**Physiology Lecture 2 and 27**
**<u>Chapter 2:</u> Acids, Bases and Salts REVIEW:**

**1. *Salts* – an ionic compounds containing other than $H^+$ or $OH^-$; can dissociate in water to form electrolytes. Electrolytes can conduct electrical currents. (See Table 2.2, page 35, and Figure 27.6, page 1042)**

**eg. NaCl ⇔ $Na^+$ + $Cl^-$**

**In their *ionized* state they play vital role in body functions,**
**Eg. minerals are metal ions.**

**<u>Common salts</u> in the ICF/ECF regulated by the kidneys:**

**$Ca_2CO_3$ ⇔ $Ca^{2+}$ + $CO_3^-$**
**KCl ⇔ $K^+$ + $Cl^-$**
**NaCl ⇔ $Na^+$ + $Cl^-$**

**2. *Acids* – a sub. that releases $H^+$ ; "a proton donor"**

**HCl ⇔ $H^+$ + $Cl^-$**
**(proton)**

**The conc. of $H^+$ is what determines the acidity of a soln. The anion ($Cl^-$ ) has no effect on acidity!**

**<u>Strong acids</u> – do dissociate readily ie, they do effect pH because many $H^+$ are donated in soln.**

**<u>Weak acids</u> – don't dissociate readily ie, they don't effect pH much because not a lot of $H^+$ are donated. They are excellent buffers!**

**<u>Examples:</u>**
*** $HC_2H_3O_2$ ; acetic acid (weak)**
*** $H_2CO_3$ ; carbonic acid (weak)**
*** $H_2SO_4$ ; sulfuric acid (strong)**

**3.** ***Bases*** **– a sub. that accepts $H^+$; "proton acceptor"**

$$NaOH \Leftrightarrow Na^+ + OH^-$$

**(proton acceptor)**

*** Weak bases – don't dissociate readily ie, they don't accept $H^+$ readily in soln. eg. $HCO_3^-$**

*** Strong bases – do dissociate readily ie, they do accept $H^+$ most readily in soln. eg. NaOH**

**Examples:**

**$HCO_3^-$ (weak base)** ***bicarbonate ion*****; most abundant in the blood and accepts $H^+$ well enough to help maintain blood pH!**

**4.** ***pH: Acid & Base Concentration*****: s(see pH scale on pages 42)**

**pH – a measure of $[H^+]$ per liter of soln. (ICF/ECF)**
**pH is logarithmic**

**5.** ***Buffers*** **– chemicals (weak acids) in the body that resist abrupt, large swings in body fluid pH.**
***(see** ***Buffer Systems*** **on page 42)**

***Cells are very sensitive to the slightest changes in pH; drastic changes in pH can damage cellular function.**

***Normal blood pH varies between 7.35 – 7.45 (a narrow range); extreme movements are FATAL!**

***Buffers resist pH change by accepting or donating $H^+$**

**Example:** ***Carbonic acid*****; a weak acid acting as a buffer**

$$H_2CO_3 \ [\text{ in 1 ml of } H_2O\ ] \Leftrightarrow H^+ + HCO_3^-$$

**(100 $H_2CO_3$ molecules) (10$H^+$) (10bicarbonates)**

**Weak acids don't easily dissociate, so they react in a predictable way…. They are excellent buffers!**

**$H_2CO_3$ ⇔ $H^+$ + $HCO_3^-$**
**(proton donor) (proton acceptor)**

**<u>Questions</u>???**
**So, if we …..**

**1) add $H^+$(acid) to the system the reaction shifts to the __?__**

**2) remove $H^+$(acid) from the system the reaction shifts to the __?__**

**$H_2CO_3$ ⇔ $H^+$ + $HCO_3^-$**
**(proton donor) (proton acceptor)**

**3) How does the buffer system respond to <u>an elevated pH</u>?**

**4) How does the buffer system respond to <u>depressed pH</u>?**

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**Chapter 27: Fluid, Electrolytes and Acid-Base Homeostasis**
**(see pages 1046 – 1051; Chap. 27)**

**Q? What is the importance of regulating [$H^+$] anyway?**

**A: All biochemical rxns. are influenced by <u>small</u> pH changes!**
**Egs. enzymes, Hb, proteins, etc..**

*** Acid subs. enter the body via food, exercise, drugs/alcohol, a low carbohydrate diet (ketones), and as metabolic byproducts (waste).**

**I. Mechanisms for maintaining [$H^+$] in the <u>body fluids</u>, ie. ICF/ECF:**

**1) Buffer Systems – accepts or releases $H^+$ in solution; the body's first line of defense. Operates w/in seconds.**

**2) Respiratory System – inhalation/exhalation of $CO_2$; slow, but very powerful. Operates w/in 1-3 minutes.**

**3) Urinary/Excretory System - eliminate $H^+$ via the excretory system(urine); slow, but powerful. Operates w/in hours to days.**

## II. Buffer Systems:

**Buffer system - a chemical mechanism in the body fluids that maintain homeostatic pH of ECF & ICF, ie. weak acids.**

**3 buffer systems in the body: (See Table 27.3, page 1049)**

1. **phosphate buffer system - ICF**
2. **protein buffer system – ICF/ECF; (most powerful buffer system!)**
3. **carbonic acid-bicarbonate buffer system – ECF**

**They all work together to maintain pH!**

**Two Main Functions of Buffers:**

**1) any substance that releases or accepts excess $H^+$ to maintain body fluid pH.**

**2) helps stabilize $[H^+]$ in the body ....**

**A) when $[H^+]$ ↑ then buffer systems accepts $H^+$**

**B) when $[H^+]$ ↓ then buffer systems donates $H^+$**

***Buffers are like chemical sponges; they can soak up or wring out $H^+$**

**A. Buffers are conjugate pairs, ie. an acid and its conjugate base (weak acids)**

**an acid ↓ proton donor; conjugate base ↓ proton acceptor**

**1. Intracellular Buffers - inside cells *(ICF)**

**a) Phosphate buffer pair – subject to excretory/urinary control (kidney tubules)**

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

**b) <u>Protein</u>s - most abundant in body cells & plasma. ** (ICF/ECF) Also, Hb inside RBC's is an excellent protein buffer.**

$$HbH \Leftrightarrow H^{+} + Hb^{-}$$

*** Proteins are made-up of long chains of amino acids.**
*** Amino acids are made of <u>two parts</u>:**
***carboxyl group* - acts as an acid (proton donor) -COOH**
***amino group* - acts as a base (proton acceptor) $-NH_2$**
*** Amino acids make excellent buffers! They are *amphoteric*!**

**<u>Question</u>?? Why are amino acids excellent buffers???**

**2. <u>Extracellular Buffers</u> - outside the cell. *(ECF)**

**a) <u>Carbonic Acid- Bicarbonate System</u> - most abundant buffer pair in the ECF & regulator of blood pH; <u>subject to respiratory control</u>.**

$$H_2CO_3 \Leftrightarrow H^{+} + HCO_3^{-}$$

| $H_2CO_3$ | | $HCO_3^-$ |
|---|---|---|
| [ 1.2 mEq/L ] | | [ 24 mEq/L ] |
| Carbonic acid | | Bicarbonate |
| (proton donor) | | functions as a base or |
| | | (proton acceptor) |

**NOTE: strong acids & bases w/ respect to body fluids are not real low pH & real high pH. We are talking about shifts of 0.1 +/-**

**Continue on <u>Extracellular Buffers</u> - outside the cell. *(ECF)**

**b) <u>Plasma</u> (ECF of the blood)- has an abundance of *proteins*. (See proteins above!)**

**<u>Question</u>? How is too much acid [$H^+$] produced in the body?**

**Chief sources of acid produced in the body:**

1. **Lactic acid - waste from *anaerobic metabolism* in skeletal muscle tissue.**
2. **Carbonic acid - $CO_2$ (cellular waste) in the blood combines with $H_2O$ in plasma.**
3. **HCl – "gastric juice" or stomach acid secretions.**
4. **Fatty acids and ketone acids – produced from fat metabolism in the absence of carbohydrates (low carb. diet), or starvation.**
5. **Phosphoric acid – metabolism of cellular proteins, i.e cell parts**

**Sample condition: Respiratory Acidosis;**
**results from an elevated $ppCO_2$ ( $>$ 45 mm Hg) in arterial blood and a blood pH of $<$ 7.35**

**Causes of:**
**1) Inadequate exhalation of $CO_2$ which ↓ blood pH**
**2) Hypoventilation from emphysema, bronchitis (shallow breathing)**
**3) Obstruction of airways, eg. choking.**
**** Any condition that reduces the movement of $CO_2$ from the blood to the lungs → to atmosphere, ie. exhalation**

$$CO_2 + H_2O \xLeftrightarrow{\text{enzymes}} H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$$

**Metabolic Byproduct** (under $CO_2$); **Carbonic acid** (under $H_2CO_3$); **Bicarbonate** (under $HCO_3^-$)

**Le Chatlier's Principle - the equation must be balanced. When the system is in equilibrium and if the equilibrium is disrupted - it will counteract & establish a new equilibrium.**

**Two examples using the above system:**

**1) Hypoventilation - [↑ $CO_2$] ; [↑ $H^+$] ; ↓ pH of blood**

*** With an increase in $CO_2$ due to hypoventilating, the rxn is driven to the right, thus producing excess $H_2CO_3$ (according to Le Chatlier). The $H_2CO_3$ dissociates and $H^+$ is made driving the pH down (acidic). This causes <u>respiratory acidosis</u>. Homeostatic pH is disrupted.**

***<u>Question?</u>***

**What is <u>one compensatory mechanism</u> that can respond to acidosis?**

**→ YES, that's right BUFFER SYSTEMS**

*** With an [↑ $H^+$] the rxn. is driven back to the left to establish a new equilibrium. The blood pH ↑ back to normal because the $H^+$ are bound (tied up) in the $H_2CO_3$ (carbonic acid).**

**<u>NOTE</u>: the carbonic acid is much less acidic with respect to $H^+$**
**(See Figure 27.7, page 1048)**

**** Other Compensatory Mechanism for Respiratory Acidosis -**

**A) an <u>increased</u> <u>excretion</u> of $H^+$ in the urine**

**B) an <u>increased</u> <u>reabsorption</u> (retention) of $HCO_3^-$ in the kidneys**

**C) increased respiratory rate; ventilation becomes rapid, so $CO_2$ is removed quickly, thus a [↓ $CO_2$] ; [↓ $H^+$] ; ↑ pH of blood**

**Sample condition #2:** Respiratory Alkalosis

2) Hyperventilation - [↓ $CO_2$] ; [↓ $H^+$] ; ↑ pH of blood

ie. the reaction is driven to the left in this case.

Respiratory Alkalosis: results from a depressed $ppCO_2$ ( < 35 mm Hg) in arterial blood and a blood pH of > 7.45

Causes of Respiratory Alkalosis:
* High altitudes
* Pulmonary disease, egs. Asthma, pneumonia, stroke
* Anxiety
* Hyperventilation due to any of the above causes, or voluntarily hyperventilating- swimmers were once encouraged to do this in order to hold their breath longer; see C below!)

** Other Compensatory Mechanism for Respiratory Alkalosis -

A) a decreased excretion of $H^+$ in the urine

B) a decreased reabsorption of $HCO_3^-$ in the kidneys.

C) decreased respiratory rate; ventilation becomes slow, so $CO_2$ accumulates, thus [↑ $CO_2$] ; [↑ $H^+$] ; ↓ pH of blood

* Also, have the subject breath into a bag and inhale the $CO_2$

## III. Metabolic Acidosis and Alkalosis:

* Any pH imbalance of ICF/ECF caused by anything other than too much or too little $CO_2$ in the blood, ie. otherwise it would be referred to as respiratory acidosis/alkalosis! (see above)

* Bicarbonate ion conc. [ $HCO_3^-$ ] in the blood above or below the normal range of 22 to 26 mEq/L is indicative of a metabolic acid/base imbalance.

Two sample metabolic conditions using the above equation:

1) Metabolic Acidosis:

[ $HCO_3^-$ ] is < 22 mEq/L; blood pH is < 7.35

**Causes of:**

1. **Severe diarrhea causes an excessive loss of $HCO_3^-$**
2. **Kidney disease; lack of $H^+$ excretion in urine**
3. **Starvation; body breaks down protein & fats which produces acidic byproducts (ketones & fatty acids)**
4. **Excessive alcohol consumption; excess acids in the blood**
5. **Lactic acid accumulation by muscle cells; anaerobic MET.**

**Sample condition #2:**

**2) Metabolic Alkalosis:**

**[ $HCO_3^-$ ] is > 26 mEq/L; blood pH is > 7.45**

**Causes of:**

1. **Vomiting; loss of stomach HCl**
2. **Excessive intake of sodium bicarbonate or antacids (a base)**
3. **Constipation; results in increased amounts of $HCO_3^-$ being reabsorbed.**

**Note: Remember, other compensatory mechanisms are *operating simultaneously* to maintain pH, ie. lungs and kidneys.**

**Extreme cases of acid-base imbalance:**

**1. Acidosis: nervous system becomes depressed → coma → death!**

**2. Alkalosis: nervous system becomes overexcited → muscle tetany (convulsions) → death from respiratory arrest!**