soaked up by chemical buffer bases
Sulfate, chloride, phosphate excreted by kidneys
H^+ combined with urinary buffers excreted by kidneys

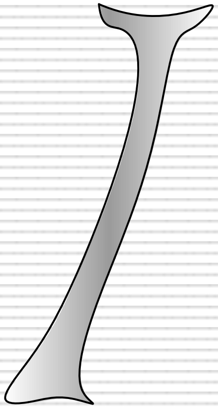
Other organs role in pH balance

- Bone
- liver
- GIT

Organs involved in the regulation of A-B-balance



- CO_2 production from complete oxidation of substrates
  - 20% of the body's daily production
- metabolism of organic acid anions
  - such as lactate, ketones and amino acids
- metabolism of ammonium
  - conversion of NH_4^+ to urea in the liver results in an equivalent production of H^+
- Production of plasma proteins
  - esp. albumin contributing to the anion gap

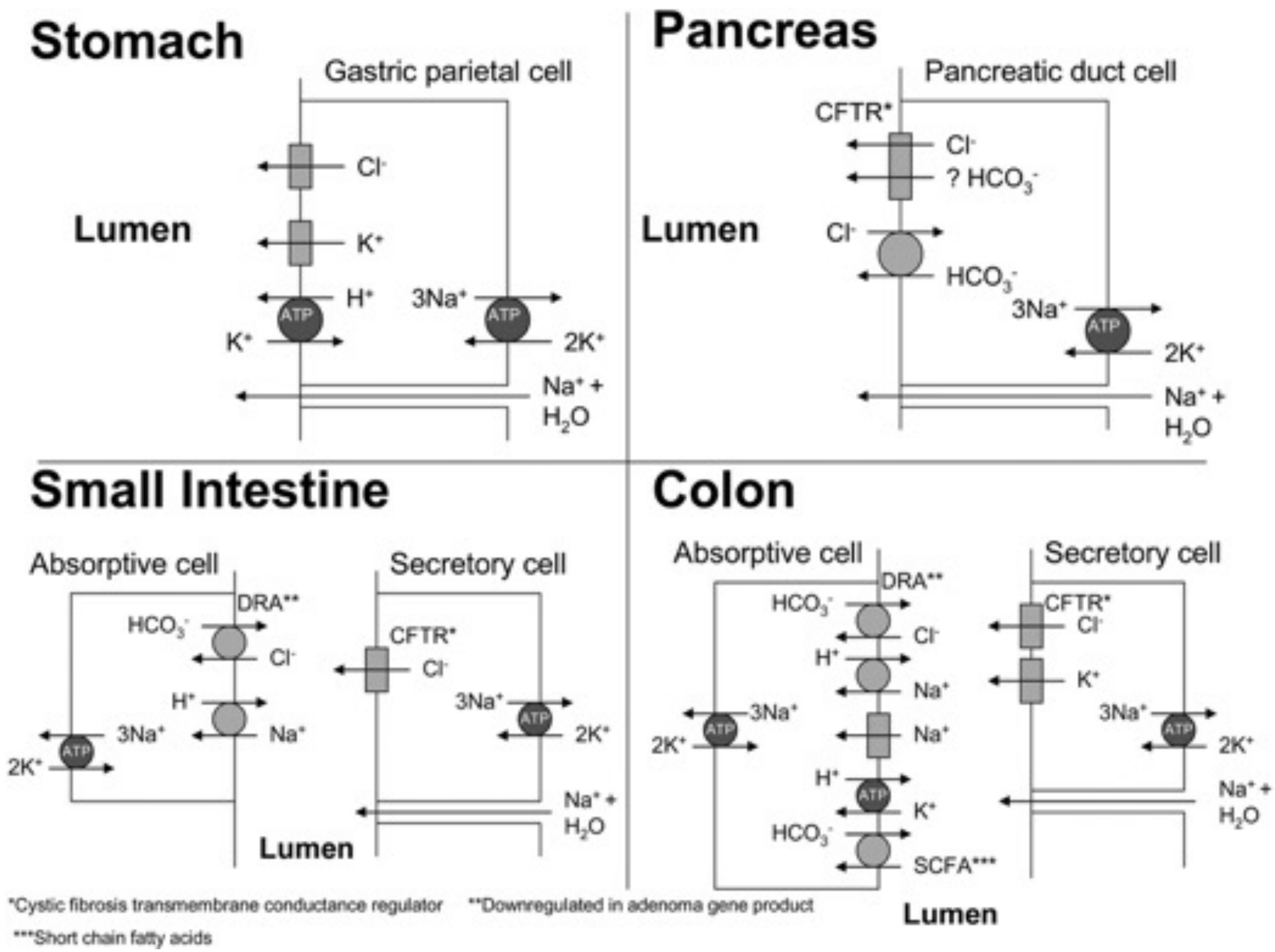


- Bone inorganic matrix consists of hydroxyapatite crystals $(Ca_{10}(PO_4)_6(OH)_2]$
  - bone can take up H^+ in exchange for Ca^{2+}, Na^+ and K^+ (ionic exchange) or release of HCO_3^-, CO_3^- or HPO_4^{2-}

GIT

- Mouth
  - Saliva- relatively alkaline
- Stomach
  - H+ secretion
  - increase after meals (serum ‘alkaline tide’)
- Duodenum/Ileum
  - Alkaline pancreatic secretions (response to acidic contents)
  - Absorption of acidic/ alkaline substances
- Colon
  - alkaline secretions (buffers bacterial acidic secretions)

Key apical membrane ion transporters and channels in various segments of the gastrointestinal tract.



F. John Gennari, and Wolfgang J. Weise CJASN 2008;3:1861-1868

CJASN

GIT

- NET- LOSS of some alkali
- Not so important in overall pH balance in health (more in its local pH balances)
- Importance in disease
  - vomiting- acid loss
  - malabsorption
  - diarrhoea- alkali loss

Disturbances of Acid-base Balance

Acid/Base Homeostasis: Overview

- Acidosis: ↓ plasma pH
  - Protein damage
  - CNS depression
- Alkalosis: ↑ plasma pH
  - Hyperexcitability
  - CNS & heart
- Buffers: HCO_3^- & proteins
- H^+ input: diet & metabolic
- H^+ output: lungs & kidney

Acid-Base Disorders

- Respiratory disorders

  Result when abnormal respiratory function causes rise or fall in CO_2 in ECF

  - **Respiratory acidosis**
  - **Respiratory alkalosis**
- Metabolic disorders

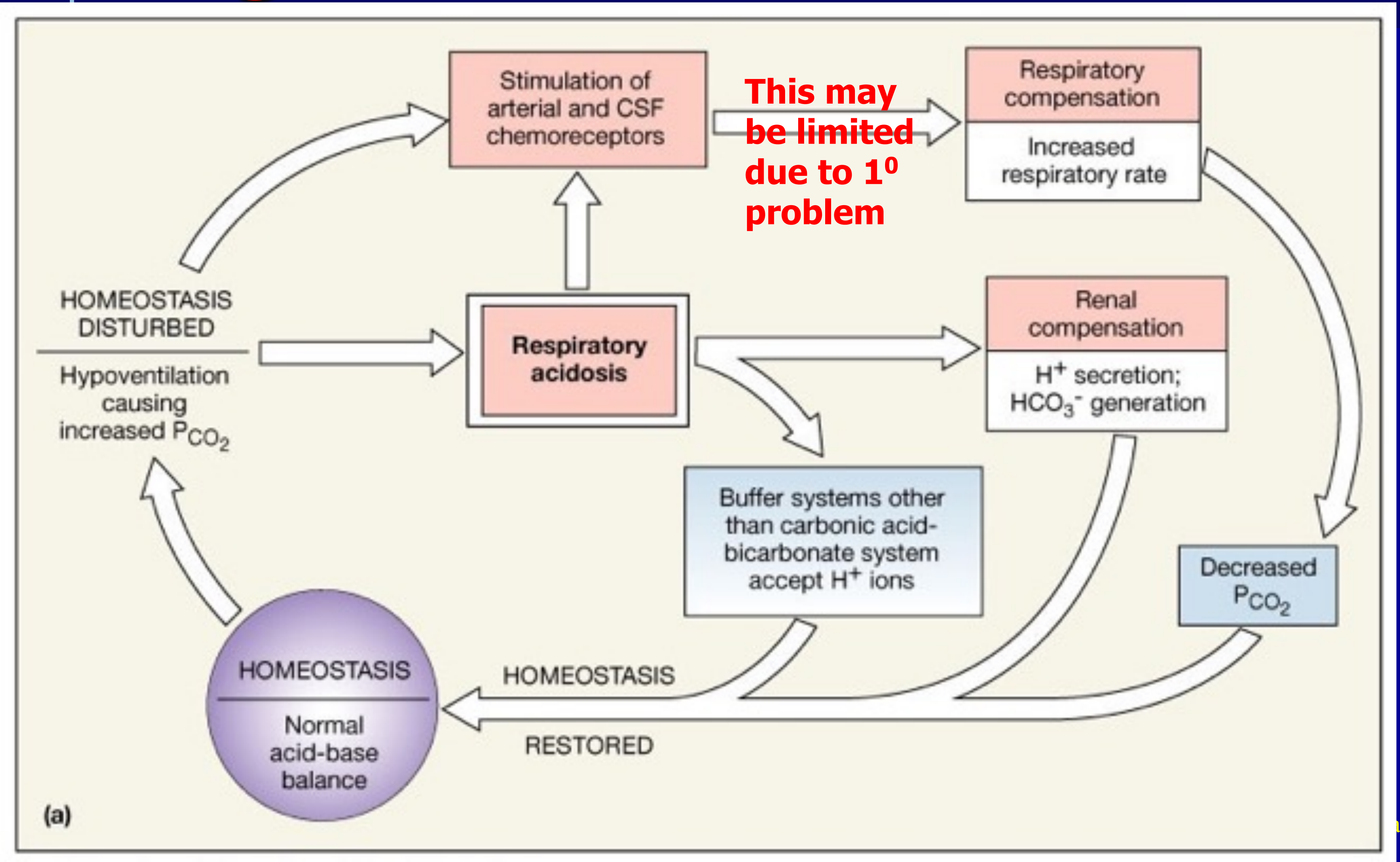
  Generation or accumilation of organic or fixed acids

  - **Metabolic acidosis**
  - **Metabolic alkalosis**

Respiratory acidosis

- Results from excessive levels of CO_2 in body fluids
  - Reduction in ventilation
    - Physical
    - Neurological

Respiratory Acid-Base Regulation



Respiratory alkalosis

- Associated with hyperventilation
  - Increased ventilation
    - Hysterical
    - Neural
    - Iatrogenic

Respiratory Acid-Base Regulation

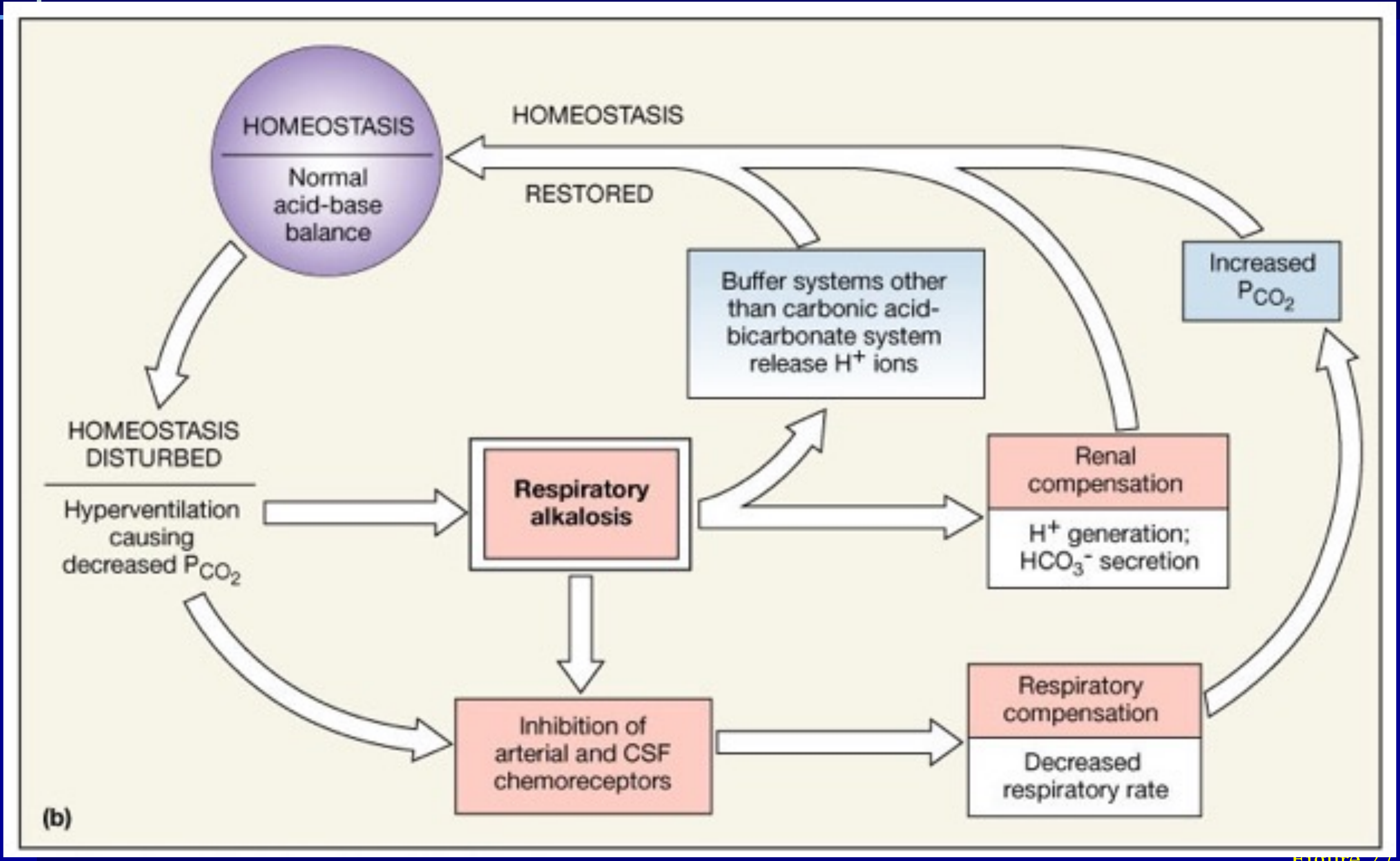


Figure 27.12b

Metabolic acidosis

- Major causes are:
  - Production of large numbers of fixed / organic acids
  - Depletion of bicarbonate reserve
  - Inability to excrete hydrogen ions at kidneys
  - Bicarbonate loss due to chronic diarrhea

The Response to Metabolic Acidosis

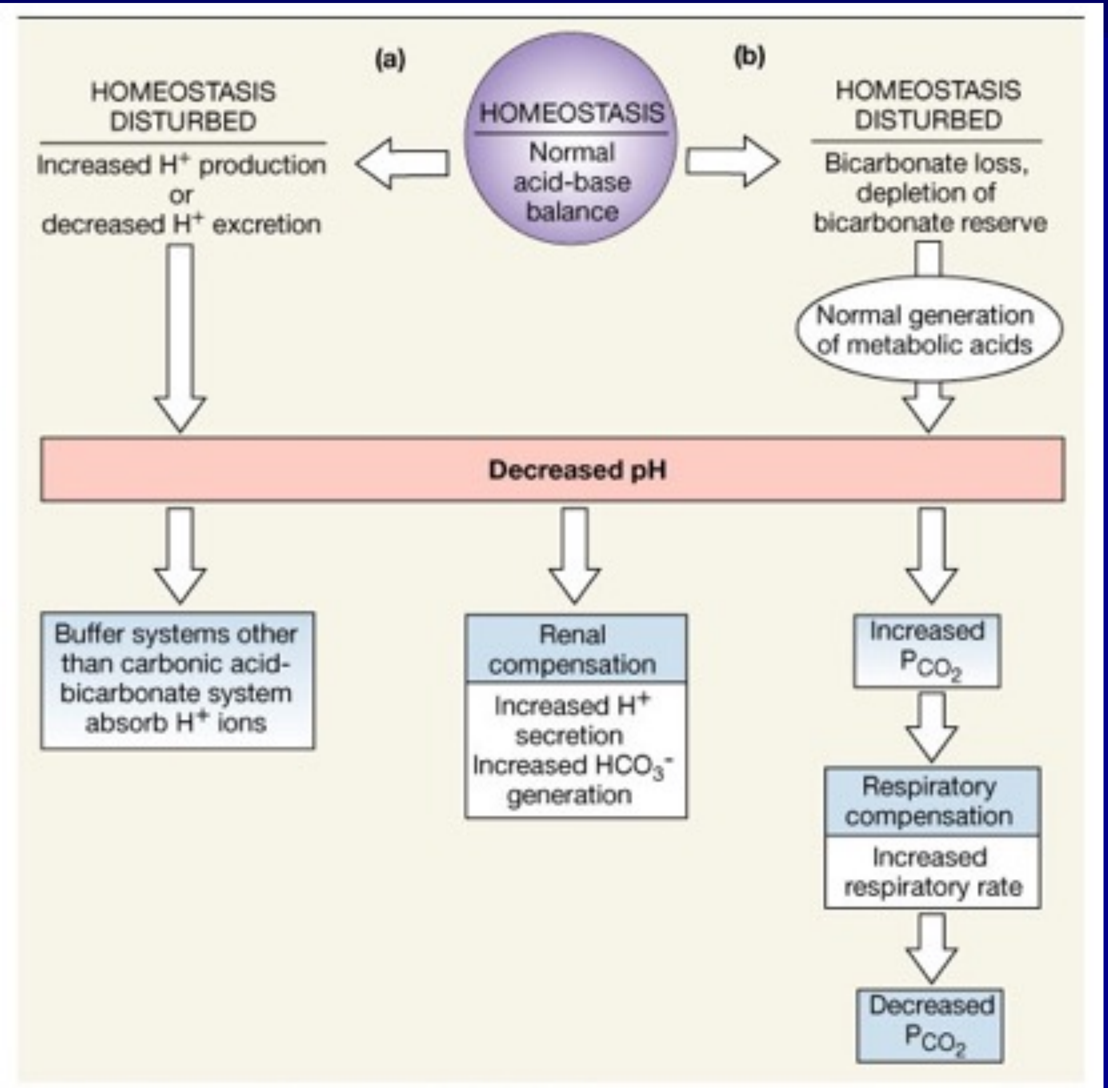


Figure 27.13

Metabolic alkalosis

- Occurs when HCO_3^- concentrations become elevated or H^+ depleted
  - Caused by repeated vomiting- Loss of acid
  - Ingestion of alkali

Metabolic Alkalosis

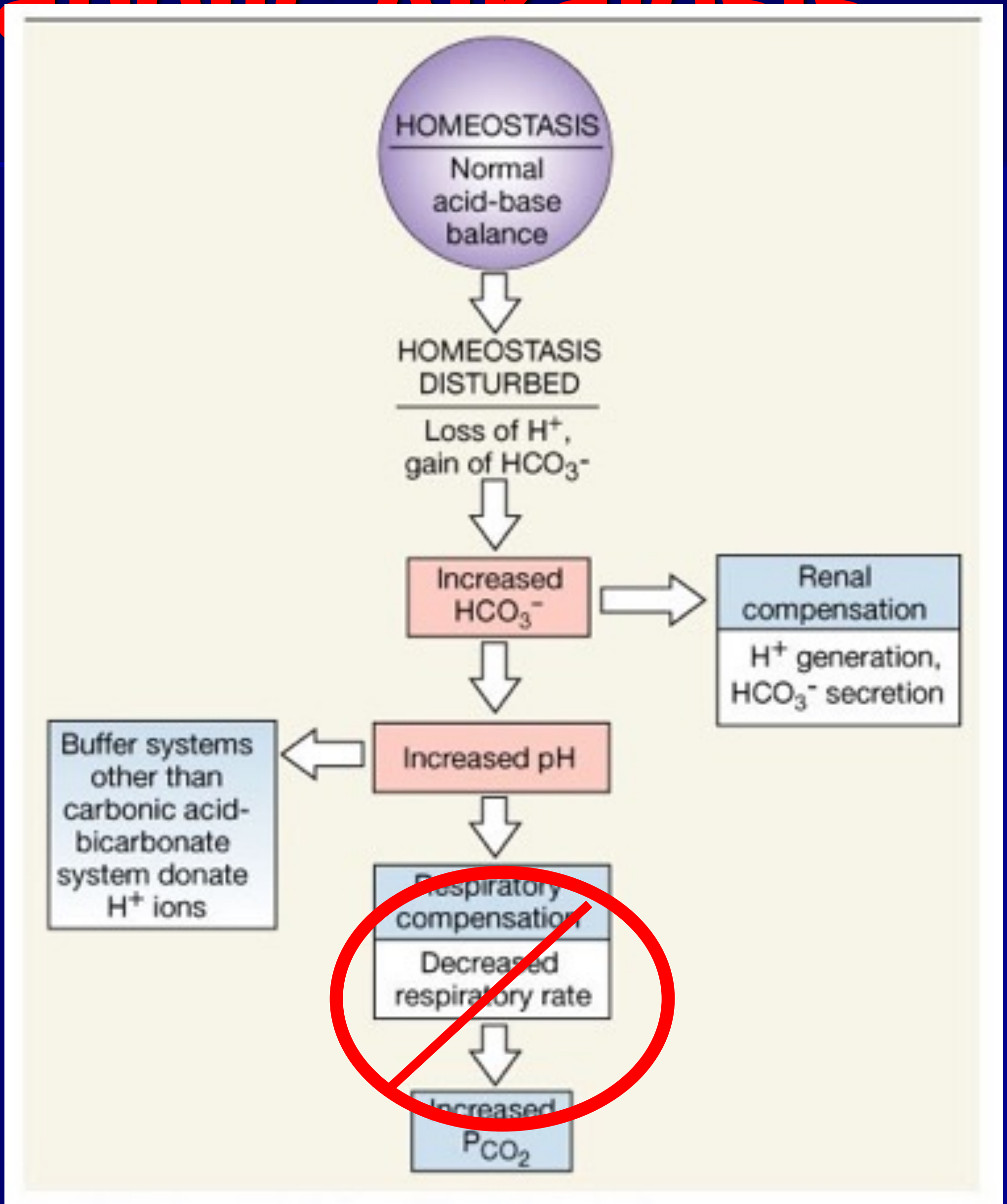


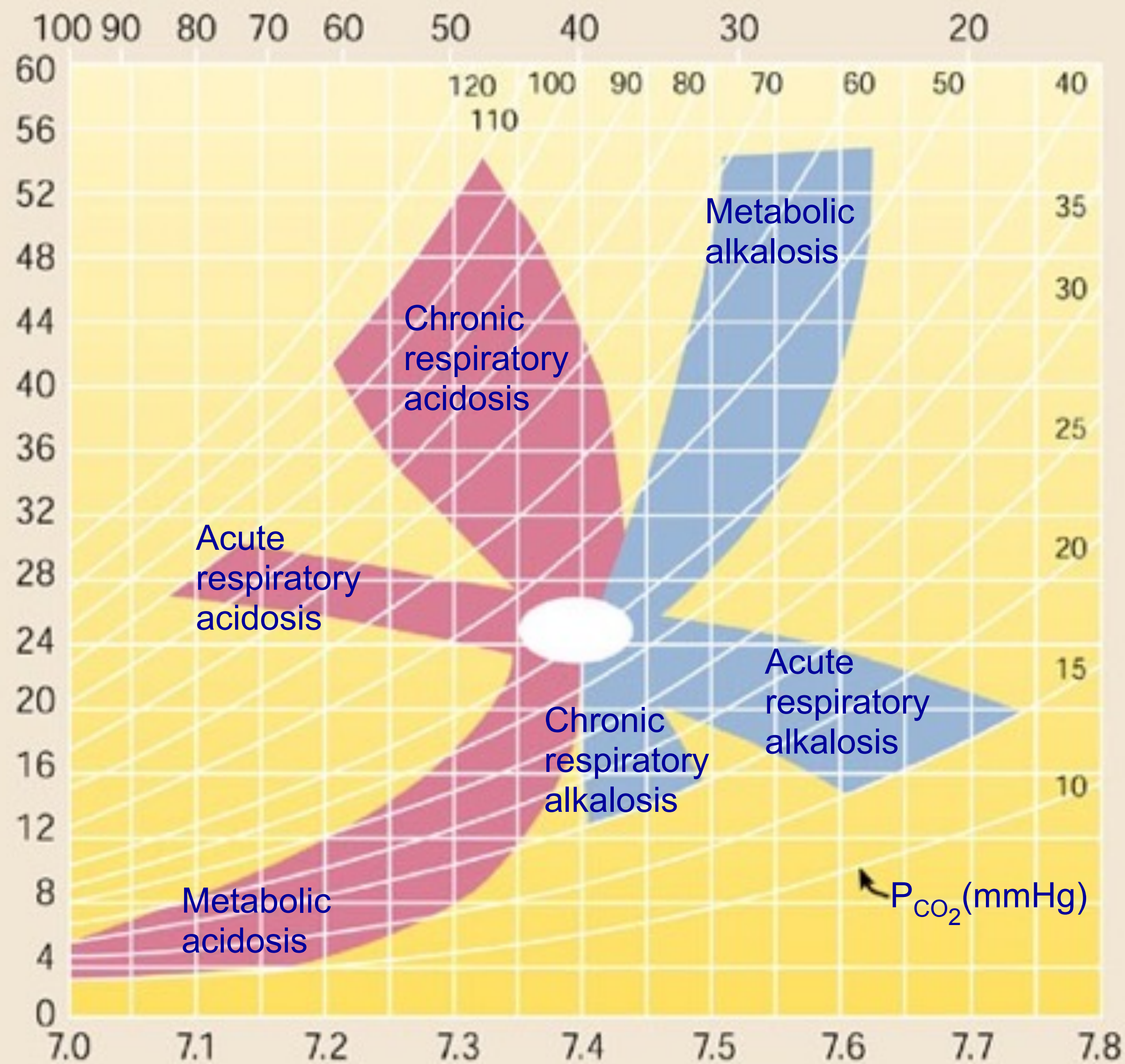
Figure 27.14

Detection of acidosis and alkalosis

- Diagnostic blood tests
  - Blood pH
  - PCO_2
  - Bicarbonate levels
- Distinguish between respiratory and metabolic

PLAY Animation: Acid-Base Homeostasis

Arterial H^+



Arterial HCO_3^-

Arterial CO_2

Arterial pH

Thank you