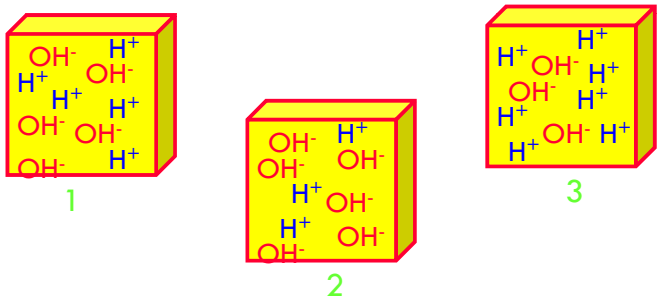
ACID BASE BALANCE

DHammoudi.MD

pH SCALE

- Pure water is **Neutral**
  - ($H^+ = OH^-$)
    - pH = 7
- **Acid**
  - ($H^+ > OH^-$)
    - pH < 7
- **Base**
  - ($H^+ < OH^-$)
    - pH > 7
- Normal blood pH is **7.35 - 7.45**
- pH range compatible with life is **6.8 - 8.0**

ACIDS, BASES OR NEUTRAL???



pH SCALE

- pH equals the logarithm (log) to the base 10 of the reciprocal of the hydrogen ion (H^+)

pH = log 1 / H^+ concentration

4×10^{-8} (0.00000004)

3

pH SCALE

- Low pH values = high H^+ concentrations
  - H^+ concentration in denominator of formula

pH = log 1 / H^+ concentration

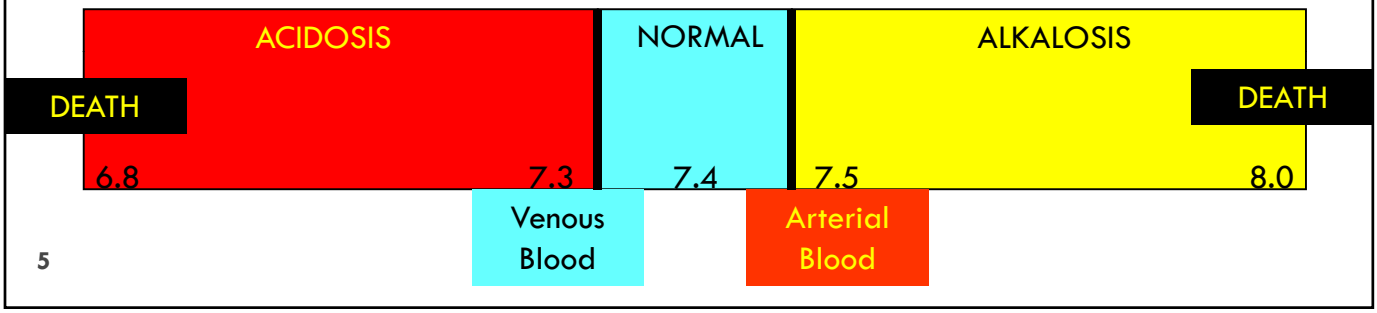
- Unit changes in pH represent a tenfold change in H^+ concentrations
  - Nature of logarithms

4×10^{-8} (0.00000004)

4

pH SCALE

- pH = 4 is more acidic than pH = 6
- pH = 4 has 10 times more free H^+ concentration than pH = 5 and 100 times more free H^+ concentration than pH = 6



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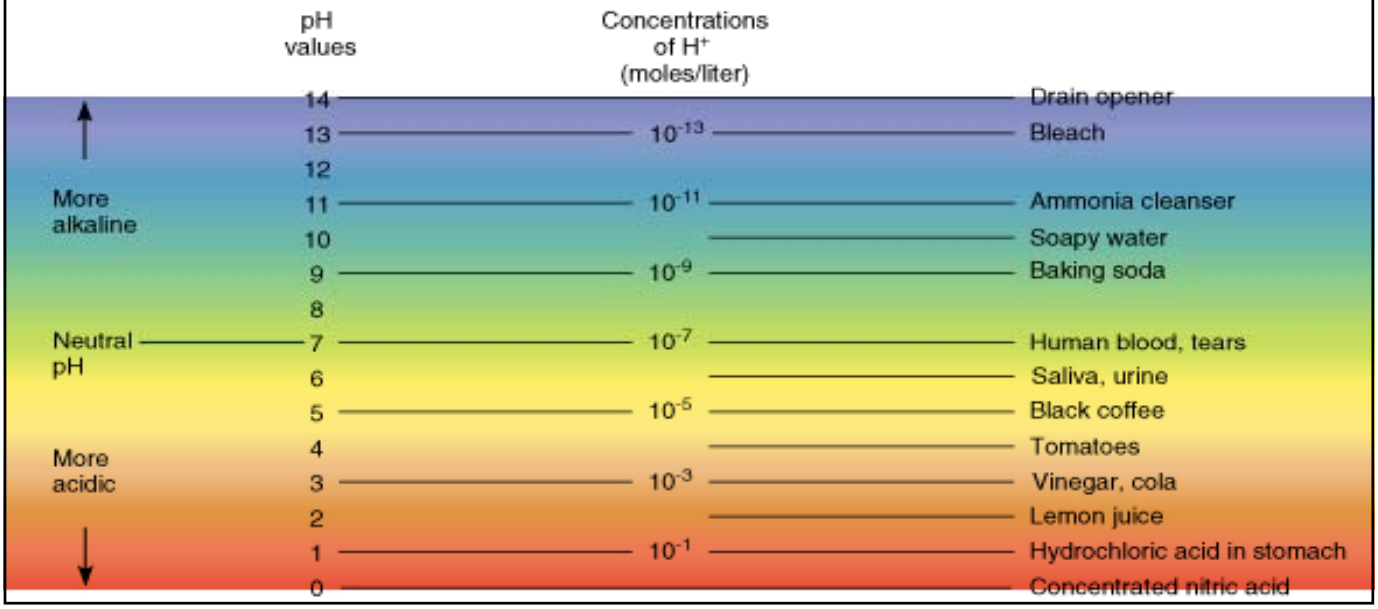
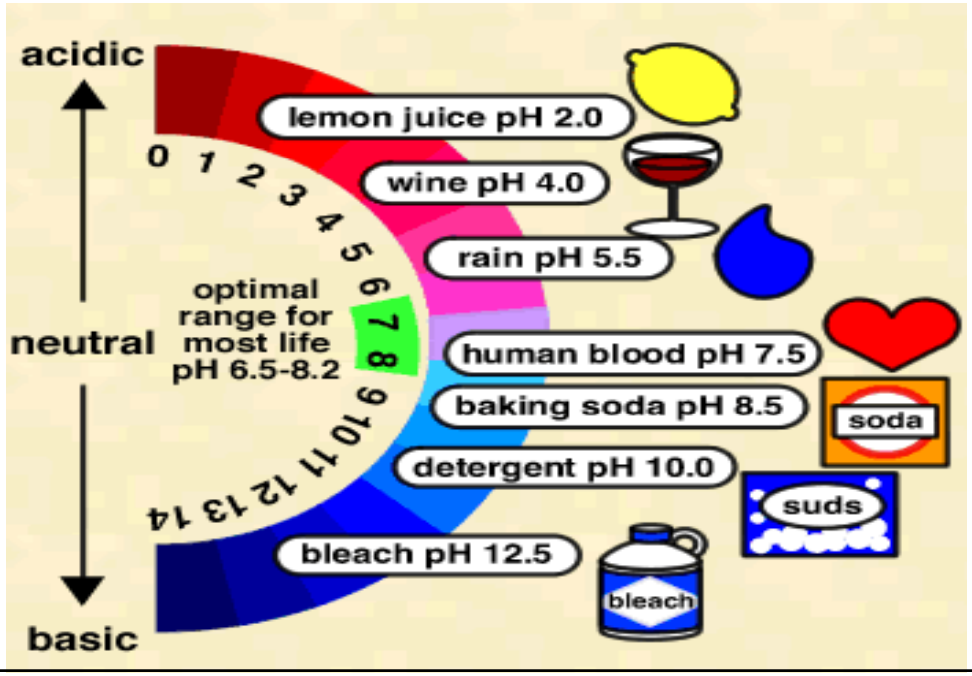
pH SCALE



pH SCALE



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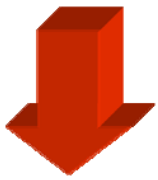
•Acid-Base homeostasis involves **chemical** and **physiologic** processes responsible for the maintenance of the acidity of body fluids at levels that allow optimal function of the whole individual

•**The chemical processes** represent the first line of defense to an acid or base load and include the extracellular and **intracellular buffers**

•**The physiologic processes** modulate acid-base composition by changes in cellular metabolism and by adaptive responses in the **excretion** of volatile acids by the **lungs** and fixed acids by the **kidneys**

EFFECTS OF pH

- The most general effect of pH changes are on enzyme function
  - Also affect excitability of nerve and muscle cells


pH

Excitability


pH

Excitability

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pH Review

- pH = - log $[H^+]$
- H^+ is really a proton
- Range is from 0 - 14
- If $[H^+]$ is high, the solution is acidic; pH < 7
- If $[H^+]$ is low, the solution is basic or alkaline ; pH > 7

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ACID-BASE BALANCE

- **Acid - Base** balance is primarily concerned with two ions:
  - **Hydrogen** (H^+)
  - **Bicarbonate** (HCO_3^-)

H^+

HCO_3^-

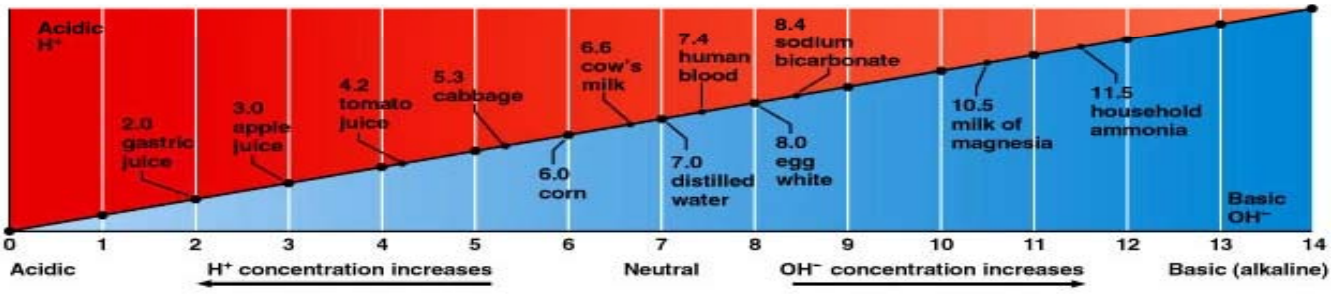
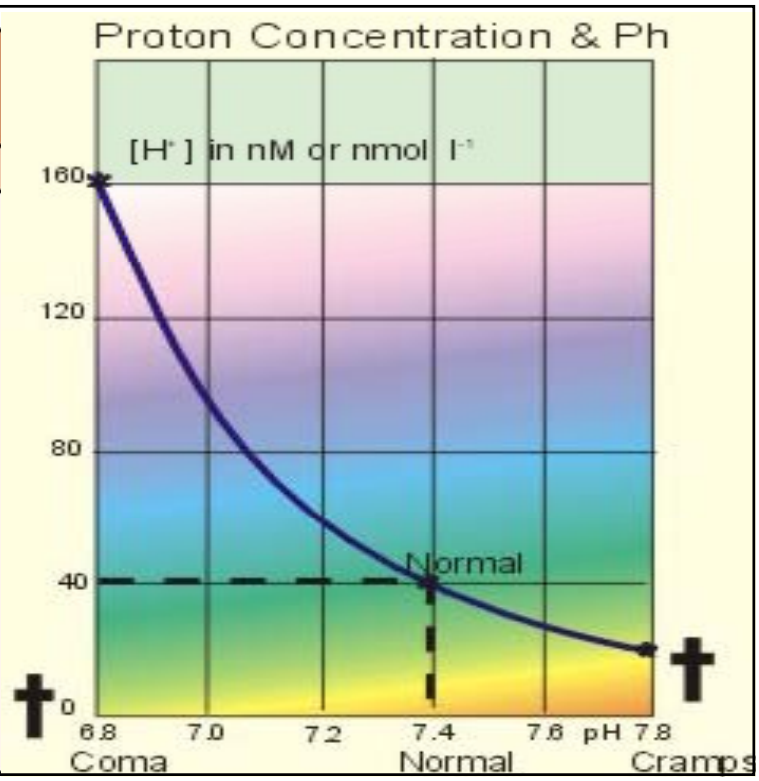


table 2.5 Hydrogen Ion Concentrations and pH

Grams of H^+ per Liter	pH	
0.00000000000001	14	↑ Increasingly basic
0.0000000000001	13	
0.000000000001	12	
0.00000000001	11	
0.0000000001	10	
0.000000001	9	
0.00000001	8	Neutral–neither acidic nor basic
0.0000001	7	
0.000001	6	
0.00001	5	
0.0001	4	
0.001	3	Increasingly acidic
0.01	2	
0.1	1	
1.0	0	↓



- Acids are H^+ donors.
- Bases are H^+ acceptors, or give up OH^- in solution.
- Acids and bases can be:
  - Strong – dissociate completely in solution
    - HCl, NaOH
  - Weak – dissociate only partially in solution
    - Lactic acid, carbonic acid

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The Body and pH

- Homeostasis of pH is tightly controlled
- Extracellular fluid = 7.4
- Blood = 7.35 – 7.45
- < 6.8 or > 8.0 death occurs
- Acidosis (acidemia) below 7.35
- Alkalosis (alkalemia) above 7.45

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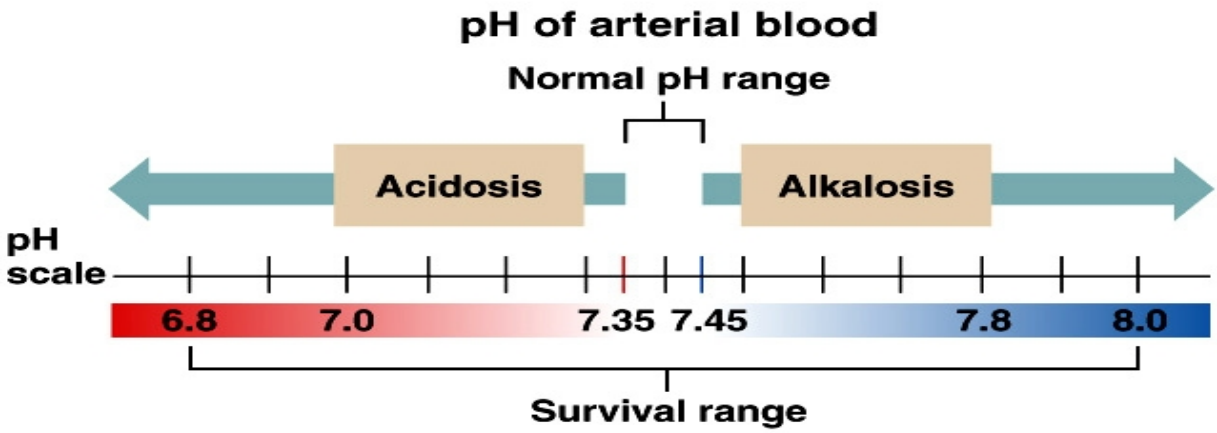

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Small changes in pH can produce major disturbances

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

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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.
- $CO_2 + H_20 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

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ACID-BASE REGULATION

- Maintenance of an acceptable pH range in the extracellular fluids is accomplished by **three** mechanisms:
  - **1) Chemical Buffers**
    - React very rapidly (less than a second)
  - **2) Respiratory Regulation**
    - Reacts rapidly (seconds to minutes)
  - **3) Renal Regulation**
    - Reacts slowly (minutes to hours)

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Control of Acids

1. **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

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Bicarbonate buffer

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

$HCl + NaHCO_3 \leftrightarrow H_2CO_3 + NaCl$

$NaOH + H_2CO_3 \leftrightarrow NaHCO_3 + H_2O$

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Phosphate buffer

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

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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.

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2. Respiratory mechanisms

- Exhalation of carbon dioxide
- Powerful, but only works with **volatile acids**
- Doesn't affect **fixed acids** like lactic acid
- $CO_2 + H_20 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
- Body pH can be adjusted by changing rate and depth of breathing

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3. Kidney excretion

- Can eliminate large amounts of acid
- Can also excrete base
- Can conserve and produce bicarb ions
- Most effective regulator of pH
- If kidneys fail, pH balance fails

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ACID-BASE REGULATION

- **Kidney Regulation**
  - Excess acid is excreted by the kidneys, largely in the form of ammonia
  - The kidneys have some ability to alter the amount of acid or base that is excreted, but this generally takes several days

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Rates of correction

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

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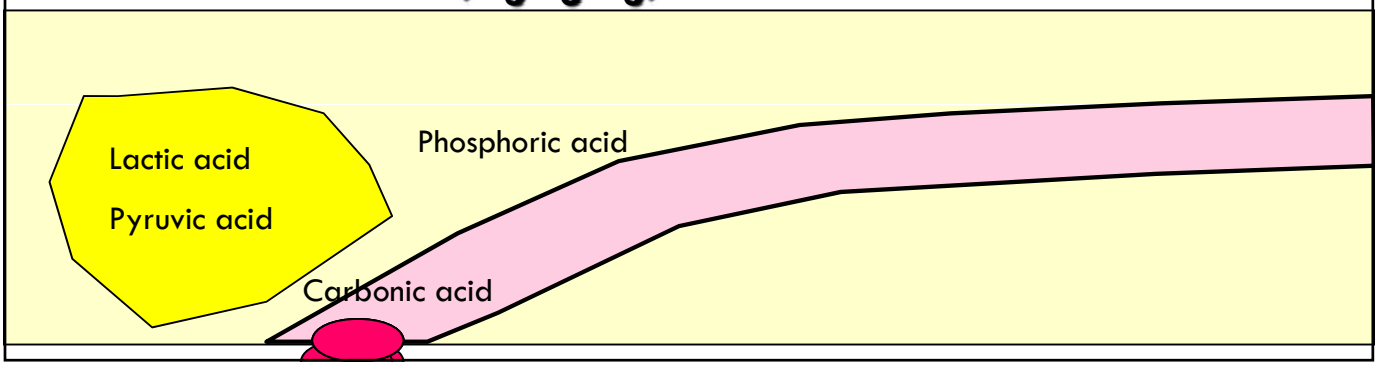
ACIDS

- Physiologically important acids include:
  - **Carbonic acid (H_2CO_3)**
  - **Phosphoric acid (H_3PO_4)**
  - **Pyruvic acid ($C_3H_4O_3$)**
  - **Lactic acid ($C_3H_6O_3$)**



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)**

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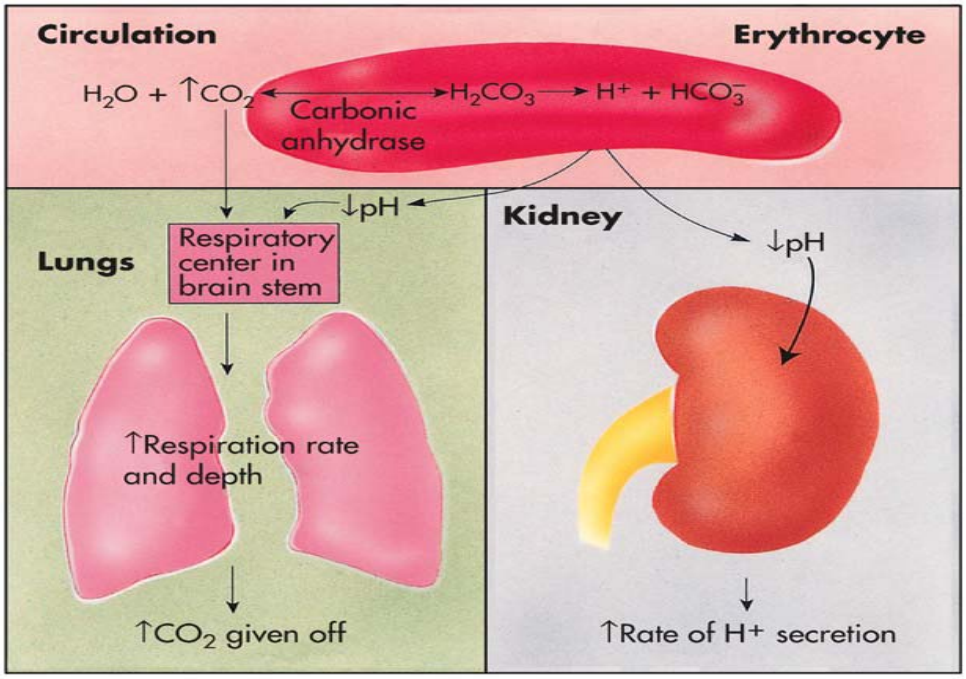

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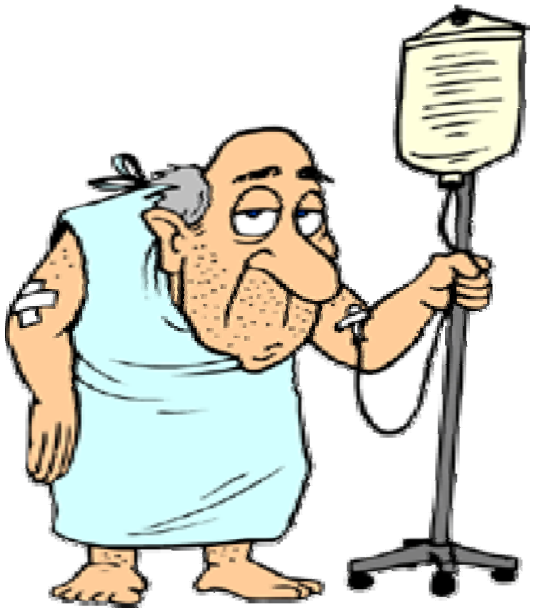
From Thibodeau GA, Patton KT: *Anatomy & physiology,* ed 5, St Louis, 2003, Mosby.

ACIDOSIS / ALKALOSIS



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ACIDOSIS / ALKALOSIS

- **Acidosis**
  - A condition in which the blood has too much acid (or too little base), frequently resulting in a decrease in blood pH
- **Alkalosis**
  - A condition in which the blood has too much base (or too little acid), occasionally resulting in an increase in blood pH

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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.

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Compensation

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

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Acidosis

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

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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

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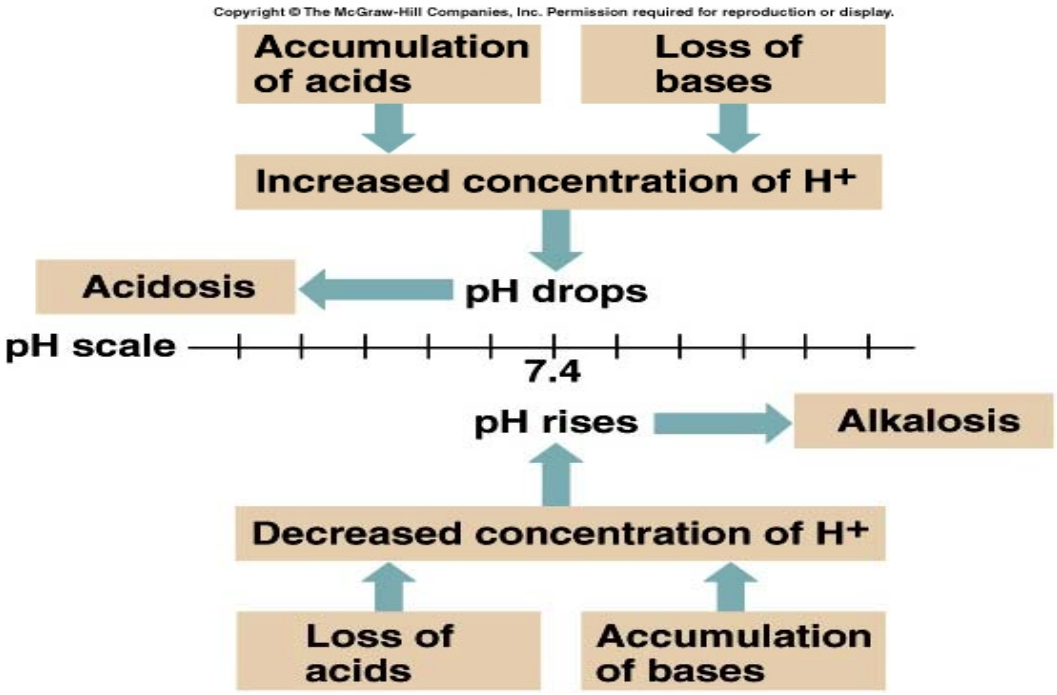

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Respiratory Acidosis

- **Carbonic acid excess** caused by blood levels of CO_2 above 45 mm Hg.
- **Hypercapnia** – high levels of CO_2 in blood
- Chronic conditions:
  - Depression of respiratory center in brain that controls breathing rate – drugs or head trauma
  - Paralysis of respiratory or chest muscles
  - Emphysema

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Respiratory Acidosis

- Acute conditons:
  - Adult Respiratory Distress Syndrome
  - Pulmonary edema
  - Pneumothorax

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Compensation for Respiratory Acidosis

- Kidneys eliminate hydrogen ion and retain bicarbonate ion

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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 CO_2

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Treatment of Respiratory Acidosis

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

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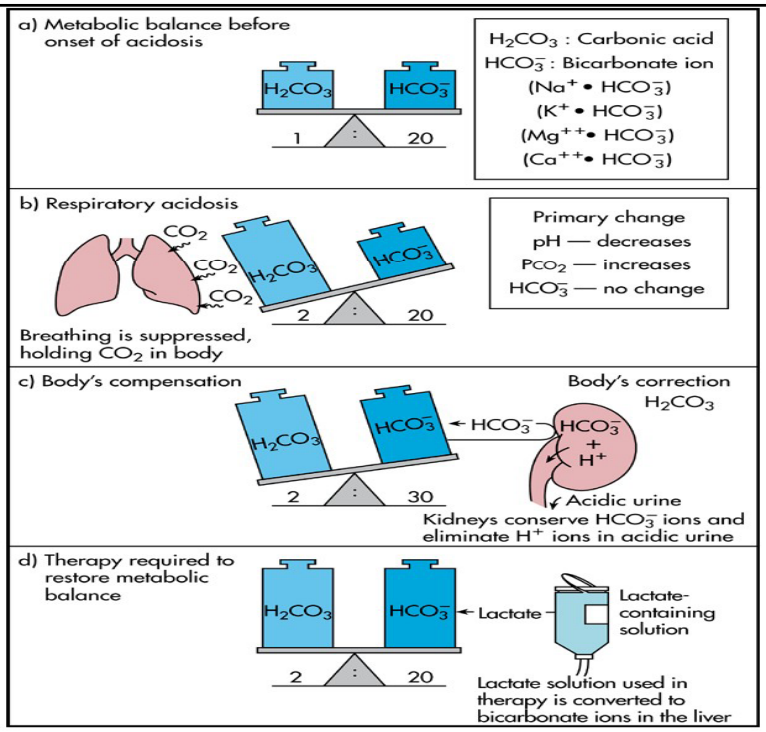

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From Thibodeau GA, Patton KT: *Anatomy & physiology*, ed 5, St Louis, 2003, Mosby.

Respiratory Alkalosis

- Carbonic acid deficit
- pCO_2 less than 35 mm Hg (hypocapnea)
- Most common acid-base imbalance
- Primary cause is hyperventilation

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Respiratory Alkalosis

- Conditions that stimulate respiratory center:
  - 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

45

Compensation of Respiratory Alkalosis

- Kidneys conserve hydrogen ion
- Excrete bicarbonate ion

46

Treatment of Respiratory Alkalosis

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

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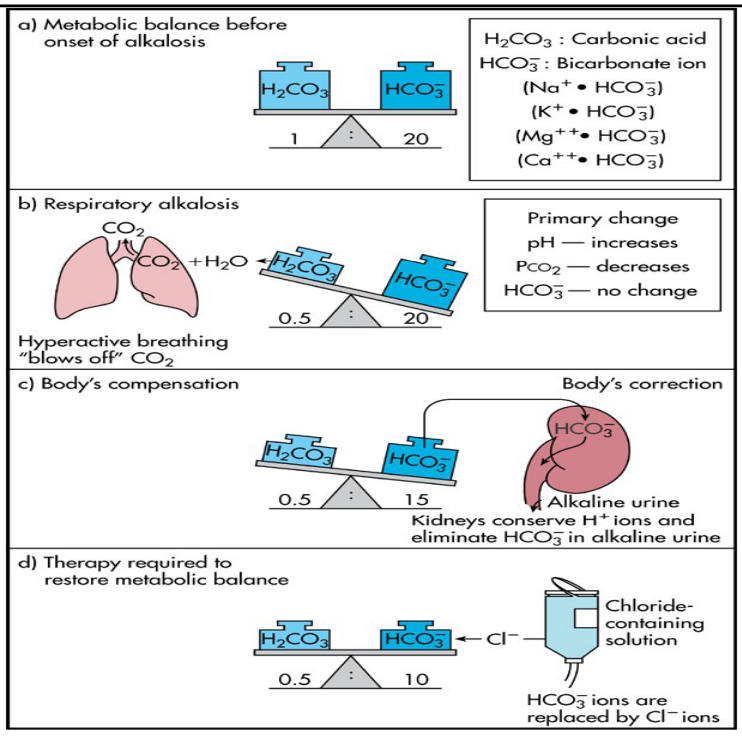

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From Thibodeau GA, Patton KT: *Anatomy & physiology,* ed 5, St Louis, 2003, Mosby.

Metabolic Acidosis

- **Bicarbonate deficit** - blood concentrations of bicarb drop below 22mEq/L
- Causes:
  - **Loss of bicarbonate through diarrhea or renal dysfunction**
  - **Accumulation of acids (lactic acid or ketones)**
  - **Failure of kidneys to excrete H+**

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Symptoms of Metabolic Acidosis

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

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Compensation for Metabolic Acidosis

- Increased ventilation
- Renal excretion of hydrogen ions if possible
- K^+ exchanges with excess H^+ in ECF
- (H^+ into cells, K^+ out of cells)

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Treatment of Metabolic Acidosis

- IV lactate solution

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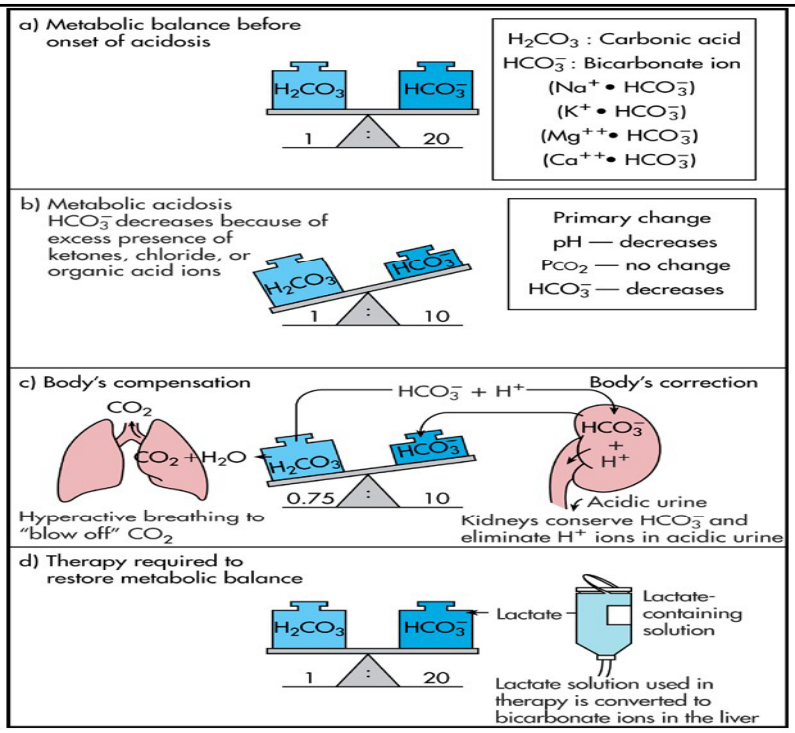

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From Thibodeau GA, Patton KT: *Anatomy & physiology*, ed 5, St Louis, 2003, Mosby.

Metabolic Alkalosis

- **Bicarbonate excess -** concentration in blood is greater than 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

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Compensation for Metabolic Alkalosis

- Alkalosis most commonly occurs with renal dysfunction, so can't count on kidneys
- Respiratory compensation difficult – hypoventilation limited by hypoxia

55

Symptoms of Metabolic Alkalosis

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

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Treatment of Metabolic Alkalosis

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

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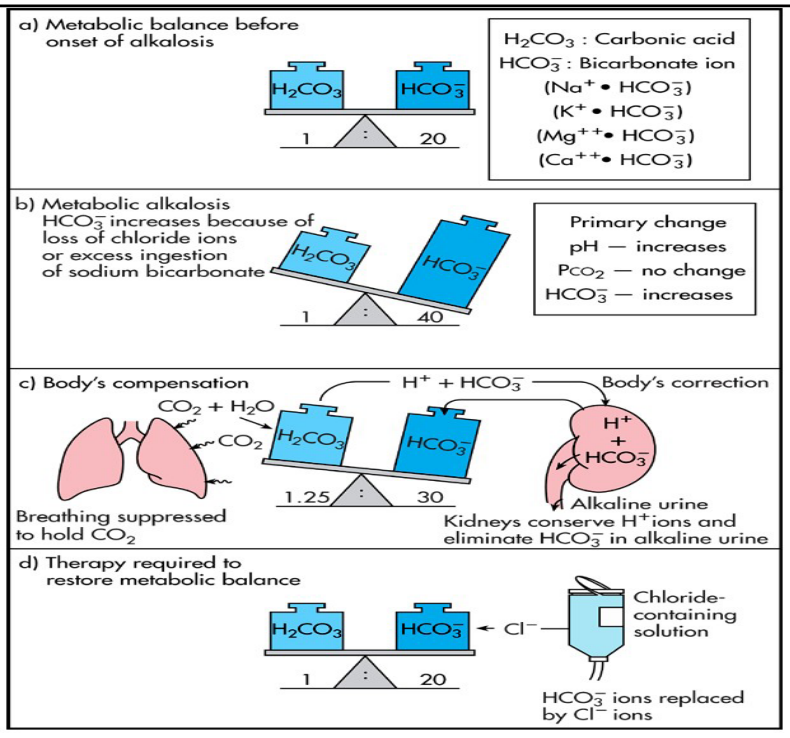

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From Thibodeau GA, Patton KT: *Anatomy & physiology*, ed 5, St Louis, 2003, Mosby.

Diagnosis of Acid-Base Imbalances

1. Note whether the pH is low (acidosis) or high (alkalosis)
2. Decide which value, pCO_2 or HCO_3^- , is outside the normal range **and** could be the **cause** of the problem. If the cause is a change in pCO_2, the problem is respiratory. If the cause is HCO_3^- the problem is metabolic.

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3. Look at the value that doesn't correspond to the observed pH change. If it is inside the normal range, there is no compensation occurring. If it is outside the normal range, the body is partially compensating for the problem.

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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)

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Diagnosis

- Metabolic acidosis
- With compensation

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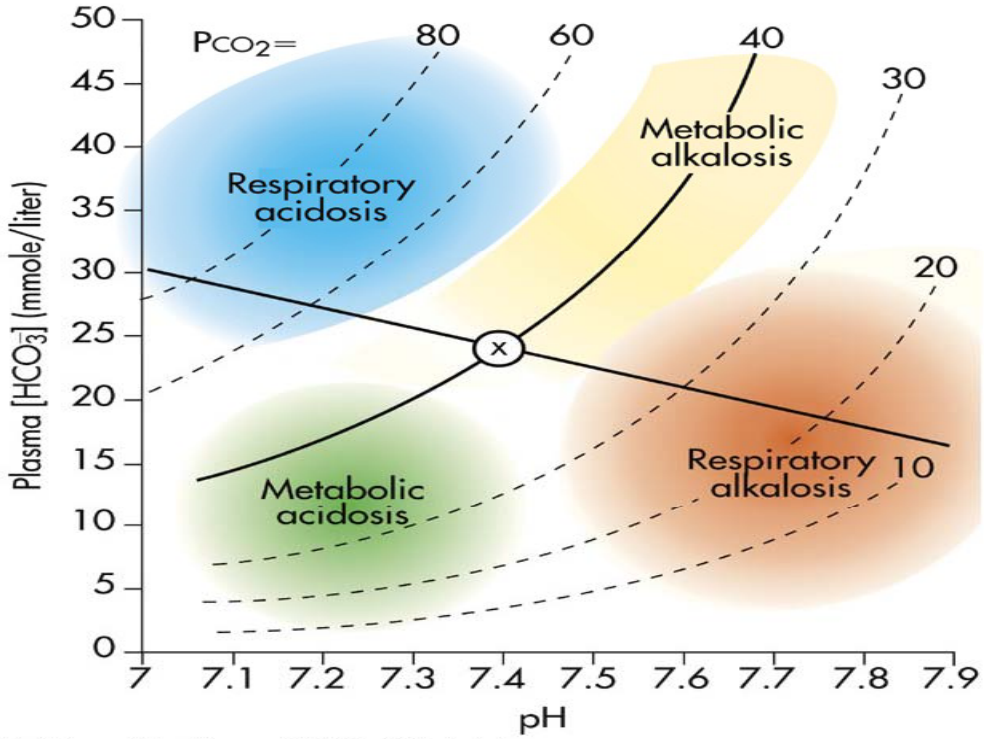

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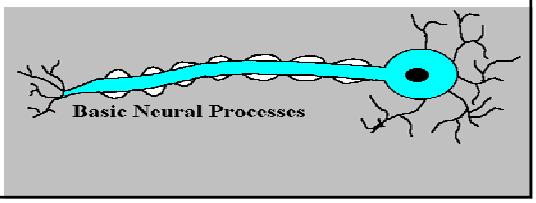
ACIDOSIS / ALKALOSIS

- pH changes have dramatic effects on normal cell function
  - **1)** Changes in excitability of nerve and muscle cells
  - **2)** Influences enzyme activity
  - **3)** Influences **K^+** levels



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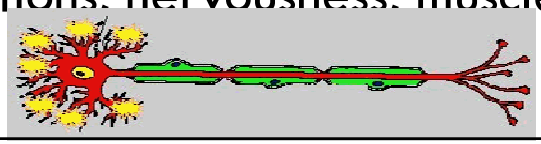
CHANGES IN CELL EXCITABILITY

- pH decrease (more acidic) depresses the central nervous system
  - Can lead to loss of consciousness
- pH increase (more basic) can cause over-excitability
  - Tingling sensations, nervousness, muscle twitches



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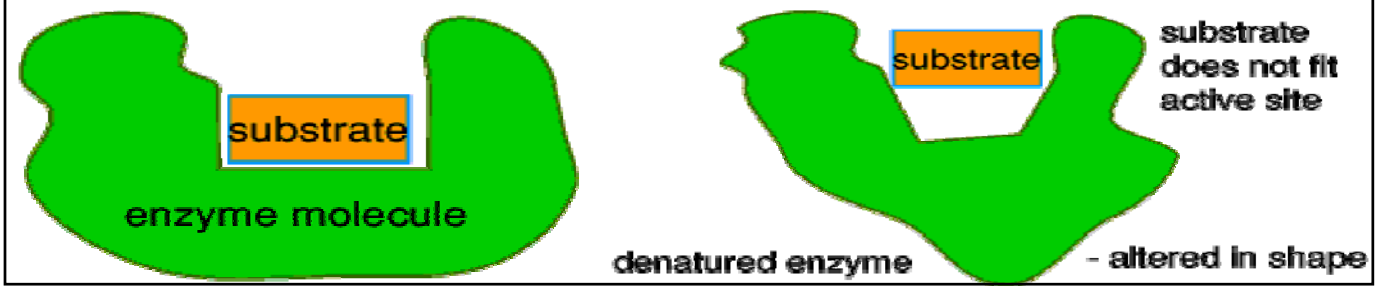
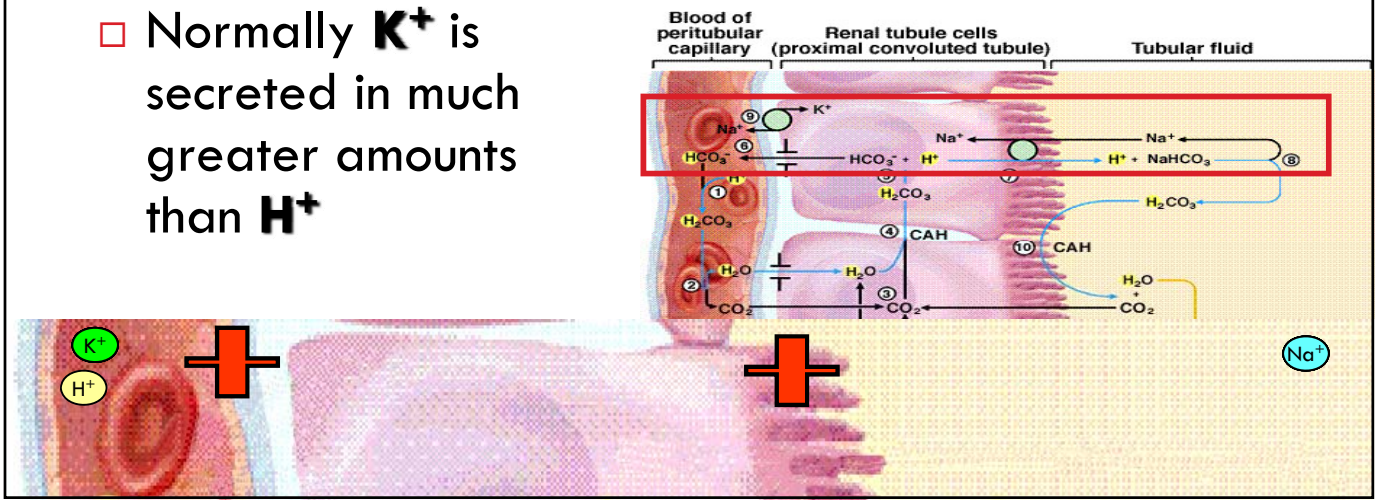
INFLUENCES ON ENZYME ACTIVITY

- pH increases or decreases can alter the shape of the enzyme rendering it non-functional
- Changes in enzyme structure can result in accelerated or depressed metabolic actions within the cell



INFLUENCES ON K^+ LEVELS

- When reabsorbing **Na^+** from the filtrate of the renal tubules **K^+** or **H^+** is secreted (exchanged)
- Normally **K^+** is secreted in much greater amounts than **H^+**



INFLUENCES ON K^+ LEVELS

- If **H^+** concentrations are high (acidosis) than **H^+** is secreted in greater amounts
- This leaves less **K^+** than usual excreted
- The resultant **K^+** retention can affect cardiac function and other systems

ACIDOSIS

- A relative increase in hydrogen ions results in **acidosis**

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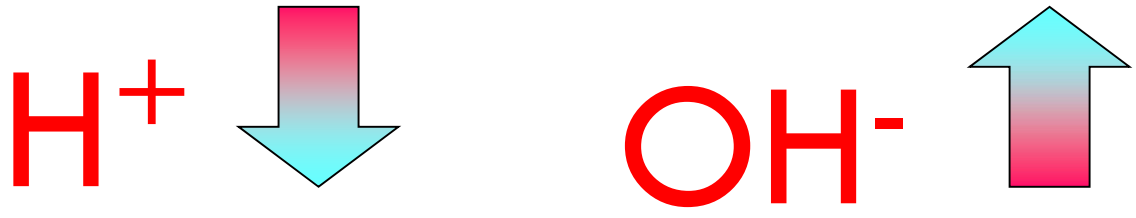
ALKALOSIS

- A relative increase in bicarbonate results in **alkalosis**



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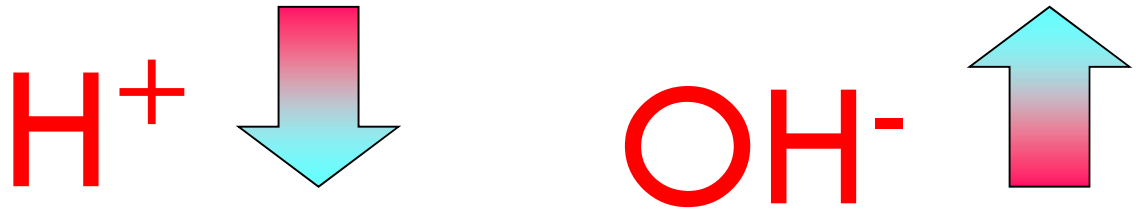
ACIDOSIS / ALKALOSIS

- **Acidosis**

- **Alkalosis**



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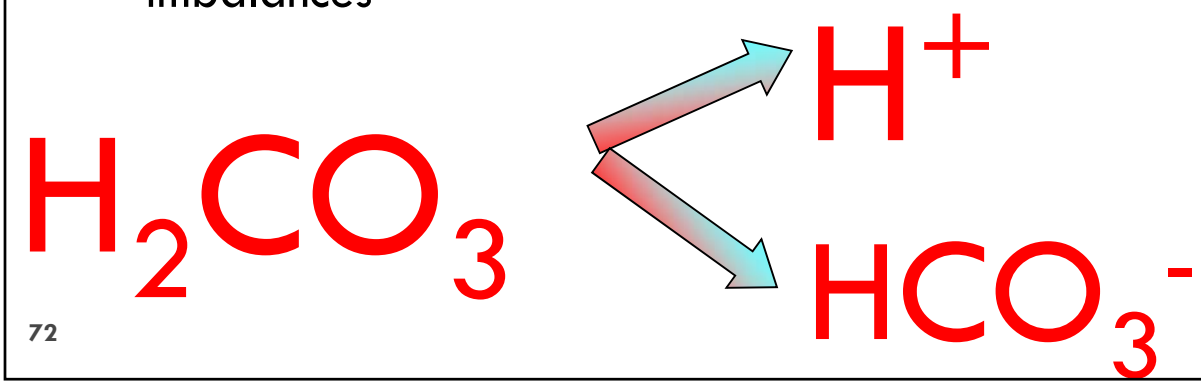
ACIDOSIS / ALKALOSIS

- Normal ratio of HCO_3^- (BASE) to H_2CO_3 (ACID) is 20:1
  - H_2CO_3 is source of H^+ ions in the body
- Deviations from this ratio are used to identify **Acid-Base** imbalances



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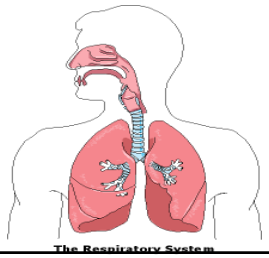
ACIDOSIS / ALKALOSIS

- **Acidosis** and **Alkalosis** can arise in two fundamentally different ways:
  - **1) Excess or deficit of CO_2 (Volatile Acid)**
    - **Volatile Acid** can be eliminated by the respiratory system
  - **2) Excess or deficit of Fixed Acid**
    - **Fixed Acids** cannot be eliminated by the respiratory system



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ACIDOSIS / ALKALOSIS

- Normal values of bicarbonate (arterial)
  - **pH** = 7.4
  - **PCO_2** = 40 mm Hg
  - **HCO_3^-** = 24 meq/L

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ACIDOSIS

- A **decrease** in a normal 20:1 base to acid ratio
  - An increase in the number of hydrogen ions (ex: ratio of 20:2 translated to 10:1)
  - A decrease in the number of bicarbonate ions (ex: ratio of 10:1)
- Caused by too much acid or too little base

ACID BASE

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ALKALOSIS

- An **increase** in the normal 20:1 base to acid ratio
  - A decrease in the number of hydrogen ions (ex: ratio of 20:0.5 translated to 40:1)
  - An increase in the number of bicarbonate ions (ex: ratio of 40:1)
- Caused by base excess or acid deficit

ACID BASE

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SOURCES OF HYDROGEN IONS

- **1) Cell Metabolism (CO_2)**
- **2) Food Products**
- **3) Medications**
- **4) Metabolic Intermediate by-products**
- **5) Some Disease processes**

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SOURCES OF HYDROGEN IONS

- **1) Cellular Metabolism** of carbohydrates release **CO_2** as a waste product
  - Aerobic respiration

$C_6H_{12}O_6 \rightarrow CO_2 + H_2O + Energy$

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SOURCES OF HYDROGEN IONS

- CO_2 diffuses into the bloodstream where the reaction:

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

- This process occurs in red blood cells
  - H_2CO_3 (carbonic acid)
  - Acids produced as a result of the presence of CO_2 is referred to as a **Volatile acid**

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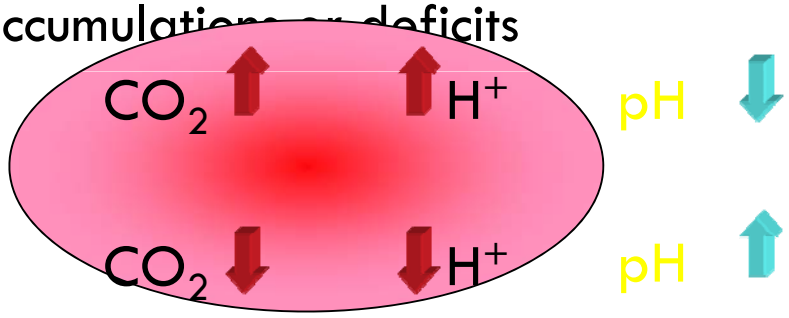
SOURCES OF HYDROGEN IONS

- Dissociation of H_2CO_3 results in the production of free H^+ and HCO_3^-
- The respiratory system removes CO_2 thus freeing HCO_3^- to recombine with H^+
- Accumulation or deficit of CO_2 in blood leads to respective H^+ accumulations or deficits



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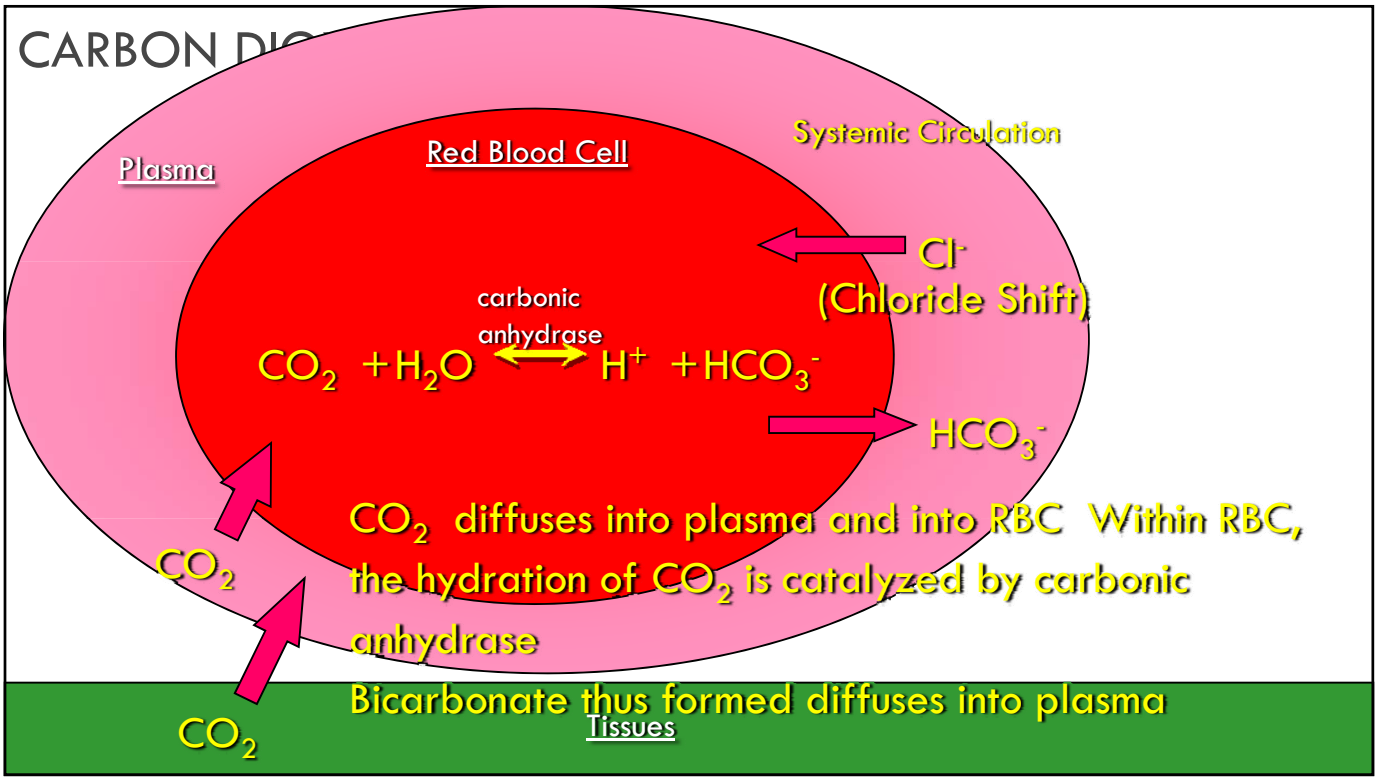
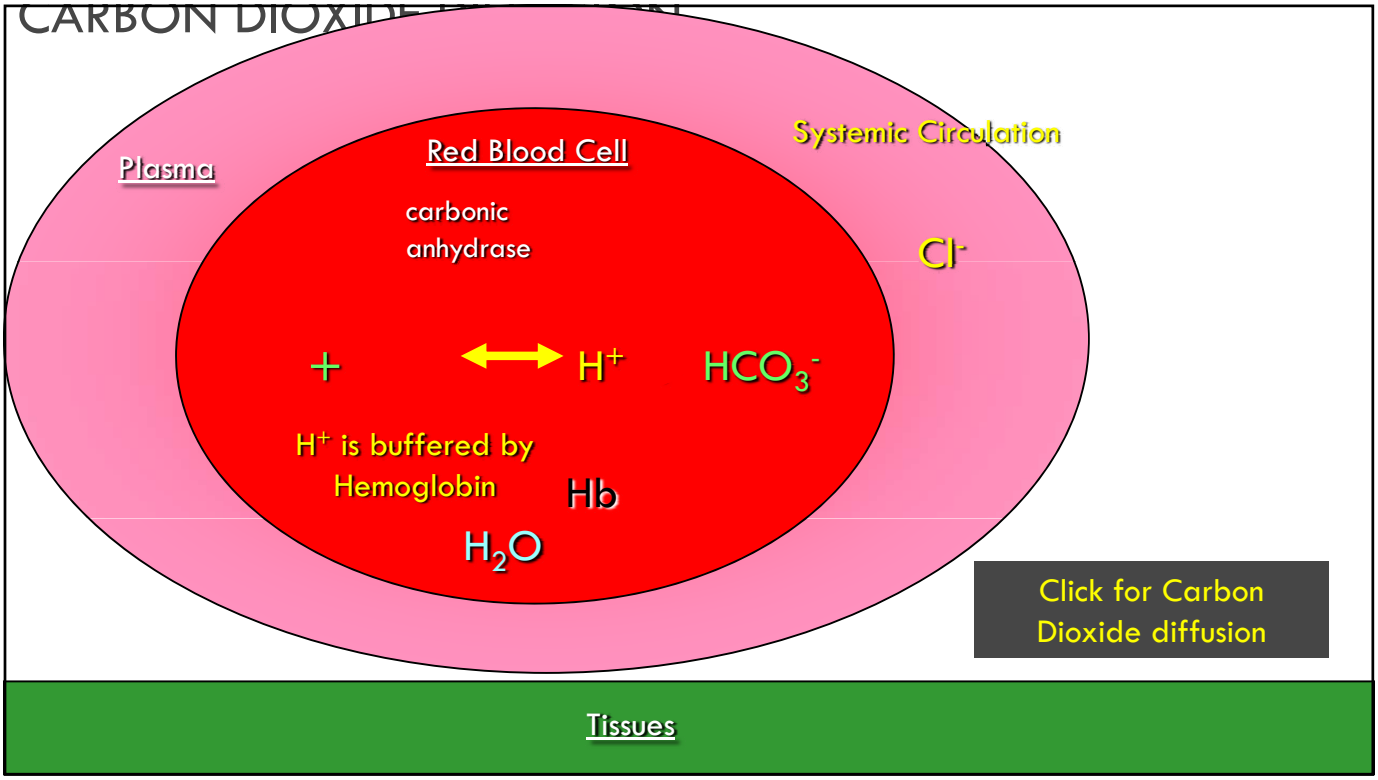

CARBON DIO
Systemic Circulation
Plasma
Red Blood Cell
Cl-
(Chloride Shift)
carbonic
anhydrase
CO2 + H2O ⟷ H+ + HCO3-
HCO3-
CO2 diffuses into plasma and into RBC Within RBC, the hydration of CO2 is catalyzed by carbonic anhydrase
CO2
Bicarbonate thus formed diffuses into plasma
CO2
Tissues


CARBON DIOXIDE
Systemic Circulation
Plasma
Red Blood Cell
carbonic
anhydrase
Cl-
+ ⟷ H+ HCO3-
H+ is buffered by
Hemoglobin
Hb
H2O
Click for Carbon Dioxide diffusion
Tissues

SOURCES OF HYDROGEN IONS

- **2) Food products**
  - Sauerkraut
  - Yogurt
  - Citric acid in fruits

SOURCES OF HYDROGEN IONS

- **3) Medications**
  - May stimulate **HCl** production by parietal cells of the stomach

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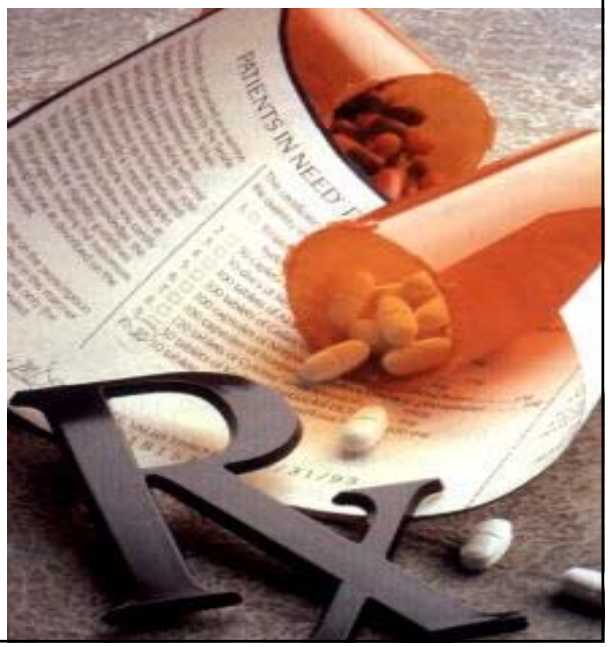
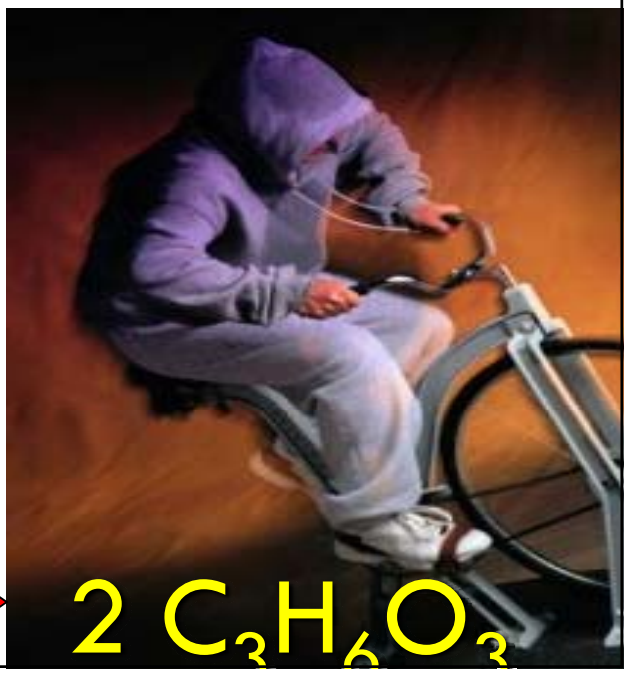


SOURCES OF HYDROGEN IONS

- **4) Metabolic Intermediate by-products**
  - Lactic acid
  - Pyruvic acid
  - Acetoacetic acid
  - Fatty acids



85 $C_6H_{12}O_6$ → $2\ C_3H_6O_3$

SOURCES OF HYDROGEN IONS

- Inorganic acids can also be produced during breakdown of nutrients
  - **Proteins** (meat products)
    - Breakdown leads to productions of sulfuric acid and phosphoric acid
  - **Fruits** and **Vegetables**
    - Breakdown produces bases which can help to equalize acid production

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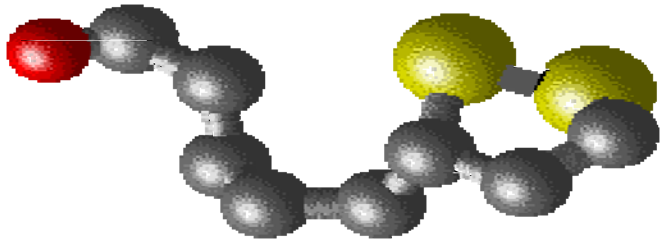
SOURCES OF HYDROGEN IONS

- **5) Some disease processes**
  - Ex: diabetes causes improper metabolism of fats which results in the generation of a waste product called a **Keto Acid**



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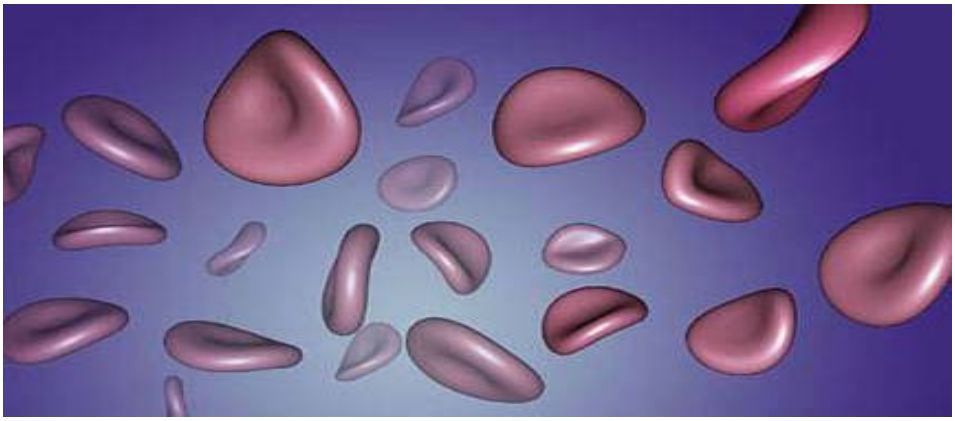
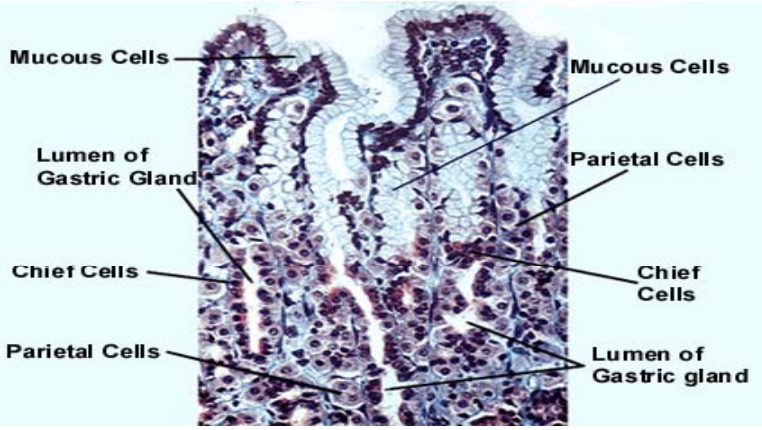
SOURCES OF BICARBONATE IONS



88

SOURCES OF BICARBONATE IONS

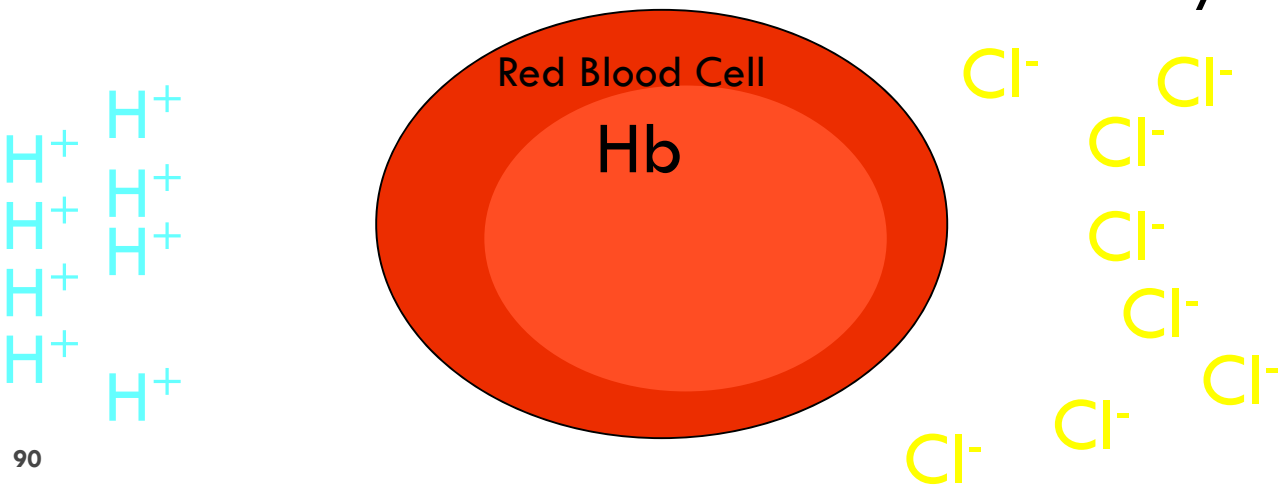
- **1) CO_2 diffusion into red blood cells**
- **2) Parietal cell secretion of the gastric mucosa**



89

1) CO_2 DIFFUSION

- Hemoglobin buffers **H^+**
- Chloride shift insures electrical neutrality



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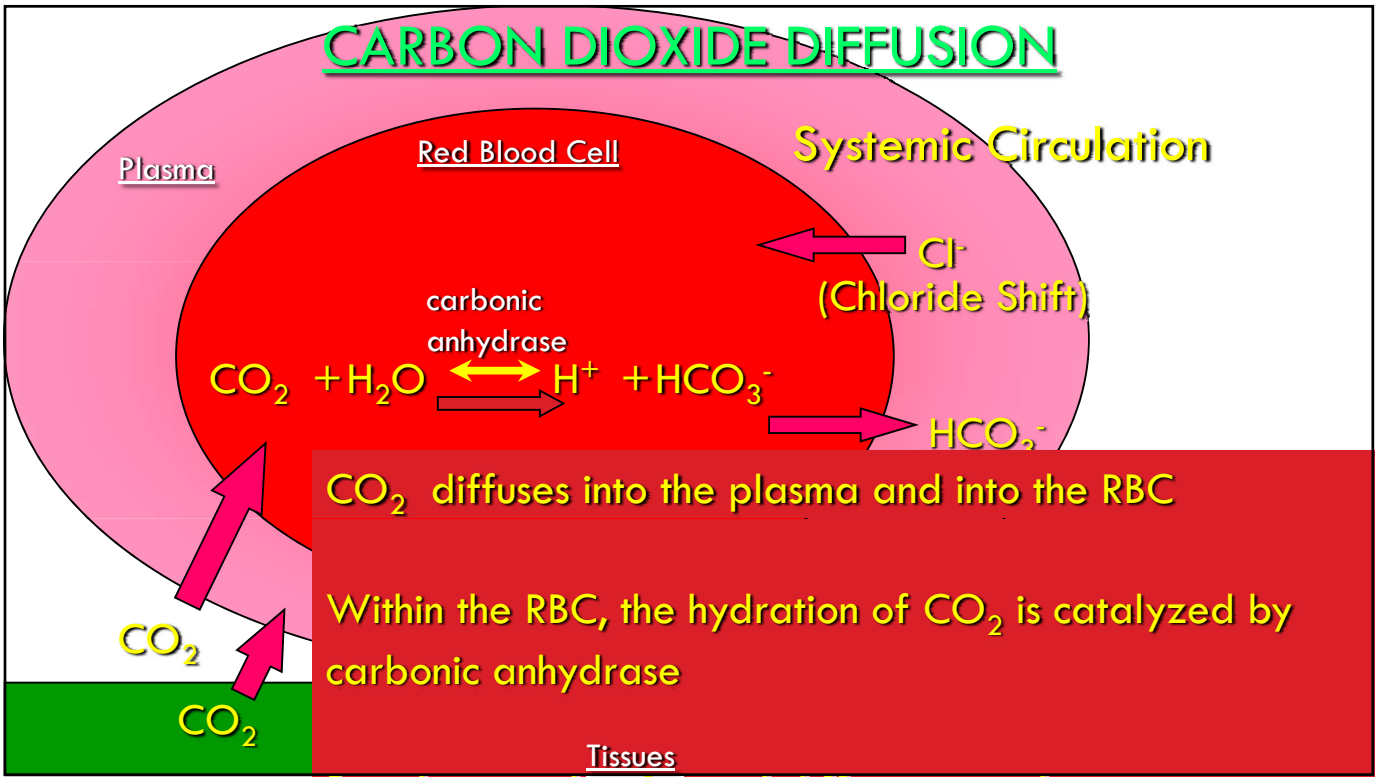
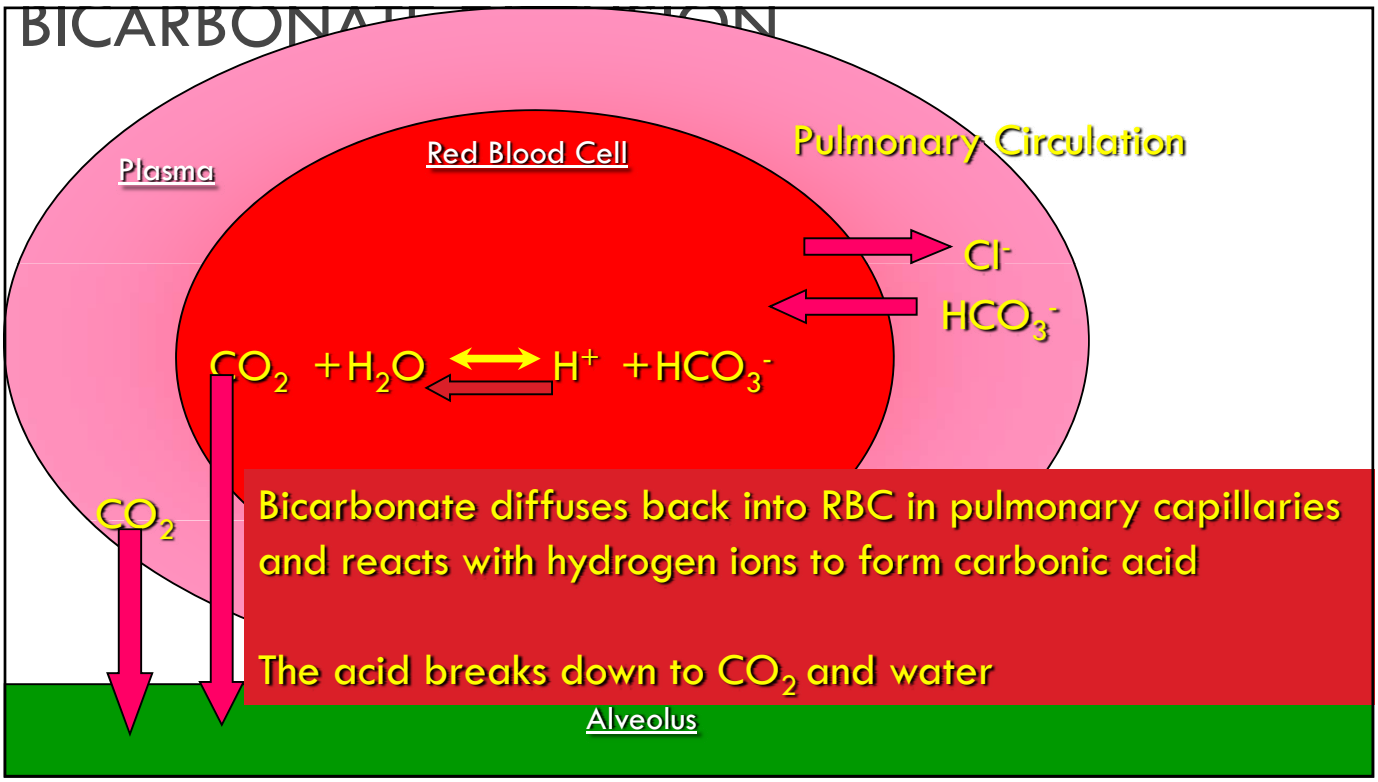
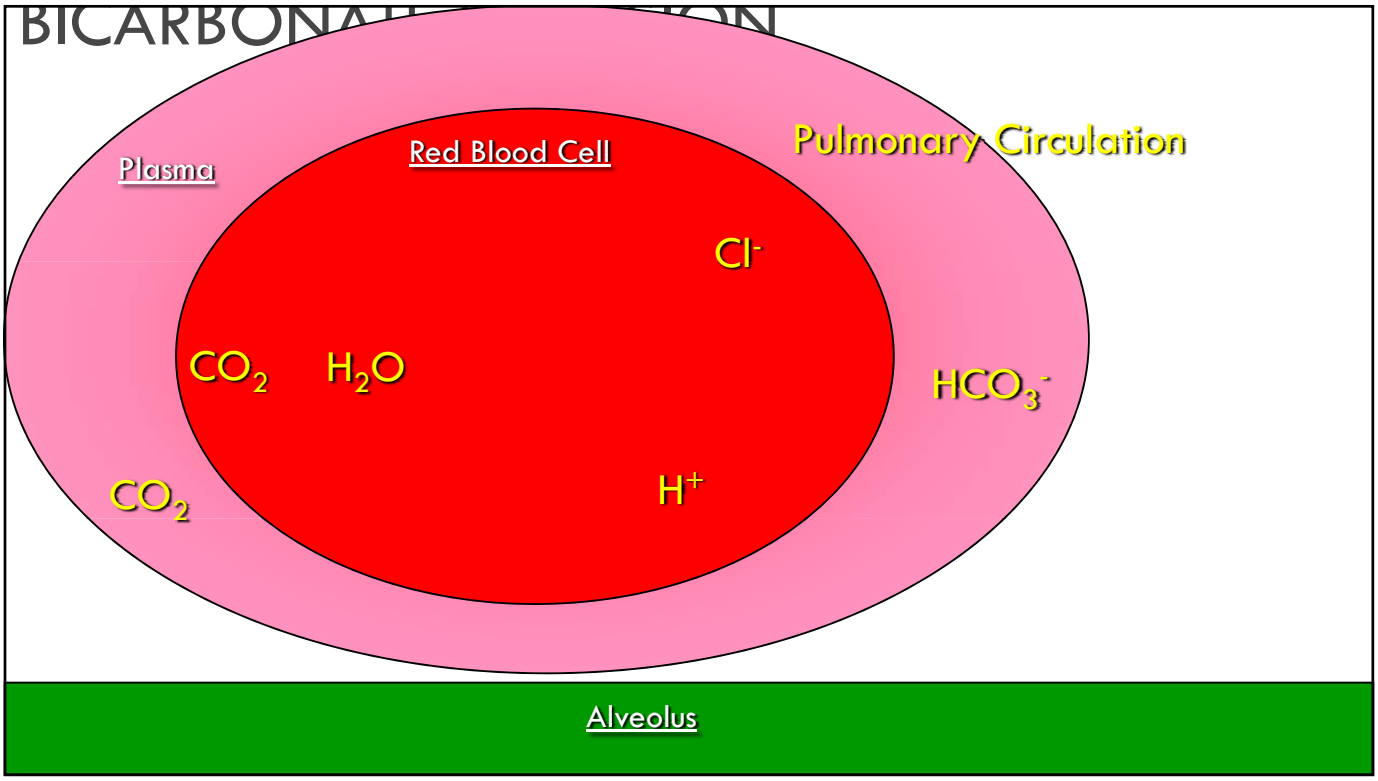

CARBON DIOXIDE DIFFUSION
Plasma
Red Blood Cell
Systemic Circulation
Cl-
(Chloride Shift)
carbonic anhydrase
CO2 +H2O H+ +HCO3-
HCO3-
CO2
CO2
Tissues
CO2 diffuses into the plasma and into the RBC
Within the RBC, the hydration of CO2 is catalyzed by carbonic anhydrase

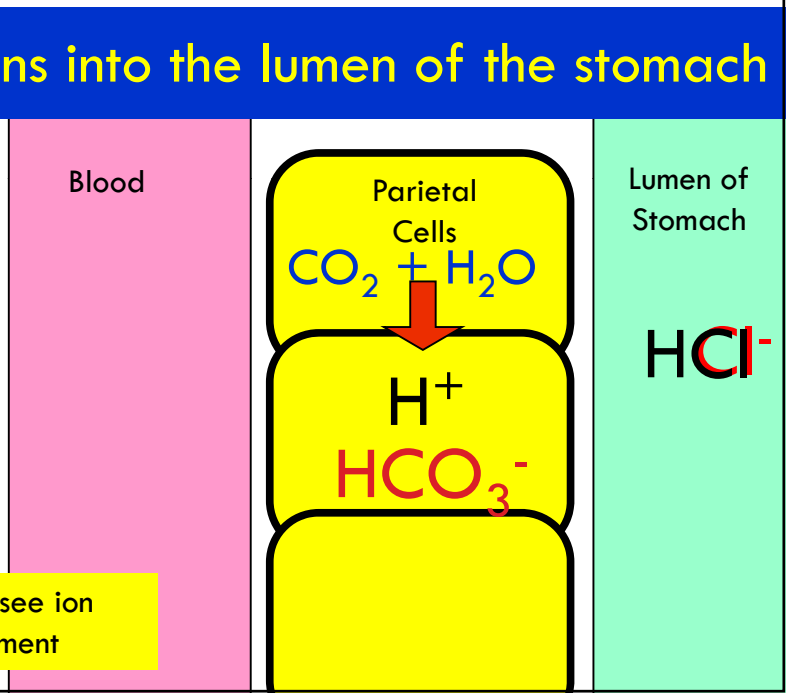

BICARBONATE
Plasma
Red Blood Cell
Pulmonary Circulation
Cl-
HCO3-
CO2 +H2O H+ +HCO3-
CO2
Alveolus
Bicarbonate diffuses back into RBC in pulmonary capillaries and reacts with hydrogen ions to form carbonic acid
The acid breaks down to CO2 and water



2) PARIETAL CELL SECRETION

♥ Secrete hydrogen ions into the lumen of the stomach

- Bicarbonate ions diffuse into the bloodstream to maintain electrical neutrality in the parietal cell



Click to see ion movement

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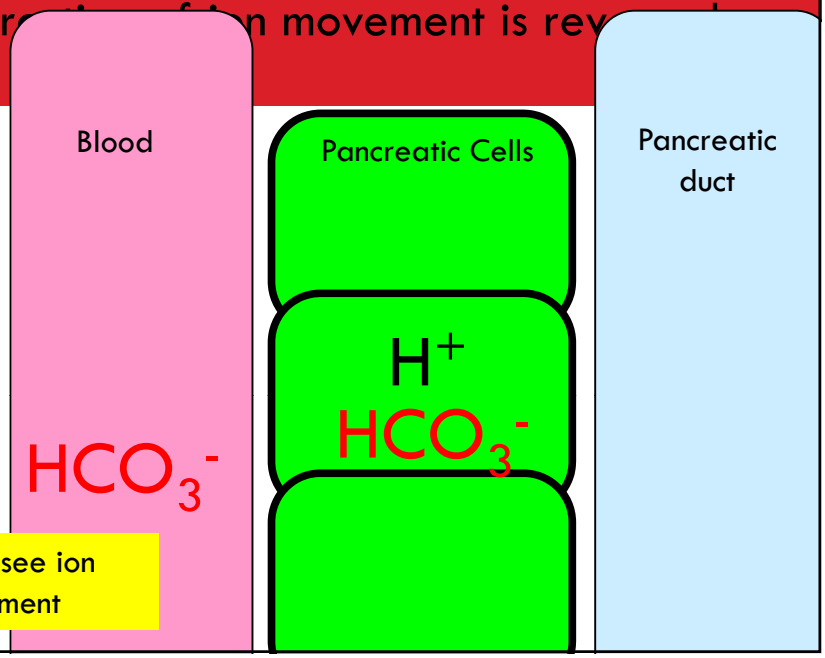
PANCREATIC CELL SECRETION

In pancreatic cells the dir[illegible]n movement is rev[illegible]

- H^+ ions are secreted into the blood and bicarbonate ions diffuse into pancreatic juice

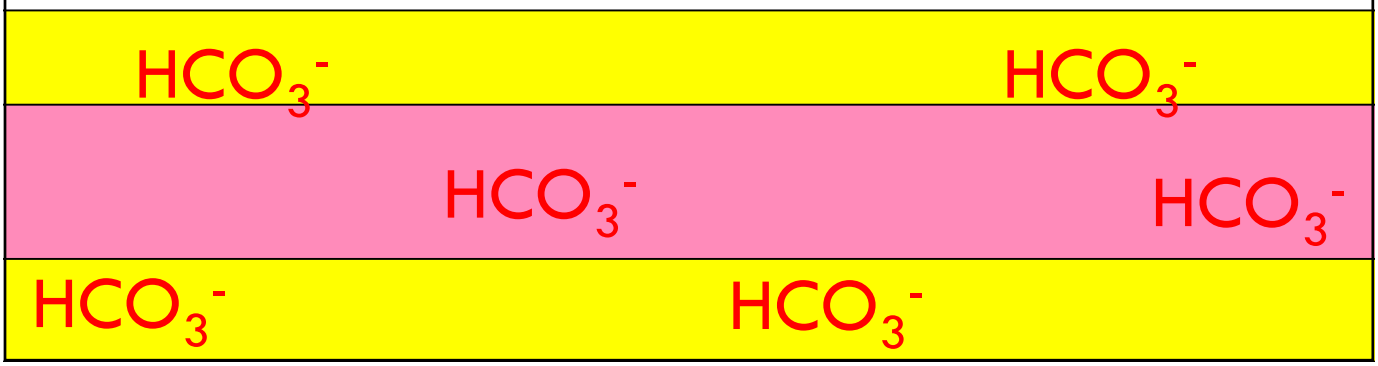


Click to see ion movement

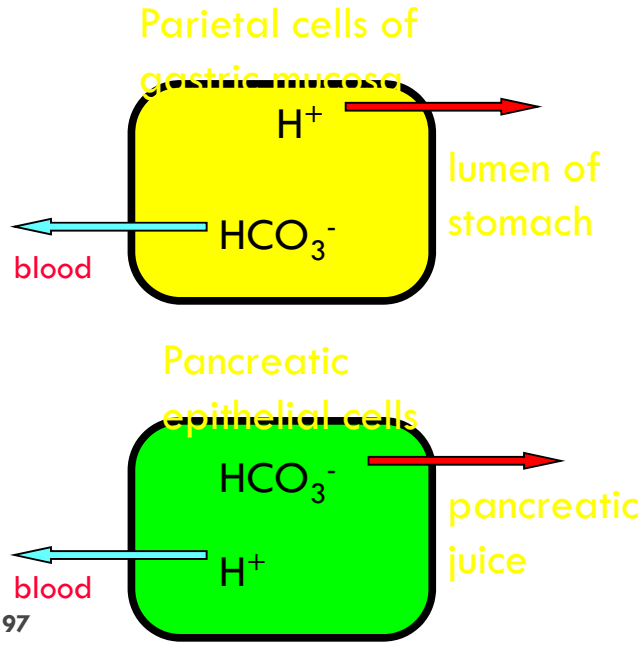
95

PARIETAL CELL SECRETION

- If the two processes are balanced, there is no net change in the amount of bicarbonate in blood
  - Loss of gastric or pancreatic juice can change that balance



BICARBONATE SECRETION



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- Cells of the gastric mucosa secrete **H^+** ions into the lumen of the stomach in exchange for the diffusion of bicarbonate ions into blood
- The direction of the diffusion of these ions is reversed in pancreatic epithelial cells

ACIDOSIS / ALKALOSIS

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ACIDOSIS / ALKALOSIS

- Deviations from normal Acid-Base status are divided into **four** general categories, depending on the source and direction of the abnormal change in H^+ concentrations
  - **Respiratory Acidosis**
  - **Respiratory Alkalosis**
  - **Metabolic Acidosis**
  - **Metabolic Alkalosis**

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ACIDOSIS / ALKALOSIS

- Acidosis and Alkalosis are categorized as **Metabolic** or **Respiratory** depending on their primary cause
  - **Metabolic Acidosis** and **Metabolic Alkalosis**
    - caused by an imbalance in the production and excretion of acids or bases by the kidneys
  - **Respiratory Acidosis** and **Respiratory Alkalosis**
    - caused primarily by lung or breathing disorders

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ACIDOSIS

- A pH of 7.4 corresponds to a 20:1 ratio of HCO_3^- and H_2CO_3
  - Concentration of HCO_3^- is 24 meq/liter and H_2CO_3 is 1.2 meq/liter

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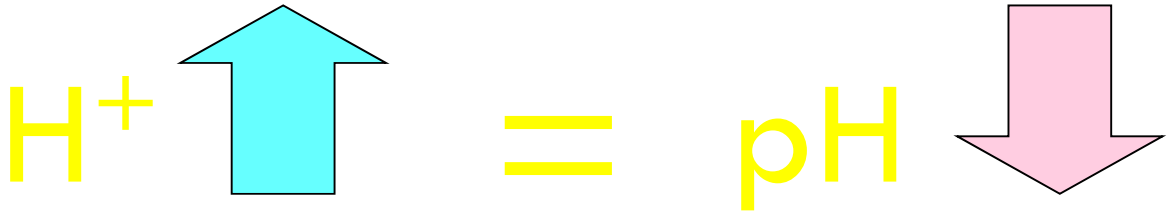
ACIDOSIS

- Acidosis is a **decrease** in pH below 7.35
  - Which means a relative increase of H^+ ions
  - pH may fall as low as 7.0 without irreversible damage but any fall less than 7.0 is usually fatal



102

ACIDOSIS

- May be caused by:
  - An increase in H_2CO_3
  - A decrease in HCO_3^-
- Both lead to a decrease in the ratio of 20:1

H_2CO_3 ↑ HCO_3^- ↓

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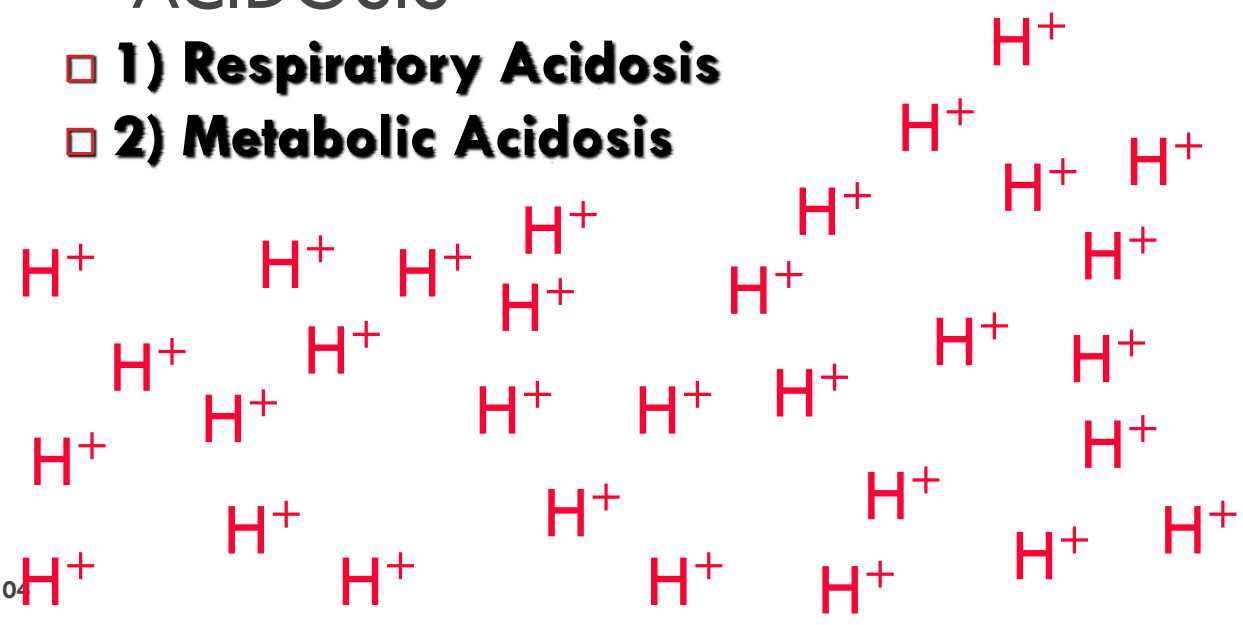
ACIDOSIS

- **1) Respiratory Acidosis**
- **2) Metabolic Acidosis**



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ALKALOSIS

- **1) Respiratory alkalosis**
- **2) Metabolic alkalosis**

H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+ H^+

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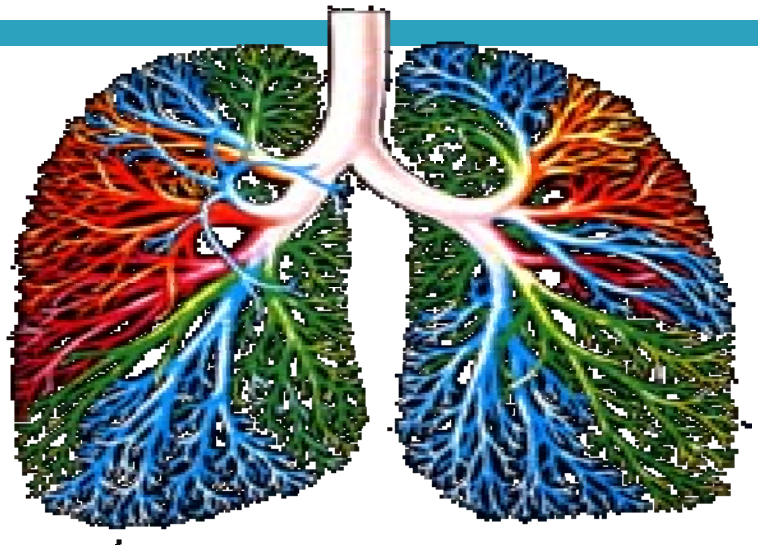
RESPIRATORY ACIDOSIS



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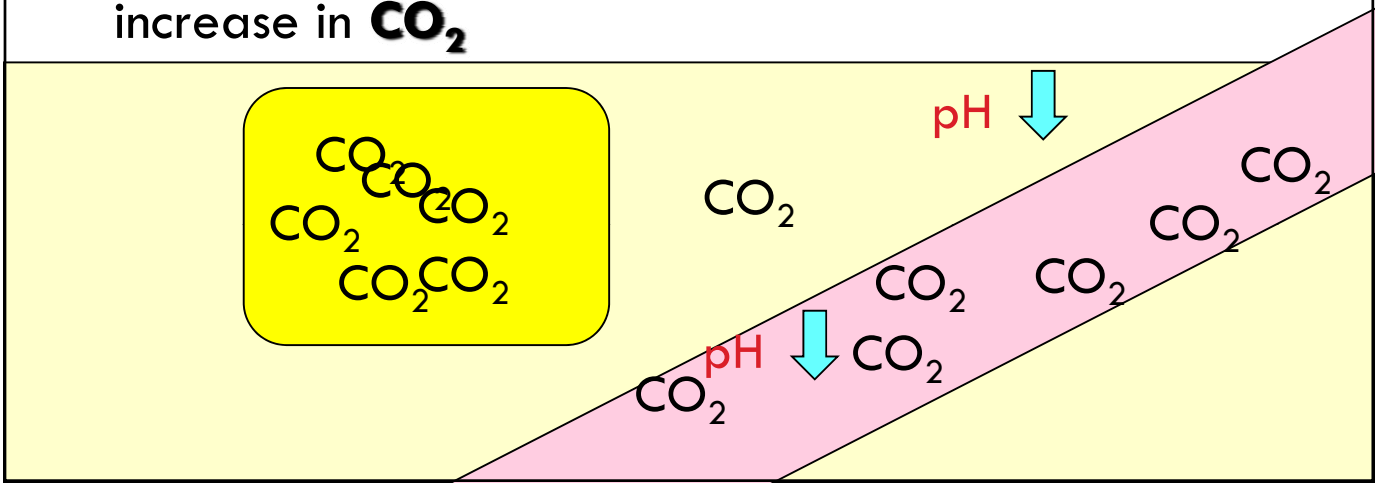
RESPIRATORY ACIDOSIS

- Caused by hyperkapnia due to hypoventilation
  - Characterized by a pH decrease and an increase in CO_2



HYPOVENTILATION

- Hypo = "Under"

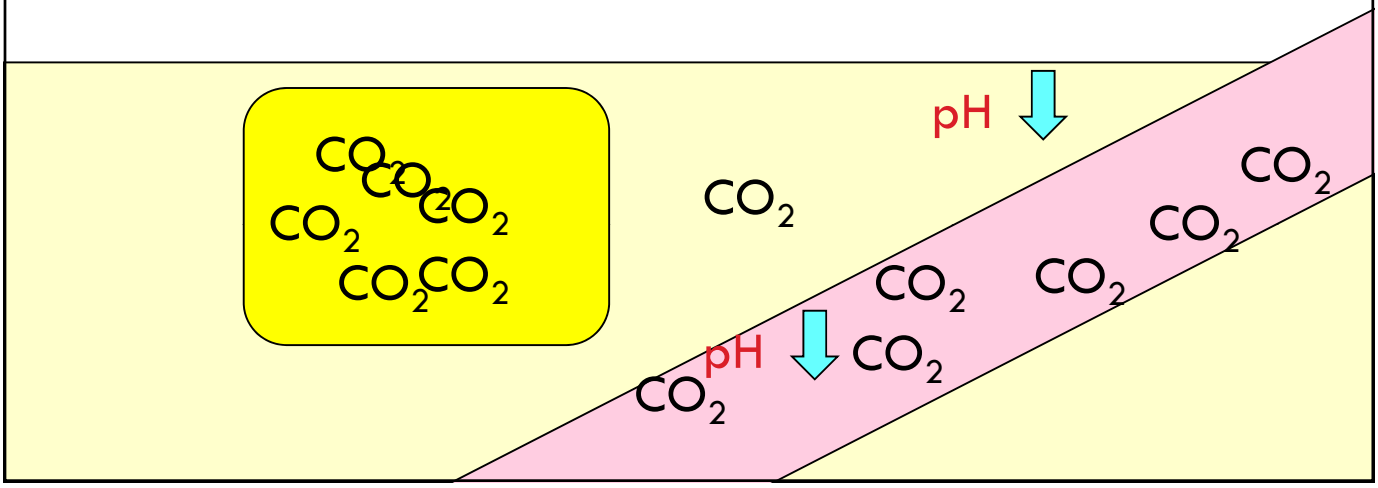
Elimination of CO_2

H^+

pH

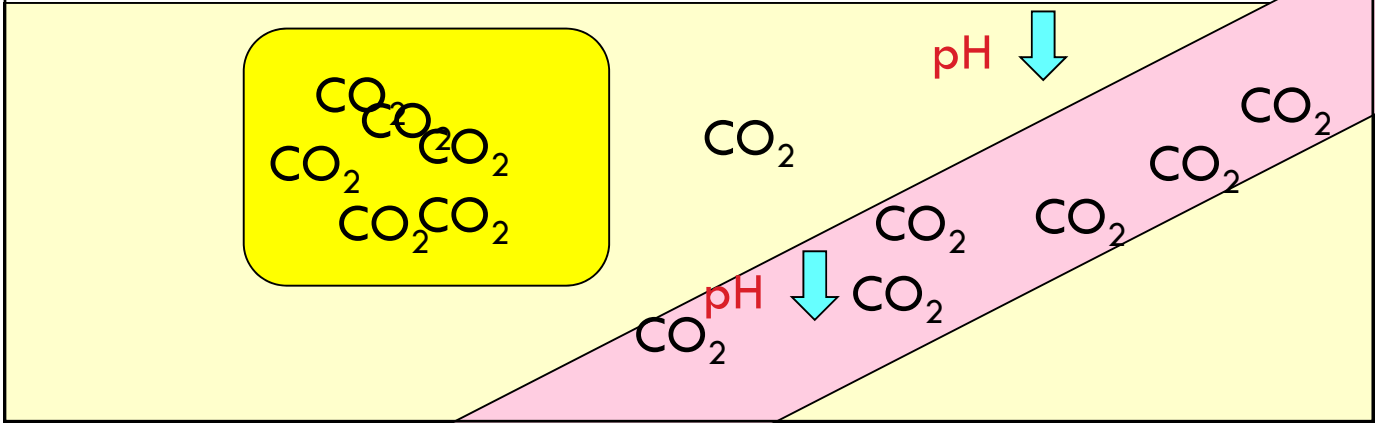
RESPIRATORY ACIDOSIS

- **Hyperkapnia** is defined as an accumulation of carbon dioxide in extracellular fluids



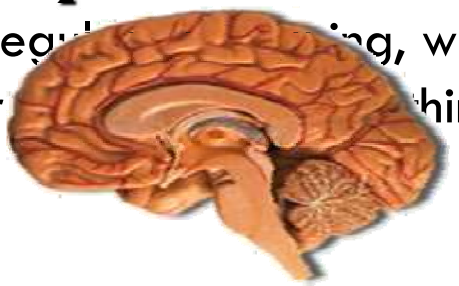
RESPIRATORY ACIDOSIS

- Hyperkapnia is the underlying cause of **Respiratory Acidosis**
  - Usually the result of decreased **CO_2** removal from the lungs



RESPIRATORY ACIDOSIS

- The speed and depth of breathing control the amount of **CO_2** in the blood
- Normally when **CO_2** builds up, the **pH** of the blood falls and the blood becomes acidic
- High levels of **CO_2** in the blood stimulate the parts of the brain that reg[illegible]ng, which in turn stimulate faster [illegible]hing



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RESPIRATORY ACIDOSIS

- Respiratory acidosis develops when the lungs don't expel **CO_2** adequately
- This can happen in diseases that severely affect the lungs, such as emphysema, chronic bronchitis, severe pneumonia, pulmonary edema, and asthma

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RESPIRATORY ACIDOSIS

- Respiratory acidosis can also develop when diseases of the nerves or muscles of the chest impair the mechanics of breathing
- In addition, a person can develop respiratory acidosis if overly sedated from narcotics and strong sleeping medications that slow res

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RESPIRATORY ACIDOSIS

- The treatment of respiratory acidosis aims to improve the function of the lungs
- Drugs to improve breathing may help people who have lung diseases such as asthma and emphysema

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RESPIRATORY ACIDOSIS

- Decreased **CO_2** removal can be the result of:
  1) **Obstruction of air passages**
  2) **Decreased respiration (depression of respiratory centers)**
  3) **Decreased gas exchange between pulmonary capillaries and air sacs of lungs**
  4) **Collapse of lung**

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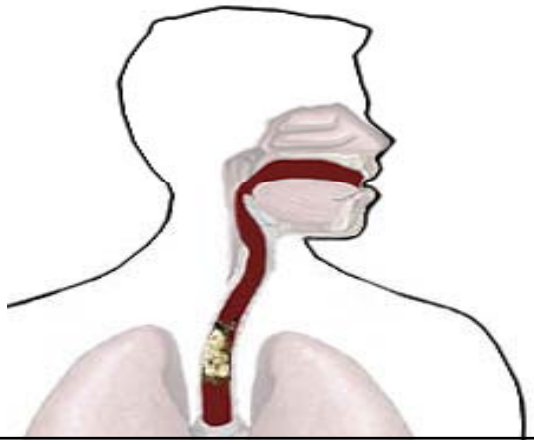
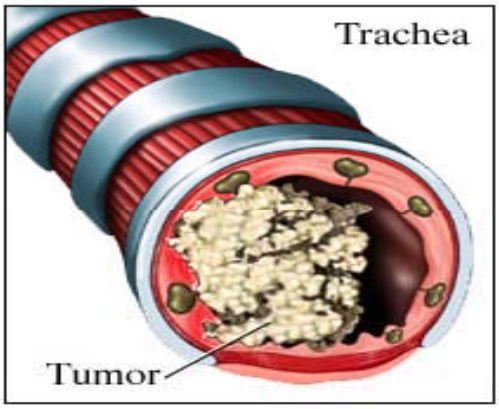
RESPIRATORY ACIDOSIS

- **1) Obstruction of air passages**
  - Vomit, anaphylaxis, tracheal cancer





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RESPIRATORY ACIDOSIS

- **2) Decreased Respiration**
  - Shallow, slow breathing
  - Depression of the respiratory centers in the brain which control breathing rates
    - Drug overdose

RESPIRATORY ACIDOSIS

- **3) Decreased gas exchange between pulmonary capillaries and air sacs of lungs**
  - Emphysema
  - Bronchitis
  - Pulmonary edema

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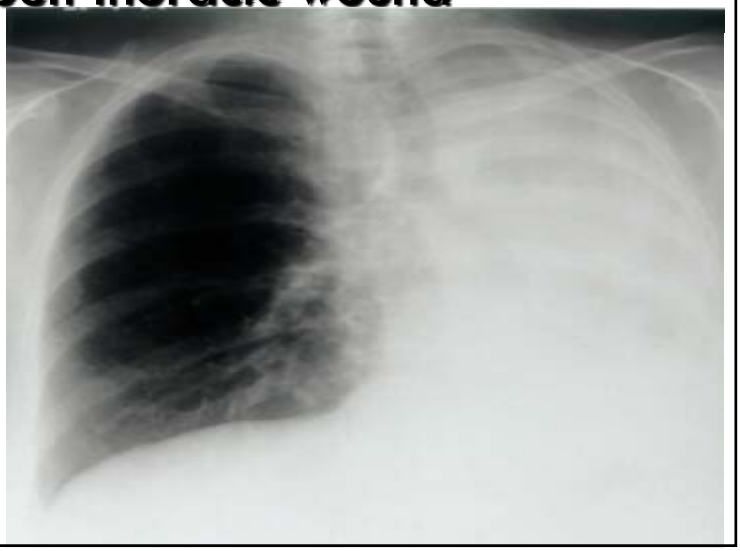
RESPIRATORY ACIDOSIS

- **4) Collapse of lung**
  - **Compression injury, open thoracic wound**

Left lung collapsed



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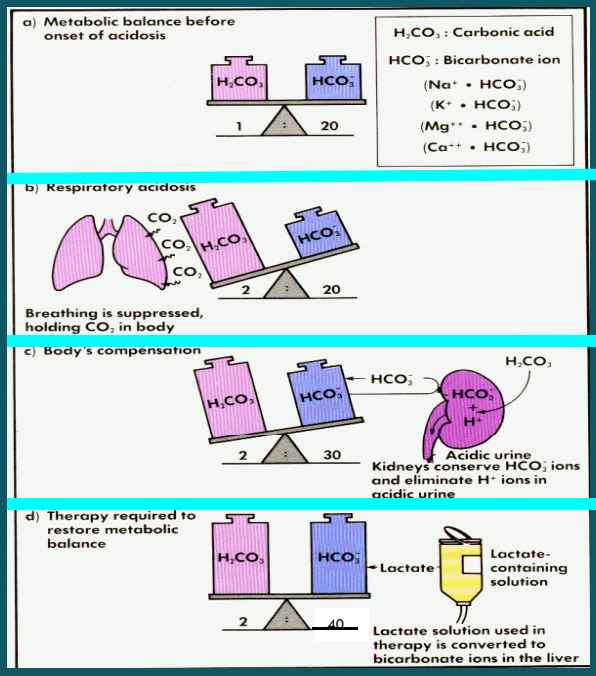
RESPIRATORY ACIDOSIS



-metabolic balance before onset of acidosis
-pH = 7.4

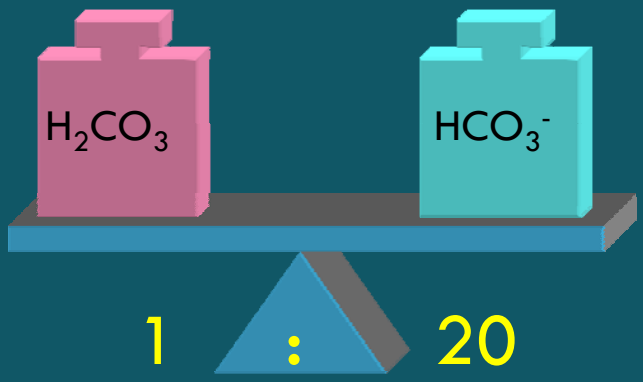
-respiratory acidosis
-pH = 7.1
-breathing is suppressed holding CO_2 in body

-body's compensation
-kidneys conserve HCO_3^- ions to restore the normal 40:2 ratio
-kidneys eliminate H^+ ion in acidic urine

- therapy required to restore metabolic balance

- lactate solution used in therapy is converted to bicarbonate ions in the liver

RESPIRATORY ACIDOSIS



H_2CO_3 : Carbonic Acid

HCO_3^- : Bicarbonate Ion

$(Na^+)\ HCO_3^-$

$(K^+)\ HCO_3^-$

$(Mg^{++})\ HCO_3^-$

$(Ca^{++})\ HCO_3^-$

- metabolic balance before onset of acidosis
- pH = 7.4

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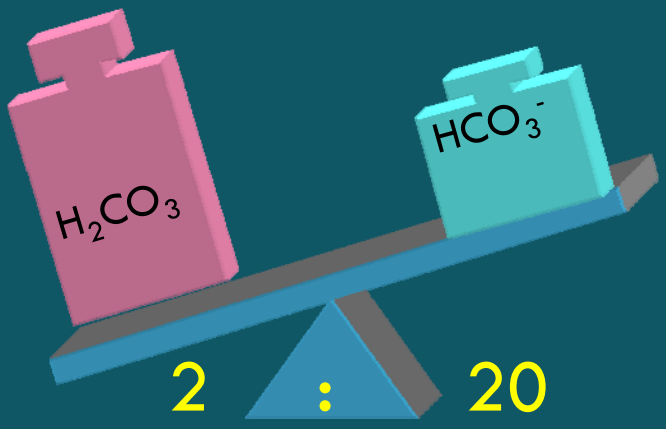
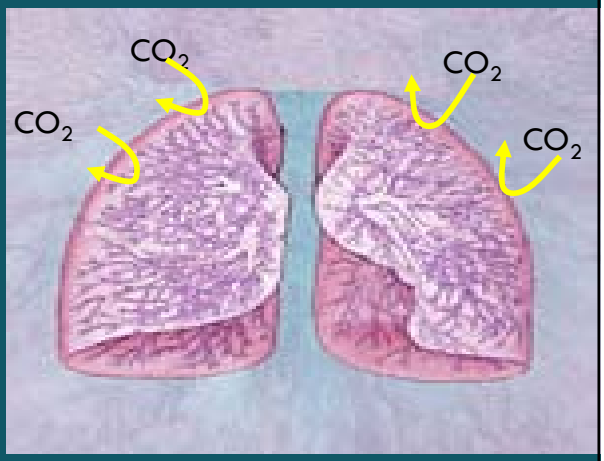
RESPIRATORY ACIDOSIS





-breathing is suppressed holding CO_2 in body

-pH = 7.1

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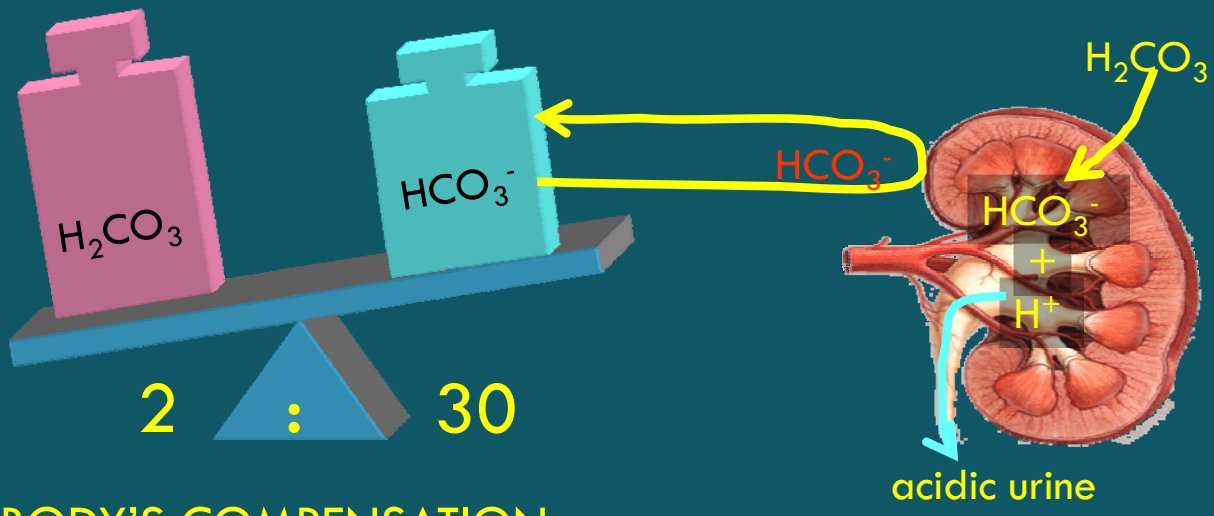
RESPIRATORY ACIDOSIS



BODY'S COMPENSATION

-kidneys conserve HCO_3^- ions to restore the normal 40:2 ratio (20:1)

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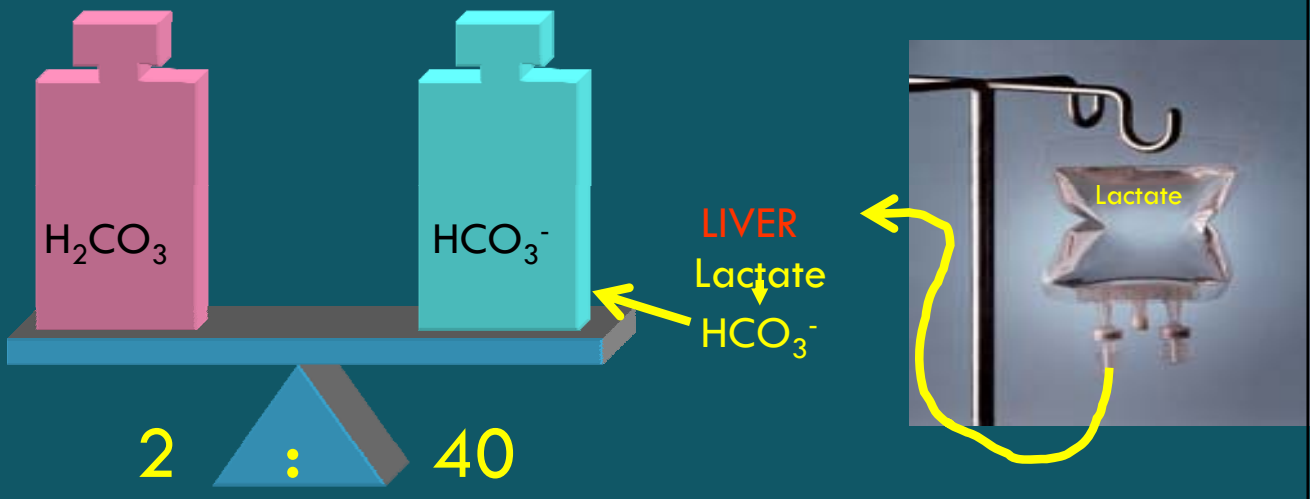
RESPIRATORY ACIDOSIS



- therapy required to restore metabolic balance
- lactate solution used in therapy is converted to bicarbonate ions in the liver

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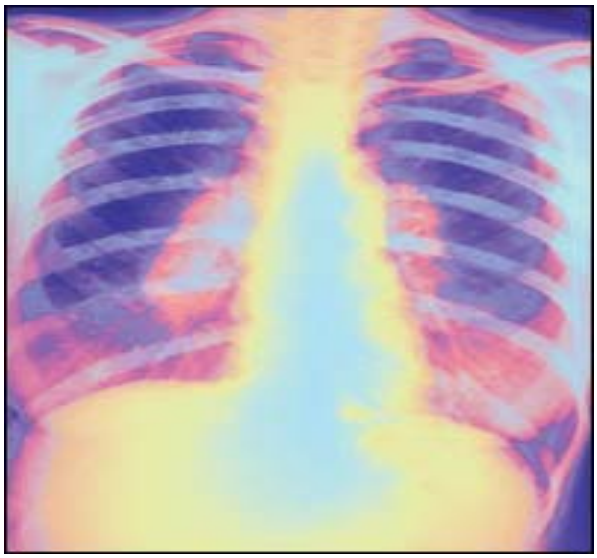
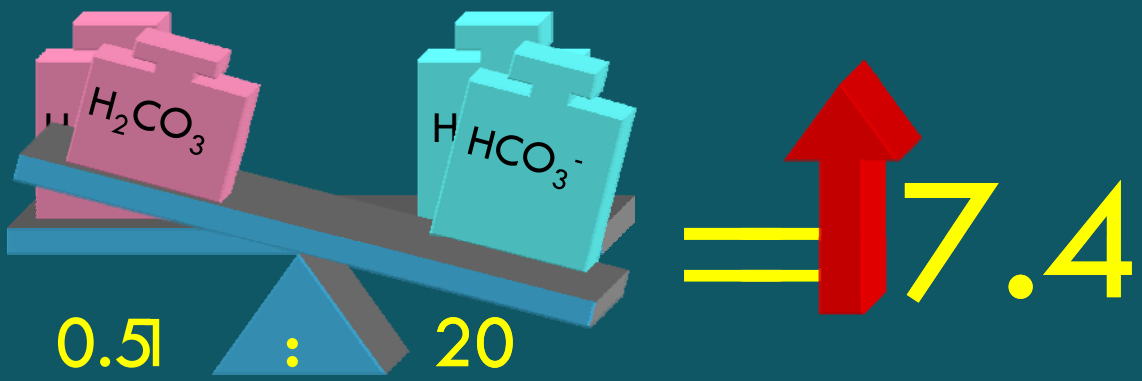
RESPIRATORY ALKALOSIS



125

RESPIRATORY ALKALOSIS

- Normal 20:1 ratio is increased
  - pH of blood is above 7.4



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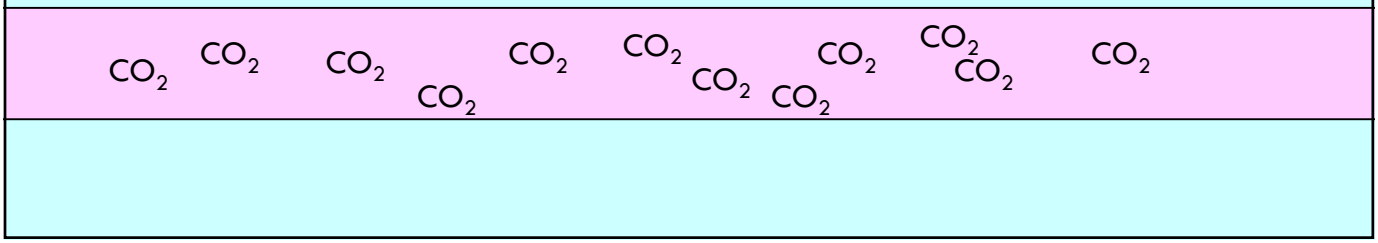
RESPIRATORY ALKALOSIS

- Cause is **Hyperventilation**
  - Leads to eliminating excessive amounts of **CO_2**
  - Increased loss of **CO_2** from the lungs at a rate faster than it is produced
  - Decrease in **H^+**



HYPERVENTILATION

- Hyper = "Over"

Elimination of CO_2

H^+

pH

RESPIRATORY ALKALOSIS

- Can be the result of:
  - **1) Anxiety, emotional disturbances**
  - **2) Respiratory center lesions**
  - **3) Fever**
  - **4) Salicylate poisoning (overdose)**
  - **5) Assisted respiration**
  - **6) High altitude (low Po_2)**

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RESPIRATORY ALKALOSIS

- **Anxiety** is an emotional disturbance
- The most common cause of hyperventilation, and thus respiratory alkalosis, is anxiety

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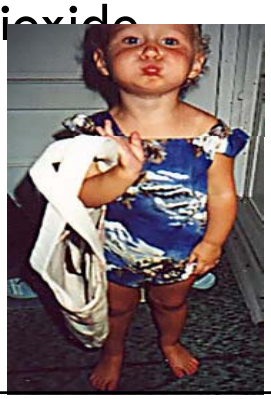
RESPIRATORY ALKALOSIS

- Usually the only treatment needed is to slow down the rate of breathing
- Breathing into a paper bag or holding the breath as long as possible may help raise the blood CO_2 content as the person breathes carbon dioxide back in after breathing it out



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RESPIRATORY ALKALOSIS

- **Respiratory center lesions**
  - **Damage to brain centers responsible for monitoring breathing rates**
    - **Tumors**
    - **Strokes**

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RESPIRATORY ALKALOSIS

- **Fever**
  - **Rapid shallow breathing blows off too much CO_2**

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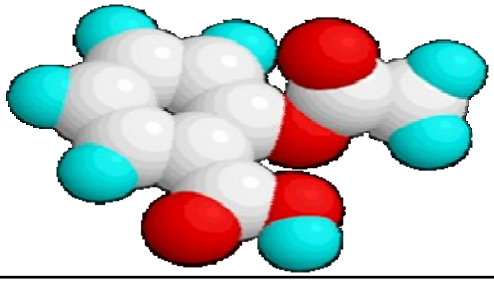
RESPIRATORY ALKALOSIS

- **Salicylate poisoning (Aspirin overdose)**
  - **Ventilation is stimulated without regard to the status of O_2, CO_2 or H^+ in the body fluids**



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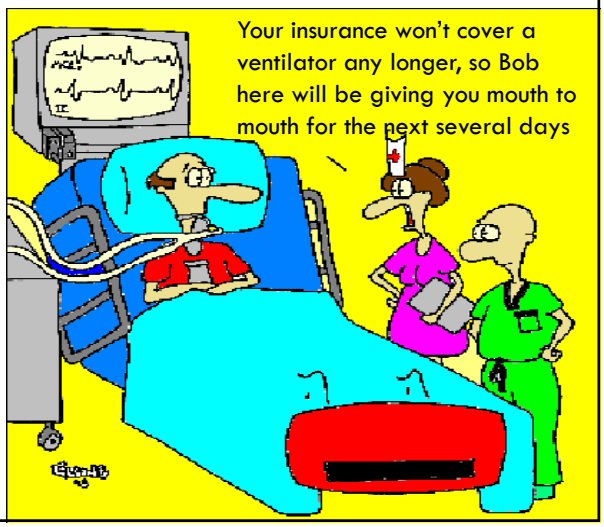
RESPIRATORY ALKALOSIS

- **Assisted Respiration**
  - Administration of CO_2 in the exhaled air of the care - giver



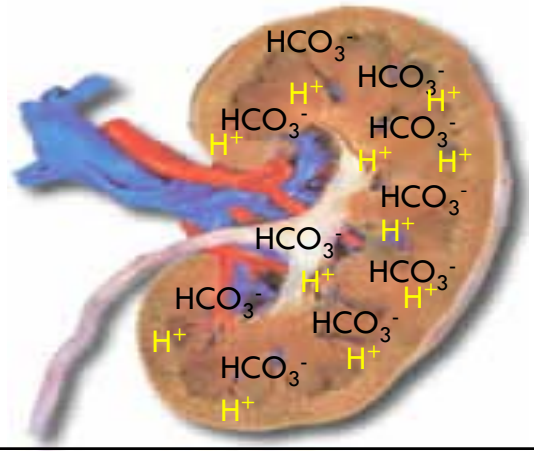
RESPIRATORY ALKALOSIS

- **High Altitude**
  - Low concentrations of O_2 in the arterial blood reflexly stimulates ventilation in an attempt to obtain more O_2
  - Too much CO_2 is "blown off" in the process

13

RESPIRATORY ALKALOSIS

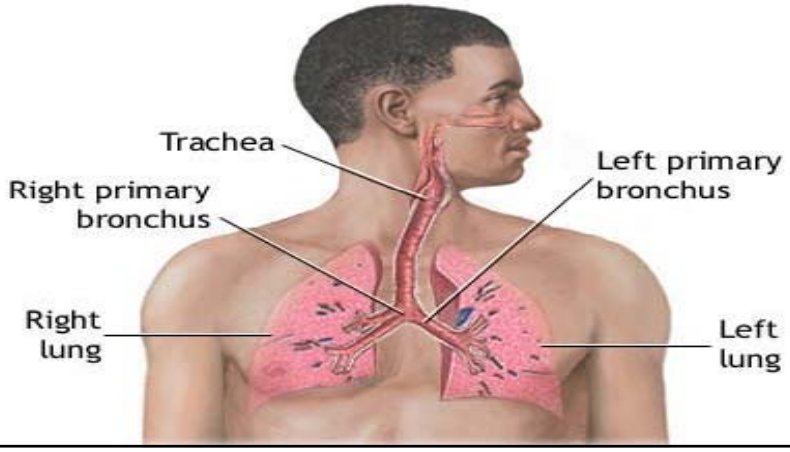
- Kidneys compensate by:
  - **Retaining hydrogen ions**
  - **Increasing bicarbonate excretion**



137

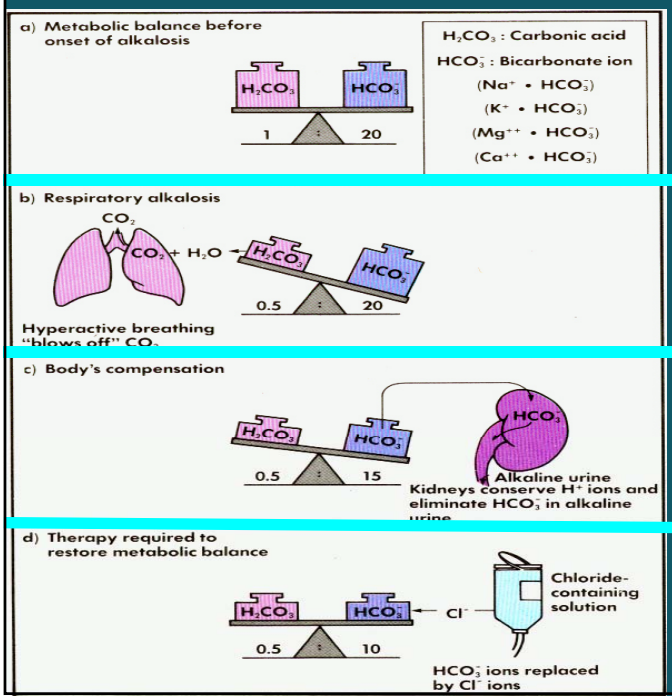
RESPIRATORY ALKALOSIS

- Decreased **CO_2** in the lungs will eventually slow the rate of breathing
  - Will permit a normal amount of **CO_2** to be retained in the lung



138

RESPIRATORY ALKALOSIS



-metabolic balance before onset of alkalosis
-pH = 7.4

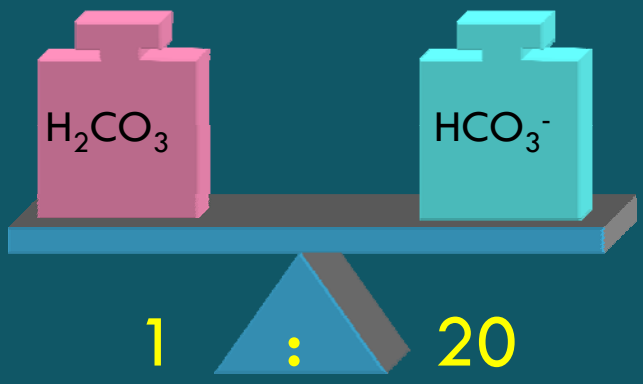
-respiratory alkalosis
-pH = 7.7
- hyperactive breathing " blows off " CO_2

- body's compensation
- kidneys conserve H^+ ions and eliminate HCO_3^- in alkaline urine

- therapy required to restore metabolic balance

- HCO_3^- ions replaced by Cl^- ions

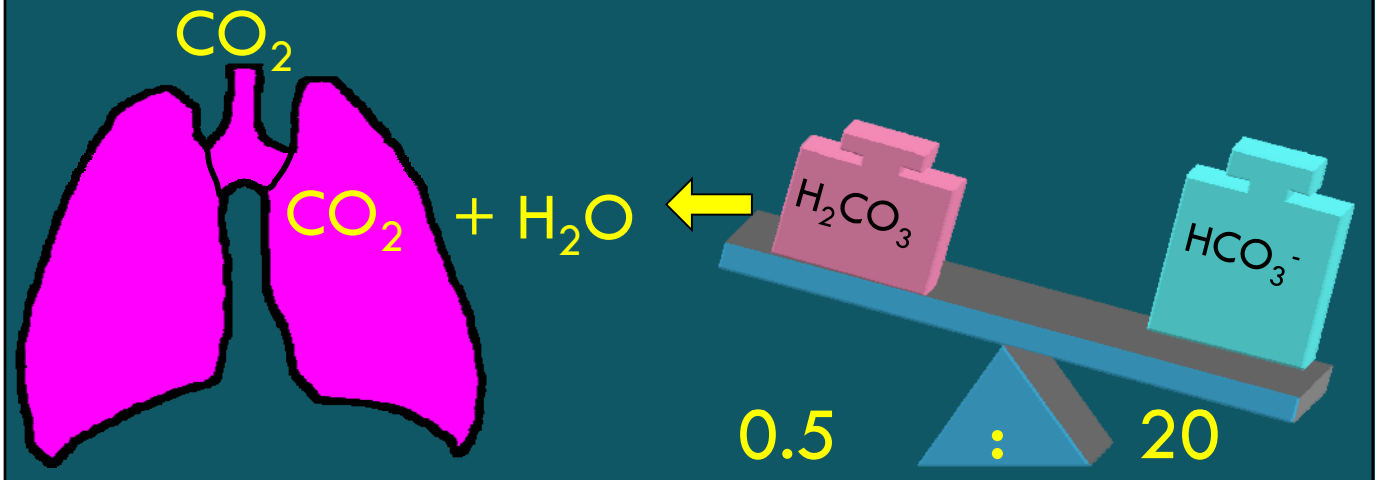
RESPIRATORY ALKALOSIS



H_2CO_3 : Carbonic Acid
HCO_3^- : Bicarbonate Ion
$(Na^+) HCO_3^-$
$(K^+) HCO_3^-$
$(Mg^{++}) HCO_3^-$
$(Ca^{++}) HCO_3^-$

-metabolic balance before onset of alkalosis
-pH = 7.4

RESPIRATORY ALKALOSIS



-respiratory alkalosis
-pH = 7.7
-hyperactive breathing " blows off " CO_2

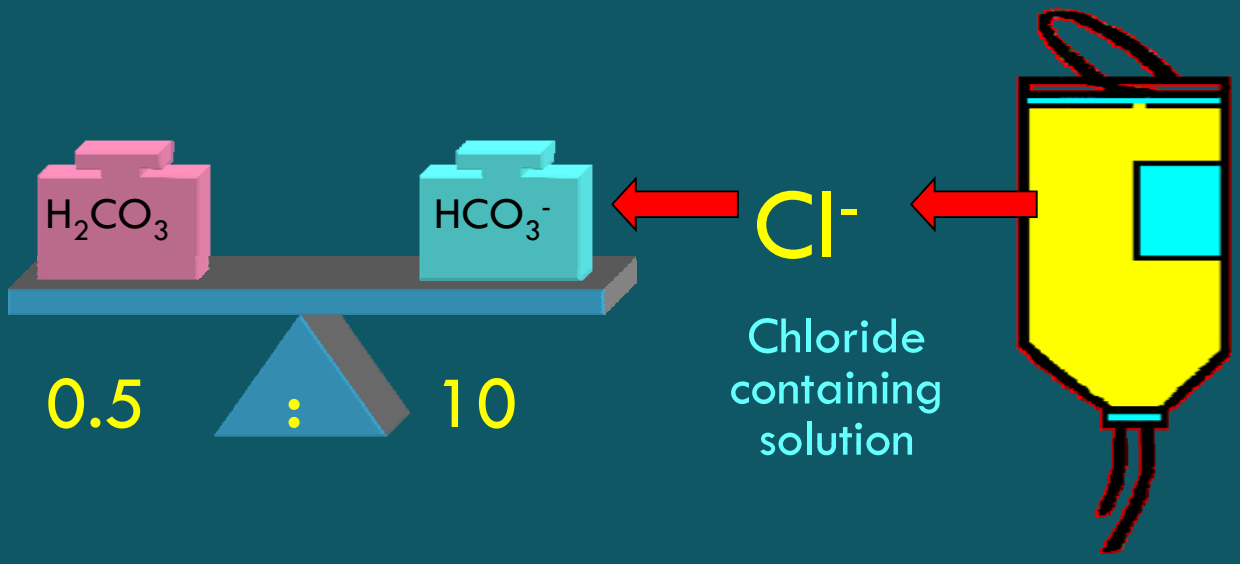
141

RESPIRATORY ALKALOSIS

BODY'S COMPENSATION
- kidneys conserve H^+ ions and eliminate HCO_3^- in alkaline urine

142

RESPIRATORY ALKALOSIS



- therapy required to restore metabolic balance
- HCO_3^- ions replaced by Cl^- ions

143

RESPIRATORY ACIDOSIS / ALKALOSIS

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Respiratory Acidosis

Respiratory Alkalosis

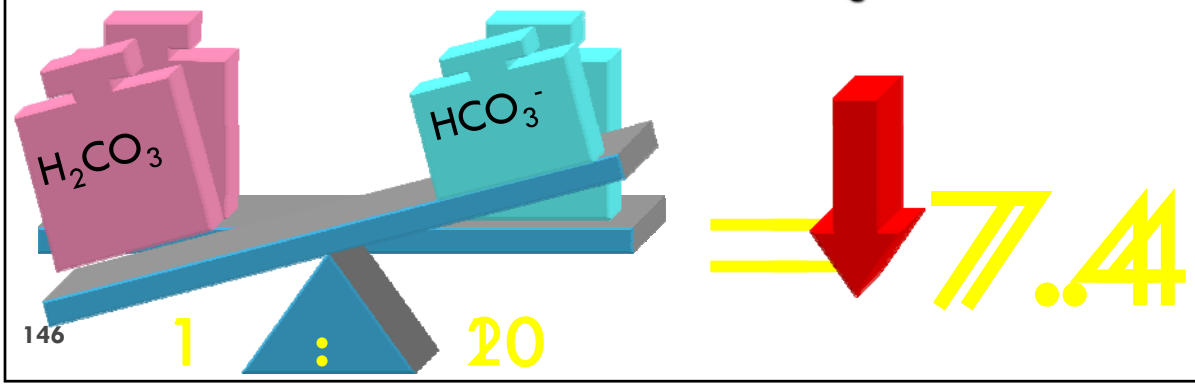
144

METABOLIC ACIDOSIS

145

METABOLIC ACIDOSIS

- Occurs when there is a decrease in the normal 20:1 ratio
  - Decrease in blood **pH** and bicarbonate level
- Excessive **H^+** or decreased **HCO_3^-**



146

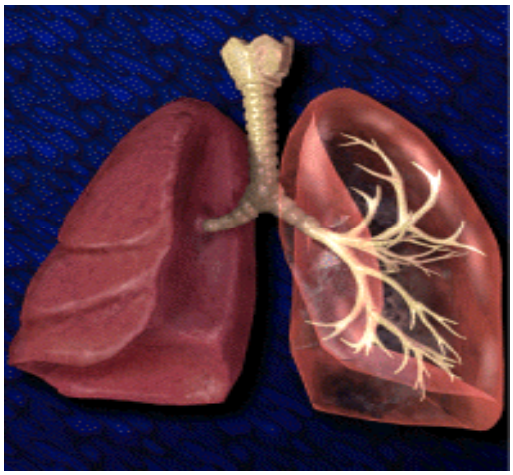
METABOLIC ACIDOSIS

- Any acid-base imbalance not attributable to **CO_2** is classified as metabolic
  - Metabolic production of **Acids**
  - Or loss of **Bases**

147

METABOLIC ACIDOSIS

- If an increase in acid overwhelms the body's **pH** buffering system, the blood can become acidic
- As the blood **pH** drops, breathing becomes deeper and faster as the body attempts to rid the blood of excess acid by decreasing the amount of carbon dioxide



148

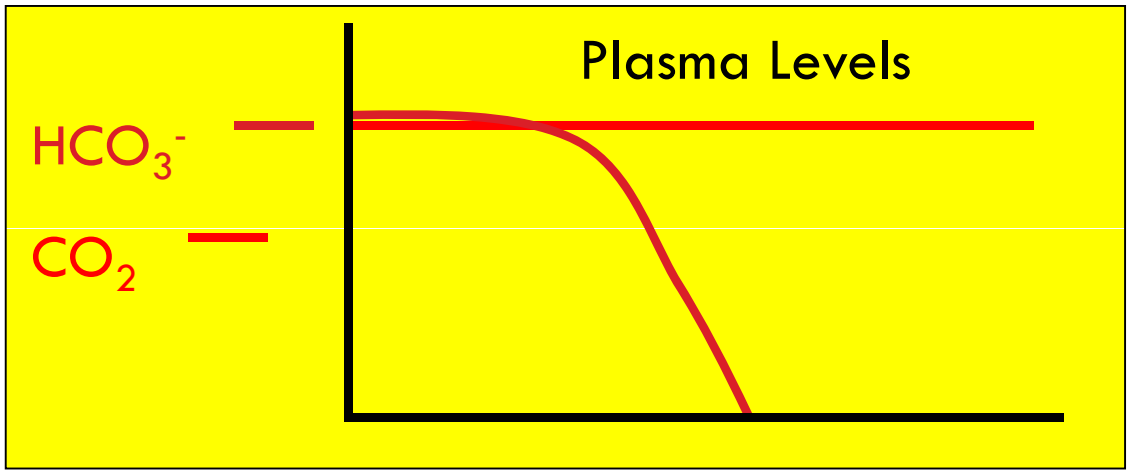
METABOLIC ACIDOSIS

- Eventually, the kidneys also try to compensate by excreting more acid in the urine
- However, both mechanisms can be overwhelmed if the body continues to produce too much acid, leading to severe acidosis and eventually a coma

149

METABOLIC ACIDOSIS

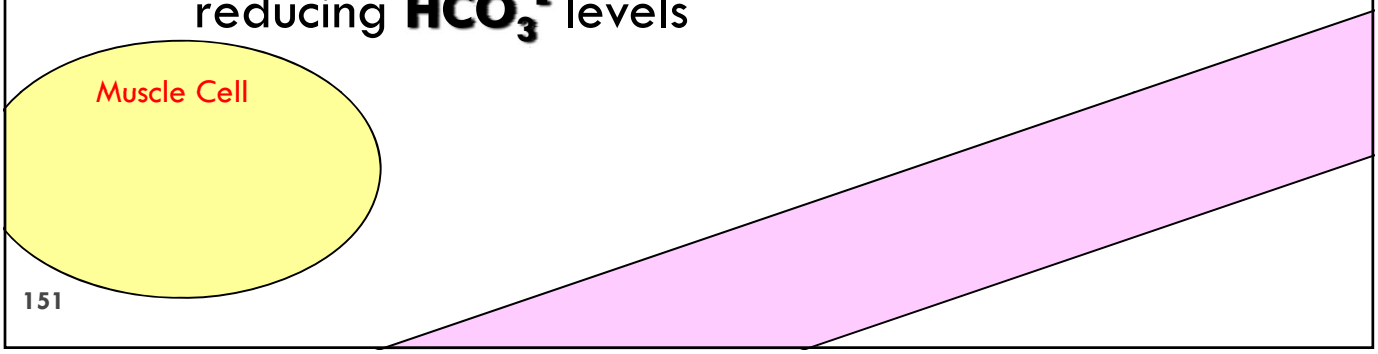
- Metabolic acidosis is always characterized by a reduction in plasma **HCO_3^-** while **CO_2** remains normal



150

METABOLIC ACIDOSIS

- Acidosis results from excessive loss of HCO_3^- rich fluids from the body or from an accumulation of acids
  - Accumulation of non-carbonic plasma acids uses HCO_3^- as a buffer for the additional H^+ thus reducing HCO_3^- levels



151

METABOLIC ACIDOSIS

- The causes of metabolic acidosis can be grouped into **five** major categories
  - **1) Ingesting** an acid or a substance that is metabolized to acid
  - **2) Abnormal Metabolism**
  - **3) Kidney Insufficiencies**
  - **4) Strenuous Exercise**
  - **5) Severe Diarrhea**

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METABOLIC ACIDOSIS

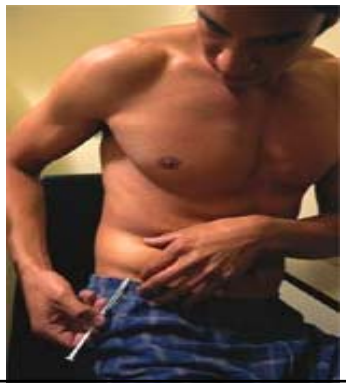
- **1) Ingesting An Acid**
  - Most substances that cause acidosis when ingested are considered poisonous
  - Examples include wood alcohol (methanol) and antifreeze (ethylene glycol)

  - However, even an overdose of aspirin (acetylsalicylic acid) can cause metabolic acidosis

153

METABOLIC ACIDOSIS

- **2) Abnormal Metabolism**
  - The body can produce excess acid as a result of several diseases
    - One of the most significant is Type I Diabetes Mellitus



154

METABOLIC ACIDOSIS

- Unregulated diabetes mellitus causes **ketoacidosis**
  - Body metabolizes fat rather than glucose
  - Accumulations of metabolic acids **(Keto Acids)** cause an increase in plasma **H^+**

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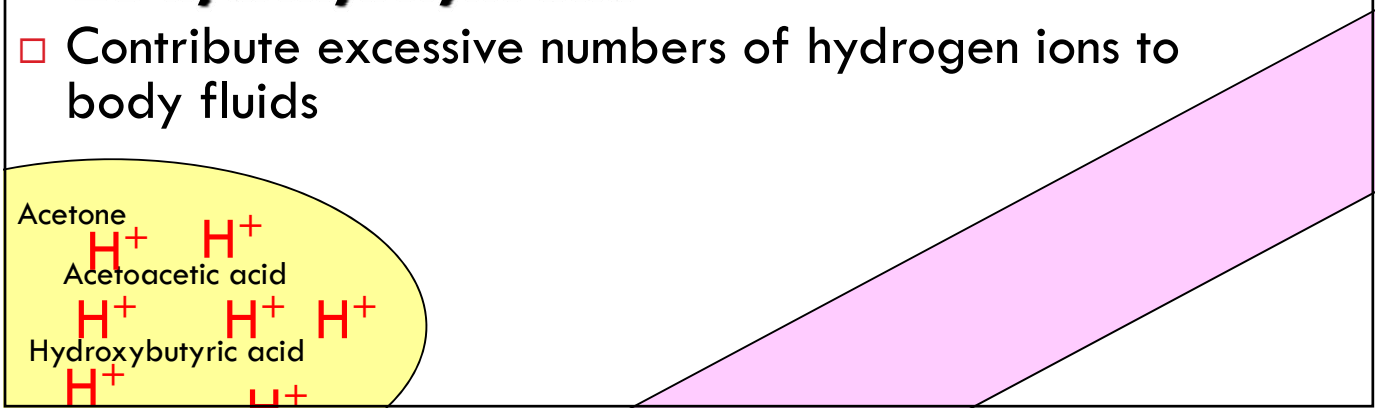
METABOLIC ACIDOSIS

- This leads to excessive production of **ketones:**
  - **Acetone**
  - **Acetoacetic acid**
  - **B-hydroxybutyric acid**
- Contribute excessive numbers of hydrogen ions to body fluids



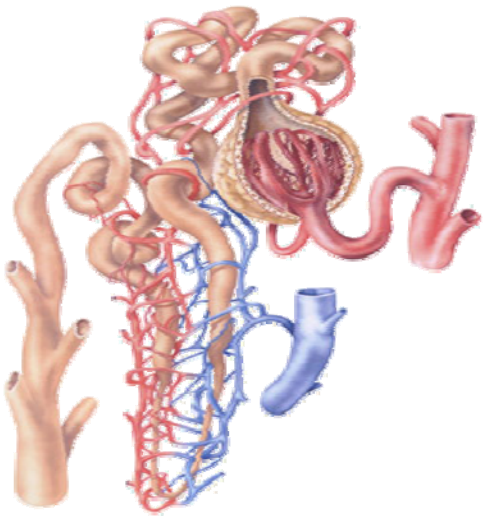
METABOLIC ACIDOSIS

- **2) Abnormal Metabolism**
  - The body also produces excess acid in the advanced stages of shock, when lactic acid is formed through the metabolism of sugar

157

METABOLIC ACIDOSIS

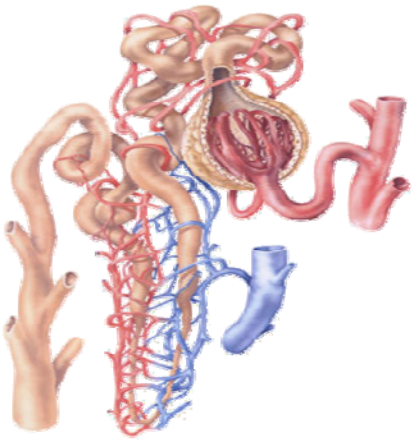
- **3) Kidney Insufficiencies**
  - Even the production of normal amounts of acid may lead to acidosis when the kidneys aren't functioning normally



158

METABOLIC ACIDOSIS

- **3) Kidney Insufficiencies**
  - Kidneys may be unable to rid the plasma of even the normal amounts of **H^+** generated from metabolic acids
  - Kidneys may be also unable to conserve an adequate amount of **HCO_3^-** to buffer the normal acid load



159

METABOLIC ACIDOSIS

- **3) Kidney Insufficiencies**
  - This type of kidney malfunction is called **renal tubular acidosis** or **uremic acidosis** and may occur in people with kidney failure or with abnormalities that affect the kidneys' ability to excrete acid

160

METABOLIC ACIDOSIS

- **4) Strenuous Exercise**
  - Muscles resort to anaerobic glycolysis during strenuous exercise
  - Anaerobic respiration leads to the production of large amounts of lactic acid

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} \underset{\text{Lactic Acid}}{2C_3H_6O_3} + ATP\ (energy)$$

161

METABOLIC ACIDOSIS

- **5) Severe Diarrhea**
  - Fluids rich in **HCO_3^-** are released and reabsorbed during the digestive process
  - During diarrhea this **HCO_3^-** is lost from the body rather than reabsorbed

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METABOLIC ACIDOSIS

- **5) Severe Diarrhea**
  - The loss of **HCO_3^-** without a corresponding loss of H^+ lowers the pH
  - Less **HCO_3^-** is available for buffering **H^+**
  - Prolonged deep (from duodenum) vomiting can result in the same situation

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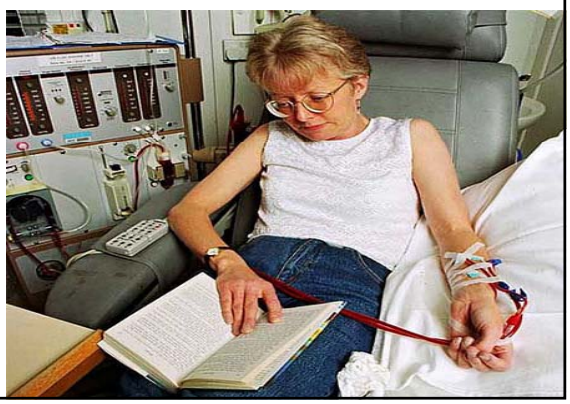
METABOLIC ACIDOSIS

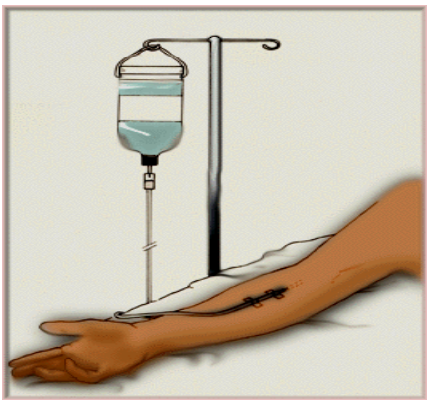
- Treating the underlying cause of metabolic acidosis is the usual course of action
  - For example, they may control diabetes with insulin or treat poisoning by removing the toxic substance from the blood
  - Occasionally dialysis is needed to treat severe overdoses and poisonings



164

METABOLIC ACIDOSIS

- Metabolic acidosis may also be treated directly
  - If the acidosis is mild, intravenous fluids and treatment for the underlying disorder may be all that's needed



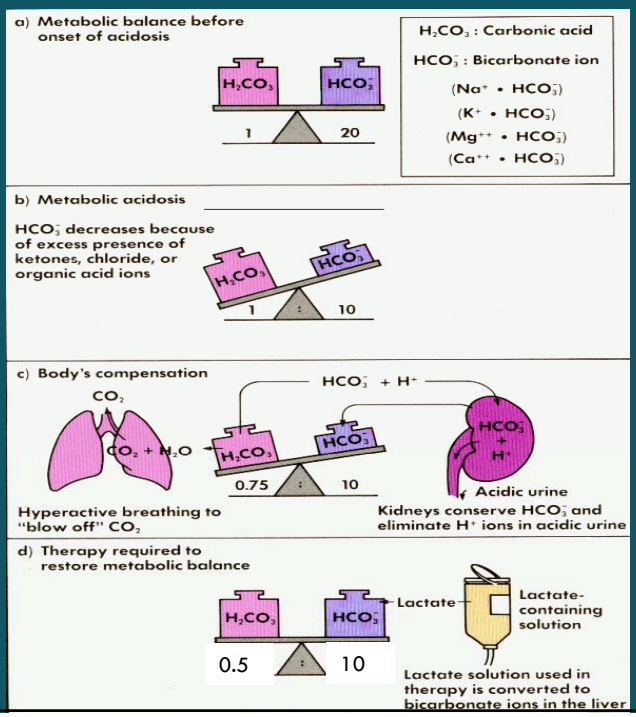
165

METABOLIC ACIDOSIS

- When acidosis is severe, bicarbonate may be given intravenously
  - Bicarbonate provides only temporary relief and may cause harm

166

METABOLIC ACIDOSIS

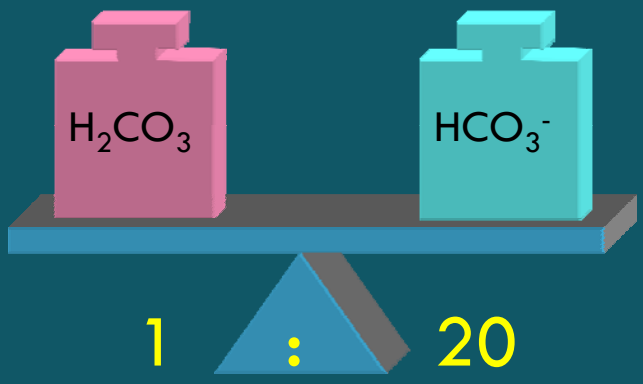


- metabolic balance before onset of acidosis
- pH 7.4

- metabolic acidosis
- pH 7.1
- HCO_3^- decreases because of excess presence of ketones, chloride or organic ions

- body's compensation
- hyperactive breathing to " blow off " CO_2
- kidneys conserve HCO_3^- and eliminate H^+ ions in acidic urine
- therapy required to restore metabolic balance
- lactate solution used in therapy is converted to bicarbonate ions in the liver

METABOLIC ACIDOSIS



H_2CO_3 : Carbonic Acid

HCO_3^- : Bicarbonate Ion

$(Na^+) HCO_3^-$

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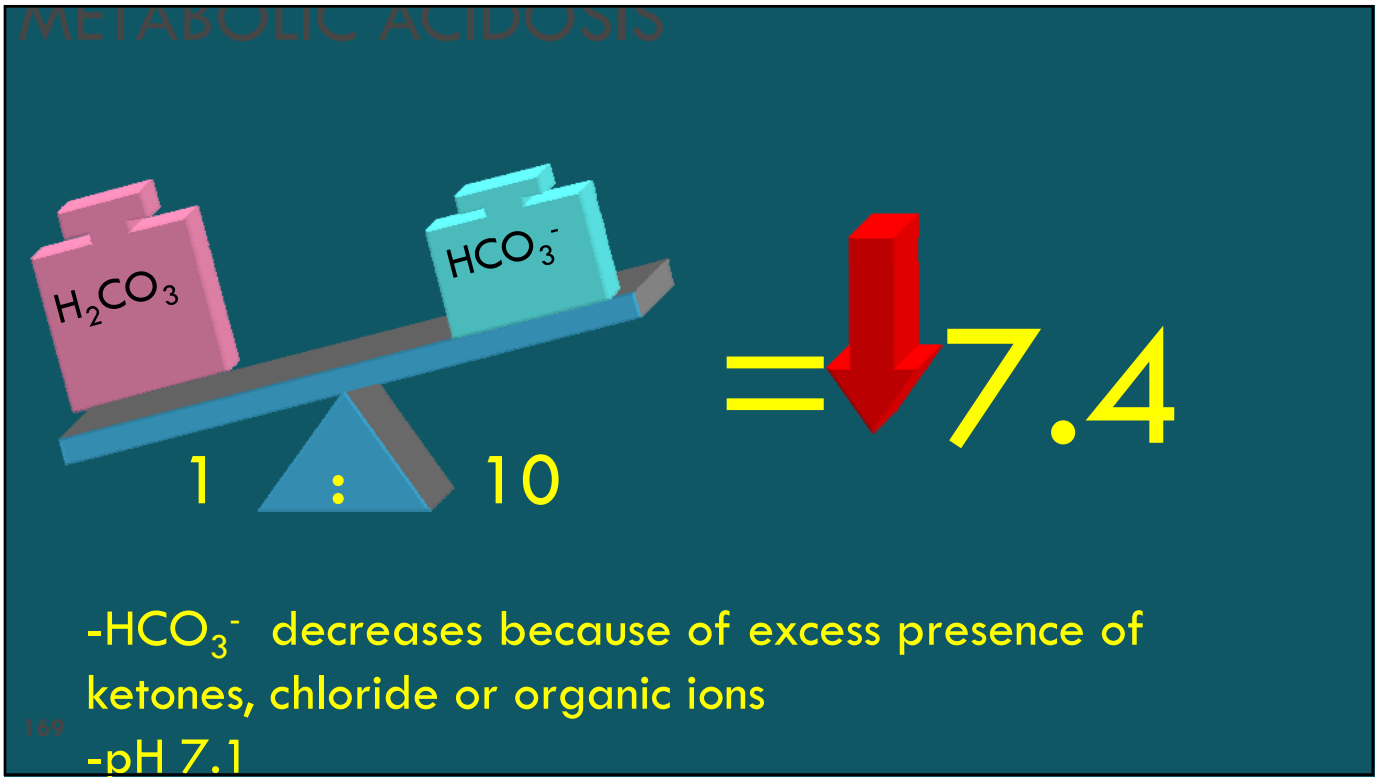
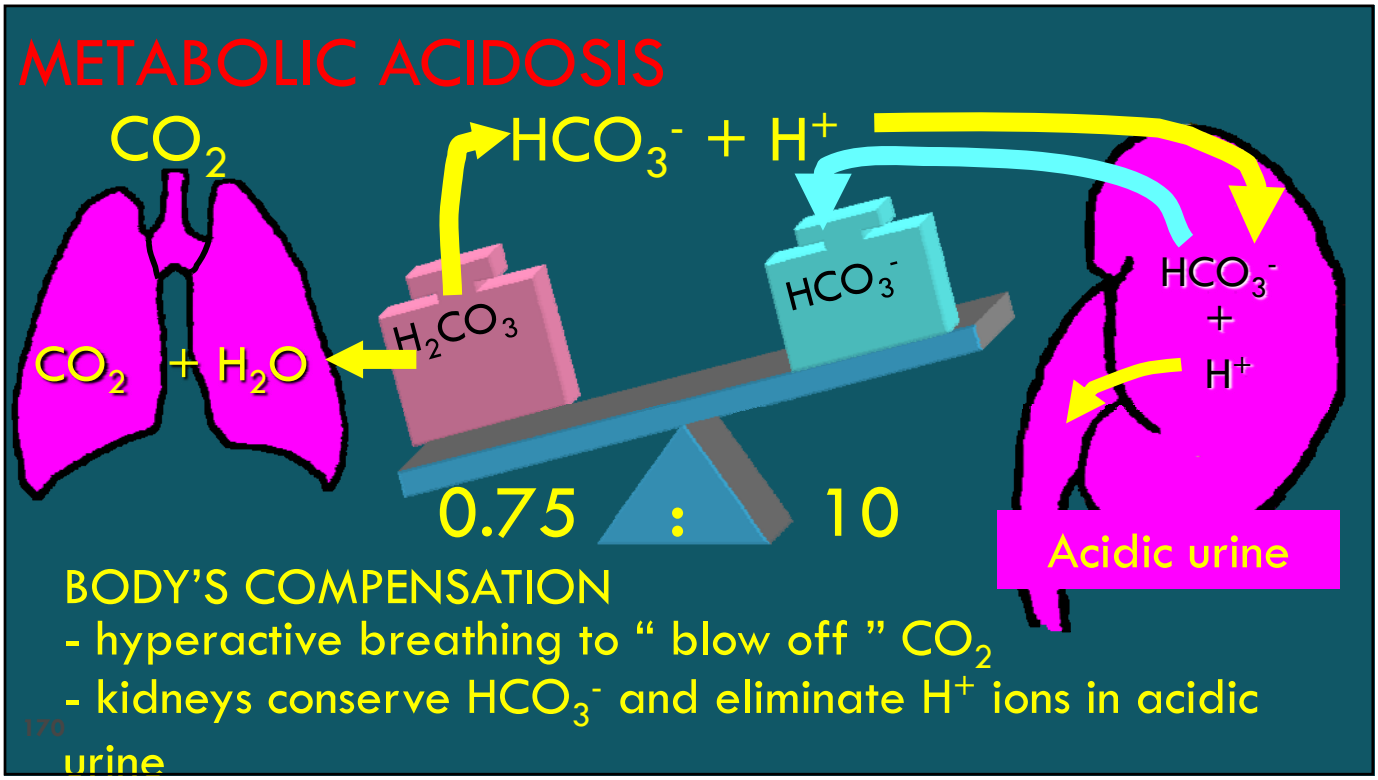
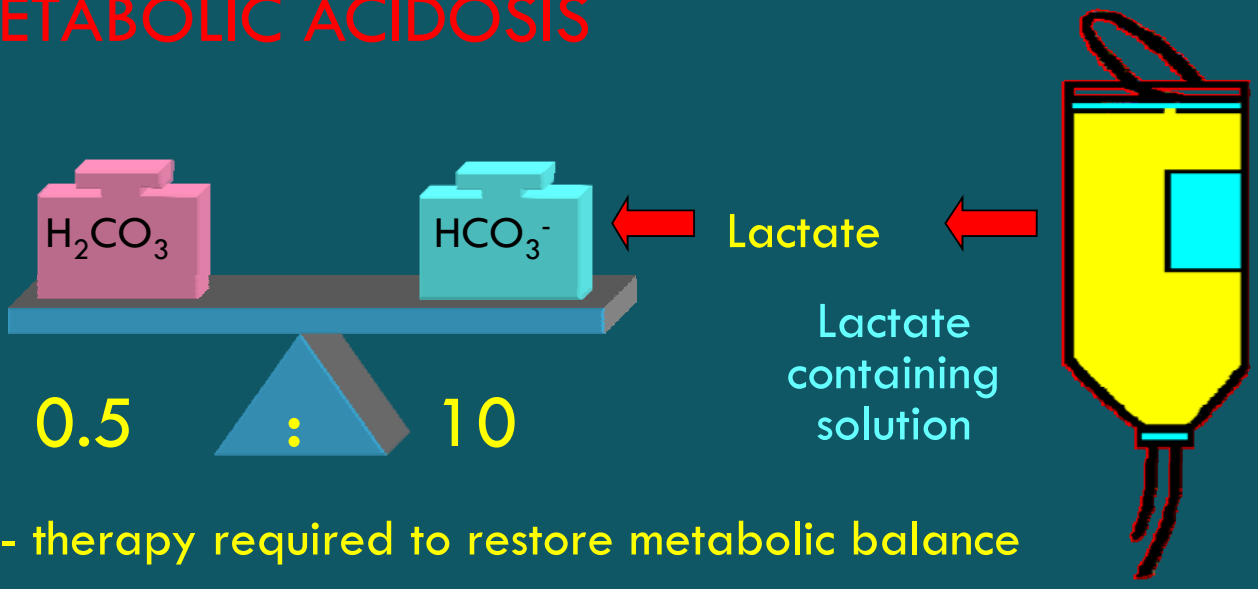
-metabolic balance before onset of acidosis

-pH 7.4


METABOLIC ACIDOSIS
H_2CO_3
HCO_3^-
1 : 10
=↓7.4
-HCO_3^- decreases because of excess presence of ketones, chloride or organic ions
-pH 7.1


METABOLIC ACIDOSIS
CO_2
$HCO_3^- + H^+$
$CO_2 + H_2O$
H_2CO_3
HCO_3^-
HCO_3^- + H^+
0.75 : 10
Acidic urine
BODY'S COMPENSATION
- hyperactive breathing to " blow off " CO_2
- kidneys conserve HCO_3^- and eliminate H^+ ions in acidic urine

METABOLIC ACIDOSIS



- therapy required to restore metabolic balance

- lactate solution used in therapy is converted to bicarbonate ions in the liver

171

METABOLIC ALKALOSIS

172

METABOLIC ALKALOSIS

- Elevation of **pH** due to an increased 20:1 ratio
  - May be caused by:
    - An **increase** of bicarbonate
    - A **decrease** in hydrogen ions
  - Imbalance again cannot be due to **CO_2**
  - Increase in **pH** which has a non-respiratory origin

173

METABOLIC ALKALOSIS

- A reduction in **H^+** in the case of metabolic alkalosis can be caused by a deficiency of non-carbonic acids
- This is associated with an increase in **HCO_3^-**

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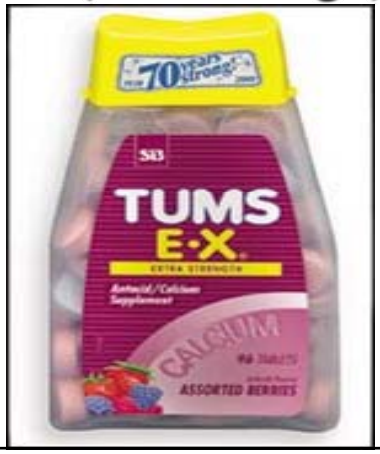
METABOLIC ALKALOSIS

- Treatment of metabolic alkalosis is most often accomplished by replacing water and electrolytes (**sodium** and **potassium**) while treating the underlying cause
- Occasionally when metabolic alkalosis is very severe, dilute acid in the form of ammonium chloride is given by IV

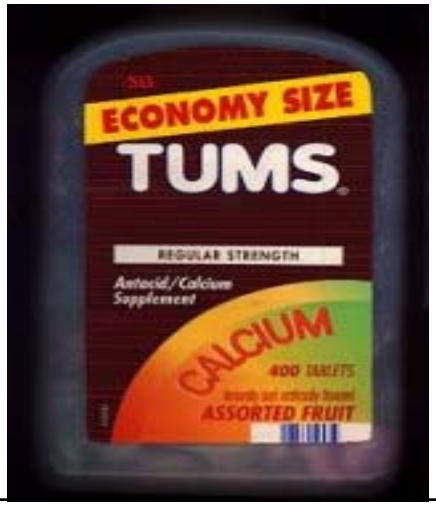
METABOLIC ALKALOSIS

- Can be the result of:
  - **1) Ingestion of Alkaline Substances**
  - **2) Vomiting (loss of HCl)**



METABOLIC ALKALOSIS

- **1) Ingestion of Alkaline Substances**
  - Influx of **$NaHCO_3$**



METABOLIC ALKALOSIS

- Baking soda (**$NaHCO_3$**) often used as a remedy for gastric hyperacidity
  - **$NaHCO_3$** dissociates to **Na^+** and **HCO_3^-**

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METABOLIC ALKALOSIS

- Bicarbonate neutralizes high acidity in stomach (heart burn)
- The extra bicarbonate is absorbed into the plasma increasing **pH** of plasma as bicarbonate binds with free H^+

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METABOLIC ALKALOSIS

- Commercially prepared alkaline products for gastric hyperacidity are not absorbed from the digestive tract and do not alter the **pH** status of the plasma

METABOLIC ALKALOSIS

- **2) Vomiting (abnormal loss of HCl)**
  - Excessive loss of H^+

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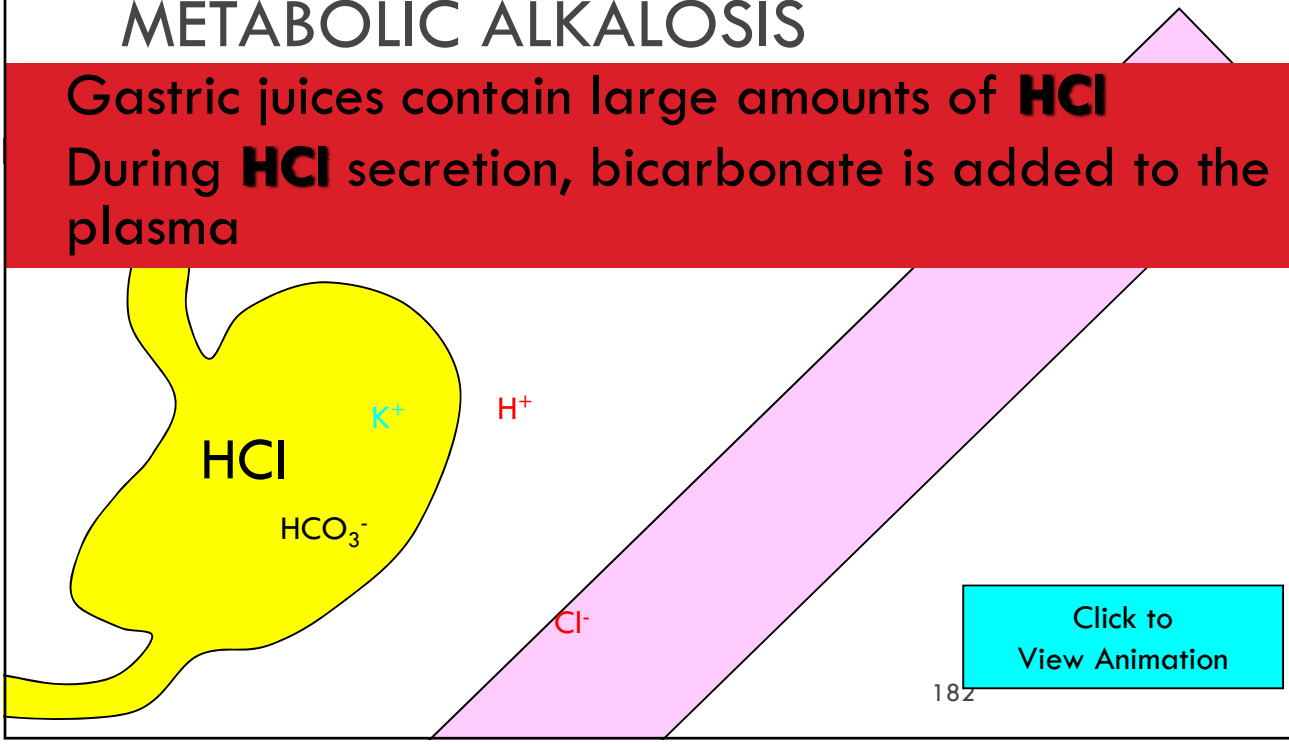
METABOLIC ALKALOSIS

Gastric juices contain large amounts of **HCl**

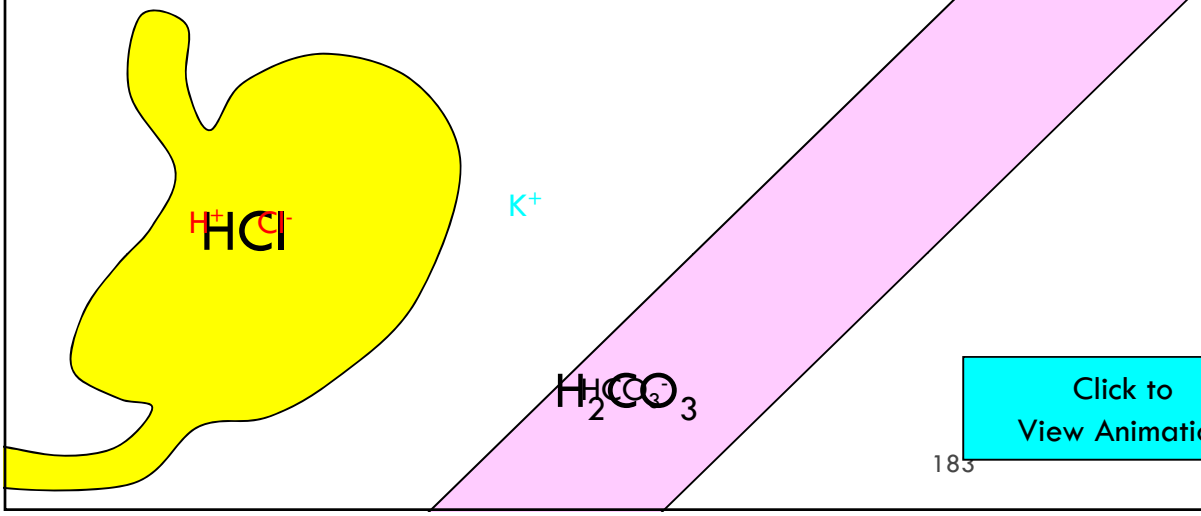
During **HCl** secretion, bicarbonate is added to the plasma



182

METABOLIC ALKALOSIS

The bicarbonate is neutralized as **HCl** is reabsorbed by the plasma from the digestive tract



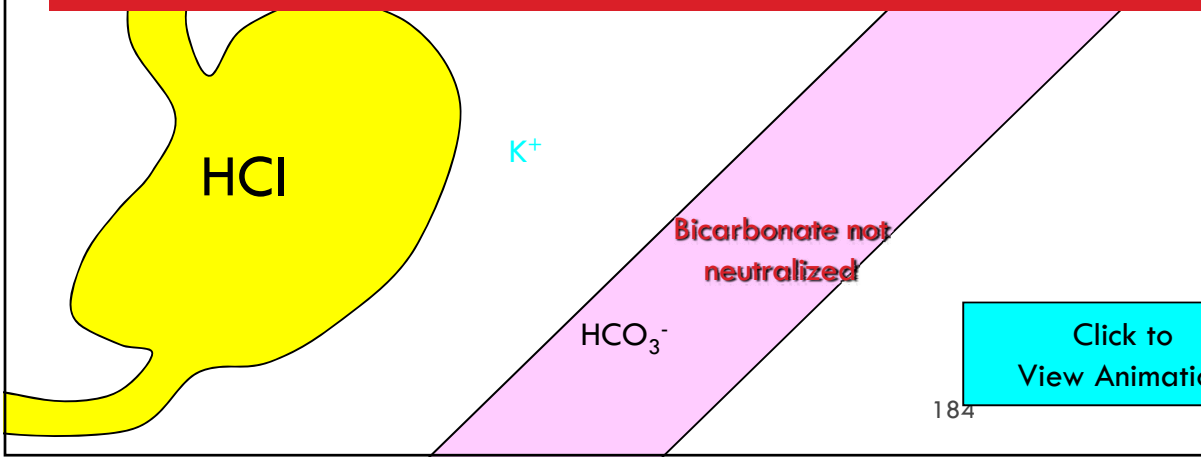
Click to View Animation

183

METABOLIC ALKALOSIS

During vomiting **H^+** is lost as **HCl** and the bicarbonate is not neutralized in the plasma

- Loss of **HCl** increases the plasma bicarbonate and thus results in an increase in **pH** of the blood

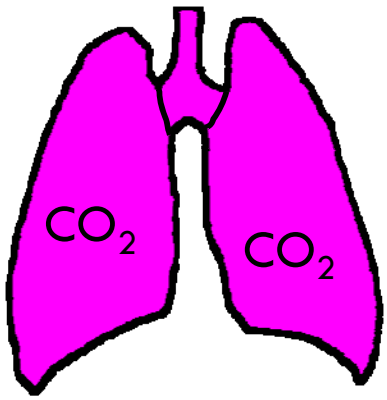


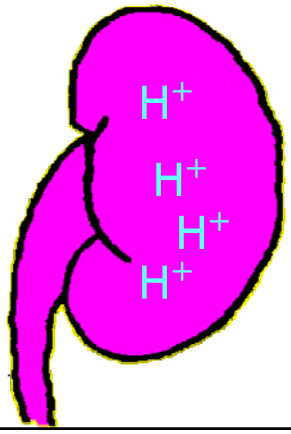
Click to View Animation

184

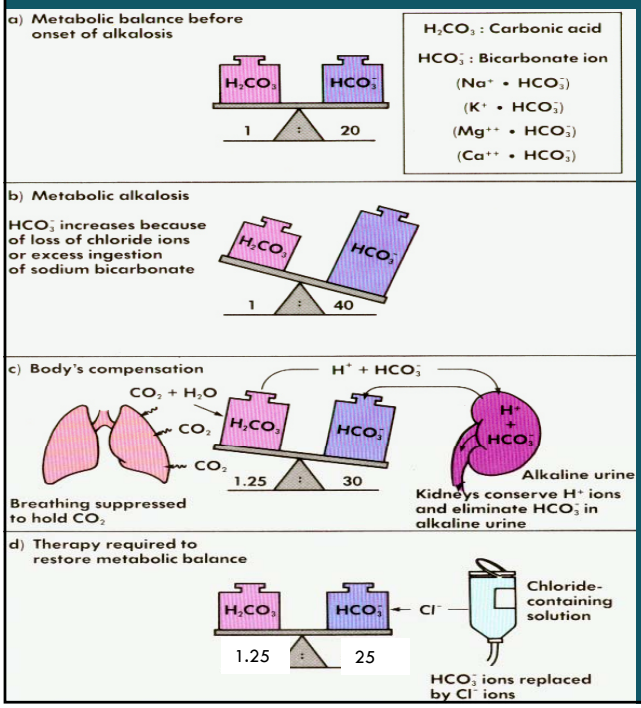
METABOLIC ALKALOSIS

- Reaction of the body to alkalosis is to lower **pH** by:
  - Retain **CO_2** by decreasing breathing rate
  - Kidneys increase the retention of **H^+**





METABOLIC ALKALOSIS



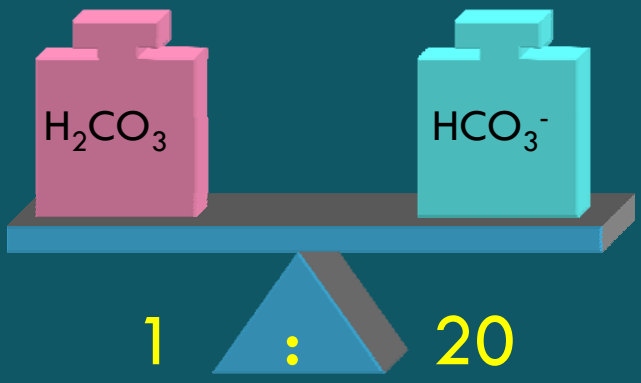
- metabolic balance before onset of alkalosis
- pH = 7.4

- metabolic alkalosis
- pH = 7.7
- HCO_3^- increases because of loss of chloride ions or excess ingestion of $NaHCO_3$

- body's compensation
- breathing suppressed to hold CO_2
- kidneys conserve H^+ ions and eliminate HCO_3^- in alkaline urine

- therapy required to restore metabolic balance
- HCO_3^- ions replaced by Cl^- ions

METABOLIC ALKALOSIS



H_2CO_3 : Carbonic Acid

HCO_3^- : Bicarbonate Ion

$(Na^+)\ HCO_3^-$

$(K^+)\ HCO_3^-$

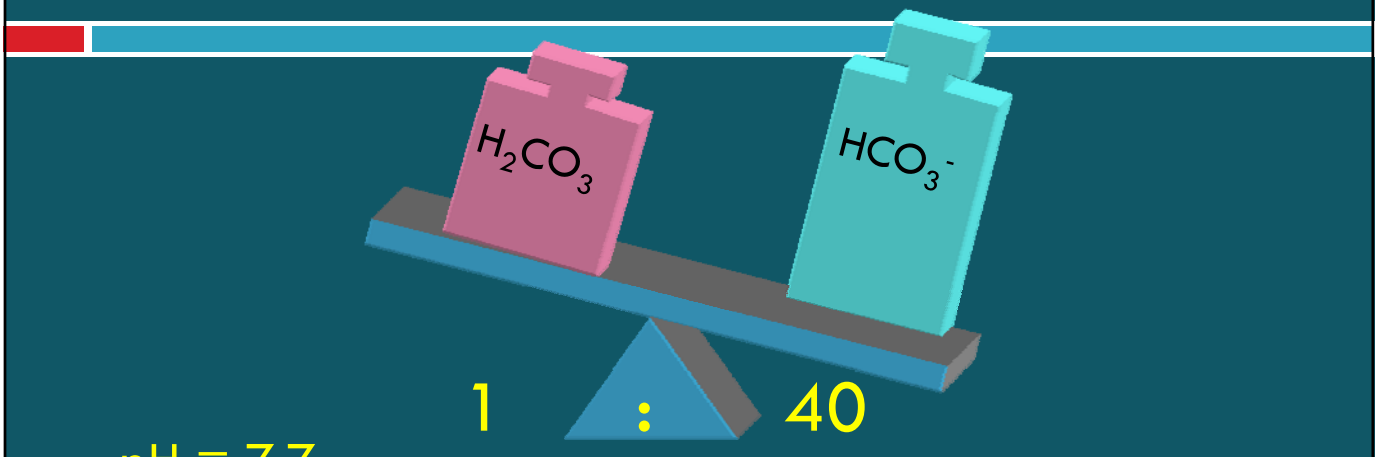
$(Mg^{++})\ HCO_3^-$

$(Ca^{++})\ HCO_3^-$

- metabolic balance before onset of alkalosis
- pH = 7.4

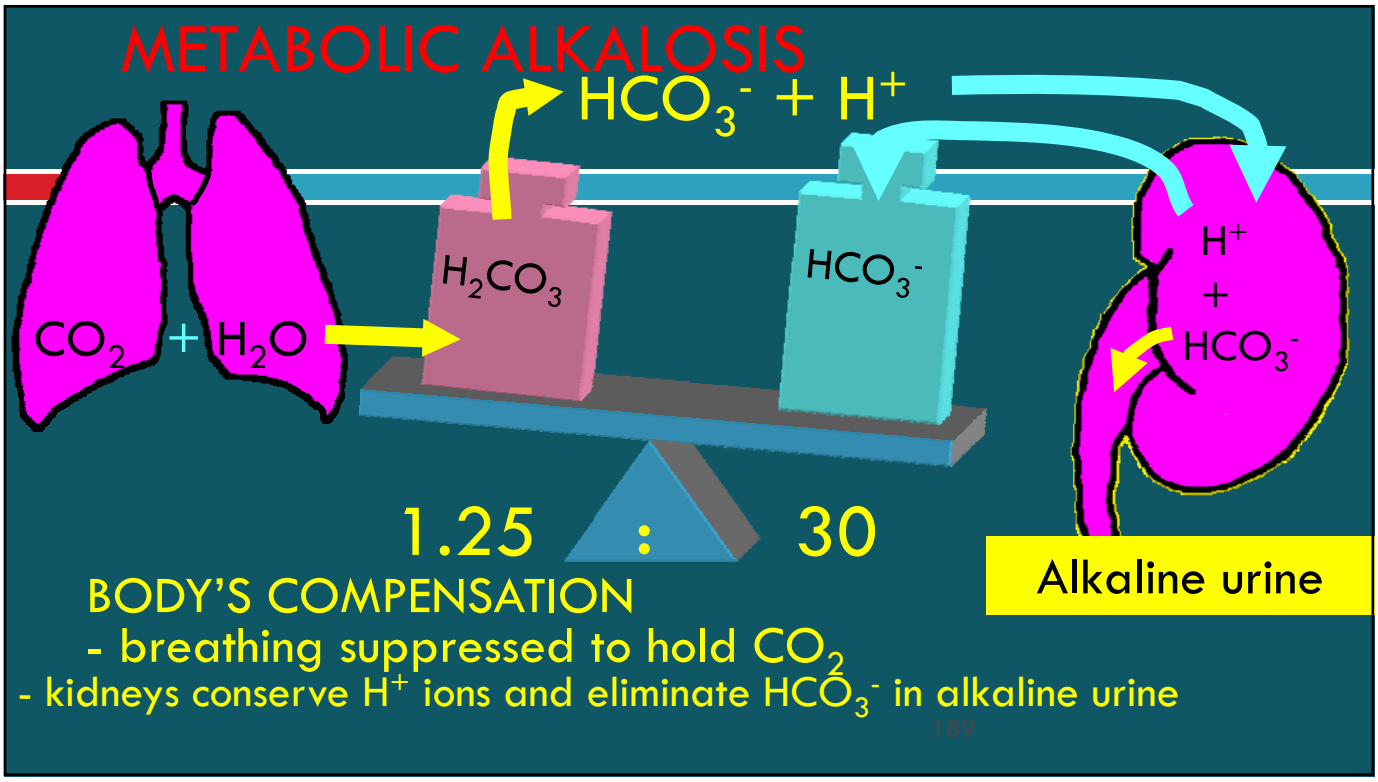
187

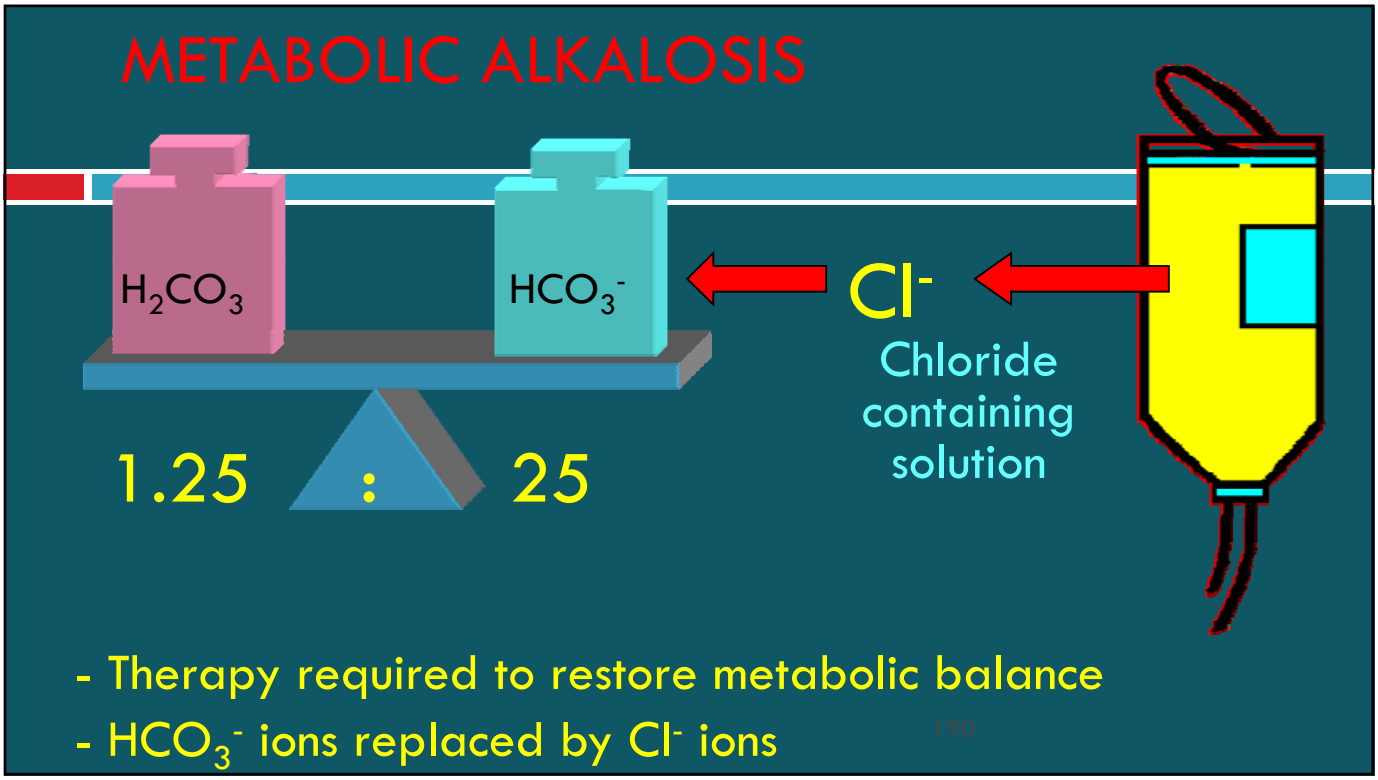
METABOLIC ALKALOSIS

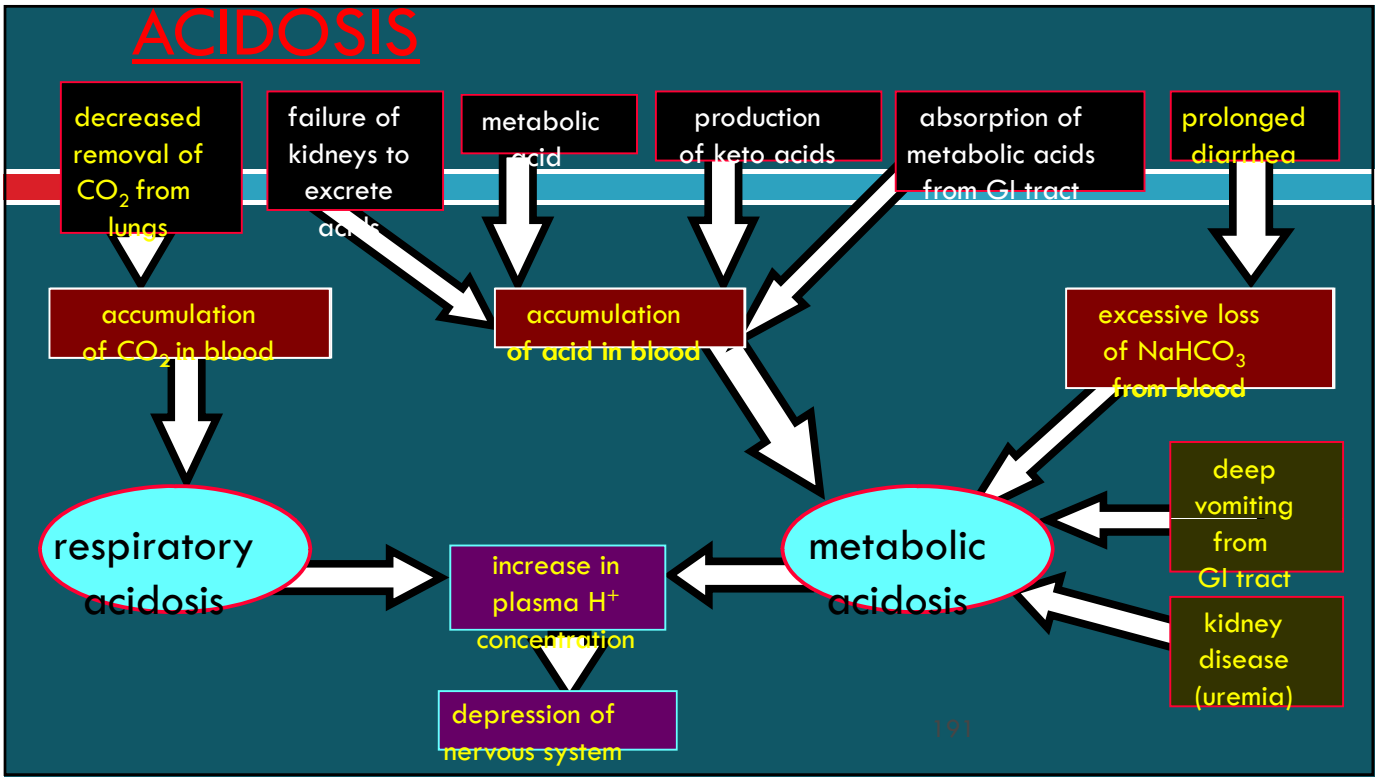


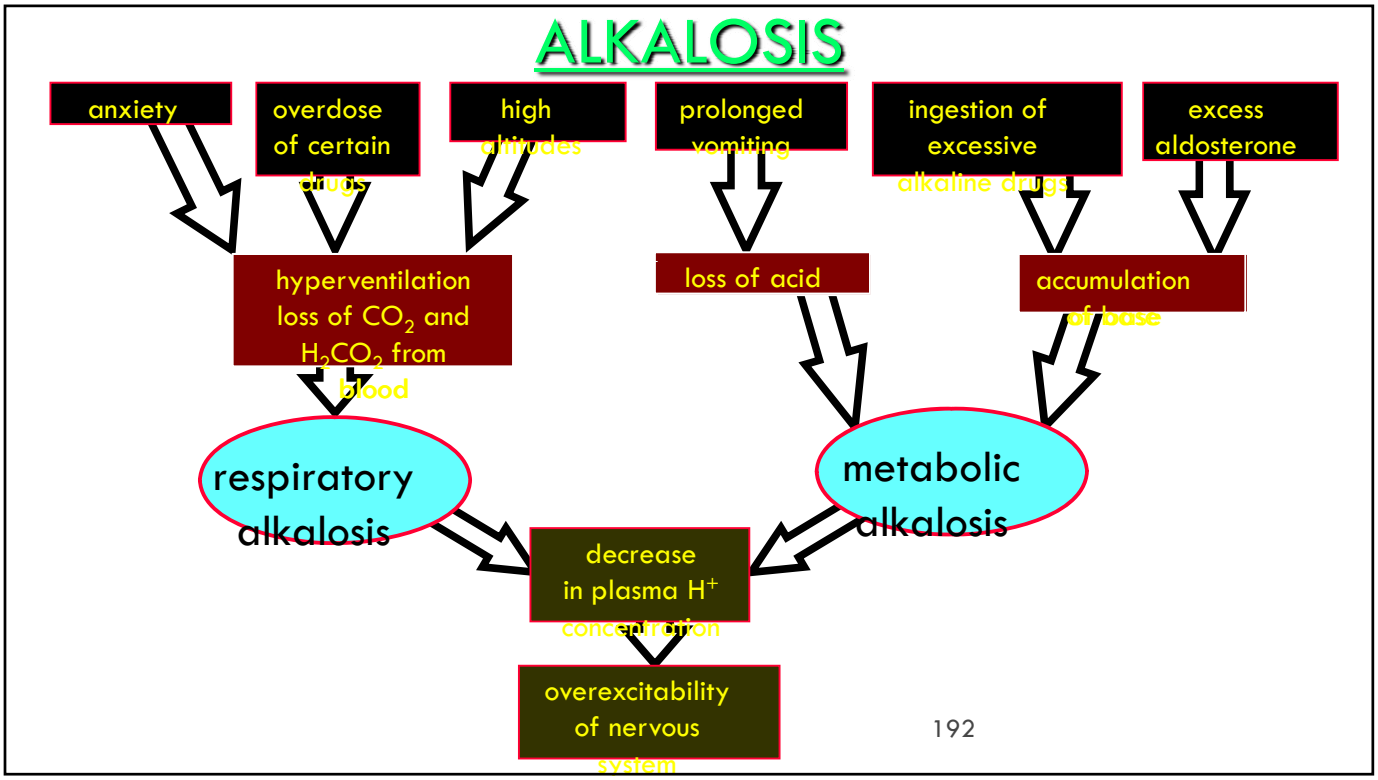
- pH = 7.7
- HCO_3^- increases because of loss of chloride ions or excess ingestion of $NaHCO_3$

188


METABOLIC ALKALOSIS
HCO_3^- + H^+
CO_2 + H_2O
H_2CO_3
HCO_3^-
H^+ + HCO_3^-
1.25 : 30
Alkaline urine
BODY'S COMPENSATION
- breathing suppressed to hold CO_2
- kidneys conserve H^+ ions and eliminate HCO_3^- in alkaline urine


METABOLIC ALKALOSIS
H_2CO_3
HCO_3^-
Cl^-
Chloride containing solution
1.25 : 25
- Therapy required to restore metabolic balance
- HCO_3^- ions replaced by Cl^- ions


ACIDOSIS
decreased removal of CO_2 from lungs
failure of kidneys to excrete
metabolic
production of keto acids
absorption of metabolic acids from GI tract
prolonged diarrhea
accumulation of CO_2 in blood
accumulation of acid in blood
excessive loss of $NaHCO_3$ from blood
deep vomiting from GI tract
kidney disease (uremia)
respiratory acidosis
metabolic acidosis
increase in plasma H^+ concentration
depression of nervous system
191


ALKALOSIS
anxiety
overdose of certain drugs
high altitudes
prolonged vomiting
ingestion of excessive alkaline drugs
excess aldosterone
hyperventilation loss of CO_2 and H_2CO_3 from blood
loss of acid
accumulation of base
respiratory alkalosis
metabolic alkalosis
decrease in plasma H^+ concentration
overexcitability of nervous system
192

ACID – BASE DISORDERS

Clinical State	Acid-Base Disorder
Pulmonary Embolus	Respiratory Alkalosis
Cirrhosis	Respiratory Alkalosis
Pregnancy	Respiratory Alkalosis
Diuretic Use	Metabolic Alkalosis
Vomiting	Metabolic Alkalosis
Chronic Obstructive Pulmonary Disease	Respiratory Acidosis
Shock	Metabolic Acidosis
Severe Diarrhea	Metabolic Acidosis
Renal Failure	Metabolic Acidosis
Sepsis (Bloodstream Infection)	Respiratory Alkalosis, Metabolic Acidosis

RESPONSES TO: ACIDOSIS AND ALKALOSIS

- Mechanisms protect the body against life-threatening changes in hydrogen ion concentration
  - **1) Buffering Systems in Body Fluids**
  - **2) Respiratory Responses**
  - **3) Renal Responses**
  - **4) Intracellular Shifts of Ions**

194

1) Buffer Systems

2) Respiratory Responses

3) Renal Responses

4) Intracellular Shifts of Ions

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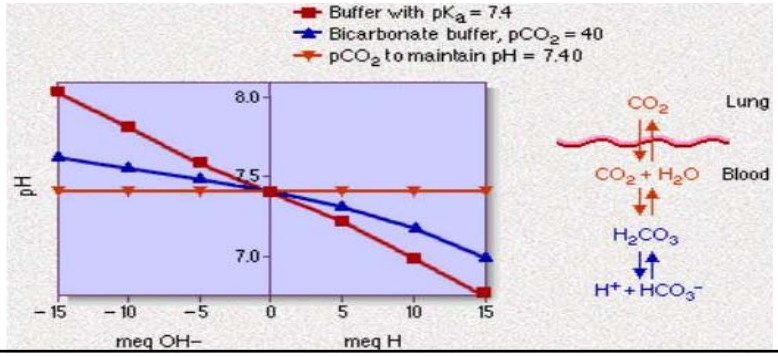
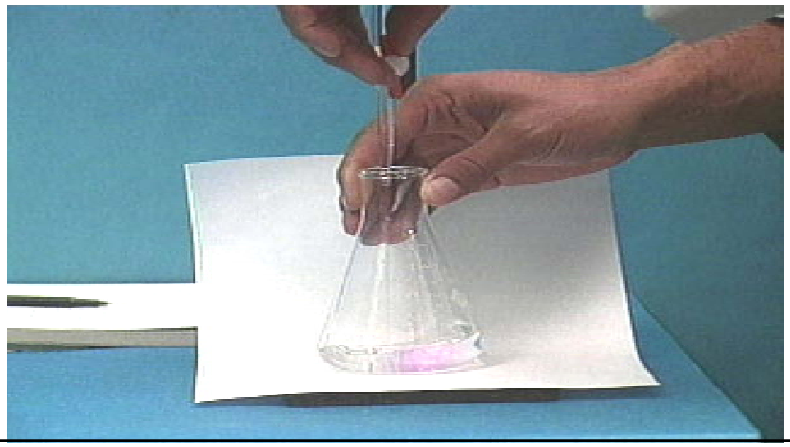
BUFFERS

- Buffering systems provide an immediate response to fluctuations in **pH**
  - **1) Phosphate**
  - **2) Protein**
  - **3) Bicarbonate Buffer System**



BUFFERS

- A buffer is a combination of chemicals in solution that resists any significant change in **pH**
- Able to bind or release free H^+ ions



BUFFERS

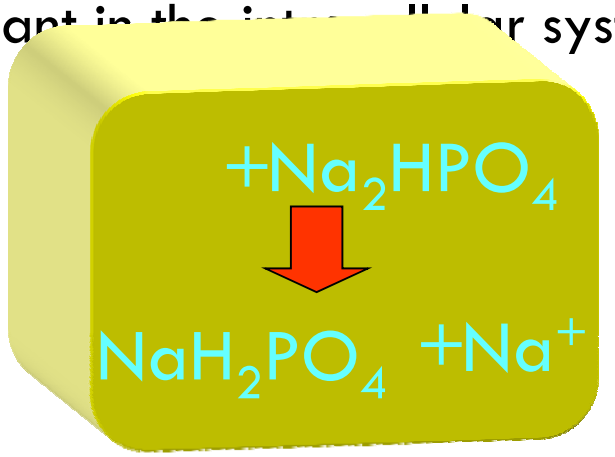
- Chemical buffers are able to react immediately (within milliseconds)
- Chemical buffers are the first line of defense for the body for fluctuations in **pH**

PHOSPHATE BUFFER SYSTEM

- **1) Phosphate buffer system**

$$Na_2HPO_4 + H^+ \rightleftharpoons NaH_2PO_4 + Na^+$$

- Most important in the intracellular system



H+

Click to animate

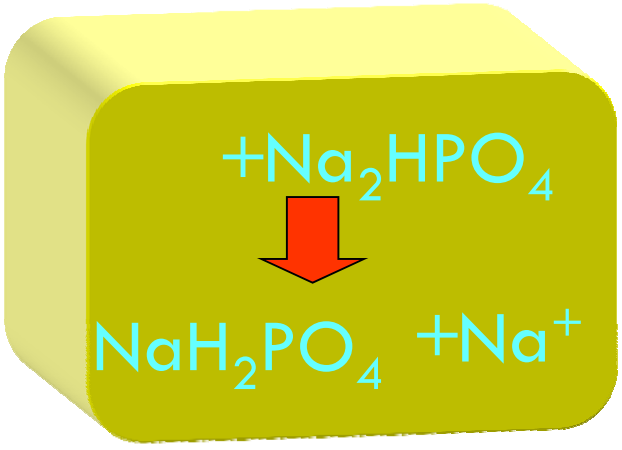
199

PHOSPHATE BUFFER SYSTEM

$$Na_2HPO_4 + H^+ \rightleftharpoons NaH_2PO_4 + Na^+$$

- Alternately switches **Na^+** with **H^+**

Disodium hydrogen phosphate



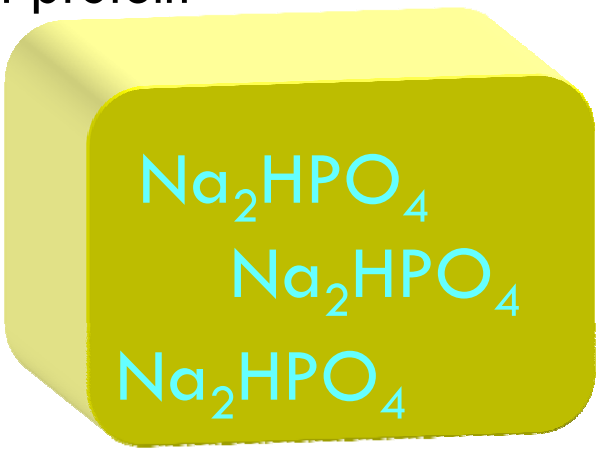
H+

Click to animate

PHOSPHATE BUFFER SYSTEM

$$Na_2HPO_4 + H^+ \rightleftharpoons NaH_2PO_4 + Na^+$$

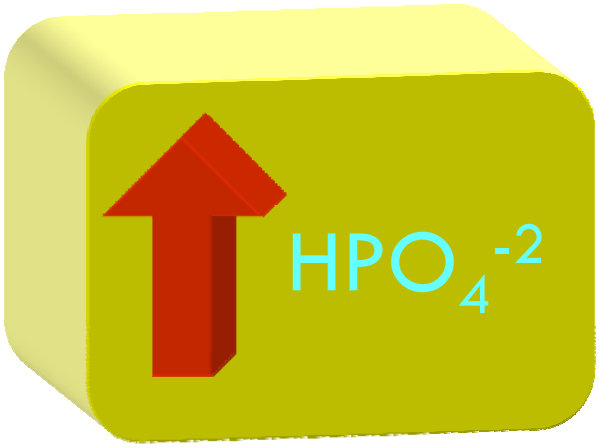
- Phosphates are more abundant within the cell and are rivaled as a buffer in the ICF by even more abundant protein



201

PHOSPHATE BUFFER SYSTEM

- Regulates **pH** within the cells and the urine
  - Phosphate concentrations are higher intracellularly and within the kidney tubules
  - Too low of a concentration in extracellular fluid to have much importance as an **ECF** buffer system

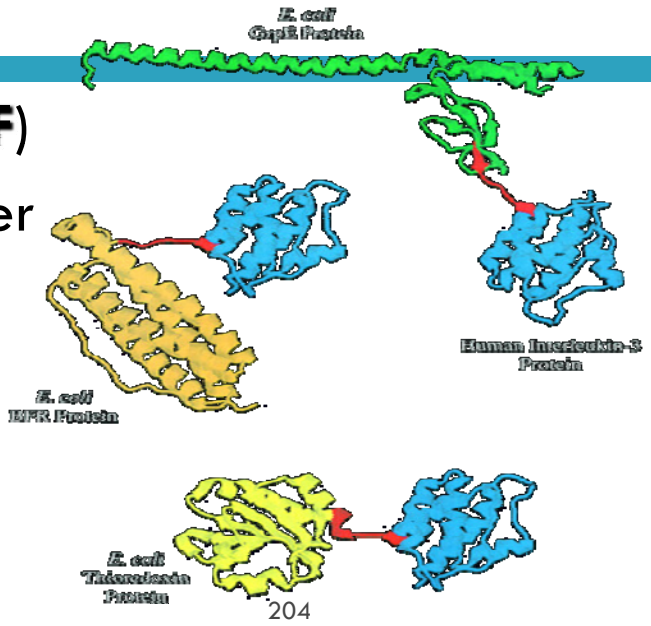


PROTEIN BUFFER SYSTEM

- **2) Protein Buffer System**
  - Behaves as a buffer in both plasma and cells
  - **Hemoglobin** is by far the most important protein buffer

PROTEIN BUFFER SYSTEM

- Most important intracellular buffer (**ICF**)
- The most plentiful buffer of the body



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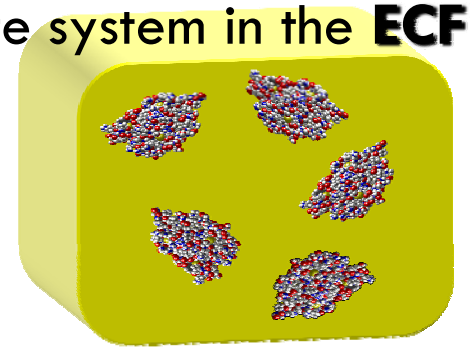
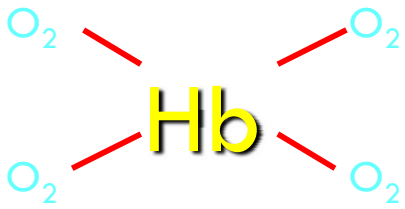
PROTEIN BUFFER SYSTEM

- Proteins are excellent buffers because they contain both acid and base groups that can give up or take up H^+
- Proteins are extremely abundant in the cell
- The more limited number of proteins in the plasma reinforce the bicarbonate system in the **ECF**



PROTEIN BUFFER SYSTEM

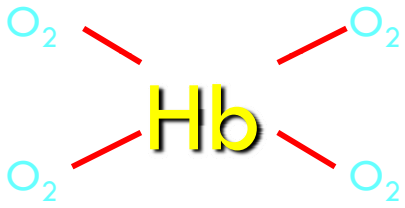
- Hemoglobin buffers H^+ from metabolically produced CO_2 in the plasma only
- As hemoglobin releases O_2 it gains a great affinity for H^+



206

PROTEIN BUFFER SYSTEM

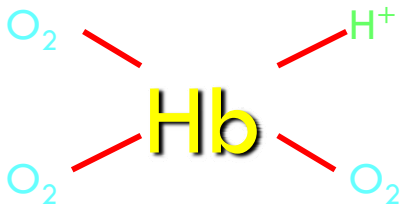
- **H^+** generated at the tissue level from the dissociation of **H_2CO_3** produced by the addition of **CO_2**
- Bound **H^+** to **Hb** (Hemoglobin) does not contribute to the acidity of blood



207

PROTEIN BUFFER SYSTEM

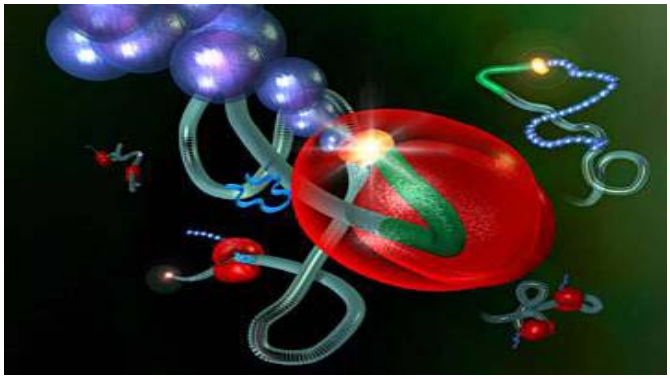
- As **H^+Hb** picks up **O_2** from the lungs the **Hb** which has a higher affinity for **O_2** releases **H^+** and picks up **O_2**
- Liberated **H^+** from **H_2O** combines with **HCO_3^-**



208

PROTEIN BUFFER SYSTEM

- Venous blood is only slightly more acidic than arterial blood because of the tremendous buffering capacity of **Hb**
- Even in spite of the large volume of H^+ generating CO_2 carried in venous blood



PROTEIN BUFFER SYSTEM

- Proteins can act as a buffer for both acids and bases
- Protein buffer system works instantaneously making it the most powerful in the body
- 75% of the body's buffer capacity is controlled by protein
  - Bicarbonate and phosphate buffer systems require several hours to be effective

$$Pr^- \rightarrow \text{added } H^+ + Pr^-$$

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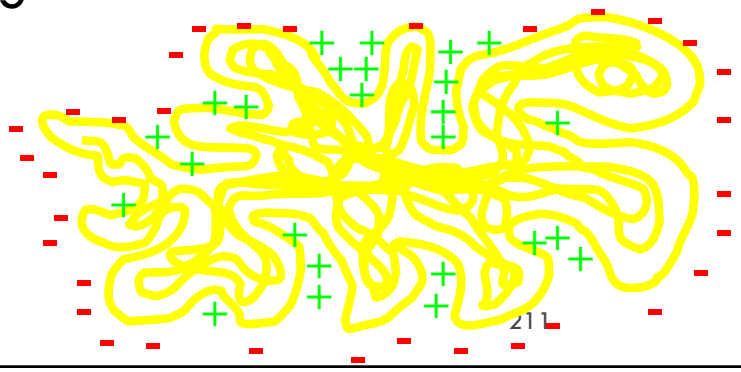
PROTEIN BUFFER SYSTEM

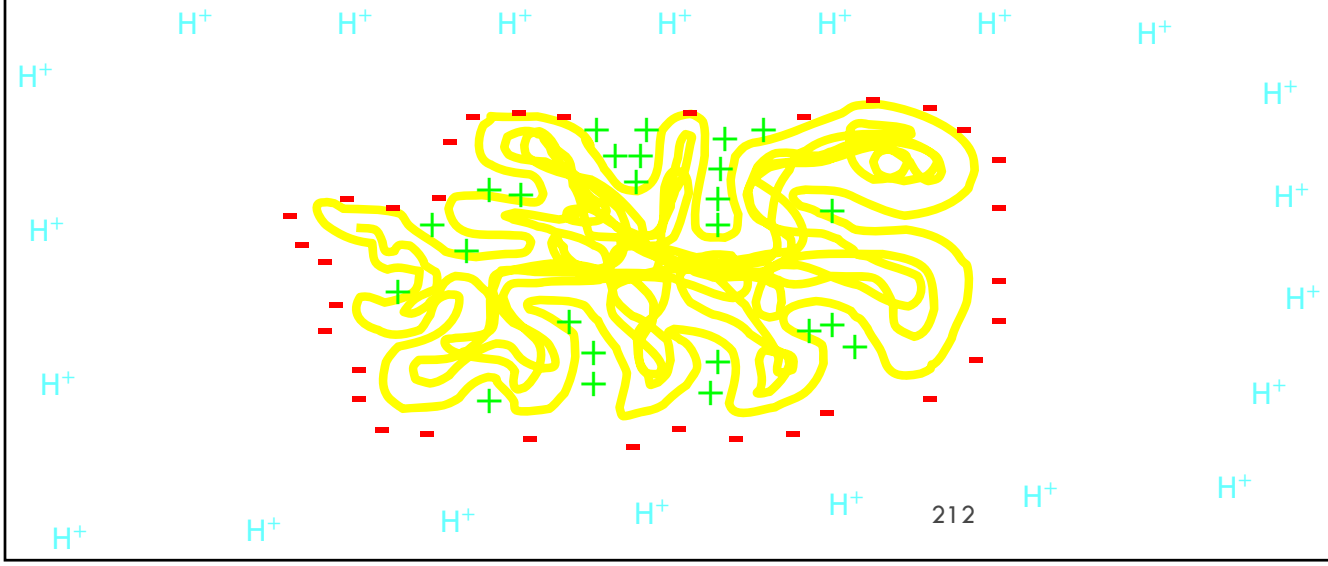
- Proteins are very large, complex molecules in comparison to the size and complexities of acids or bases
- Proteins are surrounded by a multitude of negative charges on the outside and numerous positive charges in the crevices of the molecule



211

PROTEIN BUFFER SYSTEM

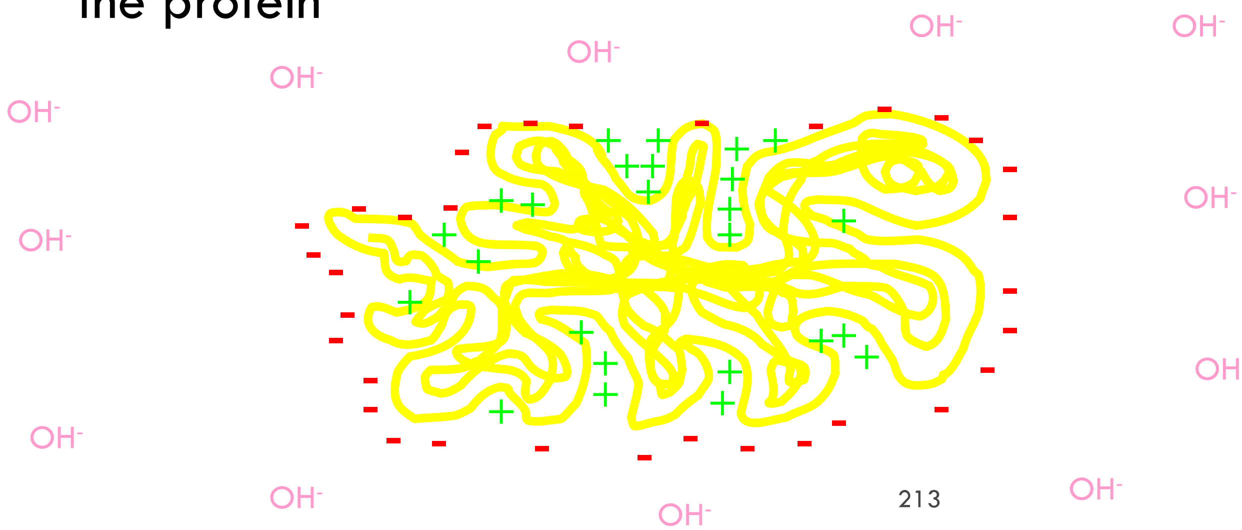
- **H^+** ions are attracted to and held from chemical interaction by the negative charges



212

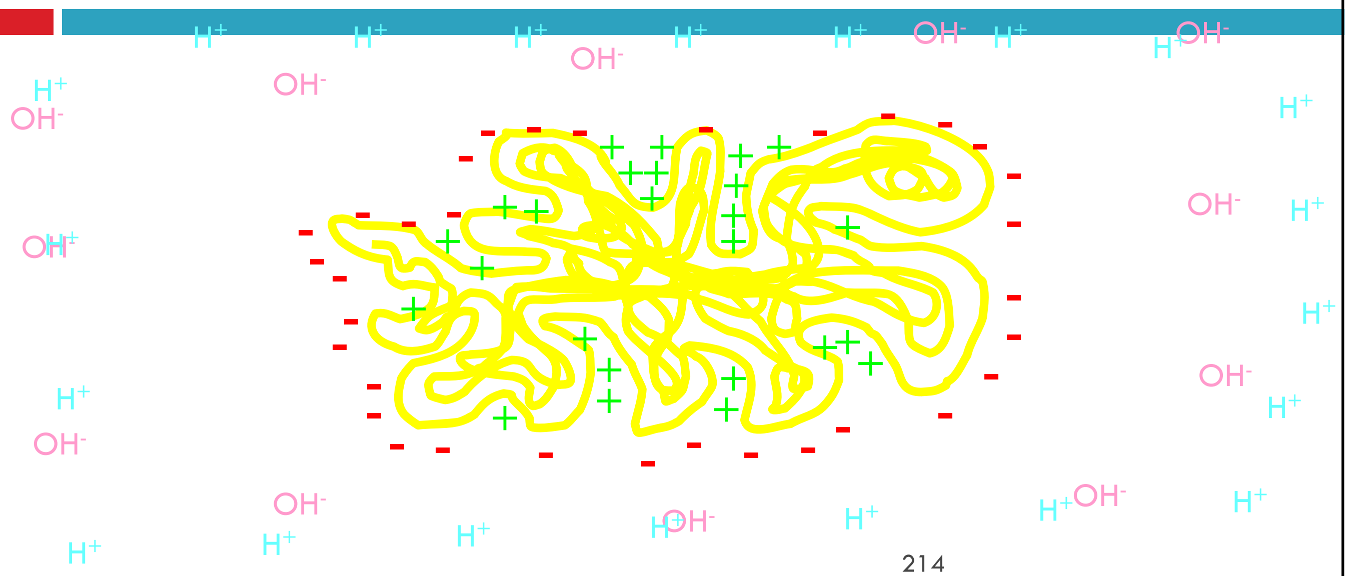
PROTEIN BUFFER SYSTEM

- OH^- ions which are the basis of alkalosis are attracted by the positive charges in the crevices of the protein



213

PROTEIN BUFFER SYSTEM



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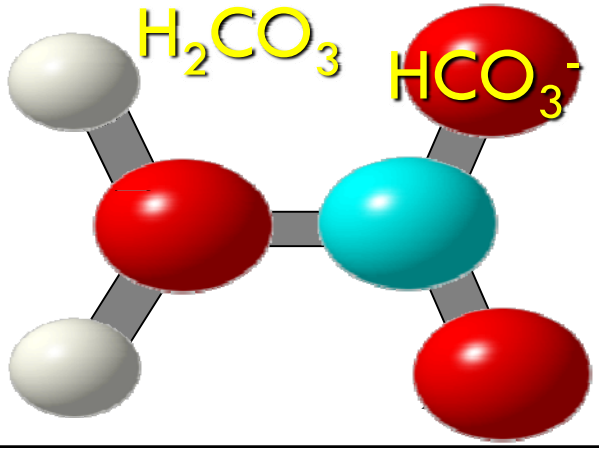
BICARBONATE BUFFER SYSTEM

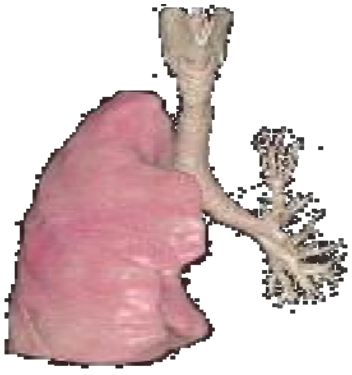
- **3) Bicarbonate Buffer System**
  - Predominates in extracellular fluid (**ECF**)

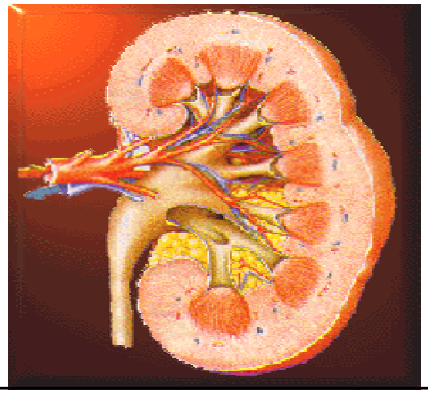
HCO_3^- + added H^+ → H_2CO_3



BICARBONATE BUFFER SYSTEM

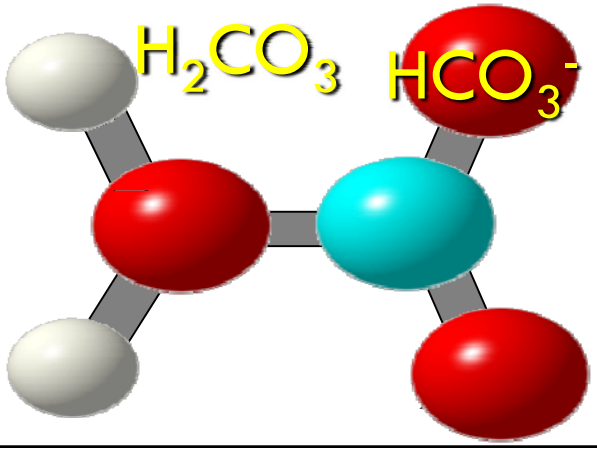
- This system is most important because the concentration of both components can be regulated:
  - **Carbonic acid** by the respiratory system
  - **Bicarbonate** by the renal system





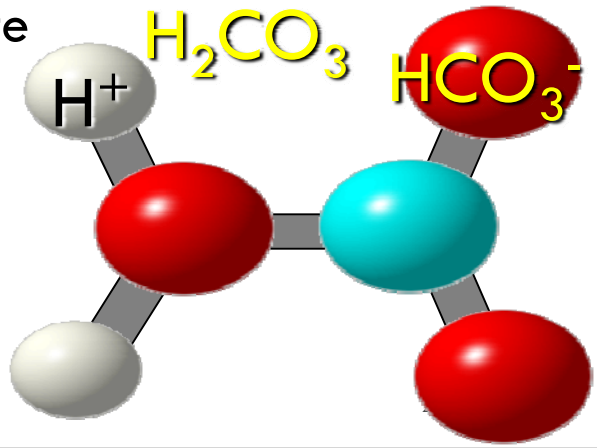
BICARBONATE BUFFER SYSTEM

- H_2CO_3 ⇌ $H^+ + HCO_3^-$
  - Hydrogen ions *generated* by metabolism or by ingestion react with bicarbonate base to form more carbonic acid

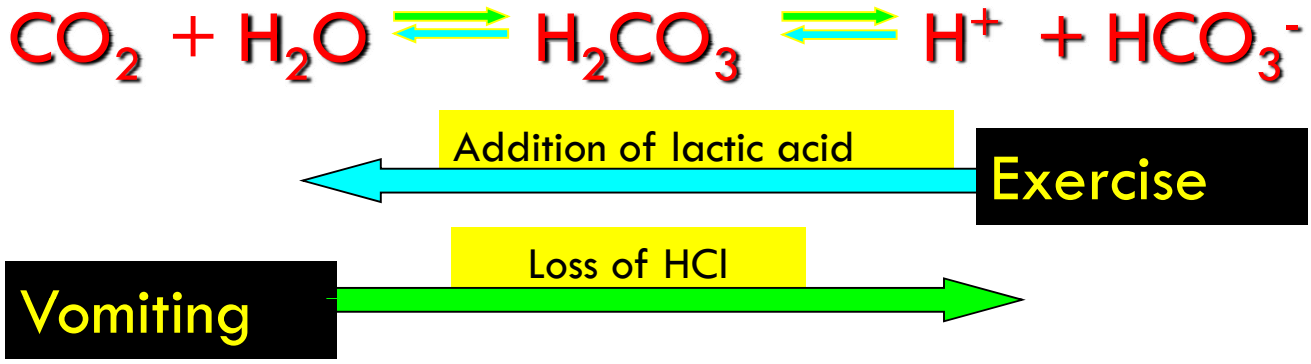


BICARBONATE BUFFER SYSTEM

- Equilibrium shifts toward the formation of *acid*
  - Hydrogen ions that are *lost* (vomiting) causes carbonic acid to dissociate yielding replacement H^+ and bicarbonate



BICARBONATE BUFFER SYSTEM



219

1) Buffer Systems

2) Respiratory Responses

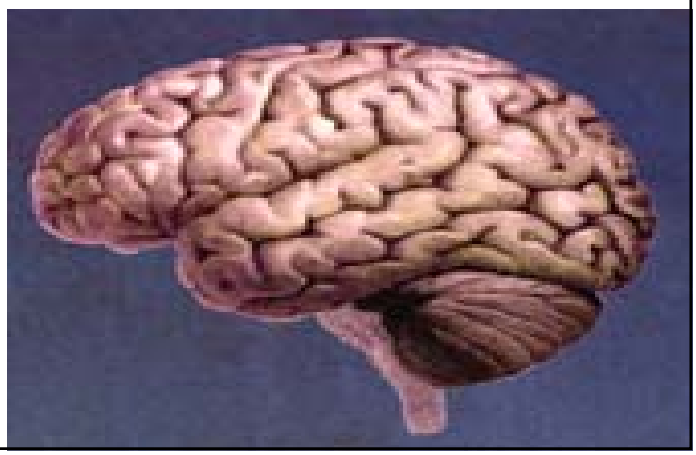
3) Renal Responses

4) Intracellular Shifts of Ions

220

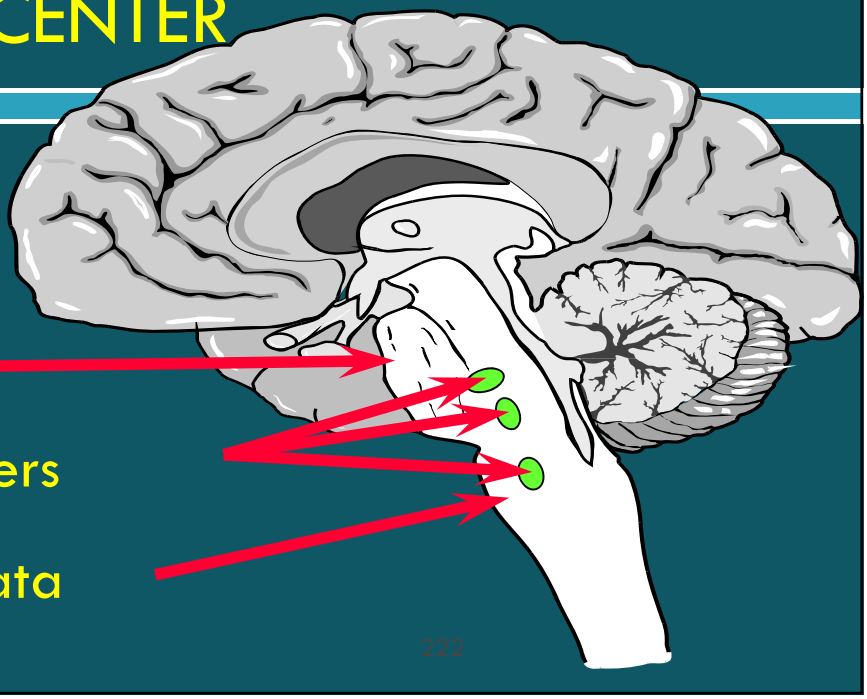
RESPIRATORY RESPONSE

- Neurons in the medulla oblongata and pons constitute the **Respiratory Center**
- Stimulation and limitation of respiratory rates are controlled by the respiratory center
- Control is accomplished by responding to CO_2 and H^+ concentrations in the blood



221

RESPIRATORY CENTER



Pons

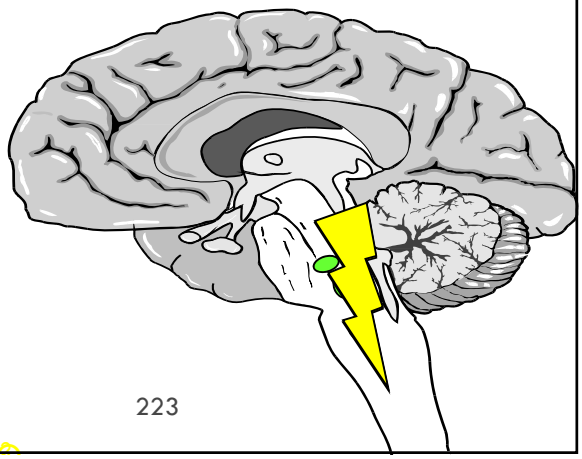
Respiratory centers

Medulla oblongata

222

CHEMOSENSITIVE AREAS

- Chemosensitive areas of the respiratory center are able to detect blood concentration levels of CO_2 and H^+
- Increases in CO_2 and H^+ stimulate the respiratory center
  - The effect is to raise respiration rates
    - But the effect diminishes in 1 - 2 minutes



Click to increase CO_2

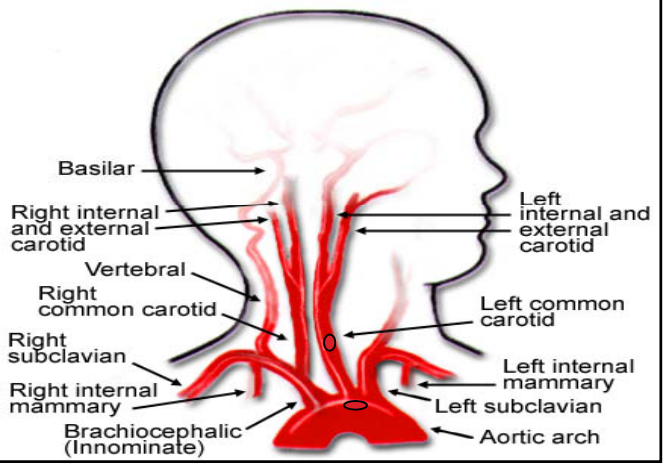
223

CHEMOSENSITIVE AREAS

- The effect of stimulating the respiratory centers by increased CO_2 and H^+ is weakened in environmentally increased CO_2 levels
- Symptoms may persist for several days

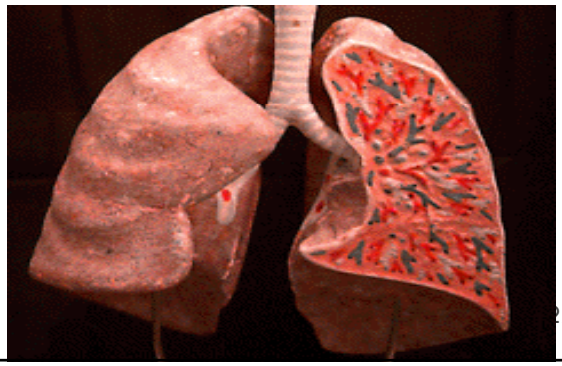
CHEMORECEPTORS

- Chemoreceptors are also present in the **carotid** and **aortic** arteries which respond to changes in partial pressures of O_2 and CO_2 or pH
- Increased levels of CO_2 (low **pH**) or decreased levels of O_2 stimulate respiration rates to increase

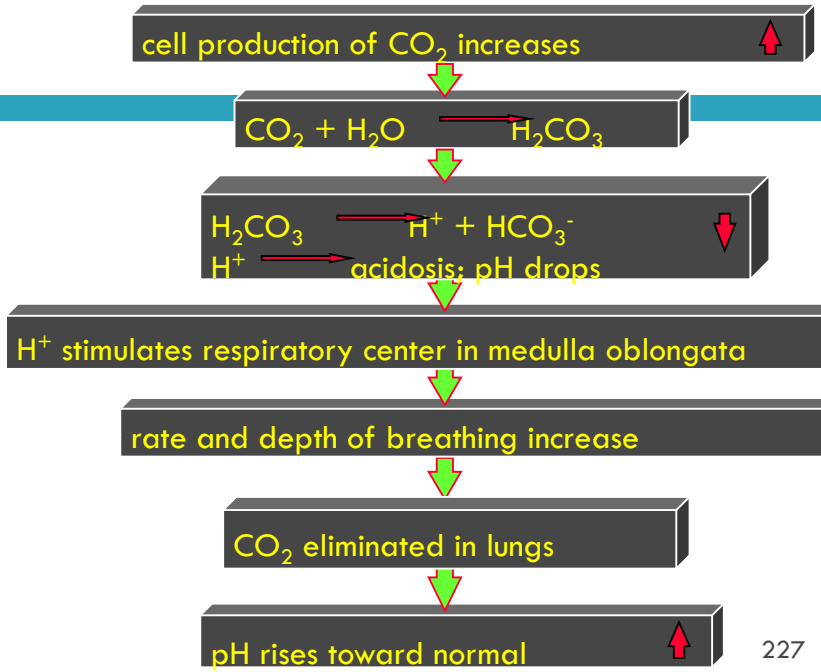


CHEMORECEPTORS

- Overall compensatory response is:
  - **Hyperventilation** in response to increased CO_2 or H^+ (low **pH**)
  - **Hypoventilation** in response to decreased CO_2 or H^+ (high **pH**)



RESPIRATORY CONTROL OF pH



227

1) Buffer Systems
2) Respiratory Responses
3) Renal Responses
4) Intracellular Shifts of Ions

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RENAL RESPONSE

- The kidney compensates for **Acid - Base** imbalance within 24 hours and is responsible for long term control
- The kidney in response:
  - **To Acidosis**
    - Retains bicarbonate ions and eliminates hydrogen ions
  - **To Alkalosis**
    - Eliminates bicarbonate ions and retains hydrogen ions

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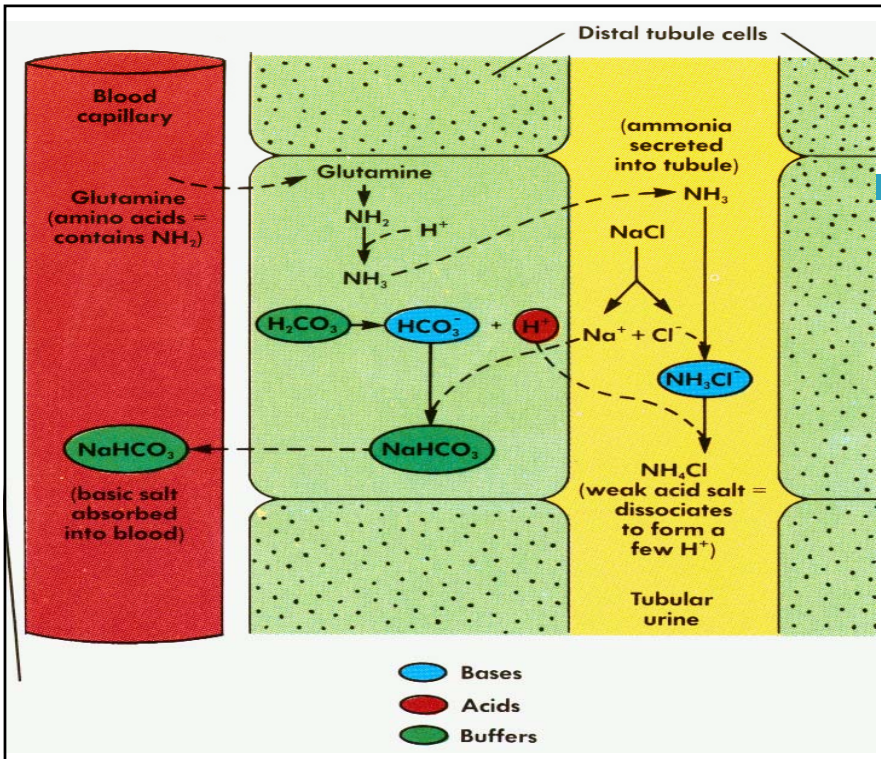
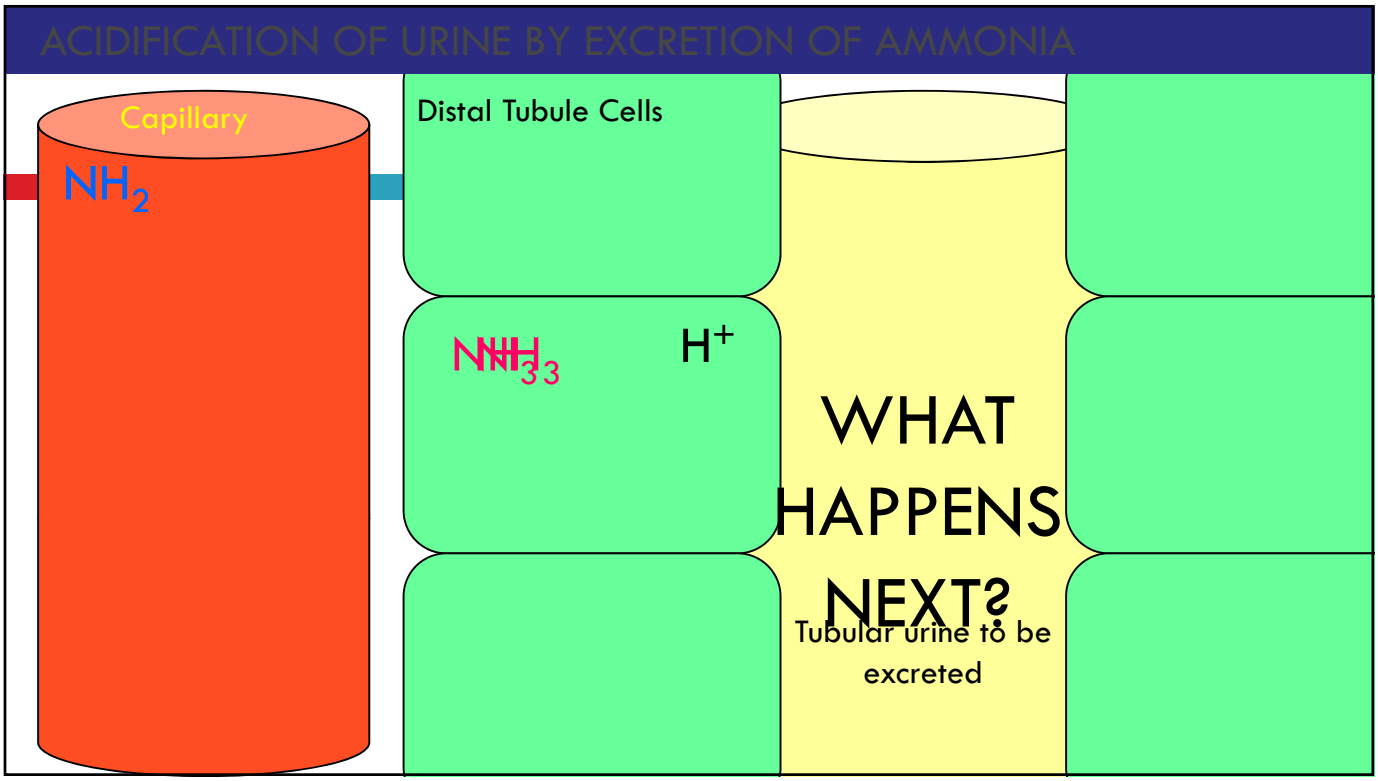
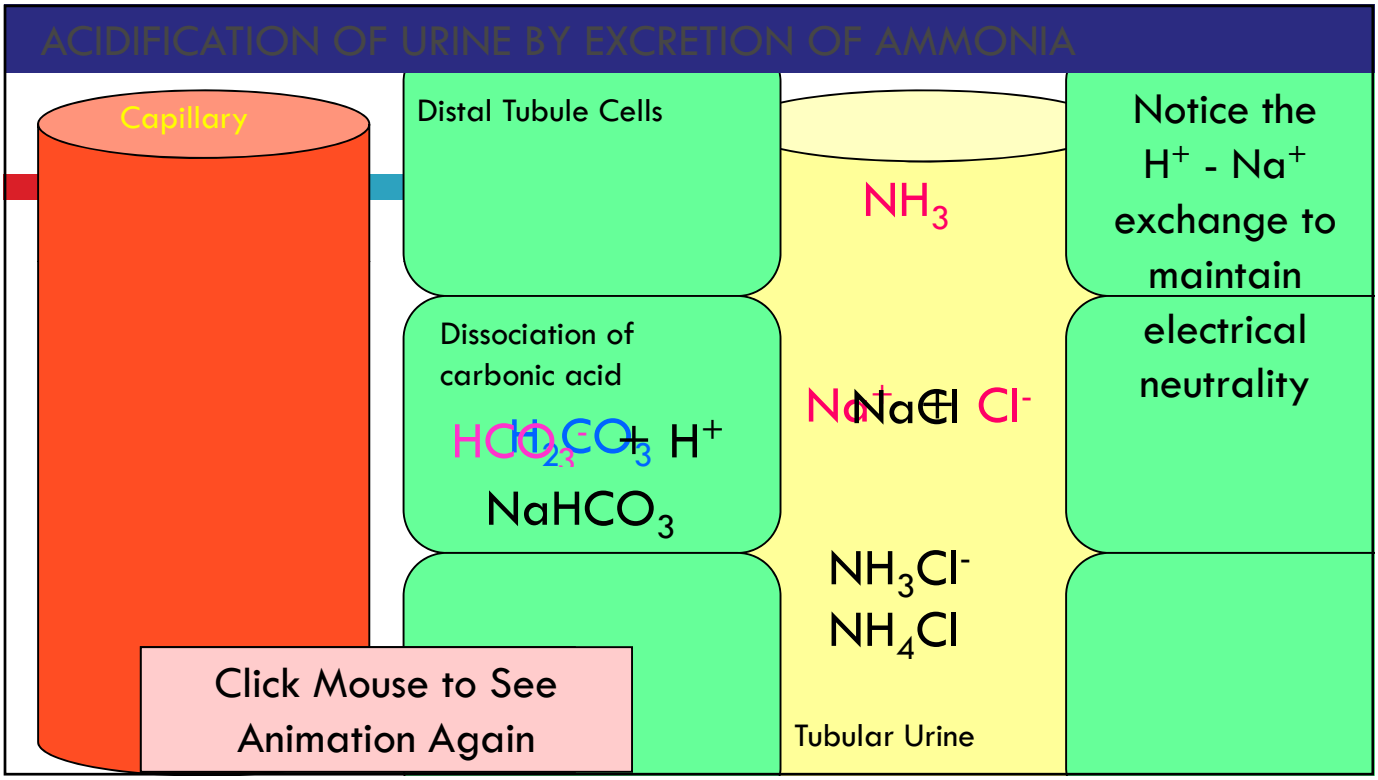


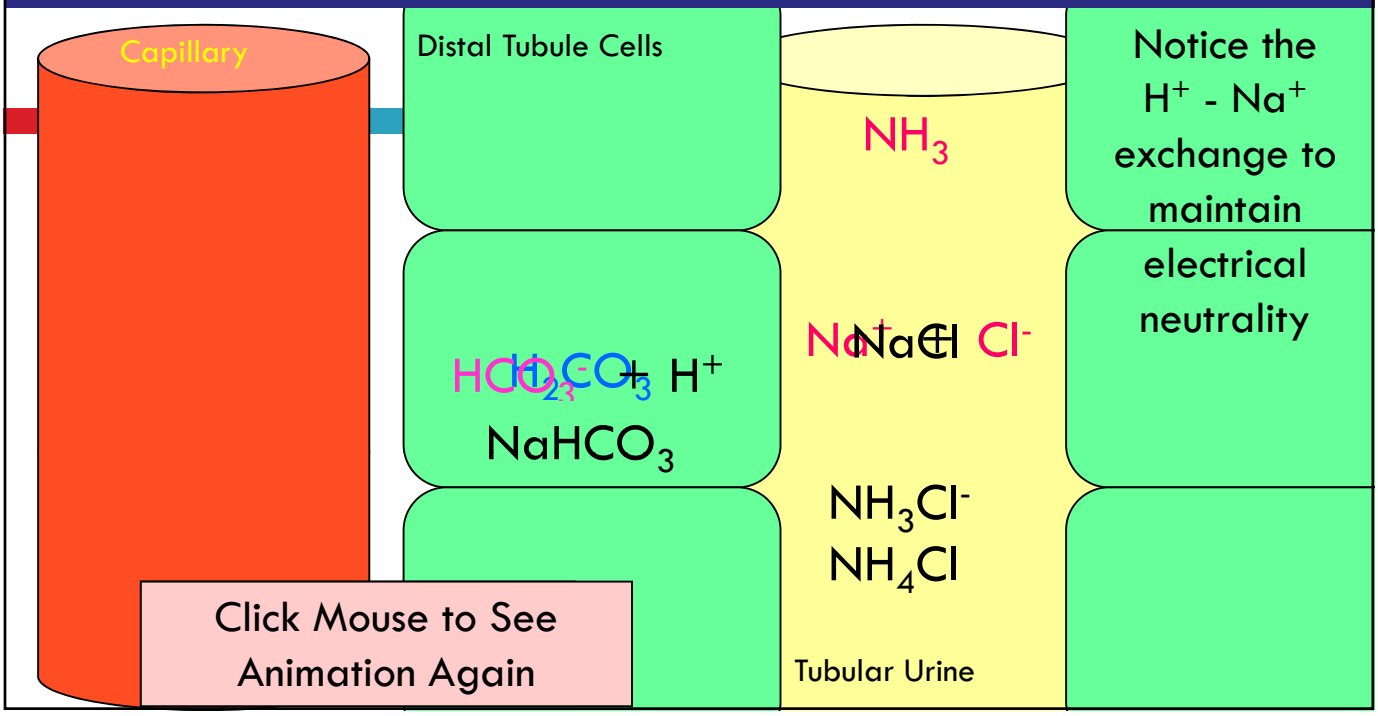
ACIDIFICATION OF URINE BY EXCRETION OF AMMONIA

230


ACIDIFICATION OF URINE BY EXCRETION OF AMMONIA
Capillary
NH_2
Distal Tubule Cells
NH_3
H^+
WHAT HAPPENS NEXT?
Tubular urine to be excreted

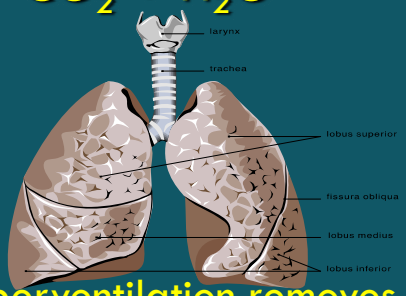

ACIDIFICATION OF URINE BY EXCRETION OF AMMONIA
Capillary
Distal Tubule Cells
NH_3
Notice the H^+ - Na^+ exchange to maintain electrical neutrality
Dissociation of carbonic acid
Na^+ Cl^-
H^+
$NaHCO_3$
NH_3Cl^-
NH_4Cl
Tubular Urine
Click Mouse to See Animation Again

ACIDIFICATION OF URINE BY EXCRETION OF AMMONIA



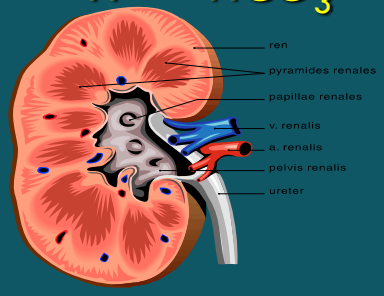
RESPIRATORY / EXCRETORY RESPONSE

$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$



Hyperventilation removes H^+ ion concentrations

Hypoventilation increases H^+ ion concentrations



Kidneys eliminate or retain H^+ or bicarbonate ions

1) Buffer Systems
2) Respiratory Responses
3) Renal Responses
4) Intracellular Shifts of Ions

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HYPERKALEMIA

- **Hyperkalemia** is generally associated with acidosis
  - Accompanied by a shift of H^+ ions into cells and K^+ ions out of the cell to maintain electrical neutrality

H^+ K^+ 

236

HYPERKALEMIA

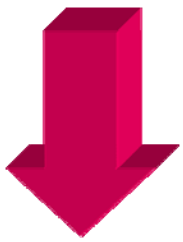
- Hyperkalemia is an elevated serum **K^+**
  - **H^+** ions are buffered in cell by proteins
- **Acidosis** may cause **Hyperkalemia** and **Hyperkalemia** may cause **Acidosis**

H^+ K^+ 

237

HYPOKALEMIA

- **Hypokalemia** is generally associated with reciprocal exchanges of **H^+** and **K^+** in the opposite direction
  - Associated with alkalosis
- Hypokalemia is a depressed serum **K^+**

H^+ K^+ 

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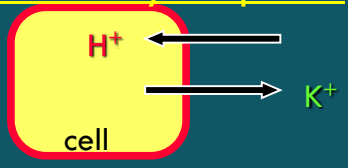
ELECTROLYTE SHIFTS

Acidosis

Compensatory Response



Result

- H^+ buffered intracellularly
- Hyperkalemia

Alkalosis

Compensatory Response

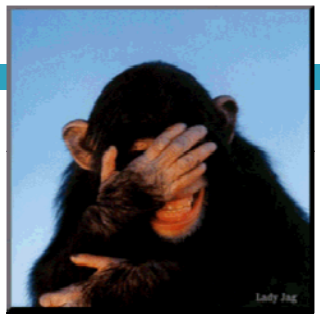
Result

- Tendency to correct alkalosis
- Hypokalemia

239

END

ACID - BASE BALANCE



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REFERENCE ACID BASE BALANCE

Instructor Terry Wiseth

NORTHLAND COLLEGE