CHAPTER 21: WATER, ELECTROLYTE, AND ACID-BASE BALANCE

OBJECTIVES:

Review from Chapter 2:

1. Define the term inorganic compound and list the major classes of substances in humans that are inorganic.

2. Discuss the characteristics of water.

3. Explain what happens to a salt when it is placed in water and discuss the significance of this event in the human body.

4. Describe what happens to an acid and base when they are placed in water, and discuss the significance of these products in the human body.

5. Illustrate the pH scale, denoting acid, neutral, and basic (alkaline) pH values. Also denote the relationship between \([H^+]\) to \([OH^-]\) at each of the above pH's, and show approximately where on that scale the following substances would fall: acetic acid, distilled water, blood and ammonia.

6. Name the value of physiological pH.

7. Define the term buffer, and explain how the carbonic acid buffering system works in humans.

Chapter 21:

8. Explain what is meant by the terms water balance and electrolyte balance, and discuss the significance of each in human cells.

9. Distinguish between extracellular and intracellular fluid compartments in terms of location, and fluid composition.

10. Explain how fluid moves from one fluid compartment to another.

11. Explain how water enters and leaves the human body and discuss the regulation of this process.

12. Explain how electrolytes enter and leave the human body and discuss the regulation of this process.
13. List the major sources of hydrogen ions in the body.

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OBJECTIVES:

14. Distinguish between strong and weak acids and bases.

15. Compare and contrast the three major acid-base buffering systems that maintain pH in humans.

16. Discuss how the respiratory center is involved in maintaining the acid-base balance.

17. Discuss the important function of the kidneys in maintaining pH homeostasis in the human body.
CHAPTER 21: WATER, ELECTROLYTE, AND ACID-BASE BALANCE

I. Introduction

Throughout this course we have stressed the importance of homeostasis, or the tendency of our body to maintain a “stable internal environment.” Water and electrolytes are also included in this delicate balance or state or equilibrium, whereby their intake must equal their output. In order to maintain stable levels of water and electrolytes, the body must utilize mechanisms that ensure that lost water and electrolytes will be replaced while excreting any excesses.

II. Review from Chapter 2: Chemistry

A. Inorganic compounds are small compounds that do not contain the atoms C and H; The most important ones in humans include carbon dioxide (CO\textsubscript{2}) water, salts, acids & bases.

- CO\textsubscript{2} is a waste product of cellular respiration (discussed further on pages 442 & 443 of this outline)

2. Water is a polar molecule that demonstrates hydrogen bonding and therefore it possesses very unique characteristics.
   a. Water is an excellent solvent (universal?)
      • Many solutes are dissolved in our body's water.
      • Many ionic compounds (i.e. NaCl) dissociate or break apart in water.
   b. Water participates in many chemical reactions.
      • Dehydration (synthesis) is when water is removed from adjacent atoms (of molecules) to form a bond between them.
      • Hydrolysis (degradation) is when water is used to break bonds between molecules.
   c. Water is an excellent temperature buffer.
      • absorbs and releases heat very slowly
   d. Water provides an excellent cooling mechanism.
      • requires a lot of heat to change from a liquid to a gas; high heat of vaporization.
   e. Water serves as a lubricant
      • mucus;
      • internal organs;
      • joints.
   f. Water is the most abundant component in cells.
CHAPTER 21: WATER, ELECTROLYTE, AND ACID-BASE BALANCE

II Review from Chapter 2:

A. Inorganic Compounds

3. Salts: See Fig 2.7, page 45.

a. Salts **dissociate (ionize) into ions** when dissolved in water.
   - an anion is formed and
   - a cation is formed.
   - Example = NaCl in water.

   \[
   \text{H}_2\text{O} \\
   \text{NaCl} \rightarrow \text{Na}^+ + \text{Cl}^-
   \]

b. These ions are referred to as **electrolytes** (charged particles).
   - Electrolytes must be maintained within a very narrow range in our blood and tissues (i.e. homeostasis);
   - Needed for muscle contraction, nerve impulses, etc.;
   - Examples include Na\(^+\), K\(^+\), Cl\(^-\), Ca\(^+\), PO\(_4\)^\(-2\); HCO\(_3\)^\(-\), etc.

4/5. Acids/Bases

a. Acids dissociate (ionize) in water into:
   - a **hydrogen cation**, H\(^+\), and
   - an anion.
   - Example = HCl (hydrochloric acid).

   \[
   \text{H}_2\text{O} \\
   \text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-
   \]

b. Bases dissociate (ionize) in water into:
   - a **hydroxyl anion**, OH\(^-\), and
   - a cation.
   - Example = NaOH (sodium hydroxide).

   \[
   \text{H}_2\text{O} \\
   \text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^-
   \]
II Review from Chapter 2:

A. Inorganic Compounds

4/5. Acids and Bases (continued)

c. pH Scale: See Fig 2.8, page 46.

- The relative concentrations of hydrogen ions and hydroxyl ions determine the pH in our blood, fluids, and tissues;
- pH in body = \([H^+] + [OH^-]\).
- pH = -log\([H^+]\);
- pH Scale ranges from 0 to 14:

\[
\begin{align*}
0 \quad \text{acid} & \quad \text{neutral} & \quad \text{basic} \\
[H^+] > [OH^-] & \quad [H^+] = [OH^-] & \quad [H^+] < [OH^-]
\end{align*}
\]

- Physiologic pH = 7.4

d. Buffering Systems

Definition: Buffers are compounds added to solutions to prevent abrupt change in pH.
- usually weak acids;
- function by donating H\(^+\) when needed and by accepting H\(^+\) when in excess;
- very important in biological systems!
- Example = the carbonic acid (H\(_2\)CO\(_3\)) buffering system.

- when pH is rising
  \[
  \begin{align*}
  \text{H}_2\text{CO}_3 & \quad \text{HCO}_3^- & \quad \text{H}^+ \\
  \text{<-----} & \quad \text{+} & \quad \text{<-----}
  \end{align*}
  \]
  when pH is falling

- carbonic acid bicarbonate ion hydrogen ion
  (H\(^+\) donor) (H\(^+\) acceptor)

- Physiologic pH = 7.4.
1. pH < 7.4 = acidosis; lethal below 7.0;
2. pH > 7.4 = alkalosis; lethal above 7.8.

CHAPTER 21: WATER, ELECTROLYTE, AND ACID-BASE BALANCE

III. Distribution of Body Fluids:

1. **Water** composes the majority of a human’s body weight:
   
   1. Males = 63% water;
   2. Females = 52% water.

2. Two Major Fluid Compartments:

   1. **Intracellular Fluid Compartment (ICF)** = fluid within cells.
      1. comprises about 63% of total water
   2. **Extracellular Fluid Compartment (ECF)** = fluid outside of cells:
      1. in interstitial spaces (interstitial fluid);
      2. in blood vessels (plasma);
      3. in lymphatic vessels (lymph).
      4. comprises about 37% of total water.

See Figures 21.1 and 21.2 on page 815 to better understand the division of these compartments and the fluid in each.

3. **Composition of Body Fluids:** Also see Fig 21.3, page 816.

<table>
<thead>
<tr>
<th>BODY FLUID</th>
<th>EXTRACELLULAR FLUID</th>
<th>INTRACELLULAR FLUID</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Concentration</td>
<td>Na⁺, Cl⁻, HCO₃⁻; plasma contains a high fraction of proteins.</td>
<td>K⁺, PO₄⁻, Mg⁺⁺; SO₃⁻; negatively charged proteins</td>
</tr>
<tr>
<td>Low Concentration</td>
<td>K⁺, Ca⁺⁺, Mg⁺⁺, PO₄⁻, SO₃⁻</td>
<td>Na⁺, Cl⁻, HCO₃⁻</td>
</tr>
</tbody>
</table>

4. **Movement of Water Between Compartments:** See Fig 21.4, page 817.

5. **Hydrostatic pressure and Osmotic pressure** regulate fluid movement.

   6. Hydrostatic Pressure drives fluid out of plasma and drives fluid into lymphatic vessels;
7. Osmotic pressure causes the return of fluid to plasma and regulates movement into and out of cells.

8. Sodium ion concentrations are especially important in fluid movement regulation (i.e. water follows sodium through cell membranes).

CHAPTER 21: WATER, ELECTROLYTE, AND ACID-BASE BALANCE

IV. WATER BALANCE

9. Water intake

10. varies from person to person;
11. Majority comes from consumption of liquid or moist foods:
   See Fig 21.5, page 817.
12. Dehydration synthesis produces some water.


14. The body loses less than 1% of its water.
15. An increase in the osmotic pressure of ECF due to water loss stimulates osmoreceptors in the thirst center (in hypothalamus).
16. Hypothalamic activity triggers thirst and the person seeks water.
17. Drinking fluids distends the stomach whose stretch receptors send nerve impulses that inhibit the thirst center.
18. Water is absorbed into ECF through walls of stomach and small intestine.
19. Osmotic pressure of ECF increases back to normal.

20. Water Output

21. occurs in a variety of ways: See Fig 21.6, page 818.

22. excretion in:
   - urine;
   - feces;
   - skin.

5. evaporation from:
   - skin (sweating);
   - lungs (expiration).
5. Urine production regulates water output through a variety of mechanisms (see below).
CHAPTER 21: WATER, ELECTROLYTE, AND ACID-BASE BALANCE

IV. WATER BALANCE

6. **Regulation of Water Output:** (Review Renin-Angiotensin System in Chapter 20):

   See Table 21.2, page 818.

7.  **In dehydration:**

8. ECF becomes more concentrated (i.e. increase in osmotic pressure).
9. Osmoreceptors in hypothalamus detect this increase in osmotic pressure.
10. Hypothalamus triggers posterior pituitary to release **antidiuretic hormone (ADH).**
11. ADH targets **distal convoluted tubules** and collecting ducts in nephrons to increase their water reabsorption (i.e. back into the blood).
12. Urine output decreases, returning osmotic pressure of ECF to normal.

13. **In water excess:**

14. ECF becomes less concentrated (i.e. decrease in osmotic pressure).
15. Osmoreceptors in hypothalamus detect this decrease.
16. Hypothalamus instructs posterior pituitary to decrease its release of ADH.
17. Renal tubules decrease their water reabsorption.
18. Urine output increases returning osmotic pressure of ECF to normal.


V. ELECTROLYTE BALANCE

Electrolyte balance exists when the intake of electrolytes from various sources equals the output of all electrolytes:

See Figure 21.7, page 819.

1. **Electrolyte Intake**

2. Important electrolytes needed for cellular function (which ones are these?) are primarily obtained from food;
3. Some may be obtained from water and other beverages.
4. Some are byproducts of metabolic reactions.
CHAPTER 21: WATER, ELECTROLYTE, AND ACID-BASE BALANCE

V. ELECTROLYTE BALANCE (continued)

2. Regulation of Electrolyte Intake
3. Electrolytes are usually obtained in sufficient quantities in response to hunger and thirst;
4. “Salt Craving” may occur in severe electrolyte deficiency (rare!).

3. Electrolyte Output
4. Most due to kidney function and urine output (see below);
5. sweating;
6. defecation.

4. Regulation of Electrolyte Output

The kidney plays a major role in maintenance of electrolyte concentrations. Recall calcium homeostasis from Chapter 6, and the renin-angiotensin system discussed in Chapter 20 to name just a few.

5. The concentrations of some positively charged ions are particularly important:
6. Vital for:
   • nerve impulse transmission
   • muscle fiber contraction
   • maintenance of Resting Membrane Potential (RMP).

2. Regulation of $\text{Na}^+$:
   • aldosterone (secreted by what gland?) increases sodium reabsorption in kidney tubules.

3. Regulation of $\text{K}^+$:
   • aldosterone also causes secretion (excretion) of excess $\text{K}^+$ into the urine. See Fig 21.8, page 819.

4. Regulation of $\text{Ca}^{++}$: See Fig 21.9, page 822.
   • calcitonin (what gland?) decreases calcium levels by targeting:
      5. Kidney tubules to secrete excess $\text{Ca}^{++}$ into urine &
      6. Inhibiting osteoclast activity.
   • parathyroid hormone (PTH) by what glands?) increases calcium levels by targeting:
      1. Kidney tubules to reabsorb $\text{Ca}^{++}$ back into blood &
      2. Activating osteoclasts to resorb bone matrix.
VI. ACID-BASE BALANCE

Review pages 4 & 5 of this outline.

-39 **Sources of Hydrogen ions (H⁺):** See Fig 21.10 on page 824.
  -38 **Aerobic respiration of glucose:**
    -37 Carbon dioxide (CO₂) produced reacts with water to form carbonic acid (H₂CO₃);
    -36 H₂CO₃ dissociates releasing H⁺ and bicarbonate (HCO₃⁻) ions.
-35 **Anaerobic respiration of glucose:**
  -34 Lactic acid production.
-33 **Fatty Acid Oxidation:**
  -32 Acidic ketone bodies.

-31 **Strengths of Acids and Bases:**

-30 A strong acid or base will completely dissociate in water:
  -29 Hydrochloric acid;
  -28 Sodium hydroxide.
-27 A weak acid or base does not tend to dissociate:
  -26 Carbonic acid;
  -25 Bicarbonate ions.

-24 **Regulation of Hydrogen Ion Concentration:**

Regulation of hydrogen ion concentration typically involves the elimination of H⁺ by either acid-buffer systems, respiratory excretion of CO₂, or the renal excretion of hydrogen ions.

-23 **Acid-buffer systems**

-22 **Bicarbonate buffer system:** H₂CO₃ <---> H⁺ + HCO₃⁻
  - When pH is rising: H₂CO₃ ----> H⁺ + HCO₃⁻;
  - When pH is falling: H₂CO₃ <---- H⁺ + HCO₃⁻.
2 Phosphate buffer system: $\text{H}_2\text{PO}_4^- \leftrightarrow \text{H}^+ + \text{HPO}_4^{2-}$

- When pH is rising: $\text{H}_2\text{PO}_4^- \rightarrow \text{H}^+ + \text{HPO}_4^{2-}$
- When pH is falling: $\text{H}_2\text{PO}_4^- \leftarrow \text{H}^+ + \text{HPO}_4^{2-}$

CHAPTER 21: WATER, ELECTROLYTE, AND ACID-BASE BALANCE

VI. ACID-BASE BALANCE

3. Regulation of Hydrogen Ion Concentration

4. Acid-buffer systems

2079388147 Protein buffer systems

- involves plasma proteins (i.e. albumin) and certain proteins in cells (i.e. hemoglobin in red blood cells)
- may involve carboxyl end of protein:
- $\text{-COOH} \leftrightarrow \text{COO}^- + \text{H}^+$
- may involve amino end of proteins:
- $\text{-NH}_2 + \text{H}^+ \leftrightarrow \text{NH}_3^+$

See Table 21.3, page 826 to summarize these three buffer systems.

2. Respiratory Excretion of CO$_2$: See Fig 21.11, page 827.

1. Recall from chapter 19 that the respiratory center is located in two specific locations in the brain stem. See Fig 19.27, page 760.

- Rhythmicity area = medulla:
- composed of dorsal respiratory group which controls the basic rhythm of breathing;
- ventral respiratory group which controls forceful breathing.
- Pneumotaxic area = pons:
- controls rate of breathing.

2. Chemical Regulation: See Fig 19.29, page 763.

- Chemoreceptors in carotid & aortic bodies of some arteries
are sensitive to low levels of oxygen & high levels of CO₂;
3. affect chemosensitive areas of respiratory center and breathing rate increases.

- Effector Sites:
  1. diaphragm/intercostals
  2. smooth muscle of terminal bronchioles

CHAPTER 21: WATER, ELECTROLYTE, AND ACID-BASE BALANCE
VI. ACID-BASE BALANCE

3. Regulation of Hydrogen Ion Concentration

4. Respiratory Excretion of CO₂ (continued)

3. In tissues, CO₂ is produced by cellular respiration.
   - This CO₂ combines with H₂O to form H₂CO₃ (Carbonic acid) which then
   - dissociates under the influence of carbonic anhydrase to release
   - H⁺ and bicarbonate ion (HCO₃⁻):
   - CO₂ + H₂O <———> H₂CO₃ <———> H⁺ + HCO₃⁻;
   - HCO₃⁻ is transported in blood back to lungs;
   - Reaction is reversed in lungs & CO₂ is expelled during expiration.


4. The kidney tubules secrete excess hydrogen ions into the urine to regulate pH;
5. Phosphates buffer hydrogen ions in urine;
6. Ammonia produced by renal cells helps transport hydrogen ions to the outside of the body:
   - NH₃ + H⁺ ———> NH₄⁺

1. Chemical Buffers act quickly;
2. Physiological buffers require minutes to several days to begin to resist pH changes.

VII. OTHERS
1. See introduction on page 814 concerning deadly heat waves.
2. Diabetes Insipidus: Box on page 818.
3. Diuretics: Box on page 818.
5. Hyper/Hypocalcemia: Box on page 822.
7. Effect of alkalosis and acidosis on neurons: Box on page 826.