

Acid Base System

Dr Siteibanat

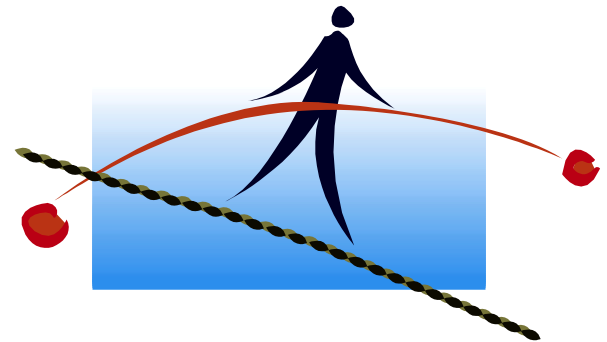
Objectives

At the end of this lecture student should be able to describe:

- 1. Acid-Base balance**
- 2. Normal range of Extracellular pH**
- 3. Identify the body systems that control against Acid-Base Imbalance**
- 4. Identify types of Acid-Base Imbalance**
- 5. Symptoms and signs of Acid-Base imbalances**
- 6. Treatments for Acid-Base imbalances**

What is Acid-base balance

- **Acid-base balance is a balance of H^+ concentration in ECF.**
- **To achieve homeostasis a balance between the intake or production of hydrogen ions and the net removal of hydrogen ions from the body.**



pH Review

- **$\text{pH} = -\log [\text{H}^+]$**
- **If $[\text{H}^+]$ is high, the solution is acidic; $\text{pH} < 7$**
- **If $[\text{H}^+]$ is low, the solution is basic or alkaline ; $\text{pH} > 7$**

<div> <div>table</div> <div>2.5</div> <div>Hydrogen Ion Concentrations and pH</div> </div>		
Grams of H^+ per Liter	pH	
0.0000000000000001	14	<div>↑</div> <div>Increasingly basic</div>
0.000000000000001	13	
0.00000000000001	12	
0.0000000000001	11	
0.000000000001	10	
0.0000000001	9	<div>Neutral—neither acidic nor basic</div>
0.000000001	8	
0.00000001	7	
0.0000001	6	
0.000001	5	
0.0001	4	<div>Increasingly acidic</div> <div>↓</div>
0.001	3	
0.01	2	
0.1	1	
1.0	0	

An Acid

- Molecules containing hydrogen atoms that can release (donate) hydrogen ions in solutions are referred to as an acid.
- Strong acids: completely dissociate (HCl , H_2SO_4)
- Weak acid: partially dissociate (H_2CO_3)



A Base

- A base is an ion that can accept a hydrogen ion.
- An example of a base is is bicarbonate ion
- (HCO_3^-)

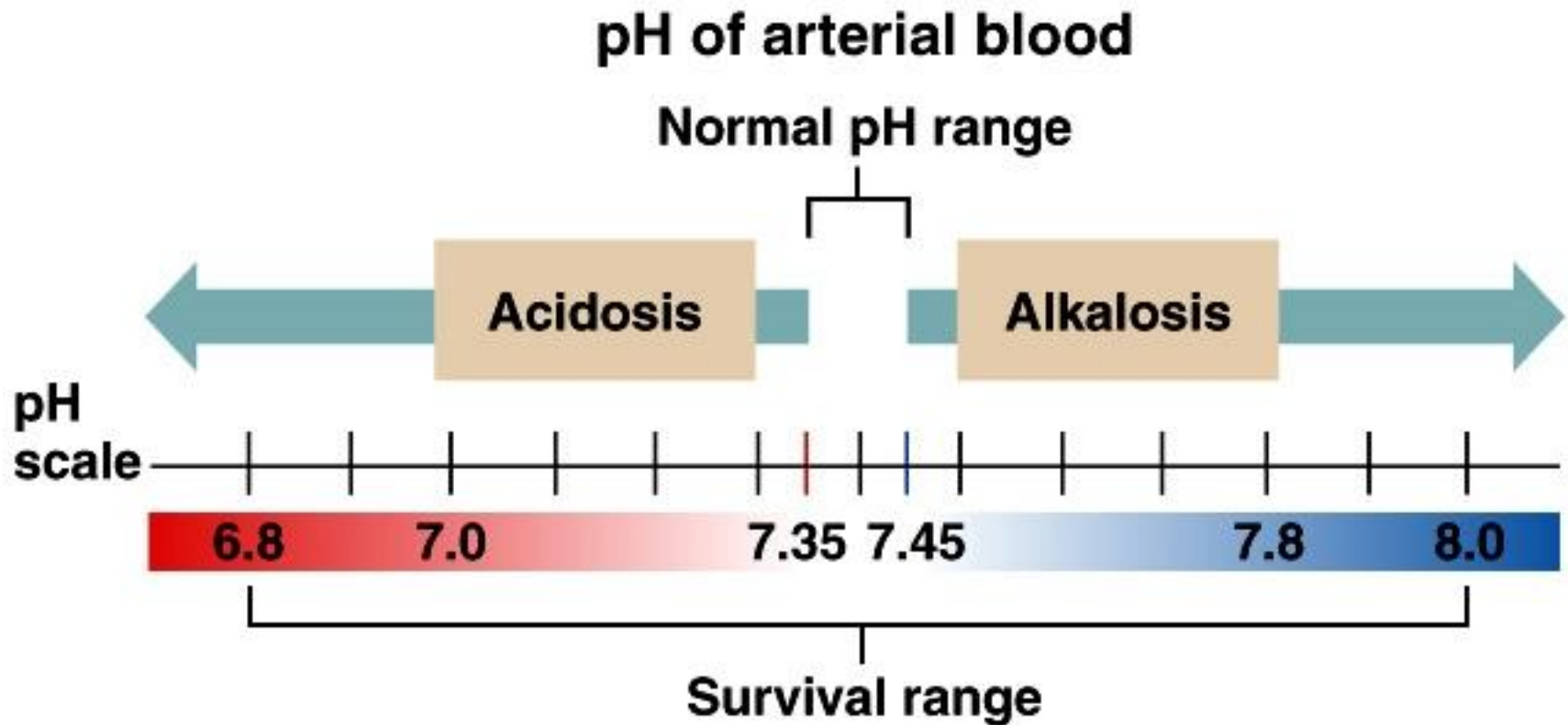


Extra cellular pH

- **Extra-cellular PH =7.4 (7.3 to 7.5)**
- **Homeostasis of pH is important for the function of body enzymes**
- **Acid-base balance can also affect electrolytes concentration (Na^+ , K^+ , Cl^-)**
- **Can also affect certain hormones**

Blood pH

- Blood pH = 7.35 – 7.45
- Blood pH can be calculated by Henderson-Hasselbach equation
- $$PH = pKa + \log_{10} \frac{[Base]}{[Acid]}$$
- Acidosis= decrease in arterial pH (< 7.4) due to excess H⁺
- Alkalosis= an elevation in arterial PH (>7.4) due to excess base
- pH < 6.8 or > 8.0 death occurs



Acid-Base Imbalances

- **pH < 7.35 acidosis**
- **pH > 7.45 alkalosis**
- **The body response to acid-base imbalance is called compensation**
- **Is complete if pH brought back within normal limits**
- **Partial compensation if range is still outside norms.**

System Compensation

- **If underlying problem is metabolic, hyperventilation or hypoventilation can help : respiratory compensation.**
- **If problem is respiratory, renal mechanisms can bring about metabolic compensation.**

Body produces more acids than bases

- **Acids take in with foods**
- **Acids produced by metabolism of lipids and proteins**
- **Cellular metabolism produces CO₂ (volatile acid)**
- **$\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-$**

Buffers

- **Buffers are substances that neutralize acids or bases**
- **Chemical reactions which reduce the effect of adding acid or base to a solution PH.**

How the Body defends against fluctuations in pH

- **Three Systems in the body:**
 - 1. Buffers in the blood**
 - 2. Breathing through the lungs**
 - 3. Excretion by the kidneys**

Blood Buffer

These buffer systems serve as a first line of defense against changes in the acid-base balance

- **Bicarbonate**
- **Protein**
- **Phosphate**
- **Haemoglobin**

Bicarbonate Buffer

- **Important extra cellular buffer**
- **$\text{HCO}_3^- = 24\text{-}28 \text{ meq/ml}$**
- **Present in larger quantities**
- **Can be regulated by respiratory and renal**

Bicarbonate Buffer

- Consist of: weak acid H_2CO_3 and Bicarbonate salt NaHCO_3
- $\text{HCO}_3^- : \text{H}_2\text{CO}_3$ Maintain at a ratio of 20:1
- $\text{pH} = 6.1 + \log \frac{\text{HCO}_3^-}{0.03 \times \text{PCO}_2}$
- If Acid is added
 - $\text{H}^+ + \text{HCO}_3^- \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{CO}_2 + \text{H}_2\text{O}$
- If Base is added
 - $\text{NaOH} + \text{H}_2\text{CO}_3 \leftrightarrow \text{NaHCO}_3 + \text{H}_2\text{O}$

Phosphates & Intracellular Buffers

- **Phosphate is an intra and extracellular buffer**
- **Minor role compare to HCO_3 or HB**
- **Intra cellular buffers (proteins & phosphate) are needed because H does not cross PM**
- **Intracellular pH is more acidic (7.2)**

Proteins

- Includes hemoglobin and plasma protein
- Acidic and basic amino acids in plasma and cell protein act as buffers
 - Carboxyl group gives up H^+
 - Amino Group accepts H^+
- Side chains that can buffer H^+ are present on 27 amino acids.
- Cannot be regulated physiological

Respiratory regulation of pH

- **Maintain normal ECF pH by changing the rate and depth of breathing to maintain constant PCO_2 (volatile acid)**
- **Controlled by chemoreceptors**
- **Respiratory doesn't affect fixed acids like lactic acid**
- **\uparrow in $\text{PCO}_2 \rightarrow \downarrow$ pH**

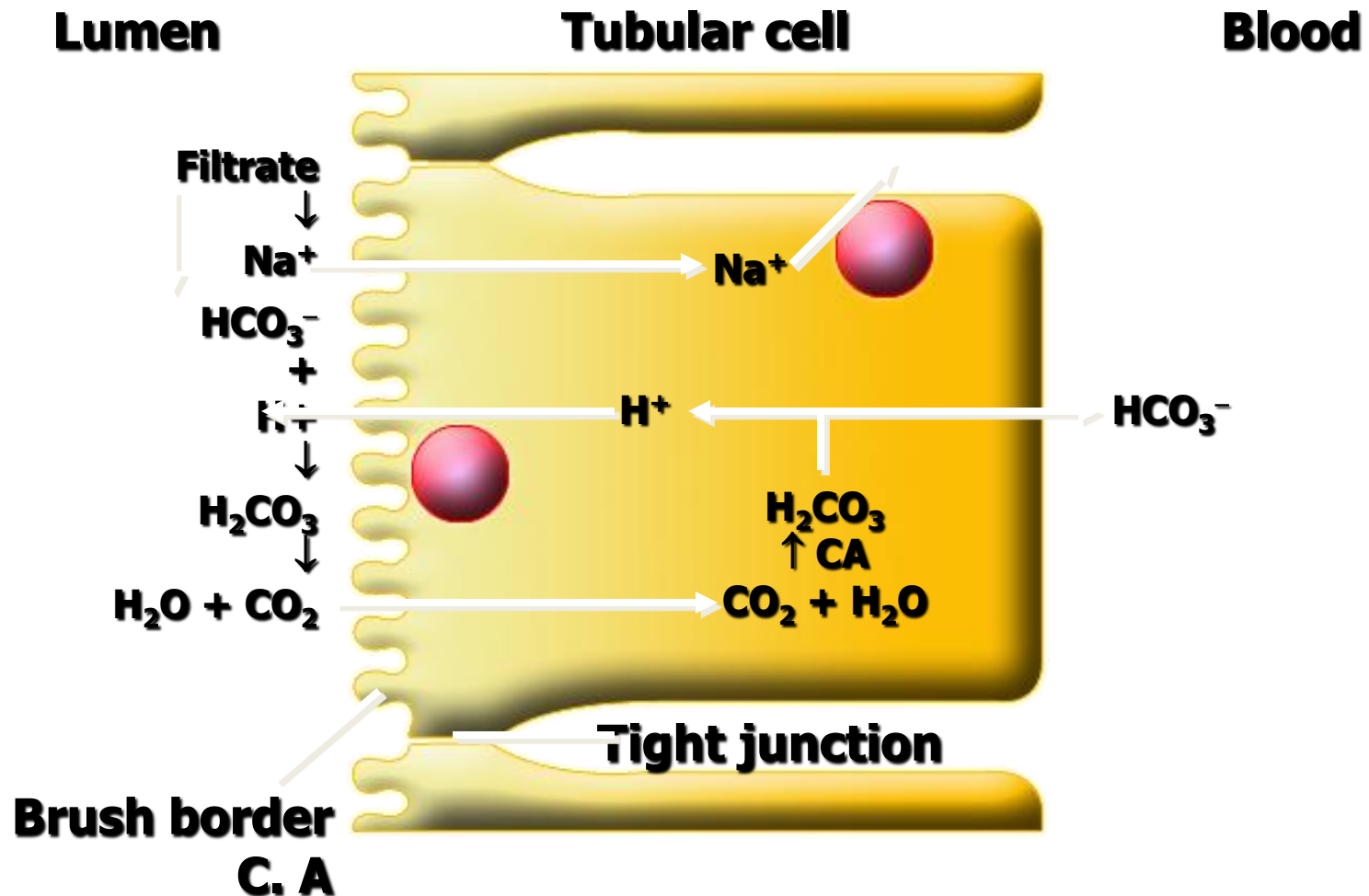
Kidney excretion

- Can eliminate large amounts of acid by tubular secretion of H^+
- Can also excrete base by adjusting tubular reabsorption of HCO_3
- Can conserve and produce bicarbonate ions
- Kidney is the most effective regulator of pH
- If kidneys fail, pH balance fails

Tubular secretion of H^+

- 1. In all parts of nephron except thin part of loop**
- 2. In PCT, thick loop and early DCT H^+ is secreted in exchange for Na^+**
- 3. Secreted H^+ is used for HCO_3 reabsorption**
- 4. In late DCT H^+ is secreted by active transport by intercalated cells acidifying Urine to pH 4.5**

Buffering of Secreted H^+ and Bicarbonate reabsorption



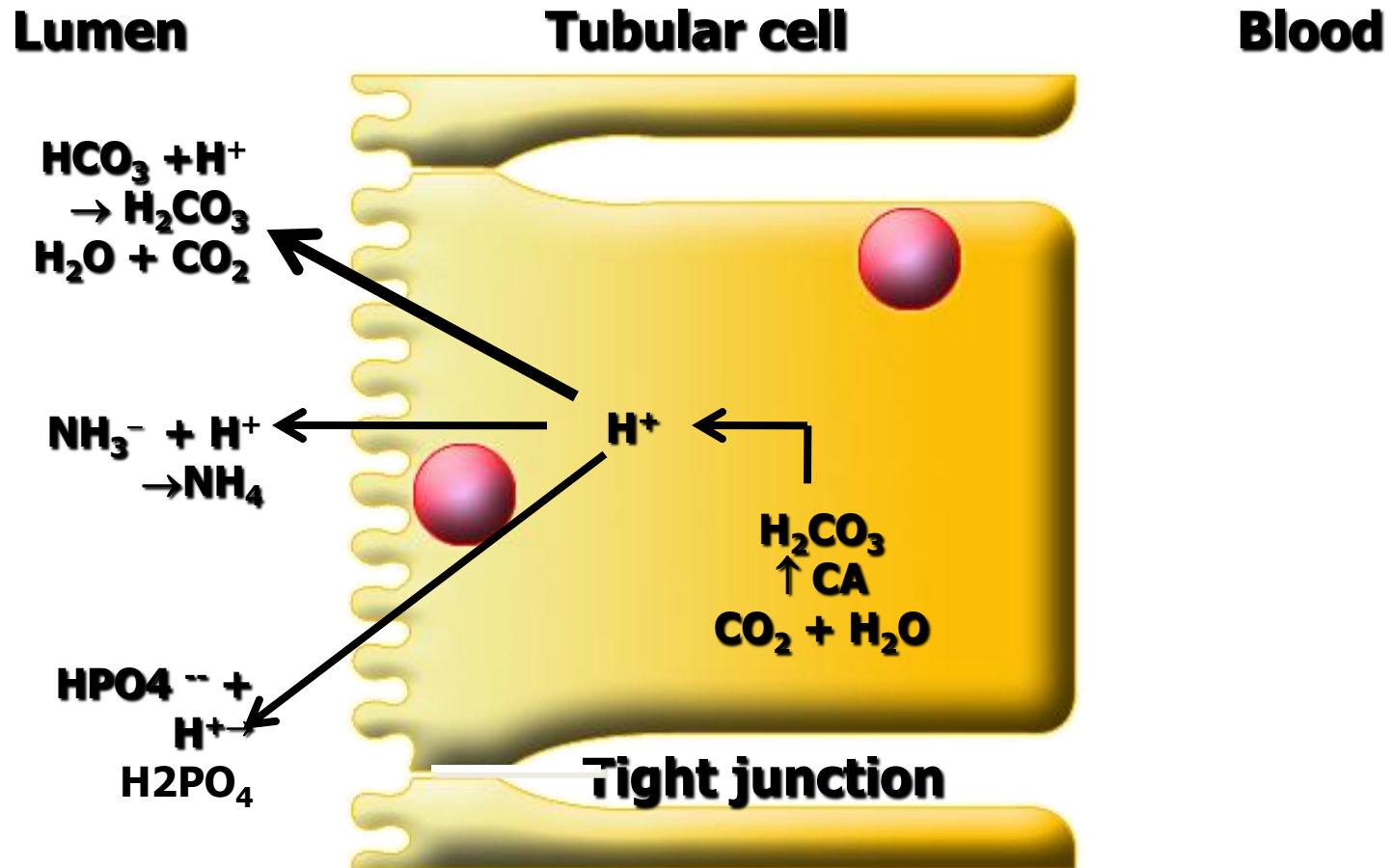
Buffering of Secreted H^+ and phosphate absorption

- 1. Excess secreted H^+ will be neutralized by phosphate buffer**
- 2. $\text{HPO}_4 + \text{H}^+ = \text{H}_2\text{PO}_4 + \text{Na}^+ = \text{Na H}_2\text{PO}_4$ (salt)**

Buffering of Secreted H^+ with ammonia buffer

- 1. Filtered ammonia $NH_3 + H^+ = NH_4$ (ammonium) not acidic excreted in urine**

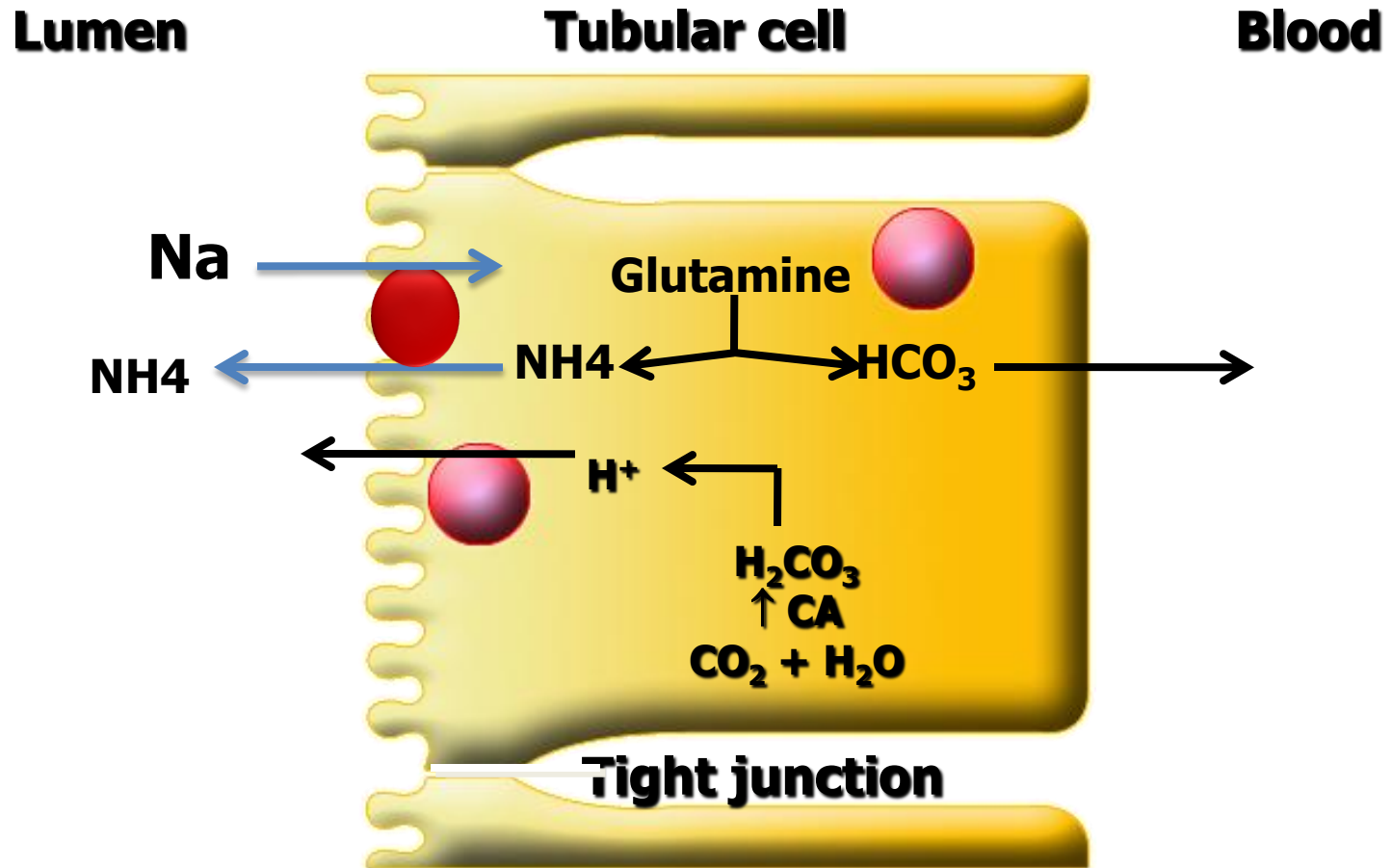
Buffering of secreted Hydrogen in urine



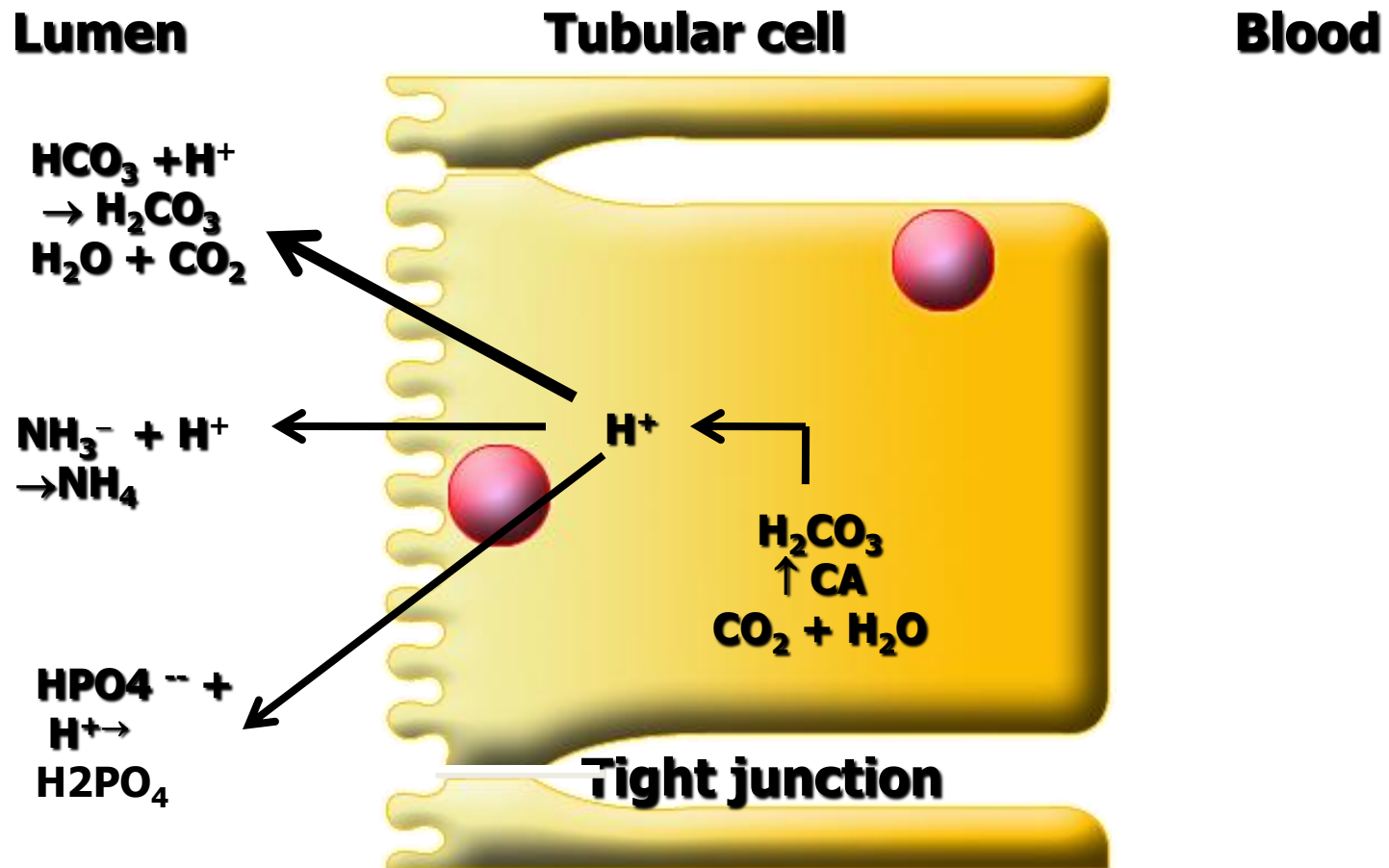
Formation of new bicarbonate by renal cells

- 1. Glutamine molecule is metabolized inside renal cell $\rightarrow 2\text{NH}_4 + 2\text{HCO}_3$ stimulated by acidosis**
- 2. NH_4 is secreted in exchange for Na^+**

Formation of new Bicarbonate



Buffering of the excreted Hydrogen



Diagnosis of Acid-Base Imbalances

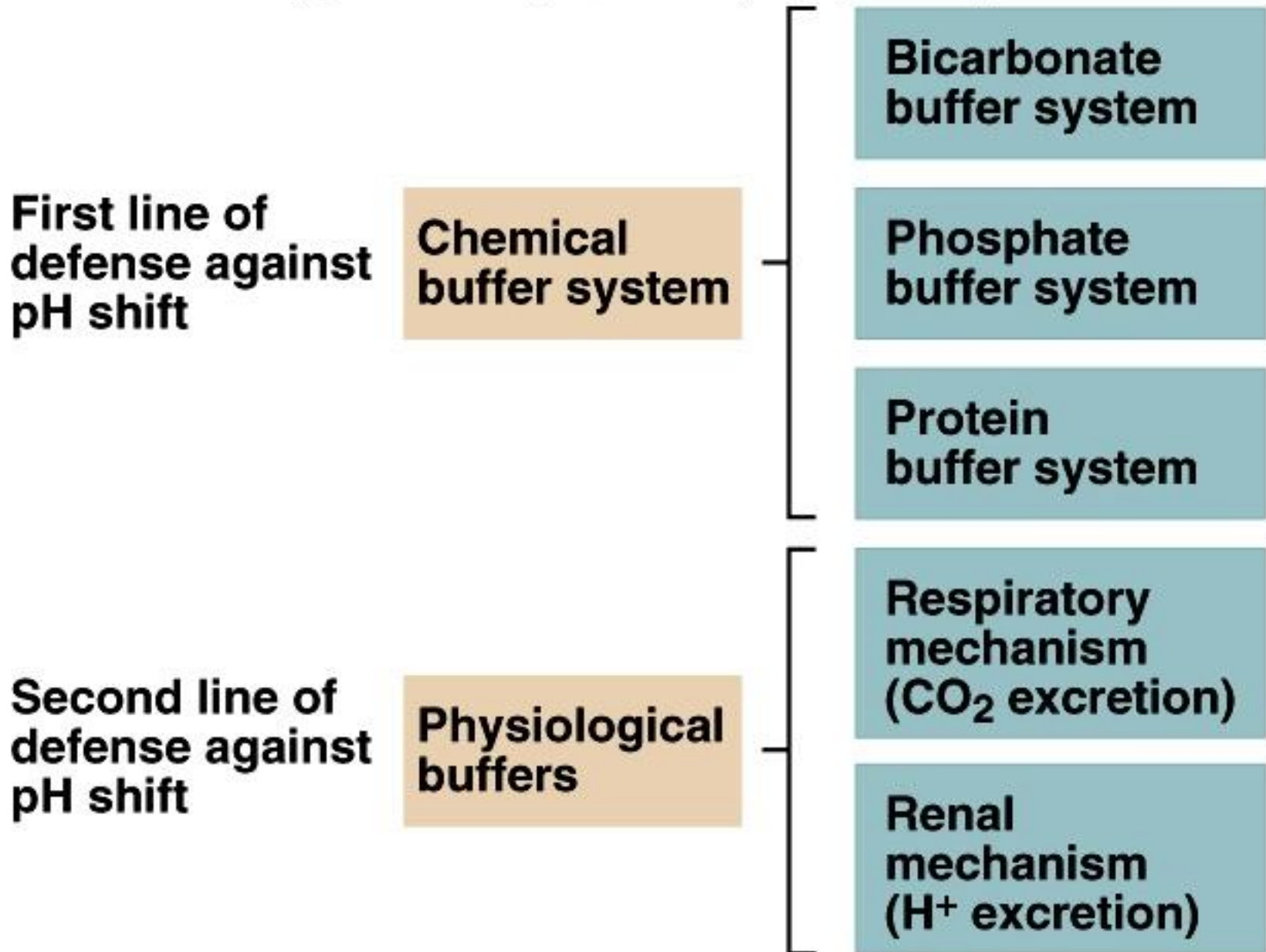
- 1. pH low (acidosis) or high (alkalosis)**
- 2. If $p\text{CO}_2$ is abnormal the problem is respiratory. If HCO_3^- is abnormal the problem is metabolic.**
- 3. If pH is within the normal range, there is full compensation. If it is outside the normal range, the body is partially compensating for the problem.**

Acid-Base Imbalances

- **pH < 7.35 acidosis**
- **pH > 7.45 alkalosis**
- **The body response to acid-base imbalance is called compensation**
- **May be complete if brought back within normal limits**
- **Partial compensation if range is still outside norms.**

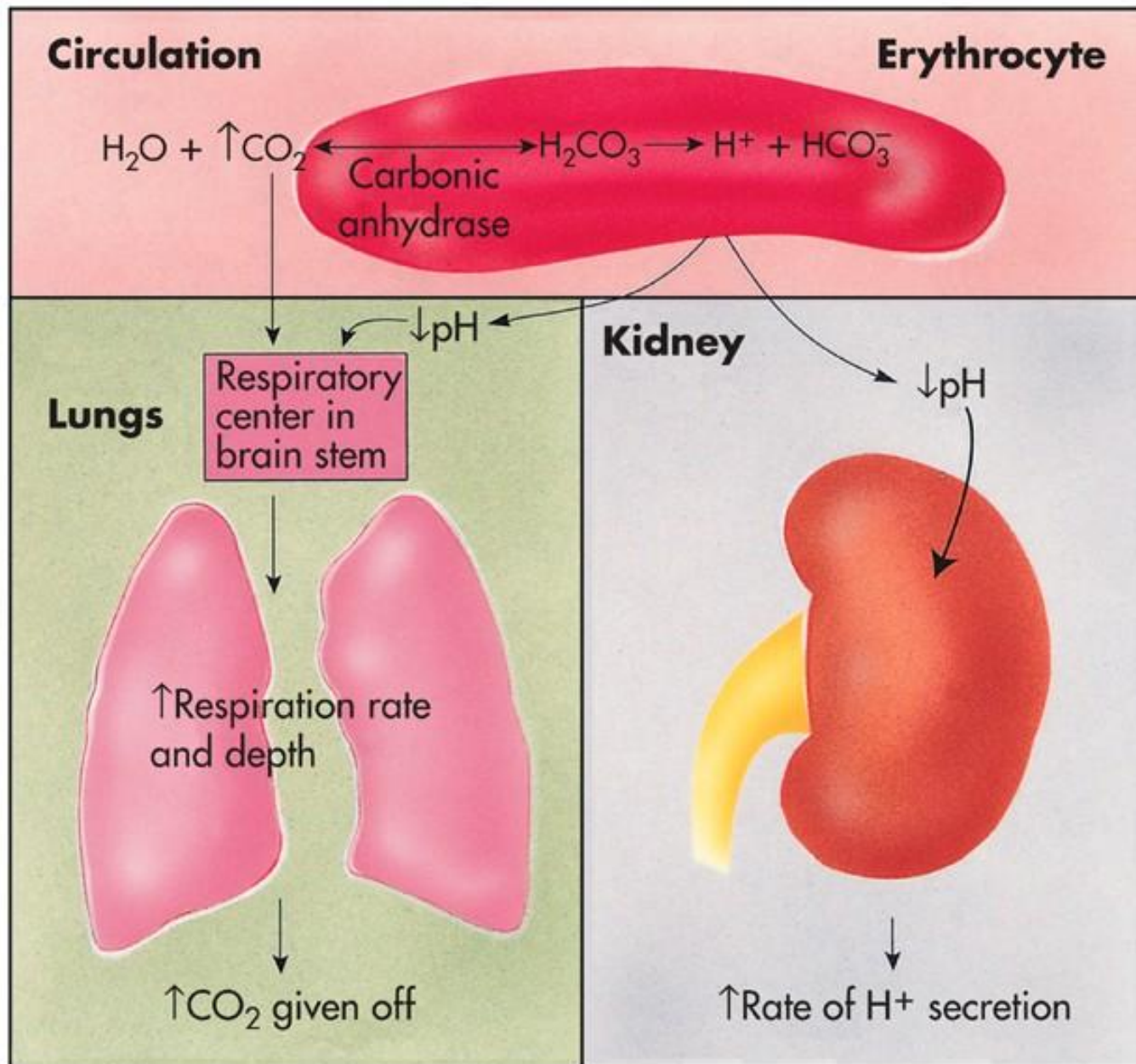
Compensation

- **If underlying problem is metabolic, hyperventilation or hypoventilation can help : respiratory compensation.**
- **If problem is respiratory, renal mechanisms can bring about metabolic compensation.**



Rates of correction

- **Buffers function almost instantaneously**
- **Respiratory mechanisms take several minutes to hours**
- **Renal mechanisms may take several hours to days**



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

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Acid Base Imbalance

1. Acidosis

- **Low pH**
- **Metabolic casuses**
- **Respiratoy casuses**

2. Alkalosis

- **High pH**
- **Metabolic casuses**
- **Respiratoy casuses**

There are 4 Types of Acid-base Imbalances

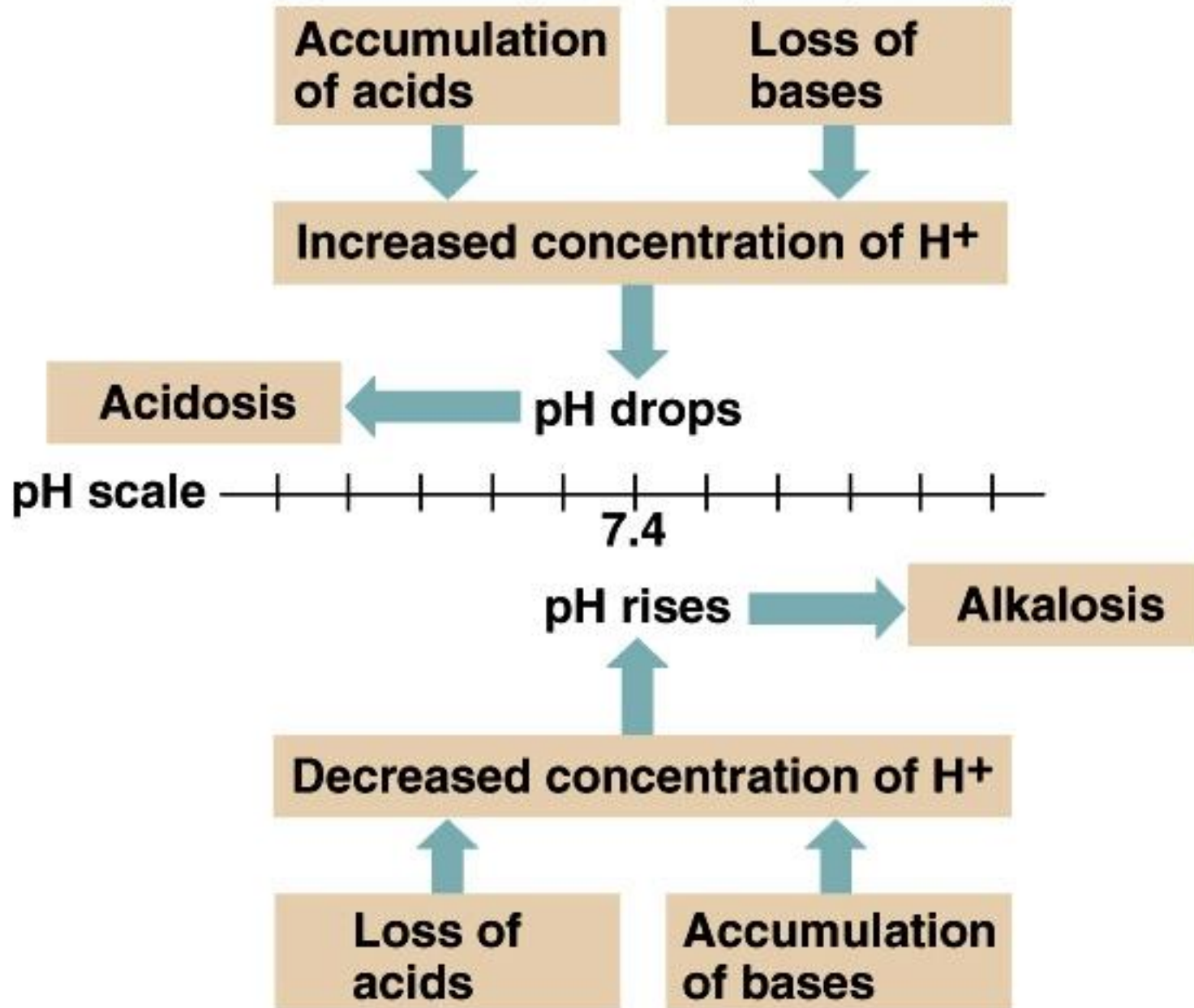
- 1. Respiratory Alkalosis**
- 2. Respiratory Acidosis**
- 3. Metabolic Alkalosis**
- 4. Metabolic Acidosis**

Acidosis

- **Principal effect of acidosis is depression of the CNS through ↓ in synaptic transmission.**
- **Generalized weakness**
- **Severe acidosis causes**
 - **Disorientation**
 - **coma**
 - **death**

Alkalosis

- **Alkalosis causes over excitability of the central and peripheral nervous systems.**
- **Numbness**
- **Lightheadedness**
- **It can cause :**
 - **Nervousness**
 - **muscle spasms or tetany**
 - **Convulsions**
 - **Loss of consciousness**
 - **Death**



Respiratory Acidosis

Respiratory acidosis

- **Low pH**
- **High PCO_2 (Hypercapnia)**
 - **Depressed ventilation**
- **$\text{HCO}_3 = \text{N}$**

Causes of Respiratory Acidosis

- **Chronic conditions:**
 - **Depression of respiratory center in brain that controls breathing rate – drugs or head trauma**
 - **Paralysis of respiratory or chest muscles**
 - **Emphysema**
- **Acute conditons:**
 - **Adult Respiratory Distress Syndrome**
 - **Pulmonary edema**
 - **Pneumothorax**

Signs and Symptoms of Respiratory Acidosis

- **Breathlessness**
- **Restlessness**
- **Lethargy and disorientation**
- **Tremors, convulsions, coma**
- **Respiratory rate rapid, then gradually depressed**
- **Skin warm and flushed due to vasodilation caused by excess CO₂**

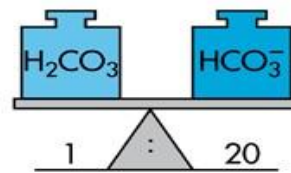
Compensation for Respiratory Acidosis

- **Kidneys eliminate hydrogen ion and retain bicarbonate ion**
- **Blood picture**
 - **pH = N**
 - **PCO₂ = High**
 - **HCO₃ = High compensation**
- **Low Urine HCO₃**

Treatment of Respiratory Acidosis

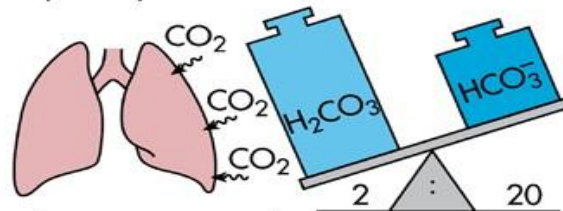
- **Restore ventilation**
- **IV lactate solution**
- **Treat underlying dysfunction or disease**

a) Metabolic balance before onset of acidosis



H_2CO_3 : Carbonic acid
 HCO_3^- : Bicarbonate ion
 $(\text{Na}^+ \bullet \text{HCO}_3^-)$
 $(\text{K}^+ \bullet \text{HCO}_3^-)$
 $(\text{Mg}^{++} \bullet \text{HCO}_3^-)$
 $(\text{Ca}^{++} \bullet \text{HCO}_3^-)$

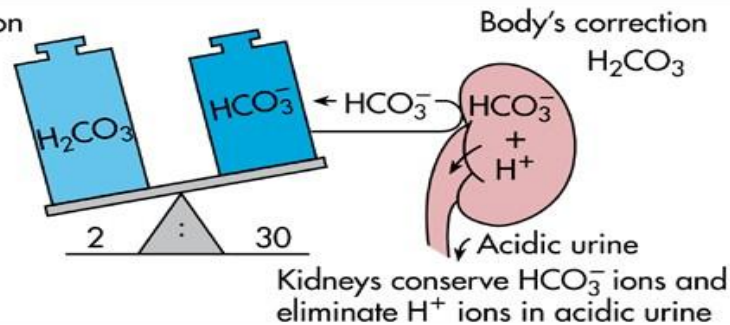
b) Respiratory acidosis



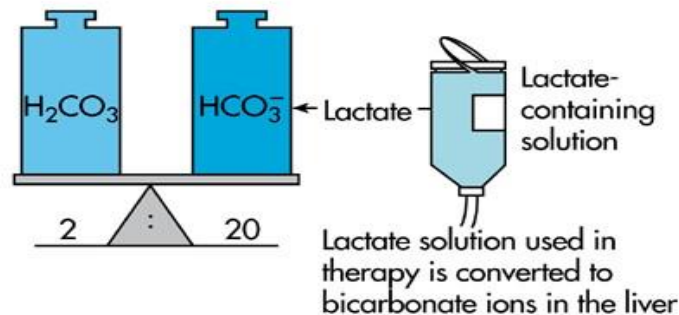
Primary change
 pH — decreases
 PCO_2 — increases
 HCO_3^- — no change

Breathing is suppressed,
 holding CO_2 in body

c) Body's compensation



d) Therapy required to
 restore metabolic
 balance



Respiratory Alkalosis

Respiratory alkalosis

- **high pH**
- **low PCO_2**
 - **hyper ventilation**
 - Hysterical
 - pneumonia
- **HCO_3 normal**

Respiratory Alkalosis

- **PCO₂ less than 35 mm Hg (hypocapnea)**
- **Primary cause is hyperventilation**

Respiratory Alkalosis

- **Oxygen deficiency at high altitudes**
- **Pulmonary disease and Congestive heart failure – caused by hypoxia**
- **Acute anxiety**
- **Fever, anemia**
- **Early salicylate intoxication**
- **Cirrhosis**
- **Gram-negative sepsis**

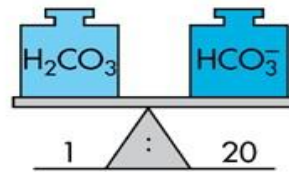
Compensation of Respiratory Alkalosis

- Kidneys conserve hydrogen ion
- Excrete more bicarbonate ion
- Blood picture
 - pH = N
 - PCO_2 = Low
 - HCO_3 = Low compensation
- High urine HCO_3

Treatment of Respiratory Alkalosis

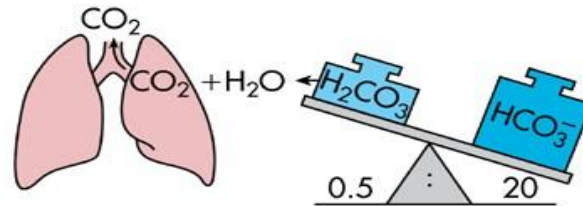
- **Treat underlying cause**
- **Breathe into a paper bag**
- **IV Chloride containing solution – Cl^- ions replace lost bicarbonate ions**

a) Metabolic balance before onset of alkalosis



H_2CO_3 : Carbonic acid
 HCO_3^- : Bicarbonate ion
 $(\text{Na}^+ \bullet \text{HCO}_3^-)$
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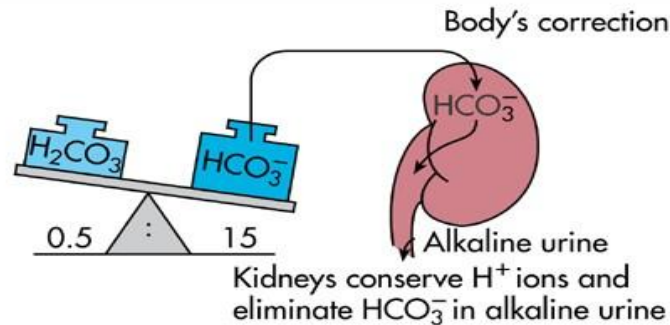
b) Respiratory alkalosis



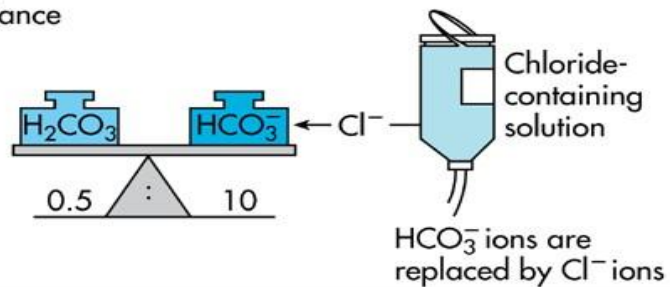
Hyperactive breathing
 "blows off" CO_2

Primary change
 pH — increases
 PCO_2 — decreases
 HCO_3^- — no change

c) Body's compensation



d) Therapy required to restore metabolic balance



Metabolic Acidosis

Metabolic Acidosis

- **Low pH**
- **Low HCO_3**
 - Production of Lactic acid (anerobic metabolism)
 - Production of ketoacid (diabetes)
 - Excessive loss of alkali (diarrhoea)
 - Renal failure
- **PCO_2 = normal**

Metabolic Acidosis

- **Bicarbonate deficit $< 22\text{mEq/L}$**
- **Causes:**
 - **Loss of bicarbonate through diarrhea or renal dysfunction**
 - **Accumulation of acids (lactic acid or ketones)**
 - **Failure of kidneys to excrete H^+**

Symptoms of Metabolic Acidosis

- **Headache, lethargy**
- **Nausea, vomiting, diarrhea**
- **Coma**
- **Death**

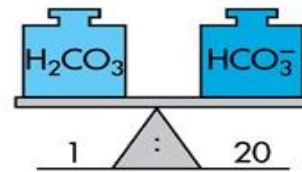
Compensation for Metabolic Acidosis

- Stimulation of ventilation (hyperventilation) $\rightarrow \downarrow \text{PCO}_2 \rightarrow \uparrow$ pH back to normal value
- Renal excretion of hydrogen ions if possible
- K^+ exchanges with excess H^+ in ECF (H^+ into cells, K^+ out of cells)
- Blood picture
 - pH = ~N
 - HCO_3^- = Low
 - PCO_2 = Low compensation

Treatment of Metabolic Acidosis

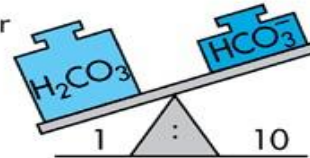
- **IV lactate solution**

a) Metabolic balance before onset of acidosis



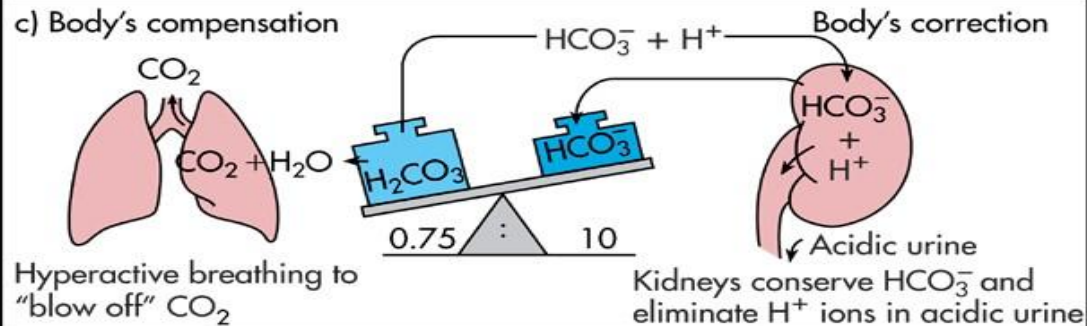
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 $(\text{Mg}^{++} \bullet \text{HCO}_3^-)$
 $(\text{Ca}^{++} \bullet \text{HCO}_3^-)$

b) Metabolic acidosis
 HCO_3^- decreases because of excess presence of ketones, chloride, or organic acid ions

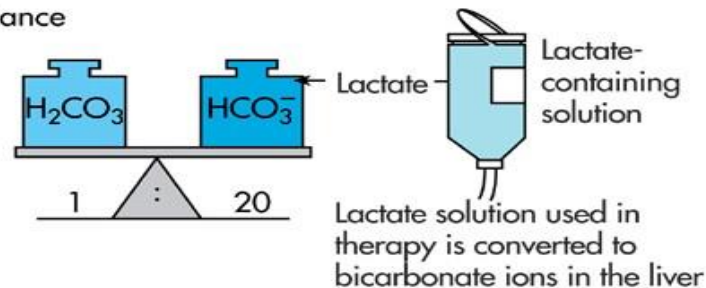


Primary change
 pH — decreases
 PCO_2 — no change
 HCO_3^- — decreases

c) Body's compensation



d) Therapy required to restore metabolic balance



Metabolic Alkalosis

Metabolic Alkalosis

- **high pH**
- **High HCO_3**
 - **Loss of gastric acid (vomiting)**
 - **Excessive intake of alkali (antiacid)**
- **PCO_2 = Normal**

Metabolic Alkalosis

- **Bicarbonate > 26 mEq/L**
- **Causes:**
 - **Excess vomiting = loss of stomach acid**
 - **Excessive use of alkaline drugs**
 - **Certain diuretics**
 - **Endocrine disorders**
 - **Heavy ingestion of antacids**
 - **Severe dehydration**

Compensation for Metabolic Alkalosis

- **Correction**
 - depress ventilation $\rightarrow \uparrow$ blood $\text{PCO}_2 \rightarrow \downarrow$ pH back to normal value (limited by hypoxia)
- Alkalosis most commonly occurs with renal dysfunction, so can't count on kidneys
- Blood picture
 - pH = ~N
 - HCO_3 = High
 - PCO_2 = High compensation

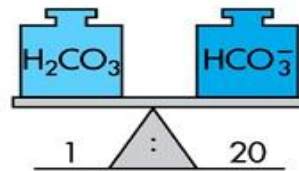
Symptoms of Metabolic Alkalosis

- **Respiration slow and shallow**
- **Hyperactive reflexes tetany**
- **Often related to depletion of electrolytes**
- **Atrial tachycardia**
- **Dysrhythmias**

Treatment of Metabolic Alkalosis

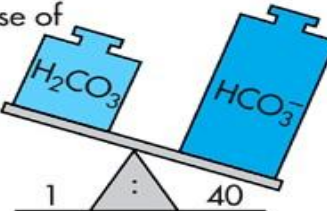
- **Electrolytes to replace those lost**
- **IV chloride containing solution**
- **Treat underlying disorder**

a) Metabolic balance before onset of alkalosis



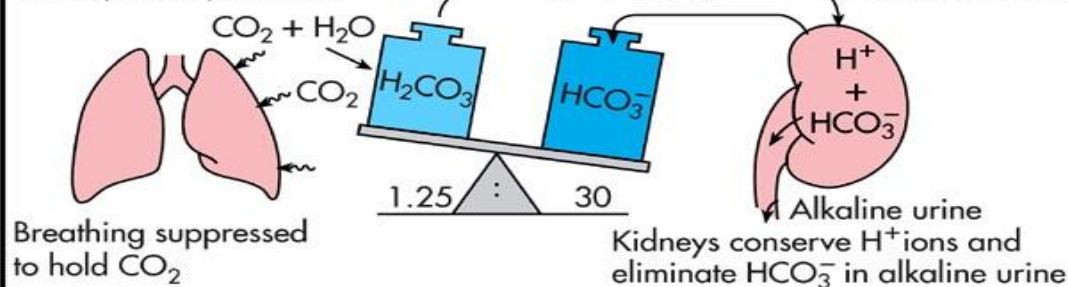
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 $(\text{Ca}^{++} \bullet \text{HCO}_3^-)$

b) Metabolic alkalosis
 HCO_3^- increases because of
 loss of chloride ions
 or excess ingestion
 of sodium bicarbonate

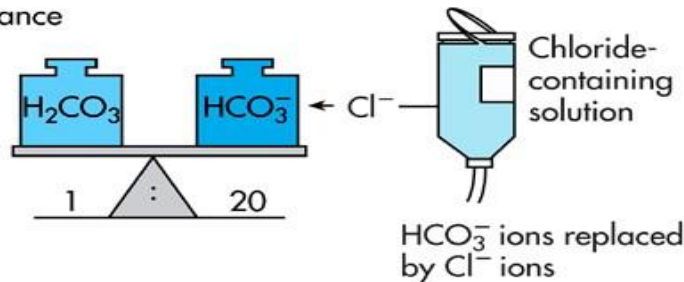


Primary change
 pH — increases
 PCO_2 — no change
 HCO_3^- — increases

c) Body's compensation



d) Therapy required to restore metabolic balance



Example

- **A patient is in intensive care because he suffered a severe myocardial infarction 3 days ago. The lab reports the following values from an arterial blood sample:**
 - **pH 7.3**
 - **HCO₃⁻ = 20 mEq / L (22 - 26)**
 - **pCO₂ = 32 mm Hg (35 - 45)**

Diagnosis

- **Metabolic acidosis**
- **With compensation**

Summary

- **Acidosis**

	Abnormalities			
pH	↓	↔	↓	↔
PCO₂	↑	↑	↔	↓
HCO₃	↔	↑	↓	↓
Type	Resp	Resp	Metab	Metab
Correction	No	Yes Metab	No	Yes Resp

Summary

- Alkalosis

	Abnormalities			
pH	↑↑	⇔	↑↑	⇔
PCO ₂	↓↓	↓↓	⇔	↑↑
HCO ₃	⇔	↓↓	↑↑	↑↑
Type	Resp	Resp	Metab	Metab
Correction	No	Yes Metab	No	Yes Resp

