Introduction to Body Fluids

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Page 1: Introduction to Body Fluids

- The fluids in your body are composed of water and dissolved substances, including electrolytes, which are crucial for body function.

Page 2: Goals

- To list the general functions and importance of water and electrolytes in the body
- To identify the fluid compartments and the relative concentrations of electrolytes within those fluid spaces

Page 3. Movement of Fluids Through the Body

- We ingest water and electrolytes through the gastrointestinal or GI tract.
  1. Absorption. These fluids are absorbed into the plasma in the intestine.
  2. Circulation. The fluids circulate within the plasma, bathing the cells in the body.
  3. Excretion. The kidneys remove excess ions and water from the body through the urine, although water is also lost at other sites, which will be described later.

Page 4. Water in Temperature Regulation

Water performs several important functions in the body.

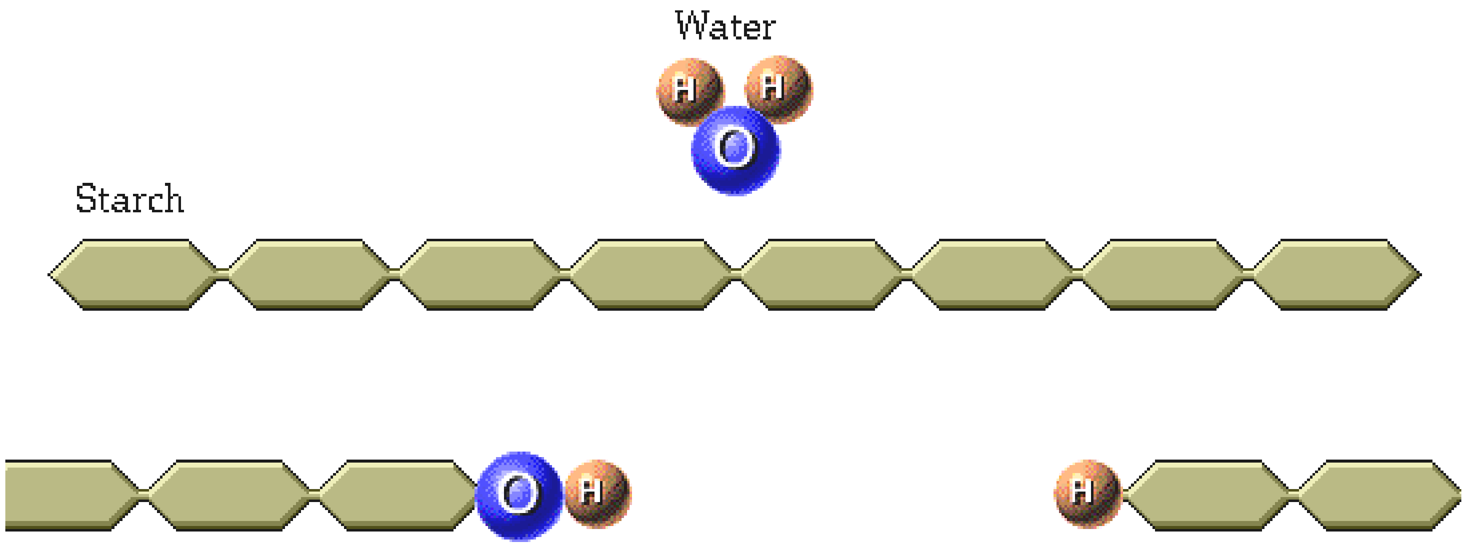
- Water helps maintain body temperature. When water vaporizes off the skin, it takes large quantities of heat with it. This process cools the body temperature down.
- Because water has a high heat capacity it can absorb and release large quantities of heat before significantly changing temperature. Because our bodies are composed of 50-70% water, that large percentage of water holds heat in the body and helps prevent fluctuation in body temperature.

Page 5. Water in Cushioning and Lubricating

- Water acts as a protective cushion in amniotic fluid and cerebrospinal fluid.
- Water acts as a lubricant in the serous fluids, joints, and gastrointestinal tract.

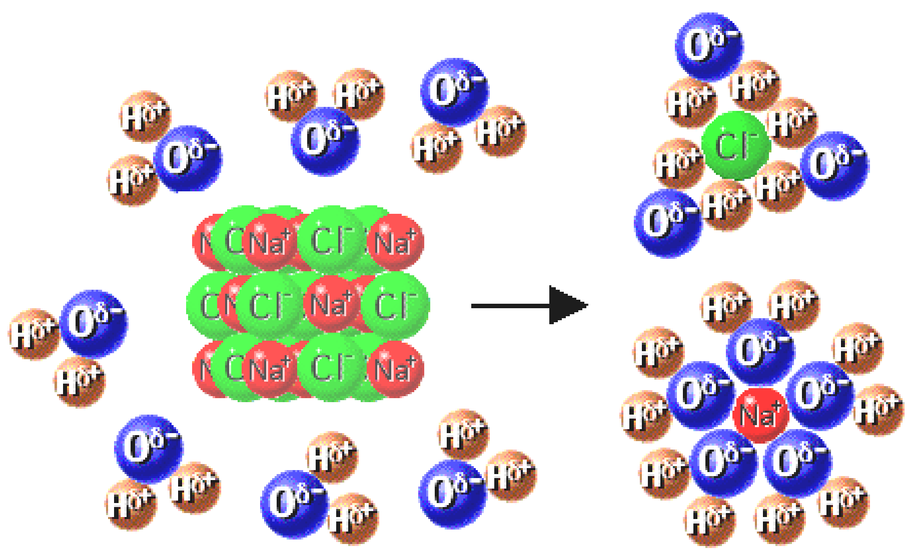
Page 6. Water as a Reactant

- Water is the reactant for hydrolysis reactions that occur in the body.
- With the help of an enzyme, water molecules are added to the bonds between the glucose units in the starch, hydrolyzing the starch to glucose.
- Note that water can also be formed during some chemical reactions in the body, such as the reactions that produce metabolic water.



Page 7. Water as a Solvent

- Water acts as a solvent to dissolve molecules and ions in the body.
- For example, if you eat a salty pretzel, the water in your saliva will dissolve the salt.
- Water is a polar molecule. When water dissolves ions the partial negative charge on the oxygen attracts positive ions such as sodium and the partial positive charge on the hydrogen attracts negative ions such as chloride.
- Except for the salts deposited in bone and teeth, most other ions in the body are dissolved because of water's ability to act as a solvent.
- Water within cells is an important solvent. It dissolves many of the proteins and other solutes.



Page 8. Water in Transport

- We are now looking at a blood vessel. Because of water's ability to dissolve ions and molecules within the body fluids, water functions as a medium for the delivery of nutrients and the removal of wastes from the cells through the plasma.

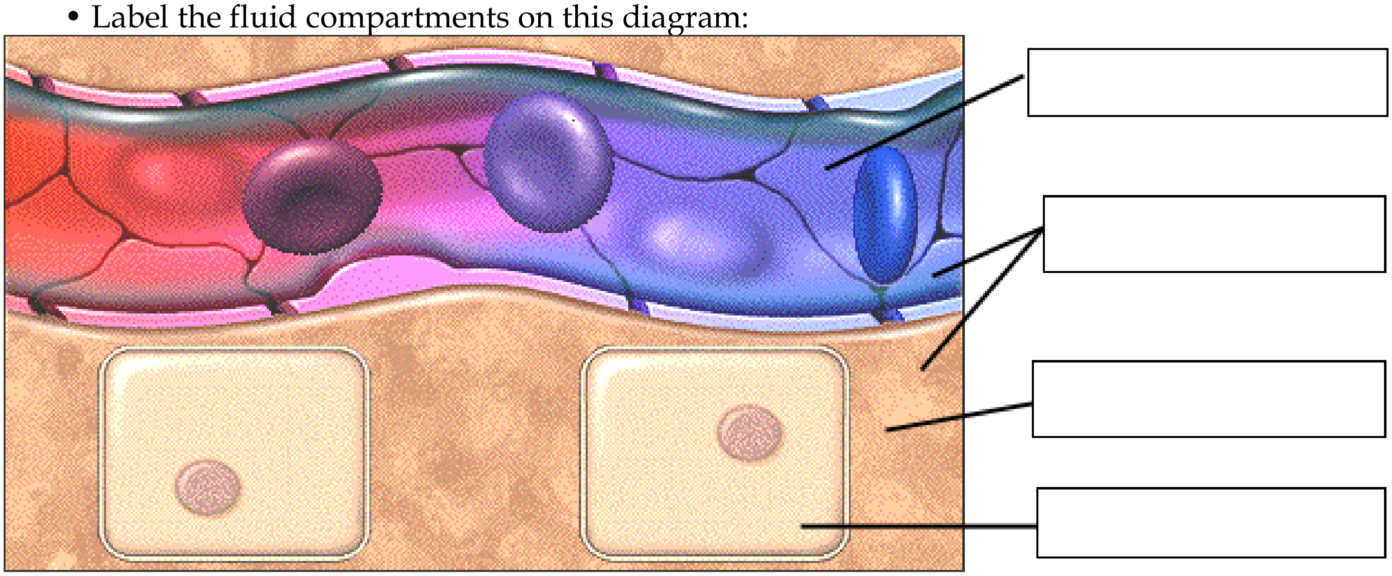
Page 9. Percentage of Water in the Body

- The percentage of water in a person depends on the amount of fat tissue, which is only about 20% water, compared to lean body mass or muscle mass which is about 65% water.

- Newborns have the highest percentage of water in their bodies.
- A healthy young man who is muscular and does not have a lot of fat in his body is about 60% water.
- A healthy young woman naturally has more fat and less muscle than a man and is about 50% water.
- The more fat a person has in his or her body, the less water is present.
- Older people tend to have less lean body mass and therefore contain less water.
- Indicate the percentage of water in the following individuals:

Page 10. Fluid Compartments

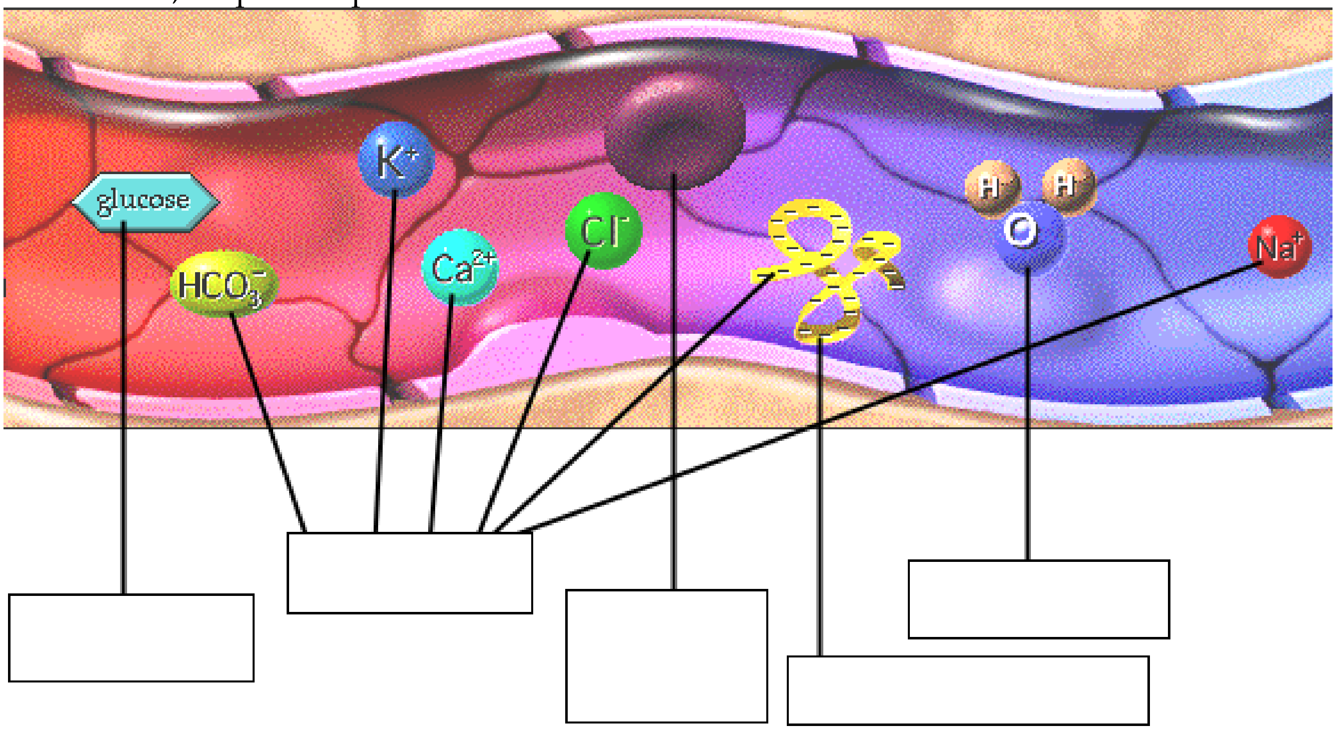
- Water, along with its dissolved solutes, occupies two main compartments within the body.
- Intracellular fluid or ICF is the fluid within cells. It is also known as cytosol.
- Extracellular fluid or ECF is the fluid found outside of cells.
- There are two major kinds of extracellular fluid:
  1. Interstitial fluid is the fluid surrounding the cells.
  2. Plasma is the fluid component of the blood.
- Label the fluid compartments on this diagram:



- Let's consider a 70 kg man. 60% of his weight or approximately 40 liters, is fluid.
  - Approximately 62% of the body's fluid is intracellular.
  - Approximately 30% of the body's fluid is interstitial.
  - Approximately 8% of the body's fluid is blood plasma.

Page 11. Composition of Body Fluids

- Label the components on this diagram as follows: nonelectrolytes, electrolytes, solvent, colloid, suspended particle:



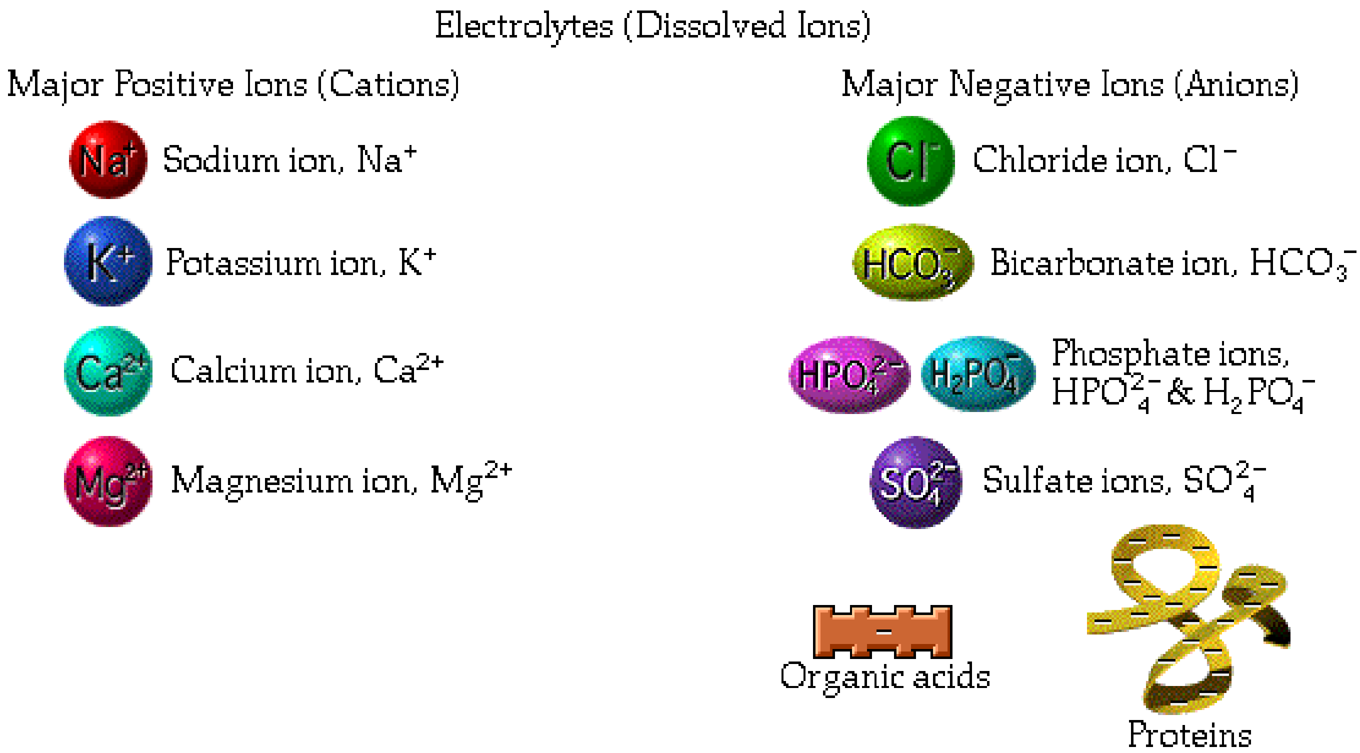
- You are looking at plasma, a typical body fluid.
- The term "body fluid" refers to the water in the body and all of the dissolved substances, which are also known as solutes. Since the water dissolves the solutes, it is the solvent.
- A typical body fluid may contain electrolytes, also known as ions.
- Proteins are considered to be colloids when dispersed in body fluids. Compared to simple ions, proteins are huge molecules. Because they bear a negative charge, we will consider them to be electrolytes.
- Nonelectrolytes are uncharged molecules found in body fluids. Glucose is an example of a nonelectrolyte.
- Blood cells do not dissolve in water. They are suspended particles and are not considered to be a part of the body fluid.

Page 12. Electrolytes

- Electrolytes are charged particles (ions) that are dissolved in body fluids.

Electrolytes (Dissolved Ions)

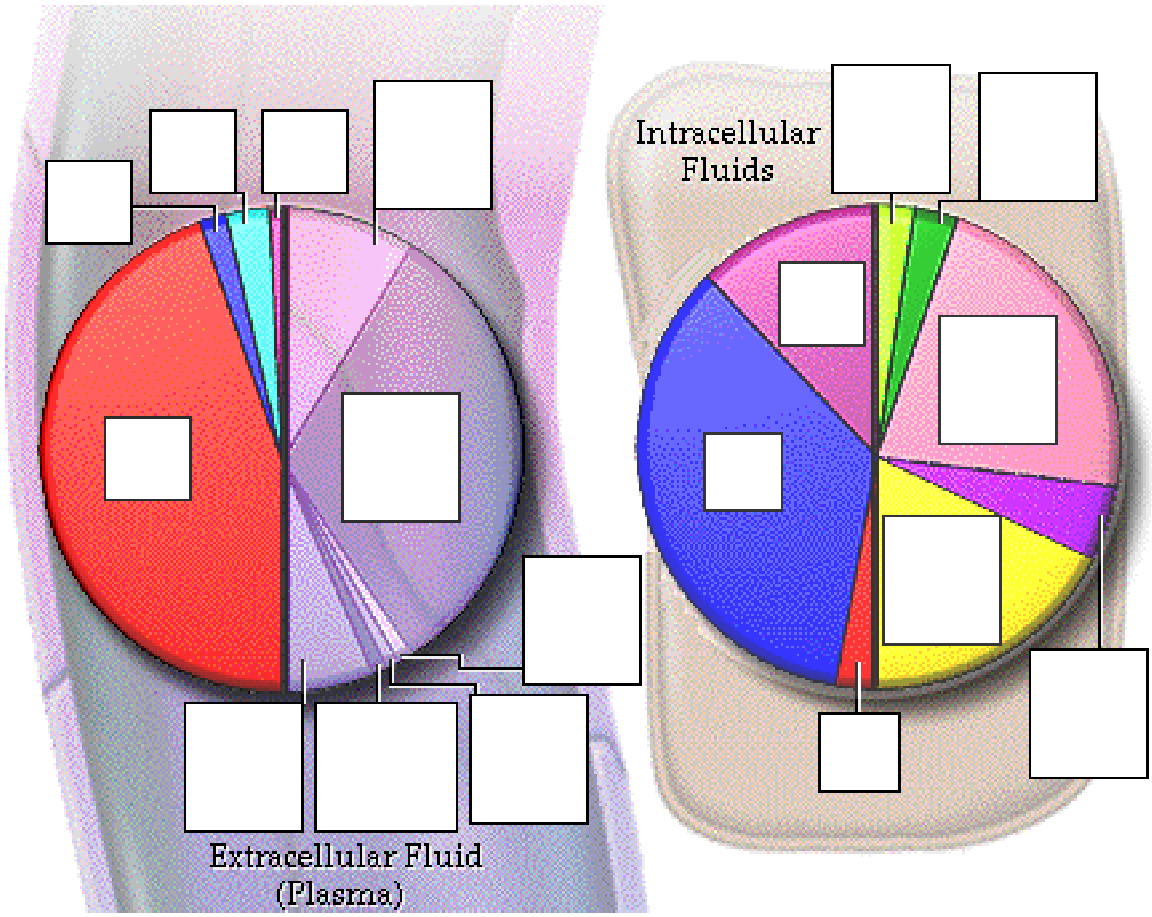
Major Positive Ions: Cations	Major Negative Ions: Anions
Sodium ion, Na^+	Chloride ion, Cl^-
Potassium ion, K^+	Bicarbonate ion, HCO_3^-
Calcium ion, Ca^{2+}	Phosphate ions, $H_2PO_4^-$ & HPO_4^{2-}
Magnesium ion, Mg^{2+}	Sulfate, SO_4^{2-}
	Organic Acids
	Proteins



Page 13. Positive Electrolytes in Body Fluids

- Each fluid compartment needs just the right types and levels of electrolytes for proper functioning of neurons, muscle cells, and other cells in the body.
- The electrolyte composition of extracellular fluids and intracellular fluids have significant differences. Filling in the pie graph will help illustrate these differences.
- Sodium is the major positive ion of the extracellular fluid.
- Extracellular fluid also contains other positive ions: potassium, calcium, and magnesium.
- Potassium is the major positive ion of the intracellular fluid.
- Intracellular fluid also contains other positive ions: sodium, and magnesium.

- Fill in this diagram:



Page 14. Negative Electrolytes in Body Fluids

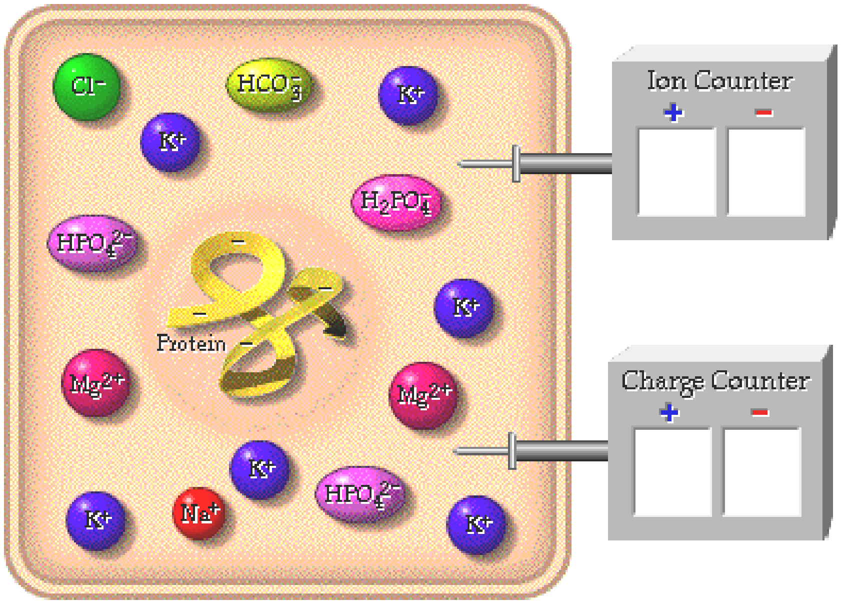
- Chloride is the major extracellular negative ion.
- Other negative electrolytes found in the extracellular fluid are protein, bicarbonate, and sulfate.
- Drag the two major intracellular negative ions to their proper places on the pie chart.
- Other negative ions found in the intracellular fluid are bicarbonate, chloride, organic acids, and sulfate.
- The composition of interstitial fluid is almost identical to that of blood plasma, except for one negative electrolyte - protein.
- To summarize, the major positive ion of the extracellular fluid is sodium and the major negative ion is chloride. The major positive ion of the intracellular fluid is potassium and the major negative ions are protein and phosphates.

Page 15. Balance of Charge

- Count the number of positive and negative ions (particles) in this sample of intracellular fluid. Are the number of positive ions equal to the number of negative ions?
- There are 6 negative ions and 9 positive ions here, so the number of ions are not equal.
- Now count the number of positive and negative charges in this sample of intracellular fluid. Are the number of positive charges equal to the number of negative charges?
- Yes, the laws of chemistry dictate that within a fluid compartment, the total number of positive charges must be equal to the total number of negative charges.
- Even though there are six negative ions and 9 positive ions here, the charges balance.

- Because the individual ions have different charges, there may not be the same number of positive and negative ions within the compartment, however the charge will always balance.

- Fill in this diagram:

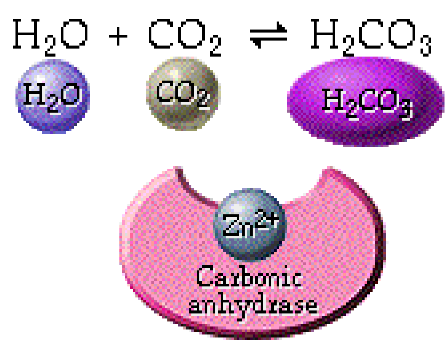


Page 16. Electrolytes as Cofactors

- Now let's look at a few of the many important functions that electrolytes perform in the body.

1. Cofactors.

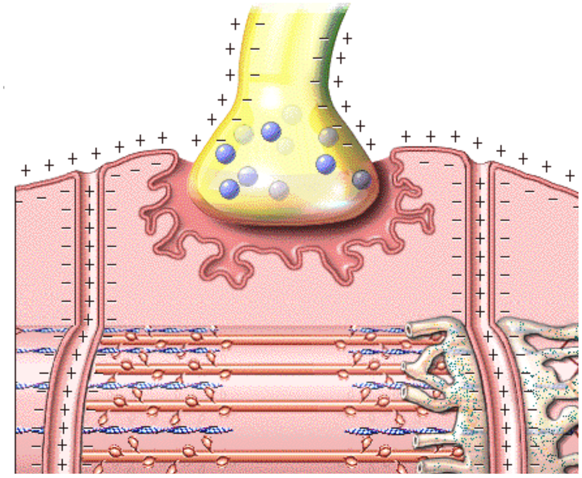
- Electrolytes serve as cofactors for enzymes.
- A very important reaction in the body occurs when carbon dioxide and water form carbonic acid. We can speed up this reaction with the enzyme carbonic anhydrase.
- Cofactors are nonprotein substances that act, along with enzymes, to speed up reactions in the body. Calcium, magnesium, and other cations such as zinc can serve as cofactors for enzymes.
- Zinc is a cofactor for this enzyme. Click on the zinc to add it to the enzyme.
- This enzymatic reaction shown here cannot occur without a zinc ion present.
- Many other enzymes in the body require positive met… cofactors in order to function.



Page 17. Electrolytes in Nerve and Muscle Function

2. Action potentials in neuron and muscle cells.

- Electrolytes in the form of sodium and potassium ions also contribute to membrane potential in all cells and are responsible for action potentials in neuron and muscle cells.



3. Secretion and action of hormones and neurotransmitters.

- Calcium ions are important electrolytes because they are involved in the secretion and action of hormones and neurotransmitters.

4. Muscle contraction.

- Calcium is also involved in muscle contraction, including the heart.

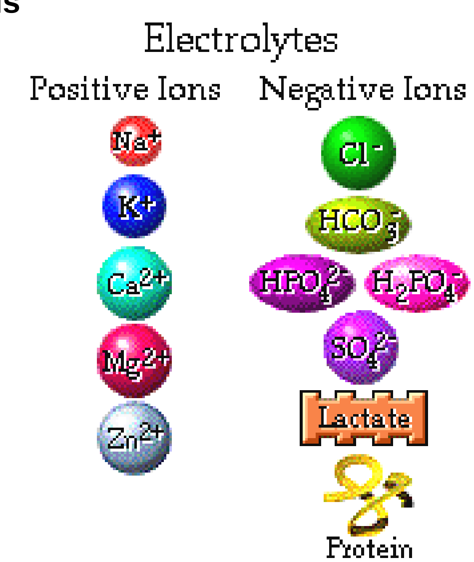
Illustrate these three functions of electrolytes on this d

Page 18. Electrolytes in Acid Balance/Transport/Osmosis

5. Acid/base balance.

- Some electrolytes such as bicarbonate, phosphate, and protein help maintain acid/base balance.

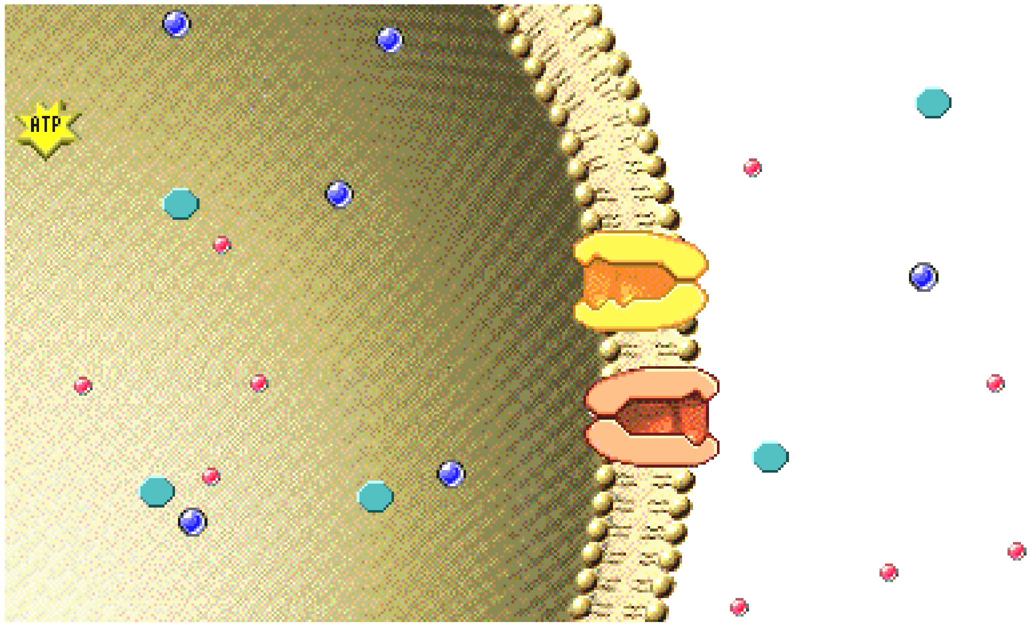
- Circle the electrolytes in this diagram that are involved in acid/base balance.



6. Secondary Active Transport.

- By pumping sodium out the cell, the sodium potassium pump expends ATP to keep the concentration of sodium low inside cells.
- During secondary active transport, some transport proteins will allow sodium to diffuse from high to low concentration and drag with it a molecule or another ion such as glucose seen here from an area of lower to higher concentration. Glucose enters the proximal convoluted tubule cells of the kidney tubules and the intestine by secondary active transport.

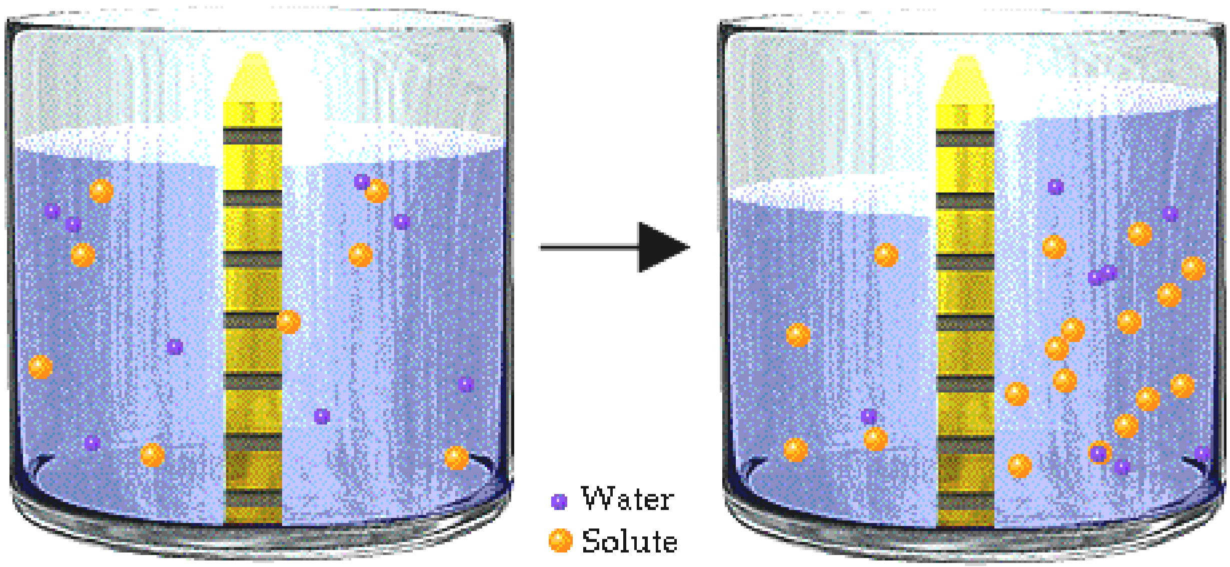
- Illustrate what happens with the sodium/potassium pump and secondary active transport on this diagram:



7. **Osmosis.** Movement of water between body compartments. Finally, electrolytes, including proteins, also play a major role in promoting the movement of water between body compartments or osmosis.

Page 19. Osmosis

- Let's take a closer look at what happens during osmosis. Osmosis is the movement of water across a selectively permeable membrane from the side that has more water, and therefore less solute, to the side that has less water and therefore more solute.
- When there are equal amounts of water particles on either side of the membrane, water moves freely back and forth across the membrane in both directions at the same rate. We say that the two solutions are isotonic, meaning that they have the same total concentration of nonpenetrating solute particles.
- Let's see what happens when more solute particles are added to the left side of the container. Click on the beaker to add more solute to the container.
- Now more solute is present on the left side and that side is hypertonic compared to the right side. Because less solute is present on the right side we say that solution is hypotonic compared to the left side.
- Note that if you increase the concentration of solute you decrease the concentration of water. Water still moves freely across the membrane in both directions. However less water will move from left to right because the higher concentration of water on the right side creates a greater chance for a collision between a water molecule and a channel on the right side. As a result more water will move from the right to the left side of the container.



Page 20. Tonicity

- Note that the level of fluid increases in the left side of the container of this experimental situation.
- In a hypotonic solution, water moves into cells and they expand.
- In a hypertonic solution, water moves out of cells and they shrink or crentate.

Page 21. Osmotic Pressure

- We measure the ability of a solution to cause osmosis in terms of osmotic pressure, which is expressed in millimeters of mercury, a unit of pressure.
- Technically the definition of osmotic pressure is the external pressure applied to the top of the fluid to prevent osmosis from occurring. For the purposes of our discussion we need to remember that the greater the number of solute particles dissolved in solution the higher the osmotic pressure.

Page 22. Osmosis and IV Fluids

- Here we see a patient ready to receive an intravenous solution. Normally patients are given an isotonic IV solution. In this patient the hypotonic and hypotonic IVs are contraindicated. Let's see what happens to the blood cells of this patient when each IV is given.
- If we put a red blood cell in an isotonic solution, what will happen to it?
  ___ It will shrink (crenate).
  ___ It will expand.
  ___ The volume will remain constant.
- The volume will remain constant because the solute concentrations are equal on both sides of the membrane.
- If we put a red blood cell in a hypertonic solution, what will happen to it?
  ___ It will shrink (crenate)
  ___ It will expand
  ___ The volume will remain constant
- The cell will shrink or crenate. There is a net flow of water out of the cell and that causes the cell to shrink. This is why hypertonic IV solutions are only used in specific clinical situations.

- If we put a red blood cell in a hypotonic solution, what will happen to it?
  ___ It will shrink (crenate)
  ___ It will expand
  ___ The volume will remain constant
- The cell will expand. If too much water enters the cell eventually it could undergo hemolysis or break open. This is why hypotonic IV solutions are only used in specific clinical situations.

Page 23. Summary

- Fluids are composed of water and all the substances (solutes) dissolved in the water in the body.
- Most fluids within the body exist in three major compartments: the intracellular compartment, the plasma, and the interstitial compartment. The interstitial compartment and the plasma constitute the extracellular compartments.
- Within a solution, positive and negative charges must balance regardless of the number of ions present.
- The concentrations of dissolved ions, or electrolytes in the intracellular compartment are very different than the concentrations of electrolytes that in the extracellular compartment.
- Both water and electrolytes have many important functions in the body.
- Osmosis is the movement of water across a membrane from the side that has more water to the side that has less water.

Notes on Quiz Questions:

Quiz Question #1: Functions of Water

- This question allows you to view clips of animations and then determine the function of water.

Quiz Question #2: Percentage of Fluids

- This question has you predict the approximate percentage of fluid in each of the major fluid spaces.

Quiz Question #3: Definition of Terms

- This question allows you do define cation, anion, colloid, suspended particle, and nonelectrolyte.

Quiz Question #4: Location of Electrolytes

- This question allows you to place the electrolytes in the appropriate compartments.

Quiz Question #5: Components of Plasma

- This question allows you to identify the components of plasma.

Quiz Question #6: Functions of Electrolytes

- This question allows you to view clips of animations and then determine the functions of electrolytes.

Quiz Question #7: Blood Cells

- This question asks you which blood cell is telling the truth.

Study Questions on Introduction to Body Fluids:

1. (Page 3.) What three processes are involved in water balance?

2. (Page 4.) What are two roles of water in temperature regulation?

3. (Page 5.) Give two examples of how water can have a cushioning effect?

4. (Page 5.) Give two examples of how water can have a lubricating effect?

5. (Page 6.) Explain how water can be a reactant in chemical reactions that occur in the body.

6. (Page 6.) Explain how water can be a product in chemical reactions that occur in the body.

7. (Page 7.) Explain why water is a polar molecule.

8. (Page 7.) Ions can be solid or dissolved. Give some examples of solid ions in the body.

9. (Page 7.) Show how water molecules surround sodium and chloride ions.

10. (Page 8.) What role does water play in transport.

11. (Page 8.) List the functions of water in the body.

12. (Page 9.) What is the relationship between the amount of fat in the body and the percentage of water in the body?

13. (Page 9.) Who tend to have more water in their bodies? a. men or woman b. a lean woman or a heavier woman c. a baby or an adult

14. (Page 10.) Label the fluid compartments on the diagram on page 10.

15. (Page 10.) Match the size of the fluid compartment to the percentage of fluid in that compartment.

62%	plasma
30%	intracellular
8%	interstitial

16. (Page 11.) Label the diagram on page 11.

17. (Page 12.) List the name and charge of four positive ions found in the body fluids.

18. (Page 12.) List the name and charge of six negative ions found in the body fluids.

19. (Page 13.) What is the most important positive ion of the extracellular fluid?

20. (Page 13.) What is the most important positive ion of the intracellular fluid?

21. (Page 14.) What is the most important negative ion of the extracellular fluid?

22. (Page 14.) What are the most important negative ions of the intracellular fluid?

23. (Page 14.) What negative ion is present in the plasma, but not in the interstitial fluid?

24. (Page 15.) Are the number of positive ions in a body solution equal to the number of negative ions in a body fluid?

25. (Page 15.) Are the number of positive chargers equal to the number of negative charges in a body fluid?

26. (Page 16-18.) List several different functions of electrolytes in the body.

27. (Page 18.) When electrolytes act as cofactors for enzymes. can the enzymes perform it's function without the cofactor?

28. (Page 19.) What is osmosis?

29. (Page 19.) What is the driving force for osmosis?

30. (Page 19.) What is a hypotonic solution? What is a hypertonic solution?

31. (Page 20, 22.) What happens to red blood cells when they are placed in a hypertonic solution?

32. (Page 20, 22.) What happens to red blood cells when they are placed in a hypotonic solution?

33. (Page 21.) What is osmotic pressure?

Water Homeostasis

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1. Water Homeostasis

- The body maintains a balance of water intake and output by a series of negative feedback loops involving the endocrine system and autonomic nervous system.

2. Goals

- To examine dehydration and hypovolemia
- To examine the role the kidneys play in regulating water homeostasis
- To understand how neural and endocrine mechanisms work to maintain water homeostasis via negative feedback mechanisms
- To examine the role thirst plays in regulating water homeostasis

3. How Water Enters and Leaves the Body

- The average adult body contains about 40 liters of water. This amount, called total body water, remains fairly constant under normal circumstances.

4. Water Tank Analogy

- On this page, the gain and loss of fluid in the human body will be represented by the gain and loss of fluid in the tank below.
- Every day we take in about 2300 milliliters of water in the form of food and beverages.
- Approximately 200 milliliters of body water is generated through cell metabolism for an approximate 2500 milliliters of total intake.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6\,H_2O + CO_2$$

- At the same time, we lose water, mostly through the kidneys, but also through the lungs, skin, and GI tract.
- We lose approximately 1500 milliliters per day from the kidneys in the form of urine.
- We also lose about 600 milliliters of water per day through the skin and 300 milliliters from the lungs in the form of water vapor in exhaled air. These two forms of water loss are called insensible loss because we are unaware of the process.
- We can lose much more than this insensible loss under conditions of extreme physical exertion. Under such conditions we can lose up to 5000 milliliters per day, through sweating.
- Under normal circumstances we also lose 100 milliliters of water per day though the GI tract.
- As you can see, maintaining water homeostasis is a balancing act. The amount of water taken in must equal the amount of water lost.
- Fill out this chart:

Water Intake		Water Output	
• Food and drink:		• Kidneys:	
• Cell metabolism:		• Skin:	
		• Lungs:	
		• GI tract:	
• Total:		**• Total:**	

*Now is a good time to go to quiz question 1:
- Click the Quiz button on the left side of the screen.
- Work through all parts of question 1.
- After answering question 1, click on the Back to Topic button on the left side of the screen.
- To get back to where you left off, click on the scrolling page list at the top of the screen.
- Choose "5. Disturbances of Water Homeostasis."

5. Disturbances of Water Homeostasis

Disturbances of water homeostasis:
- Gain or loss of extracellular fluid volume
- Gain or loss of solute

In many instances disturbances of water homeostasis involve imbalances of both volume and solutes. We will discuss four specific examples of water homeostasis:
- Hypervolemia
- Overhydration
- Hypovolemia
- Dehydration

Fill out this chart:

	Water and Solute	Water Only
Gain		
Loss		

6. Hypervolemia

- Hypervolemia occurs when too much water and solute are taken in at the same time. Although extracellular fluid volume increases, plasma osmolarity may remain normal.

- Show what happens when hypervolemia occurs:

7. Overhydration

- Overhydration occurs when too much water is taken in without solute. Volume increases, but because solute is not present, plasma osmolarity decreases.

- Show what happens when overhydration occurs:

8. Hypovolemia

- Hypovolemia occurs when water and solutes are lost at the same time. This condition primarily involves a loss of plasma volume. Plasma osmolarity usually remains normal even though volume is low.

- Show what happens when hypovolemia occurs:

9. Dehydration

- When water, but not solute, is lost, dehydration occurs.
- Dehydration involves a loss of volume but, because solutes are not lost in the same proportion, plasma osmolarity increases.
- Show what happens when dehydration occurs:

10. Disturbances of Water Homeostasis Exercise

- Here are four examples of conditions that disturb water homeostasis. Drag each one into its correct location in the table.

Blood loss

Infusion of isotonic intravenous fluid

Sweating

Drinking too much water

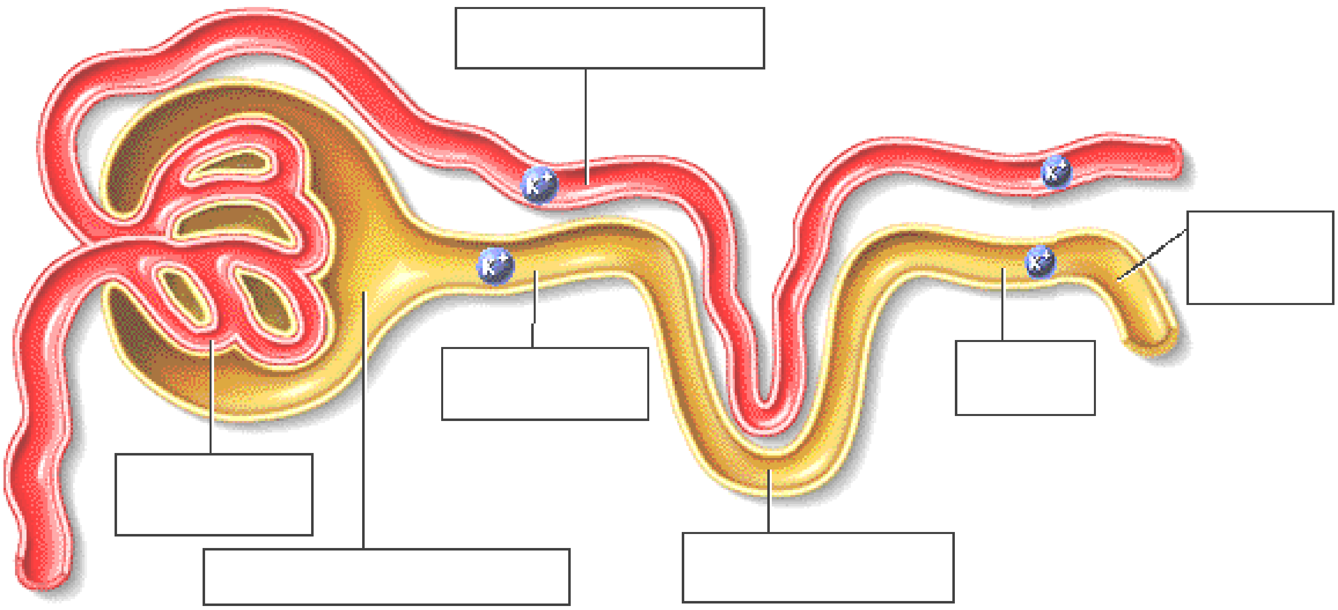
	Water and Solute	Water Only
Gain	Hypervolemia	Overhydration
Loss	Hypovolemia	Dehydration

- Blood loss involves a loss of water and solutes resulting in hypovolemia.
- Although sweating causes the loss of some solute through the skin, much more water is lost, and the person becomes dehydrated.
- Too much IV fluids can increase plasma volume dramatically, but with an isotonic solution the plasma osmolarity would remain normal and result in hypervolemia.
- Drinking too much water would dilute the plasma and the osmolarity would decrease resulting in overhydration.

11. The Kidney: Filtration

- The major way that we regulate water loss from the body is through the kidneys. Before we continue let's quickly review how the nephron of the kidney works.
- The kidneys are composed of millions of microscopic structures called nephrons, where urine is formed.

- Blood vessels wrap around the nephron allowing exchanges between the plasma and the filtrate, or forming urine.
- Label this diagram:



- Let's review the three steps involved in urine formation:
  ____ Reabsorption
  ____ Secretion
  ____ Glomerular filtration.
- What is the first step in urine formation?
- During glomerular filtration, small solutes and water will move from the plasma in the glomerular capillaries into the glomerular capsule, beginning the process of urine formation.

12. The Kidney: Reabsorption

- Drag the potassium ion in the direction it would move if it was reabsorbed into the plasma in the diagram above.
- Reabsorption occurs along the renal tubules and involves the selective uptake of specific substances back into the blood. Water follows via osmosis.

13. The Kidney: Secretion

- Drag the potassium ion in the direction it would move if it was secreted in the diagram above.
- Certain substances are secreted from the blood back into filtrate. Note that there is normally more reabsorption than secretion.
- Urine is formed at the end of the renal tubules.

14. Mechanisms of Fluid Balance

- Our bodies have mechanisms that regulate fluid levels within a narrow range. In this topic we will explore how the body's fluids remain within certain physiological limits, an important aspect of homeostasis.
- Four primary mechanisms regulate fluid homeostasis:
  Antidiuretic hormone or ADH
  Thirst mechanism
  Aldosterone

Sympathetic nervous system

- Three of these mechanisms involve the kidneys.
- Let's look at a marathon runner to see how fluid balance is maintained. Notice that the runner is sweating. If he continues to lose water and, to a lesser extent, salts, he may become dehydrated.

15. Effect of ADH

- When the runner loses water by sweating, his plasma becomes more concentrated in solutes.
- Osmoreceptors in the hypothalamus detect the increased osmolarity or concentration of solutes in the plasma.
- In response to this increased concentration, antidiuretic hormone is released into the blood at the posterior pituitary.
- The targets for ADH are the collecting duct cells in the kidney.

16. ADH in the Nephron

- These cells become permeable to water only in the presence of ADH.
- ADH promotes the addition of water channels into the cells of collecting duct, allowing water to move from the filtrate to the plasma by way of osmosis.
- ADH therefore increases the reabsorption of water.

17. ADH Exercises

- What effect would ADH have on the concentration of the plasma?
  ___ Plasma becomes more concentrated.
  ___ Plasma becomes more dilute.
- Because more water is reabsorbed, the plasma becomes more dilute.
- The greater amount of water in the plasma reduces the plasma concentration of solutes and increases the volume of the plasma, somewhat.
- What effect does antidiuretic hormone have on the volume and osmolarity of urine produced?
  ___ ADH reduces the volume of urine and increases the osmolarity of the urine.
  ___ ADH increases the volume and decreases the osmolarity of the urine.
- Because more water is reabsorbed, there is less urine and that urine has an increased osmolarity.
- All of the effects of antidiuretic hormone help to prevent further fluid loss. ADH will probably still be secreted until the runner drinks enough fluid to dilute the plasma. After drinking fluids, the plasma osmolarity decreases to normal, returning the secretion of antidiuretic hormone to baseline levels, completing the negative feedback loop.

*Now is a good time to go to quiz questions 2-3:

- Click the Quiz button on the left side of the screen.
- Work through all parts of questions 2-3.
- After answering question 3, click on the Back to Topic button on the left side of the screen.
- To get back to where you left off, click on the scrolling page list at the top of the screen.
- Choose "18. Thirst Mechanism."

18. Thirst Mechanism

- The thirst mechanism is the primary regulator of water intake and involves hormonal and neural input as well as voluntary behaviors.
- There are three major reasons why dehydration leads to thirst:

1. When saliva production decreases, the mouth and throat become dry. Impulses go from the dry mouth and throat to the thirst center in the hypothalamus, stimulating that area.
2. When you are dehydrated, blood osmotic pressure increases, stimulating osmoreceptors in the hypothalamus and the thirst center in the hypothalamus is now further activated.
3. Decreased blood volume causes a decrease in blood pressure that is signaled by baroreceptors and stimulates the release of renin from the kidney. This causes the production of angiotensin II which stimulates the thirst center in the hypothalamus.

- Stimulation of the thirst center in the hypothalamus gives you the desire to drink.

19. Results of Fluid Ingestion

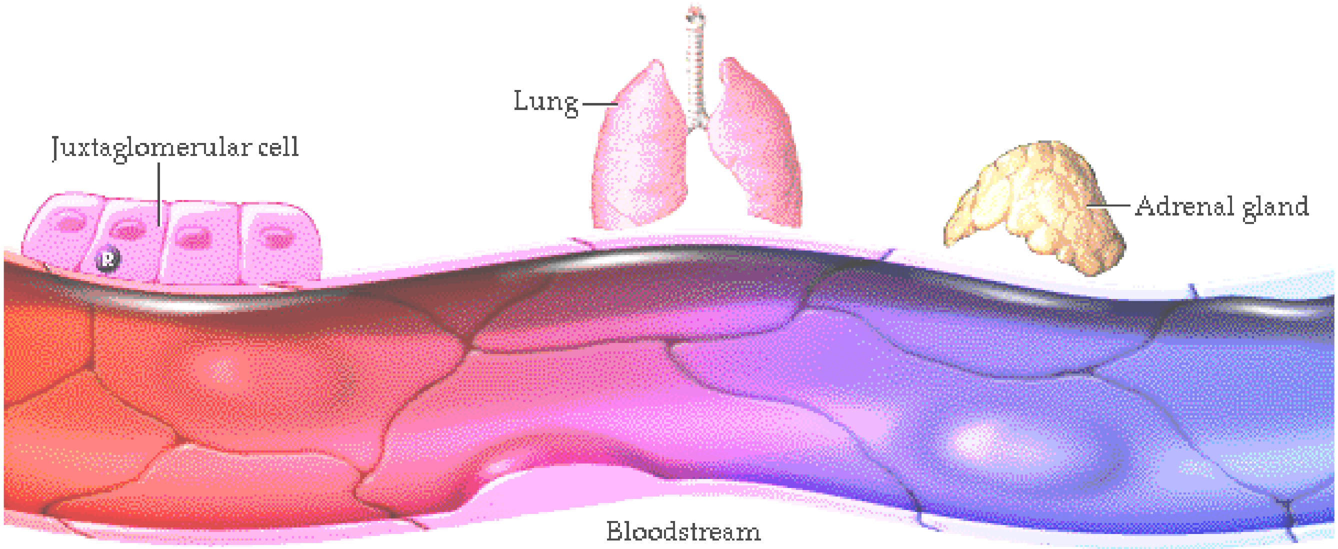
- This fluid ingestion:
  1. Relieves the dryness in the mouth and throat.
  2. Fluid ingestion also stimulates stretch receptors in the stomach and intestine to send inhibitory signals to the thirst center.
  3. When normal fluid osmolarity and volume is restored, dehydration is relieved, and the thirst center is no longer stimulated.

20. Effect of Aldosterone

- When a person donates large amounts of blood, they lose salts as well as water. When electrolytes and water are lost at the same time, blood volume decreases, threatening hypovolemia.
- When blood volume is lost, what happens to the blood pressure?
  __ blood pressure increases
  __ blood pressure decreases
- When a person experiences blood loss, blood pressure decreases.
- Because a hypovolemic person experiences a decrease in blood pressure, granular cells in the arterioles of the kidney release renin.

21. Renin to Aldosterone

- As renin travels through the bloodstream, it binds to an inactive plasma protein, angiotensinogen, activating it into angiotensin I.
- As angiotensin I passes through the lung and other capillaries, an enzyme called Angiotensin Converting Enzyme, or ACE, converts angiotensin I to angiotensin II.
- Angiotensin II continues through the blood stream until it reaches the adrenal gland. Here it stimulates the cells of the adrenal cortex to release the hormone aldosterone.
- Angiotensin II also has a vasoconstriction effect that helps to increase the blood pressure.
- On this diagram show how the steps in the formation of aldosterone:



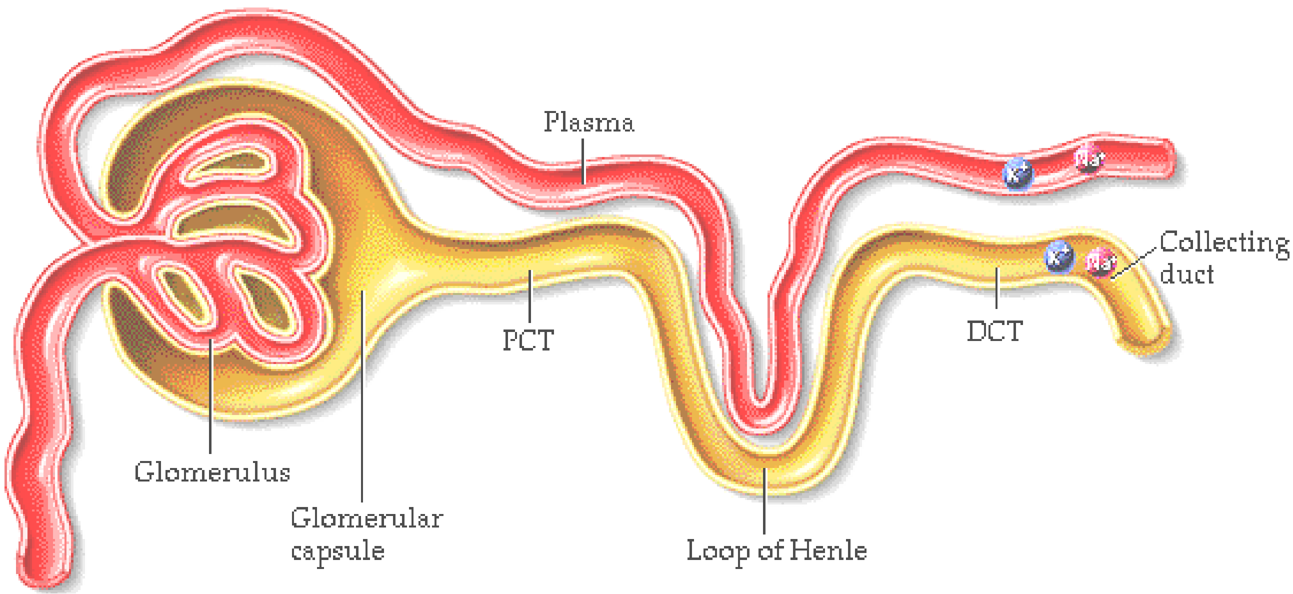
- Aldosterone can also be released when potassium concentrations in the blood are high.

22. Aldosterone in the Nephron

- In the absence of aldosterone, the cells in the distal convoluted tubule and collecting ducts allow little sodium and potassium ions to pass because there are few sodium and potassium channels in the cell membrane facing the kidney tubule. There are also few sodium-potassium ATPase pumps on the basal side of these cells.
- Aldosterone exerts its effect by inserting additional channels in the distal convoluted tubule and collecting duct of the kidney. This allows more sodium to move from the filtrate into the blood and potassium to move from the blood into the filtrate.

23. Aldosterone Exercises

- Drag the sodium in the direction it will move if aldosterone is present.
  - In the presence of aldosterone, sodium moves from the filtrate to the plasma.
- Drag the potassium in the direction it will move if aldosterone is present.
  - In the presence of aldosterone, potassium moves from the plasma to the filtrate.
- If antidiuretic hormone is also present, water will follow the sodium into the plasma by osmosis.
- This movement of water and sodium into the blood causes the blood pressure to increase, completing the negative feedback loop.
- Show the movement of sodium and potassium ions on this diagram:



24. Results of Aldosterones Action

- The net result of aldosterones action is the reabsorption of sodium and the secretion of potassium.
- If ADH is also present, water is reabsorbed into the blood at the kidney, preventing further water loss from the body. As a result, blood volume and blood pressure are stabilized until water is consumed.

25. Sympathetic Stimulation

- A decrease in blood volume and therefore blood pressure will further stimulate the sympathetic nervous system.
- When blood pressure is low, baroreceptors in the heart, aortic arch, and carotid arteries send sensory information to the medulla.
- The information sent from the baroreceptors to the medulla will cause an increase in the sympathetic impulses to the kidney.

26. Sympathetic Stimulation in the Nephron

- Release of neurotransmitters from the sympathetic nerves in the kidney stimulates smooth muscle cells in the afferent arteriole to constrict.
- This process causes a decrease in blood flow into the glomerulus and a drop in glomerular filtration rate and results in less urine formation. Less water leaves the body.
- Sympathetic stimulation also causes the release of renin which, by stimulating aldosterone secretion, will increase the reabsorption of sodium.
- As a result, blood volume will stop decreasing and blood pressure may stabilize. However because the blood pressure and blood volume have not yet returned to normal, the baroreceptors will continue to be stimulated to prevent further loss of blood volume.
- In order to bring this person back into to homeostasis, we need to increase the blood volume by drinking fluids. In fact after an individual has given blood, they are encouraged to drink juice to increase their plasma level.

27. Summary

- To maintain homeostasis, water intake must equal water output.

- There are many categories of water and solute imbalances. We use the term overhydration to describe an excess of water only. Hypervolemia involves an excess of both water and solute.
- Dehydration is the loss of water from the body, without significant loss of solute. Hypovolemia is a loss of both water and solute. A person may exhibit more than one type of imbalance at the same time.
- Water balance is maintained within a narrow range by negative feedback loops involving the hormones ADH and aldosterone as well as the thirst mechanism and the sympathetic nervous system.

*Now is a good time to go to quiz questions 4-6:
- Click the Quiz button on the left side of the screen.
- Work through all parts of questions 4-6.

Notes on Quiz Questions:

Quiz Question #1: Water Enters and Leaves

- This question has you predict how water enters and leaves the body.

Quiz Question #2: Dehydration

- This question has you predict the affects of dehydration.

Quiz Question #3: Antidiuretic Hormone

- This question has you list the sequence of events in the secretion and action of ADH.

Quiz Question #4: Thirst

- This question allows you to answer questions about thirst.

Quiz Question #5: Aldosterone

- This question allows you to predict the sequence of events that occur when an individual is experiencing blood loss.

Quiz Question #6: Diabetes Insipidus

- This question allows you to predict what happens when an individual has diabetes insipidus.

Study Questions on Water Homeostasis:

1. (Page 3.) About how many liters of water are there in the average adult? What is this water called?

2. (Page 4.) What are the two ways that water enters the body?

3. (Page 4.) Explain where the water from cell metabolism is derived from?

4. (Page 4.) What are the four ways that water leaves the body?

5. (Page 4.) What is insensible water loss?

6. (Page 4.) Fill out the diagram on page 4.

7. (Page 4.) Why is maintaining water homeostasis a balancing act?

8. (Page 5.) What are two ways we can develop imbalances in water homeostasis?

9. (Pages 6-9.) Explain the problem in each of the situations below:
   a. Hypervolemia
   b. Overhydration
   c. Hypovolemia
   d. Dehydration

10. (Page 5-9.) Fill out the chart on page 5.

11. (Page 6-9.) On the diagrams on page 6-9, indicate the level of water and solute in each of these cases:
   a. Hypervolemia
   b. Overhydration
   c. Hypovolemia
   d. Dehydration

12. (Page 10.) Classify the following as problems associated with either hypervolemia, overhydration, hypovolemia, or dehydration.
   a. Blood loss
   b. Infusion of isotonic intravenous fluid
   c. Sweating
   d. Drinking too much water

13. (Page 11.) Label the diagram on page 11.

14. (Page 11.) Describe the first step in urine formation?

15. (Page 12, 13.) Describe the other two steps in urine formation?

16. (Page 14.) What are the four primary mechanisms regulate fluid homeostasis?

17. (Page 15.) Why would sweating cause the secretion of antidiuretic hormone?

18. (Page 15.) What the target cells for antidiuretic hormone?

19. (Page 16.) What is the affect of antidiuretic hormone on the cells of the late distal convoluted tubule and collecting duct cells in the kidney?

20. (Page 17.) What effect would ADH have on the concentration of the plasma?

21. (Page 17.) What effect does antidiuretic hormone have on the volume and osmolarity of urine produced?

22. (Page 17.) When will the secretion of ADH stop?

23. (Page 18.) Where is the thirst center located?

24. (Page 18.) List the three major reasons why dehydration leads to thirst.

25. (Page 19.) How does fluid ingestion relieve thirst?

26. (Page 20.) When blood volume is lost, what happens to the blood pressure?

27. (Page 20.) When there is a decrease in blood pressure, what happens in the juxtaglomerular cells in the arterioles of the kidney ?

28. (Page 21.) Starting with renin, list the steps in the secretion of aldosterone.

29. (Page 21.) On the diagram on page 21, show how the steps in the formation of aldosterone.

30. (Page 21.) How does angiotensin II help to increase the blood pressure?

31. (Page 21.) What else, besides renin/angiotensin, will cause the release of aldosterone?

32. (Page 22.) What is the effect of aldosterone?

33. (Page 23.) In the presence of aldosterone, show the movement of both sodium and potassium ions on the diagram on page 23.

34. (Page 23.) In the presence of aldosterone, if ADH is also present, which way will water move: from Blood to filtrate or from filtrate to blood?

35. (Page 24.) What is the net result of aldosterone in terms of reabsorption and secretion?

36. (Page 25, 26.) List the steps in the sympathetic secretion of renin.

Electrolyte Homeostasis

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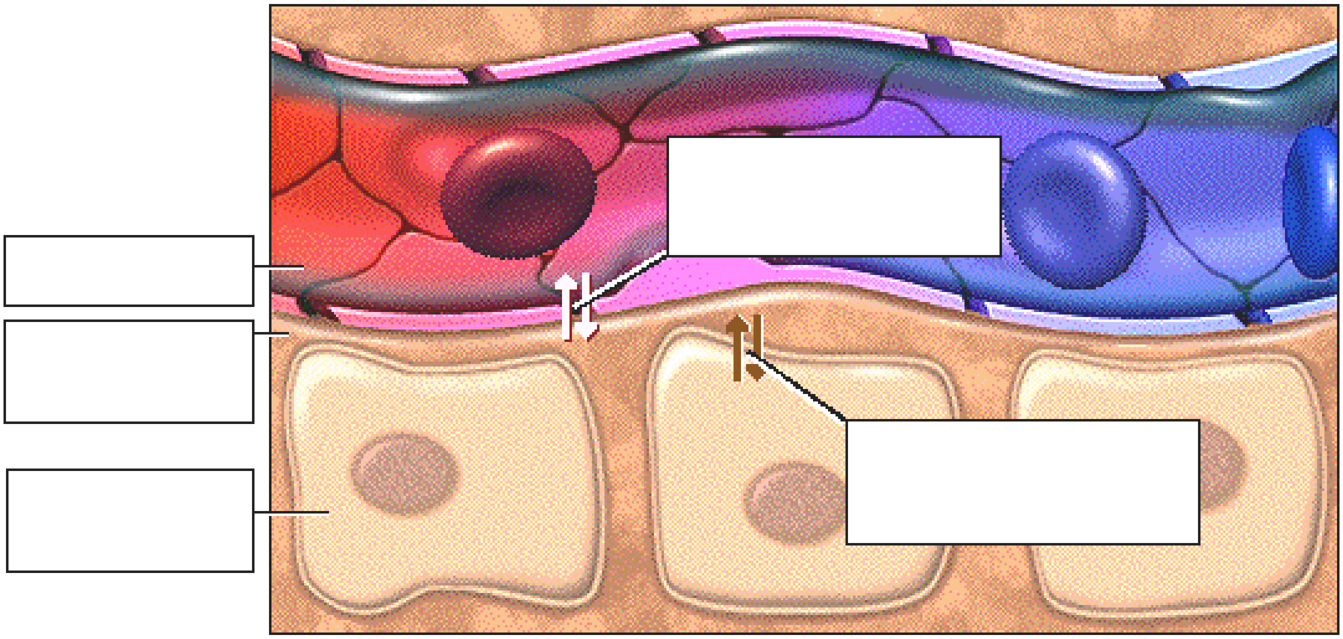
1. **Electrolyte Homeostasis**
   - The fluid surrounding the cells in the body must maintain a specific concentration of electrolytes for the cells to function properly. Let's look more closely at how electrolyte homeostasis is maintained in the body.

2. **Goals**
   - To recognize that electrolytes must be maintained in a narrow concentration range in order for cells of the body to function properly
   - To examine in general how electrolyte composition of the fluid compartments are maintained
   - To learn the importance of sodium, potassium, and calcium homeostasis
   - To learn the consequences of disturbances of sodium, potassium, and calcium homeostasis
   - To examine how fluid movement is regulated in the body

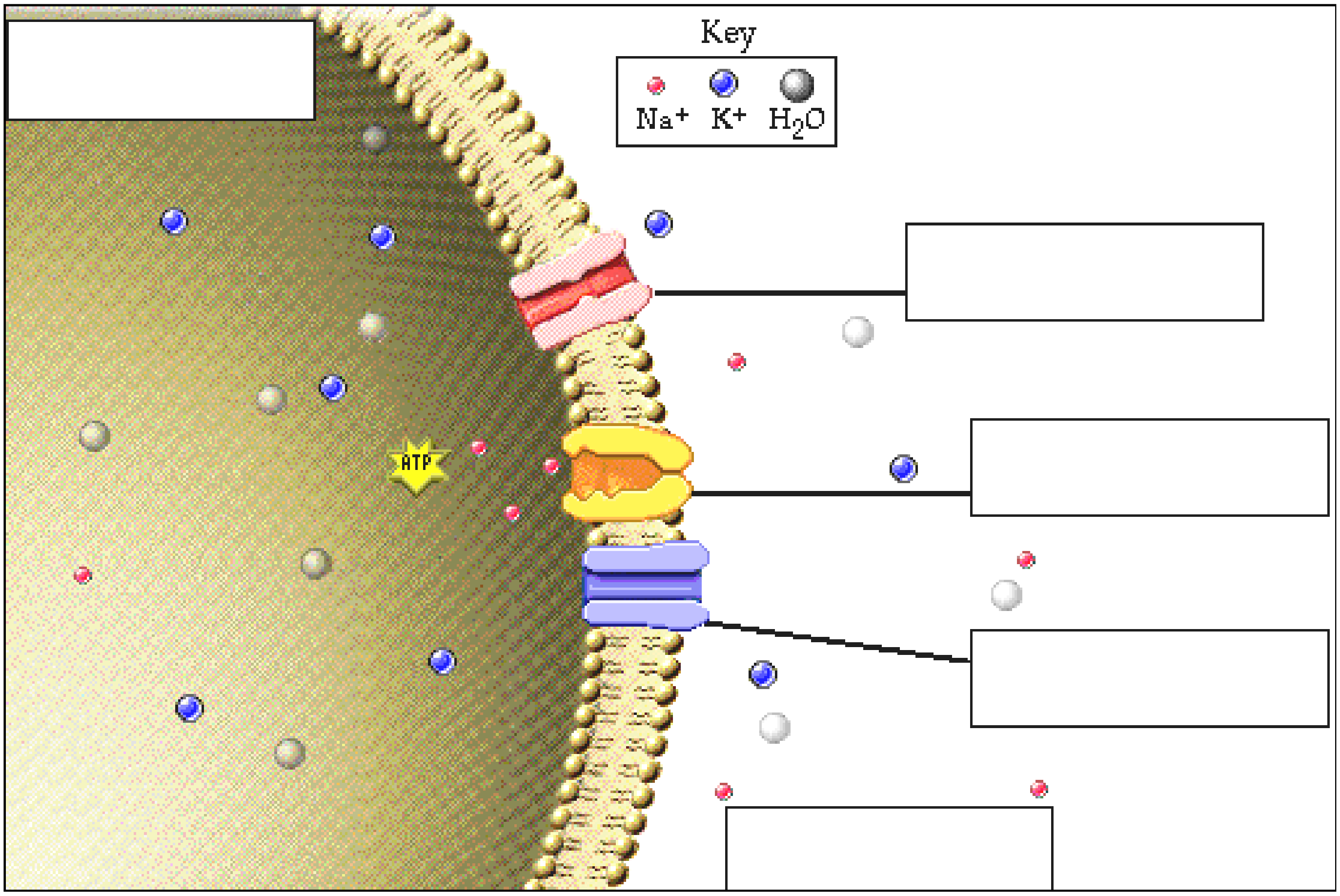
3. **Electrolyte Balance**
   - Electrolytes are a major component of body fluids. They enter the body in the food we eat and the beverages we drink.
   - While electrolytes leave the body mainly through the kidneys by way of the urine, they also leave through the skin and feces.
   - Severe vomiting and diarrhea can cause a loss of both water and electrolytes from the body, resulting in both water and electrolyte imbalances.
   - The concentrations of electrolytes in body fluids must be maintained within specific limits, and even a small deviation outside these limits can have serious or life-threatening consequences.
   - In this topic we will concentrate on the three most clinically significant electrolytes sodium ions, potassium ions, and calcium ions.

4. **Fluid Movement Across the Cell Membrane**
   - One of the important functions of electrolytes, particularly sodium, is to control fluid movement between fluid compartments.
   - The movement of fluid across the cell membrane differs from the movement of fluid between the interstitial compartment and plasma.
   - Label this diagram:



5. Fluid Movement: Sodium/Potassium Ion Pump

- The cell membrane acts as a barrier to separate intracellular and interstitial fluid compartments.
- Electrolytes move across the cell membrane through channels and ion pumps that are selective for specific ions.
- The sodium/potassium ion pump to see the actively transports sodium and potassium.
- Ion pumps in the membrane help move ions against their concentration gradient from an area of lower concentration to an area of higher concentration. These pumps require an input of energy in the form of ATP.
- Label the diagram below and show the direction of movement of sodium and potassium ions through the sodium/potassium pump.



6. Fluid Movement: Sodium Ion Channel

- Channels specific for sodium ions allow these ions to diffuse from areas of higher to areas of lower concentration. Since most cells have few sodium channels, not many sodium ions move across the membrane.
- Show the direction of sodium ion movement through the channel on the diagram above.

7. Fluid Movement: Potassium Ion Channel

- The channels specific for potassium ions allow these ions to move across the membrane from areas of higher to areas of lower concentration.
- Differences in ion concentration between intracellular and interstitial fluids are caused by these selective ion channels and ion pumps in the cell membrane.
- These differences make the membrane potential possible and they facilitate a number of important physiological processes.
- Show the direction of potassium ion movement through the channel on the diagram above.

8. Fluid Movement: Water

- We have seen how ions move across the cell membrane, now let's show water movement across the membrane. The cell membrane is freely permeable to water, which moves from the area of higher water concentration to lower water concentration.
- When there is a higher concentration of solute in the interstitial fluid, which way will water move?
- Water will move from the inside to the outside of the cell.

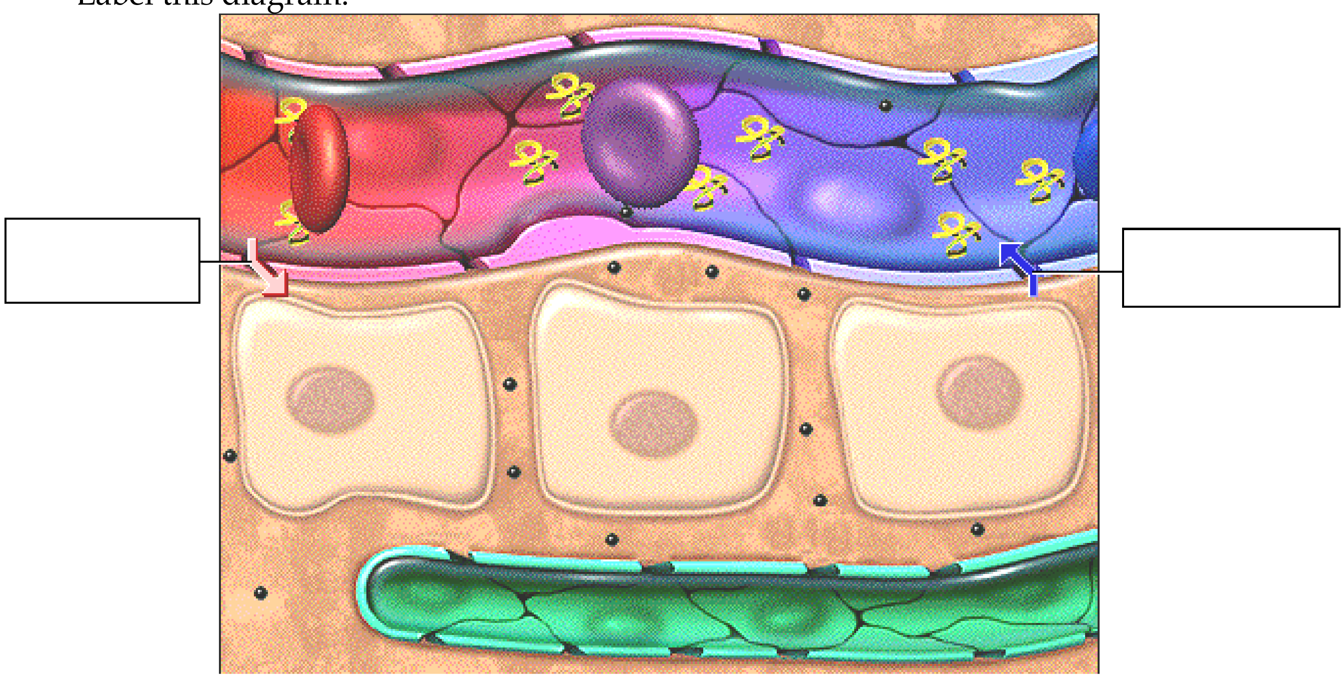
- Through osmosis, water moves to the side of the membrane with the higher solute concentration or the lower water concentration. You can see how sodium exerts a significant osmotic effect on water and therefore effects its movement.
- Show the direction of water movement on the diagram on the previous page.

9. Fluid Movement Between Interstitial Fluid and Plasma

- We've seen how water moves between the intracellular and interstitial fluid compartments.
- Fluid movement between the interstitial compartment and plasma is quite different from the movement between the interstitial compartment and intracellular compartment.
- Click on the endothelial cell to see how fluids move between plasma and interstitial fluid.
- Ions, other small solutes, and water can move freely between the plasma and the interstitial fluid through gaps between endothelial cells.
- In most cases, proteins are too big to leave the blood capillaries.
- Proteins that do escape from the blood capillaries are removed by the lymph capillaries and are moved back into the plasma by way of the lymph.
- Because the protein concentration in the interstitial fluid is low compared to the concentration in the plasma, the protein in the plasma exerts an osmotic effect called the colloid osmotic pressure.

10. Fluid Movement Exercise

- Plasma proteins exert an osmotic effect and water will move from the interstitial fluid into the plasma.
- At the same time, capillary hydrostatic pressure, the blood pressure in the capillaries, forces fluid out of the capillary and into the interstitial space.
- Fluid will move from the blood to the interstitial fluid.
- Label this diagram:



11. Bulk Flow

- The osmotic effect of the protein and the hydrostatic pressure oppose each other. At the arterial end of a capillary bed the hydrostatic pressure is typically stronger than the osmotic effect of the protein, and forces fluid, along with nutrients, into the interstitial fluid space.

- At the venous end of a capillary bed, the osmotic effect of the protein is greater than the hydrostatic pressure, and there is a net movement of fluid containing carbon dioxide and wastes into the plasma.
- This exchange of fluids between the interstitial space and plasma is called bulk flow. The net result of bulk flow is fluid movement out of the capillary at the arterial end and into the capillary at the venous end. This process allows for nutrient/waste exchange.
- Now let's consider what will happen if the sodium concentration of the plasma increases. What would happen to the concentration of sodium ions in the interstitial fluid?
  ___ Increase
  ___ Decrease
- Sodium would move into the interstitial fluid, followed by water.
- What effect would an increase in sodium concentration have on the cells that are bathed by the interstitial fluid?
- The cells will shrink. The high concentration of sodium and other small solutes in the extracellular fluid exerts significant osmotic pressure on cells and contributes to determining the fluid levels in the intracellular compartment.

12. Edema

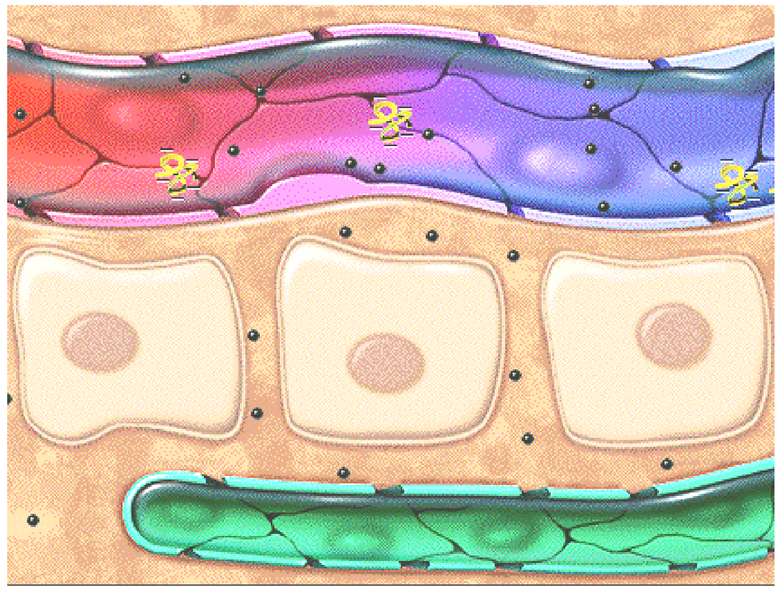
- Edema is an accumulation of fluid in the interstitial compartment, and can occur either locally, in a specific area of the body, or generally, throughout the body.
- Although edema first appears to be a disturbance of water levels in the body, in many cases it occurs as a result of electrolyte imbalance. A lack of plasma protein commonly causes edema.
- Let's look at four causes of edema:
  Decreased capillary colloid osmotic pressure
  Increased capillary hydrostatic pressure
  Increased capillary permeability
  Lymphatic obstruction

13. Edema: Decreased OP_c

- Albumin is a protein made in the liver and secreted into the plasma. Like other proteins, it has an abundance of negative charge.
- Proteins exert an osmotic effect on plasma which, as you remember, is called capillary colloid osmotic pressure. Through this osmotic effect, albumin and other plasma proteins help maintain blood volume by pulling water into the plasma.
- In the presence of liver disease, the synthesis of plasma proteins, including albumin, decreases.
- What will happen to capillary colloid osmotic pressure?
  ____ Colloid osmotic pressure decreases
  ____ Colloid osmotic pressure increases
- The colloid osmotic pressure will decrease because there is less protein.
- In which direction will water move?
  ____ Into the interstitial fluid
  ____ Into the plasma
- Because protein synthesis is decreased, plasma colloid osmotic pressure decreases. While fluid moves out of the plasma into the interstitial compartment, less fluid moves into the plasma from the interstitial compartment, resulting in fluid accumulation in the interstitial compartment.

- What do you think will happen to the blood pressure?
  ____ Blood pressure increases
  ____ Blood pressure decreases
- Generalized edema is significant because blood volume can drop dramatically along with blood pressure. In addition, increased fluid volume in the interstitial compartment impinges on the capillaries, restricting blood flow.

- Explain the defect that occurs when edema occurs due to decreased colloid osmotic pressure.



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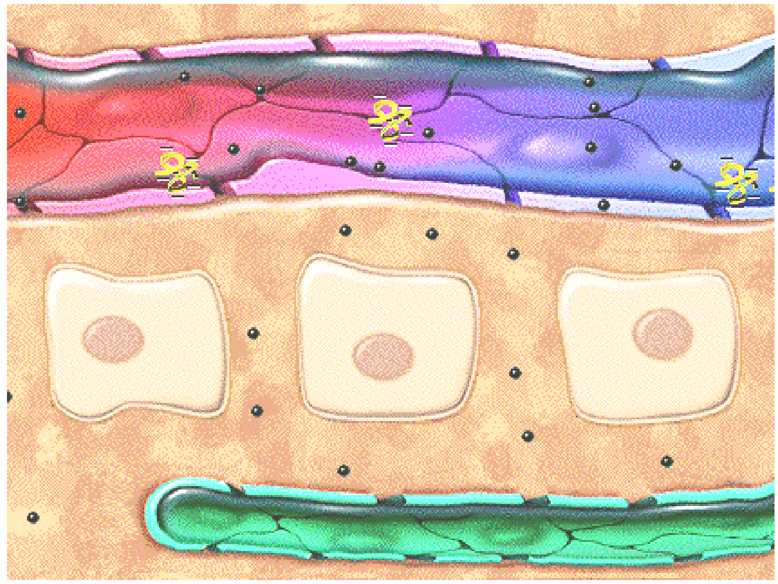
14. Edema: Increased HP_c

- Edema can also occur as a result of increased hydrostatic pressure.
- For example, in congestive heart failure, the heart is unable to pump all of the blood returned to it. Blood backs up in the veins, causing an increase in capillary hydrostatic pressure.

- Explain the defect that occurs when edema occurs due to increased hydrostatic pressure.



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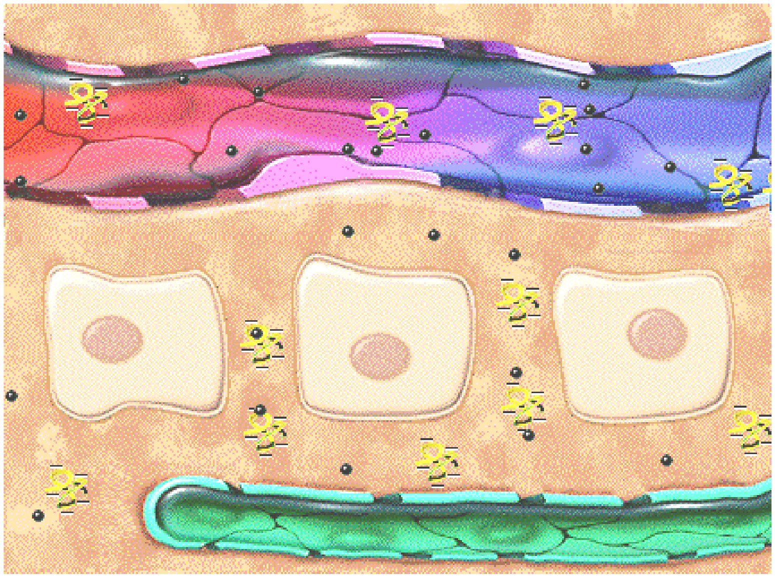
15. Edema: Increased Capillary Permeability

- Local edema can occur as a result of injury or inflammation, such as the swelling that occurs with a sprained ankle.
- In this case, capillaries become more permeable in the area of injury and proteins move more freely into the interstitial compartment.
- What do you think happens to fluid movement now?
  ____ Fluid moves into plasma
  ____ Fluid moves into interstitial fluid
- The protein movement creates an osmotic effect that pulls more fluid into the interstitial compartment.
- When the localized inflammation ends, fluid and proteins move through the lymph back to the plasma and the capillary bed returns to 'normal'.

- Explain the defect that occurs when edema occurs due to increased capillary permeability.



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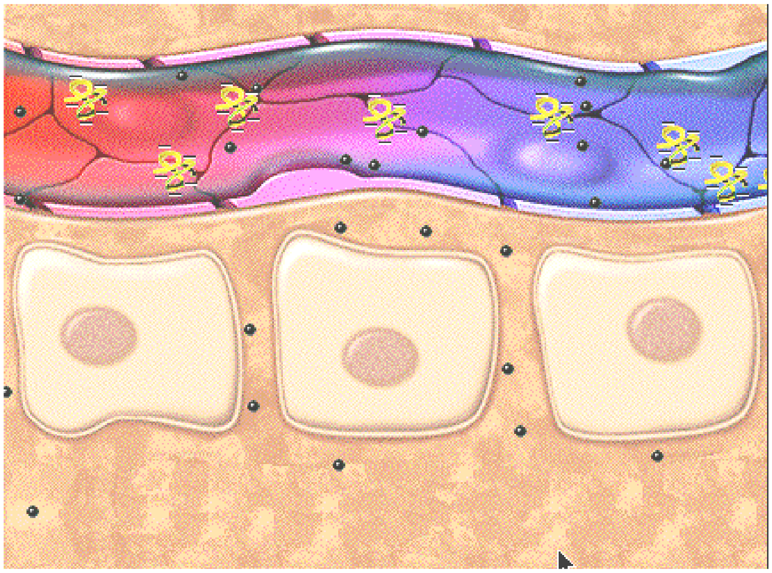
16. Edema: Lymphatic Obstruction

- Obstruction of the lymphatic capillaries, which can occur with surgical removal of lymph nodes, hinders the return of interstitial fluid to the venous capillary.
- The interstitial fluid is trapped in the interstitial compartment. This type of edema is significant because the increased interstitial fluid volume impinges on capillaries and hinders blood flow.
- Explain the defect that occurs when edema occurs due to lymphatic obstruction.



____________________________________ ________

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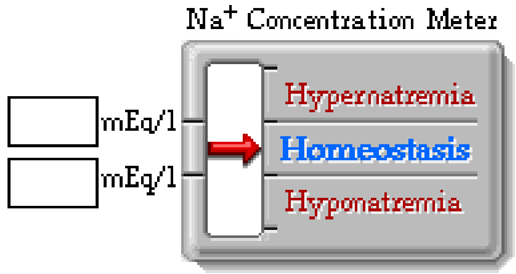
17. Sodium Homeostasis

- The normal concentration range of sodium in the plasma is 136 - 145 milliequivalents per liter, making sodium the ion with the most significant osmotic effect in the extracellular fluid.
- Fill in the blanks below:



18. Hypernatremia

- Now let's consider what will happen if the sodium concentration of the blood plasma increases, as in hypernatremia.
- What effect would this increase in sodium concentration have on the cells that are bathed by the interstitial fluid?
  ___ Cells swell
  ___ Cells shrink
- The high concentration of sodium in the extracellular fluid exerts osmotic pressure and helps determine the fluid levels in the intracellular space.

19. Hyponatremia

- What effect would this decrease in sodium concentration have on the cells that are bathed by the interstitial fluid?
  ___ Cells swell
  ___ Cells shrink
- The water moves into the cell, and the cell expands slightly.

20. Roles of Sodium in the Body

- In addition to playing a pivotal role in nerve impulse conduction and muscle contraction, as the major extracellular positive ion, sodium is the primary regulator of water movement in the body because water follows sodium by osmosis.
- If sodium levels in the plasma change, those changes determine fluid levels in the other compartments.

21. Causes and Symptoms of Hypernatremia

- You have learned that the normal plasma sodium level is 136 to 145 milliequivalents per liter. Hypernatremia occurs when the plasma sodium level is greater than 145 milliequivalents per liter. You have seen what happens to cells when the sodium concentration rises too high.
- Let's use the marathon runner to see the effect of hypernatremia on the body. The plasma sodium concentration may increase for two reasons:
  1. Too much water is lost from the blood without a corresponding loss of sodium.
  2. Too much sodium is added to the blood without adding more water.
- Which of these reasons would most likely cause hypernatremia in the marathon runner?
  ____ Too much sodium added
  ____ Too much water lost
- Although the runner would lose sodium, he would lose far more water from sweating. Plasma sodium concentration rises resulting in hypernatremia.

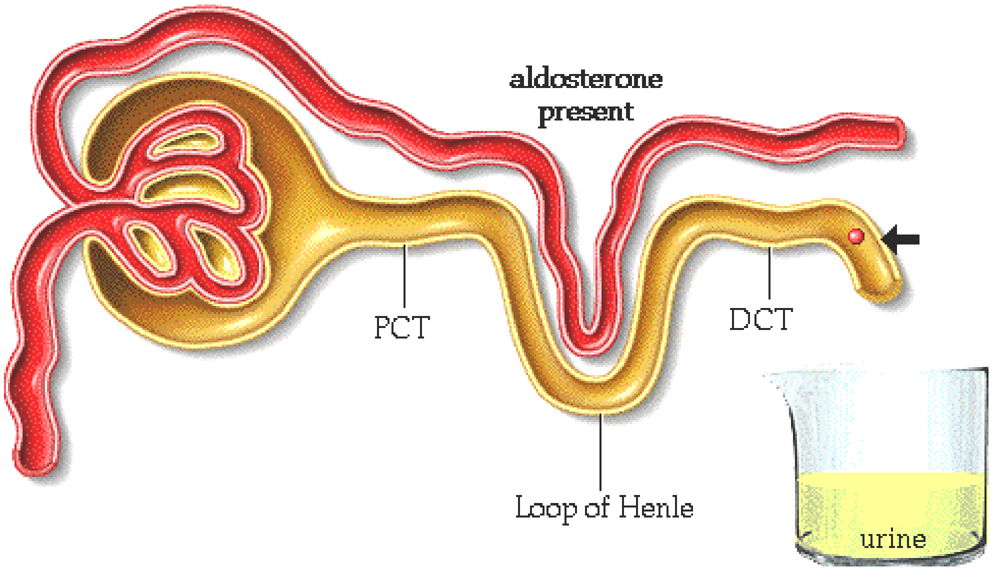
- Notice that the runner appears to be confused and disoriented. Symptoms of hypernatremia include non-specific signs of central nervous system dysfunction such as confusion and lethargy, and in severe cases, seizures and death.
- What do you think causes these symptoms?
  ___ Neurons shrink
  ___ Neurons swell
- Because the osmolarity of the extracellular fluid is higher than that of the intracellular fluid, water will be drawn out of cells, including neurons, to balance the concentration.
- From your knowledge of water homeostasis, see if you can determine what symptoms the runner will exhibit.
- What will happen to thirst?
  ___ Thirst increases
  ___ Thirst decreases
- The high plasma sodium will trigger the thirst mechanism prompting the runner to drink more.
- What will happen to urine output?
  ___ Increase
  ___ Decreases
- When plasma osmolarity increases, antidiuretic hormone is released, resulting in reabsorption of water and decreased urine output.
- Remember that water movement is greatly influenced by sodium. Many of the symptoms our runner would experience are also a result of dehydration.

22. Urinary Regulation of Sodium

- One of the functions of the kidney is to fine-tune the concentration of sodium in the plasma.
- Sodium is filtered at the glomerulus. The higher the glomerular filtration rate, the more sodium is filtered out of the plasma.
- Normally 85-90% of that sodium is reabsorbed into the plasma at the proximal convoluted tubule and loop of Henle.

23. Effect of Aldosterone on Sodium

- In the absence of aldosterone, the remaining sodium will remain in the filtrate and end up in the urine.
- In the presence of aldosterone, the remaining sodium will get reabsorbed at the distal convoluted tubule and collecting duct.
- If aldosterone is present, drag the sodium ion to its proper location, urine or plasma.



- When aldosterone is present, sodium is reabsorbed into the plasma.
- Note that although sodium can be reabsorbed in the distal convoluted tubule and collecting duct, it is never secreted.
- Would high or low blood pressure cause the secretion of aldosterone?
  ___ high blood pressure
  ___ low blood pressure
- When blood pressure is low, renin is secreted, causing the formation of Angiotensin I. Angiotensin I then promotes the formation of Angiotensin II which stimulates the release of aldosterone.

24. Effect of ADH and Aldosterone on Sodium

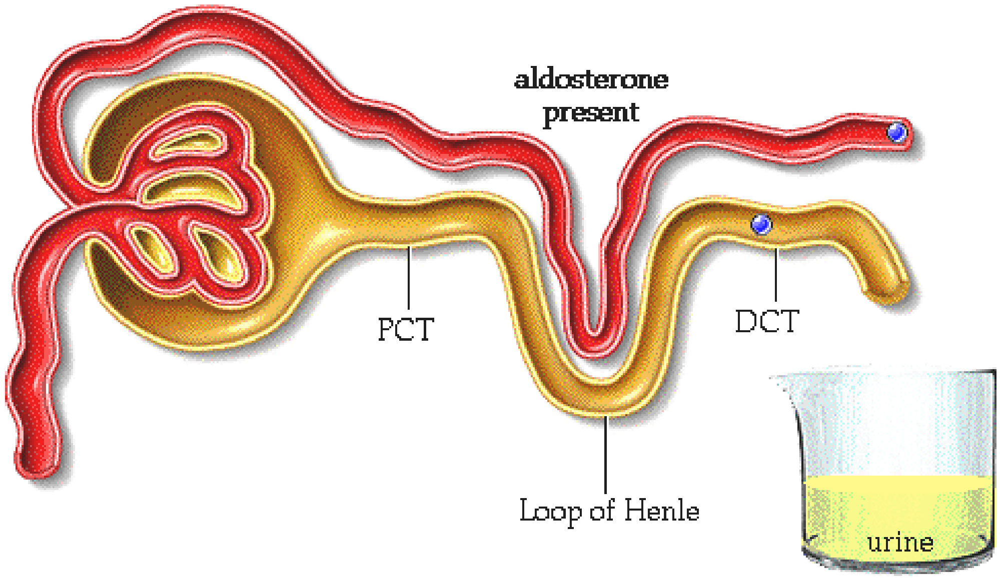
- Will water follow the sodium reabsorption if ADH is present?
  ___ yes ___ no
- If ADH is present, water will follow the sodium from the filtrate to the plasma.
- What effect would water reabsorption have on blood pressure?
  ___ Increases blood pressure ___ Decreases blood pressure
- Blood pressure will increase.
- If aldosterone is not present, drag the sodium ion to its proper location (urine or plasma) on the diagram above.
- More sodium will be found in the urine.

25. Urinary Regulation of Potassium

- Aldosterone also has an effect on potassium. Potassium is filtered at the glomerulus.
- About 90% of potassium is reabsorbed in the PCT and Loop of Henle.
- The kidney handles sodium and potassium differently. While the remaining sodium can be reabsorbed in the late distal convoluted tubule and collecting duct, the remaining potassium is only reabsorbed sometimes. Most often, it is secreted and excreted in the urine.

26. Effect of Aldosterone on Potassium

- If the plasma levels of potassium is high, aldosterone is secreted from the adrenal gland.
- Drag the potassium ion to where it will go in the presence of aldosterone:



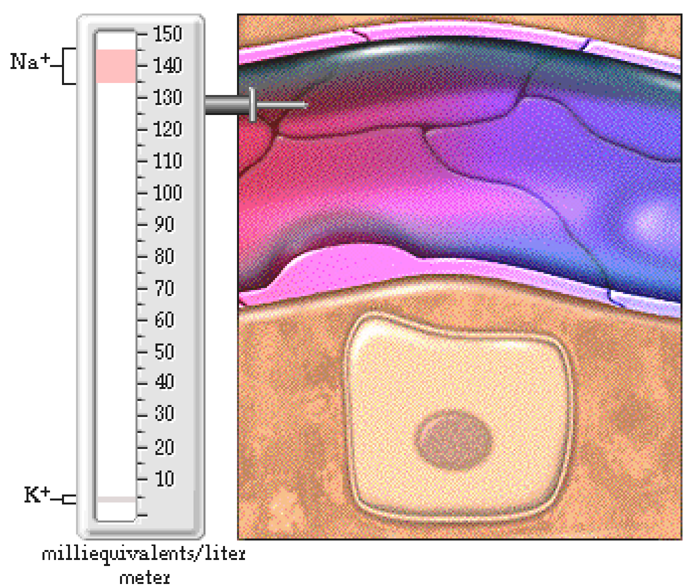
• In the presence of aldosterone, excess extracellular potassium is secreted into the filtrate from the plasma within the distal convoluted tubule and collecting duct and even more potassium ends up in the urine.
• To summarize, aldosterone is secreted from the adrenal gland when angiotensin II is present and/or when potassium levels are high. The effect of aldosterone is to reabsorb sodium into the plasma and secrete potassium into the filtrate within the kidney.

27. Effect of Diuretics

• By promoting urine formation, some diuretics will cause a potassium deficiency.
• The potassium ion that is not reabsorbed in the PCT passes into the urine. Potassium ion deficiency cannot be corrected without ingesting additional potassium ion.
• One reason why a low plasma potassium concentration, or hypokalemia, is clinically significant is because there is no mechanism to compensate for renal losses of potassium.

28. Potassium Homeostasis

• The normal range of sodium in the plasma is 135-145 milliequivalents per liter. Compare this range to the normal range of potassium in the plasma which is 3.5 to 5.1 milliequivalents per liter.



- Because potassium has a much smaller range, the loss of a small amount of potassium can make a significant difference in the body.
- Although most potassium ion is found inside cells, its concentration is measured in the plasma. It ends up in the extracellular fluids in two ways:
  1. Like water and sodium, potassium is constantly entering the body in food and leaving the body mostly through the urine.
  2. Because the cell membrane is more permeable to potassium than sodium, more potassium leaks out of cells.

29. Roles of Potassium: Osmosis

- Let's look at the roles of potassium in the body.
- As the major intracellular positive ion, potassium is responsible for intracellular fluid volume, through osmosis.
- What would happen if there was a slight increase in potassium ions in the extracellular fluid?

  ____ Cells would shrink

  ____ Cells would expand
- Cells will shrink slightly due to osmosis.

30. Roles of Potassium: Membrane Potential

- Because most cells in the body leak potassium but not other ions, potassium will leave the cells though ion channels. Notice that a significant amount of positive charge is leaving the cell.
- What charge will be left inside of the cell?

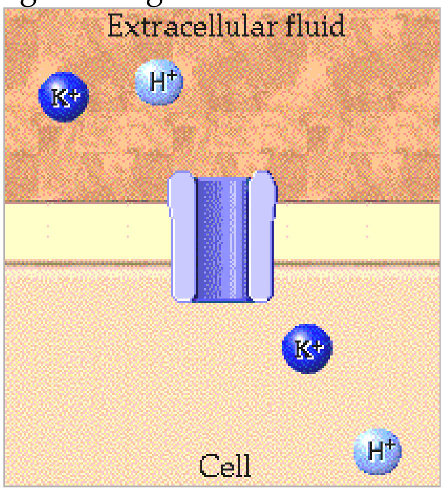
  ___ Positive charge

  ___ Negative charge
- A negative charge is present inside the cell.
- Potassium plays a key role in maintaining resting membrane potential, and therefore a major role in nerve impulse conduction, muscle contraction, and maintenance of normal cardiac rhythm.

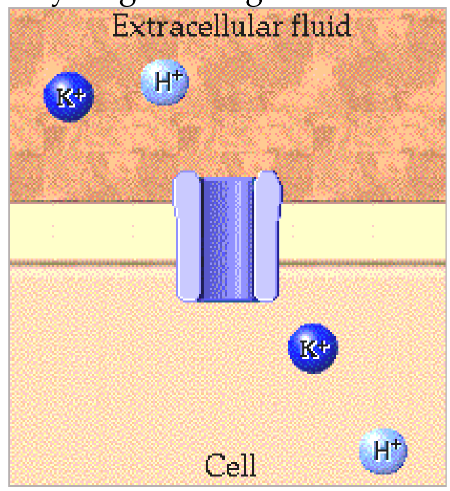
31. Roles of Potassium: Acid/Base Balance

- Potassium also plays a role in acid/base balance.
- As hydrogen ions move into and out of the cells in the body, there is a corresponding movement of potassium in the opposite direction by ion transport proteins that link hydrogen ion movement to potassium ion movement. This movement helps maintain electrical balance inside the cells.

- In acidosis, there is an excess of hydrogen ions (which determines the pH) in the extracellular fluids. The hydrogen ions exchange for potassium ions, increasing the extracellular potassium level.
- Indicate the direction that potassium and hydrogen ions go in acidosis:



- In conditions causing alkalosis, there will be a lack of hydrogen ions in the extracellular fluid. Drag the potassium ion in the direction it will go in alkalosis.
- Indicate the direction that potassium and hydrogen ions go in alkalosis:



- Because there is less hydrogen ion in the extracellular fluids in alkalosis, hydrogen ions move into the extracellular compartment in and potassium ions move into the cells. This movement may cause a decrease of potassium ions in the extracellular fluid.
- An increase or decrease of potassium in the extracellular fluid may influence action potentials in excitable membranes.

32. Potassium Exercise

- Hyperkalemia occurs if the plasma potassium level is greater than 5.1 milliequivalents per liter.
- Hypokalemia occurs if the plasma potassium level is less than 3.5 milliequivalents per liter.
- Predict whether or not the following conditions would cause hyperkalemia or hypokalemia.

____________________ Excessive intake of potassium, such as overuse of salt substitutes.
Eating too much potassium could lead to hyperkalemia.

____________________ Alkalosis
In alkalosis, hydrogen ion comes out of the cells in exchange for potassium ion. The potassium ion in the extracellular fluid decreases, leading to hypokalemia.

____________________ Taking diuretics.
Some diuretics can cause too much potassium to leave the body through the urine, resulting in hypokalemia.

____________________ Decreased ability of the kidneys to excrete potassium, such as occurs in renal failure.
The failure of the kidneys to excrete potassium may cause hyperkalemia.

____________________ A decreased intake of potassium, such as in an unbalanced diet.

Because the body absorbs potassium through food and beverages, a poor diet could cause hypokalemia.

____________________ Severe vomiting or diarrhea.

Loss of potassium from the body leads to hypokalemia.

____________________ Acidosis.

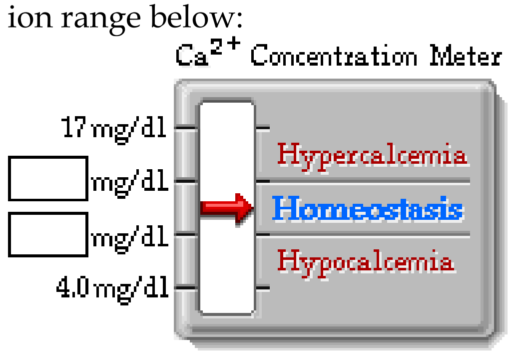
In acidosis, potassium leaves the cells in exchange for hydrogen ion, resulting in hyperkalemia.

- Because potassium plays a pivotal role in maintaining membrane potential, the effects of both hyperkalemia and hypokalemia are reflected in changes in neuromuscular functioning.
- Mild hyperkalemia may cause:
  - intestinal cramping
  - diarrhea
  - restlessness
  - changes in the electrocardiogram
- Severe hyperkalemia may cause:
  - muscle weakness progressing to paralysis
  - slowed heart conduction
  - cardiac arrest
- Hypokalemia causes:
  - decreased neuromuscular excitability
  - skeletal muscle weakness
  - cardiac dysrhythmias
- If hypokalemia continues untreated, the skeletal muscle weakness may progress to respiratory arrest.
  - respiratory arrest

33. Calcium Homeostasis

- Calcium homeostasis is crucial to normal body function. Even small changes in calcium ion concentration can be deadly.
- Normally, total calcium level in the plasma varies between 9 and 11 milligrams per 100 milliliters.

- Fill in the normal calcium ion range below:

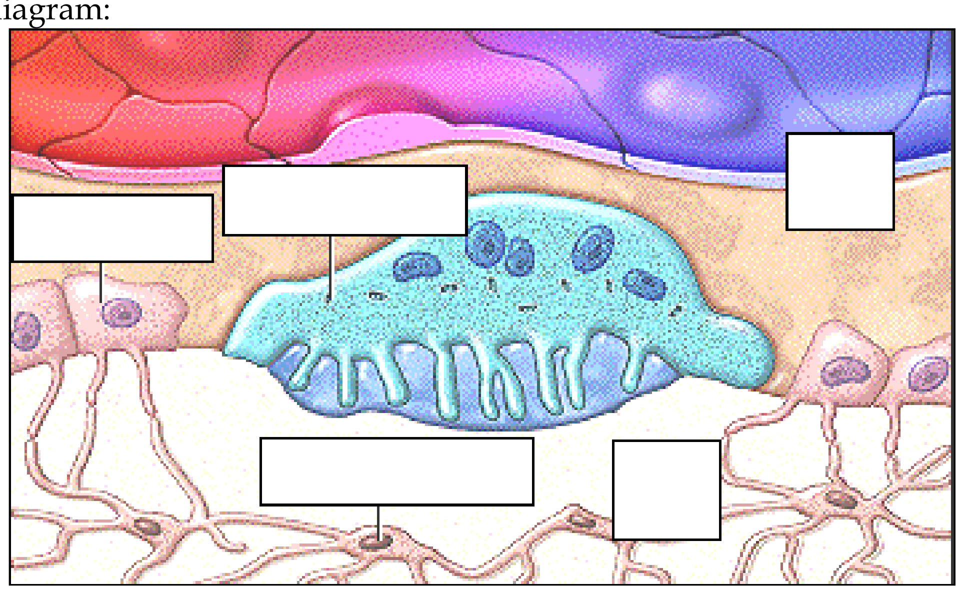


34. Hypercalcemia and Hypocalcemia

- If the level of calcium gets too high, heart dysrhythmias can occur. Other symptoms of hypercalcemia include fatigue, confusion, nausea, coma, cardiac arrest, and calcification of the soft tissues. The heart can stop if the calcium level gets too high.
- If the level of calcium gets too low muscle spasms can occur.
- When the calcium level is very low a person can go into tetanus. If the calcium level goes too low breathing will stop.
- As you can see, it is very important to maintain calcium levels within a specific range.

35. Effects of Calcitonin

- Approximately 99% of the calcium in the body resides in bone as a salt and about 1% is dissolved in the extracellular fluids. Label the diagram below
- When levels of plasma calcium get too high, the thyroid gland may sense the high calcium concentration and may release calcitonin hormone into the blood.
- The target tissue of calcitonin in children and pregnant women is bone.
- Label this diagram:



- Calcitonin inhibits the action of osteoclasts, which breakdown bone, and stimulates osteoblasts, which cause bone formation.
- This process accelerates the uptake of calcium and phosphate into bone matrix.
- The osteocytes seen here maintain bone tissue.
- The net effect of calcitonin is a decrease in blood calcium and phosphate concentrations. Calcitonin appears to be a hormone more important in children than adults.

36. Effects of PTH in the Bone

- When levels of plasma calcium get too low, the parathyroid gland senses the low calcium concentration and releases parathyroid hormone.
- One of the target tissues of parathyroid hormone is bone.
- In bone parathyroid hormone increases the number and activity of osteoclasts releasing calcium ion and phosphate into the plasma.
- The other target tissue of parathyroid hormone is the kidney. Click on the parathyroid gland to see what happens there.
- In the kidney, parathyroid hormone increases the uptake of calcium ion and magnesium ion from the filtrate back into the plasma.

- It also inhibits the reabsorption of phosphate by the kidneys and more is excreted in the urine.

37. Effects of Calcitriol

- Parathyroid hormone also promotes the activation of dietary vitamin D into the hormone calcitriol in the kidney. The liver is also involved in the activation of vitamin D.
- Calcitriol will increase the rate of calcium ion, and phosphate absorption from the gastrointestinal tract.
- Click on the arrows that indicate what would happen to calcium ion as a net result of parathyroid hormone secretion:

- Plasma levels of calcium increase to normal.
- When the plasma calcium level returns to normal parathyroid hormone secretion slows, which is the final step in this negative feedback loop.

38. Summary

- To maintain homeostasis, the extracellular fluid must maintain specific concentrations of electrolytes for the cells they bathe to function properly.
- One important function of electrolytes, particularly sodium, is to control fluid movement between the fluid compartments.
- Sodium and potassium balance are maintained by the kidney through the hormone aldosterone.
- Calcium balance is maintained by parathyroid hormone and clacitriol. Calcitonin also plays a role in children and pregnant women.

*Now is a good time to go to quiz questions 1-6:
- Click the Quiz button on the left side of the screen.
- Work through all parts of questions 1-6.

Notes on Quiz Questions:

Quiz Question #1: Fluid Movement Between Compartments

- This question has you predict how substances enter cells and how substances leave the plasma.

Quiz Question #2: Congestive Heart Failure and Hypertension

- This question has you predict what happens with congestive heart failure and hypertension.

Quiz Question #3: Electrolyte Imbalance

- This question has you predict the type of electrolyte imbalance a patient has.

Quiz Question #4: Sodium and Potassium

- This question allows you to answer questions about where sodium and potassium ions go in the presence and absence of aldosterone.

Quiz Question #5: Diuretics

- This question asks you to predict the type of electrolyte imbalance a patient has.

Quiz Question #6: Osteoporosis

- This question asks you to predict the effects of osteoporosis.

Study Questions on Electrolyte Homeostasis:

1. (Page 1.) The fluid surrounding the cells in the body must maintain a _____________________________________ for the cells to function properly.

2. (Page 3.) How do electrolytes enter the body?

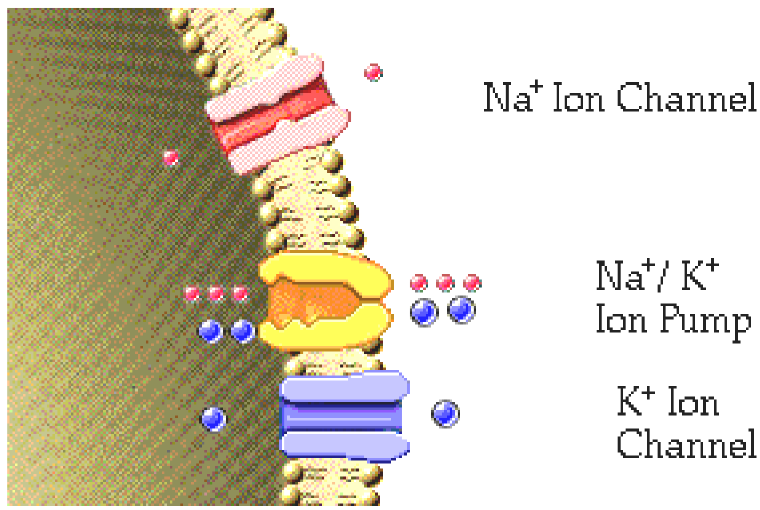
3. (Page 3.) How do electrolytes leave the body?

4. (Page 4.) Label the diagram on page 4.

5. (Page 5.) Label the diagram on page 5.

6. (Page 5.) How do electrolytes move across the cell membrane?

7. (Page 5-7.) Indicate the direction of ion movement for the:
   a. Na^+/K^+ Ion Pump
   b. Na^+ Ion Channel
   c. K^+ Ion Channel



8. (Page 8.) a. When there is a higher concentration of solute in the interstitial fluid, which way will water move? b. When there is a higher concentration of solute inside the cell, which way will water move?

9. (Page 9.) How do ions and other small solutes move freely between the plasma and the interstitial fluid?

10. (Page 9.) Can proteins freely leave the blood capillaries?

11. (Page 9.) What happens to proteins that do escape from the blood capillaries?

12. (Page 9.) What causes the colloid osmotic pressure of the plasma?

13. (Page 10.) a. On the diagram on page 10, which arrow represents the fluid movement that results from the colloid osmotic pressure? b. On the diagram on page 10, which arrow represents the fluid movement that results from the hydrostatic pressure?

14. (Page 11.) What is bulk flow?

15. (Page 11.) Will happen if the sodium concentration of the plasma increases?

16. (Page 12.) What is edema?

17. (Page 12.) List four causes of edema?

18. (Page 13.) Explain how edema can occur due to decreased colloid osmotic pressure.

19. (Page 14.) Explain how edema can occur due to increased hydrostatic pressure.

20. (Page 15.) Explain how edema can occur due to increased capillary permeability.

21. (Page 16.) Explain how edema can occur due to lymphatic obstruction.

22. (Page 17.) Which is the normal concentration range for sodium in the plasma?
   a. 9 and 11 milligrams per 100 milliliters
   b. 136 - 145 milliequivalents per liter
   c. 3.5 to 5.1 milliequivalents per liter

23. (Page 18.) What will happen if the sodium concentration of the blood plasma increases. What effect would this increase in sodium concentration have on the cells that are bathed by the interstitial fluid? Would the cells shrink or swell?

24. (Page 19.) What will happen if the sodium concentration of the blood plasma decreases. What effect would this increase in sodium concentration have on the cells that are bathed by the interstitial fluid? Would the cells shrink or swell?

25. (Page 21.) Which of these reasons would most likely cause hypernatremia in the marathon runner?
   a. Too much sodium added   b. Too much water lost

26. (Page 21.) Why would a person with hypernatremia be confused and disoriented?

27. (Page 21.) What will happen to thirst in hypernatremia?

28. (Page 22.) What percentage of sodium is reabsorbed into the plasma at the proximal convoluted tubule and loop of Henle?

29. (Page 23.) What will happen to urine output in hypernatremia?

30. (Page 23.) In the absence of aldosterone, will the remaining sodium will remain in the filtrate or end up in the urine?

31. (Page 23.) In the presence of aldosterone, will the remaining sodium will remain in the filtrate or end up in the urine?

32. (Page 23.) Would high or low blood pressure cause the secretion of aldosterone?

33. (Page 24.) What effect would water reabsorption have on blood pressure?

34. (Page 25.) What percentage of potassium is reabsorbed in the PCT and Loop of Henle?

35. (Page 25.) What is the major way difference between how sodium and potassium is handled in the late distal convoluted tubule and collecting duct?

36. (Page 26.) In the absence of aldosterone, will the remaining potassium will remain get secreted or remain in the plasma?

37. (Page 26.) In the presence of aldosterone, will the remaining sodium will remain in the filtrate or end up in the urine.

38. (Page 27.) Why do some types of diuretics cause a potassium deficiency?

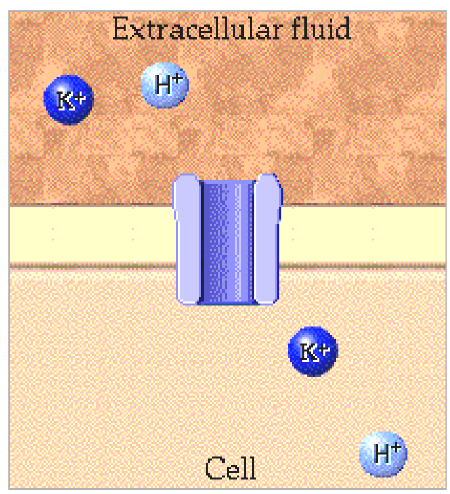
39. (Page 28.) Which is the normal concentration range for potassium in the plasma?
   a. 9 and 11 milligrams per 100 milliliters
   b. 136 - 145 milliequivalents per liter
   c. 3.5 to 5.1 milliequivalents per liter

40. (Page 28.) List two ways that potassium enters the extracellular fluids.

41. (Page 29.) What would happen if there was a slight increase in potassium ions in the extracellular fluid? Would cells shrink or expand?

42. (Page 30.) Because most cells in the body leak potassium but not other ions, potassium will leave the cells though ion channels. What charge will be left inside of the cell?

43. (Page 31.) Indicate the direction that potassium and hydrogen ions go in:
   a. acidosis
   b. alkalosis



44. (Page 32.) Predict whether or not the following conditions would cause hyperkalemia or hypokalemia.
   a. Excessive intake of potassium, such as overuse of salt substitutes.
   b. Alkalosis
   c. Taking diuretics.
   d. Decreased ability of the kidneys to excrete potassium, such as occurs in renal failure.
   e. A decreased intake of potassium, such as in an unbalanced diet.
   f. Severe vomiting or diarrhea.

g. Acidosis.

45. (Page 33.) Which is the normal concentration range for calcium in the plasma?
   a. 9 and 11 milligrams per 100 milliliters
   b. 136 - 145 milliequivalents per liter
   c. 3.5 to 5.1 milliequivalents per liter

46. (Page 34.) What happens if plasma calcium levels get too high?

47. (Page 34.) What happens if plasma calcium levels get too low?

48. (Page 35.) What percentage of calcium in the body resides in bone as a salt and what percentage of calcium is dissolved in the extracellular fluids?

49. (Page 35.)When levels of plasma calcium get too high, the ___________ may sense the high calcium concentration and may release __________ hormone into the blood.

50. (Page 35.) Label the diagram on page 35.

51. (Page 35.) What are the function of osteocytes, osteoclasts, and osteoblasts?

52. (Page 35.) What is the function of calcitonin?

53. (Page 36.)When levels of plasma calcium get too low, the ___________ may sense the low calcium concentration and may release __________ hormone into the blood.

54. (Page 36.) What is the function of parathyroid hormone?

55. (Page 37.) What hormone activates vitamin D to calcitriol in the kidney?

56. (Page 37.) What is the function of calcitriol?

Acid/Base Homeostasis

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1. Acid/Base Homeostasis

- Chemical buffers, the respiratory system, and the urinary system work together to ensure that the pH of body fluids remain within a specific narrow limit.

2. Goals

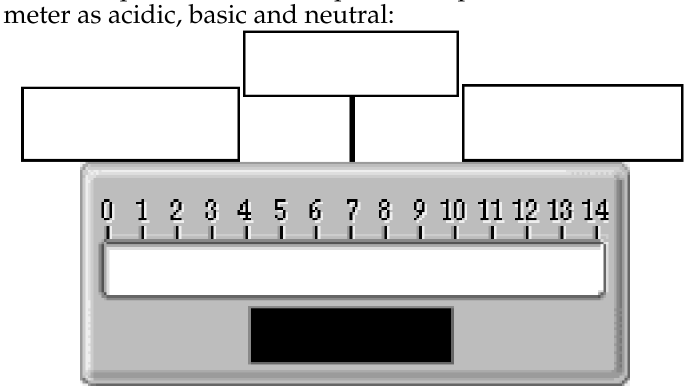
- To compare the pH differences of the various fluid compartments and exocrine secretions
- To describe the three homeostatic mechanisms the body uses to regulate pH
- To describe the causes and results of the four major acid/base disturbances
- To understand the compensation mechanisms involved in acid/base homeostasis

3. Maintaining a Balance of Acids and Bases

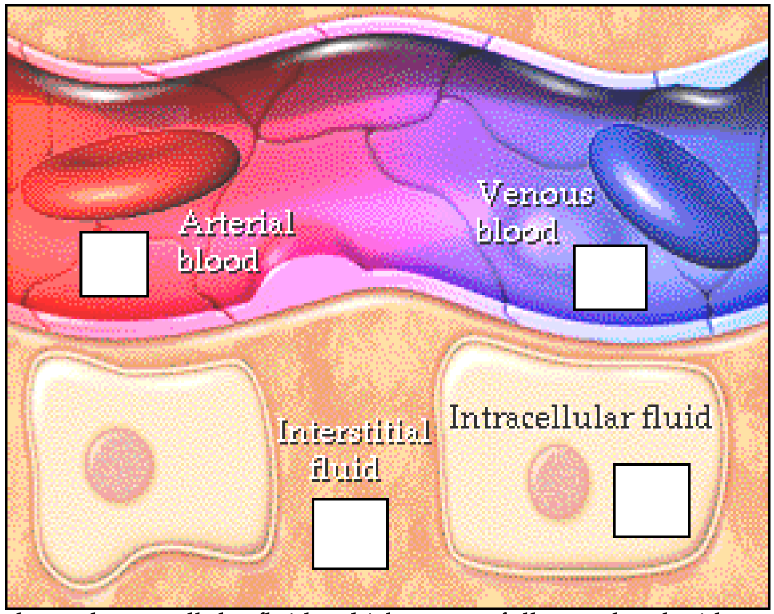
- Maintaining a balance of acids and bases is an important process in the body.
- We measure the acidity or basicity of a solution in units of pH, which is a measurement of the concentration of free hydrogen ion in solution.
- Acids and bases in our bodies come from the food we eat.
- Other acids come from metabolism. Lactic acid generated during exercise is an example.
- In order to maintain acid/base homeostasis, our bodies constantly need to adjust the pH of body fluids.

4. Concept of pH

- Which pH is the most acidic, pH 4 or 8? _______
- The lower the pH, the more acidic the solution is.
- When H^+ increases, acidity increases, and pH decreases.
- When H^+ decreases, acidity decreases, and pH increases.
- Which pH has the greater concentration of H^+ in it, pH 7 or 8? ______
- When a solution has more H^+ it is more acidic, and it has a lower pH.
- When we increase or decrease the pH by one pH unit, we are changing the concentration of H^+ by a factor of 10. So there is 10 times less H^+ in a pH 8 solution compared to a pH 7 solution.
- Label the parts of this pH meter as acidic, basic and neutral:



5. pH of Body Fluids



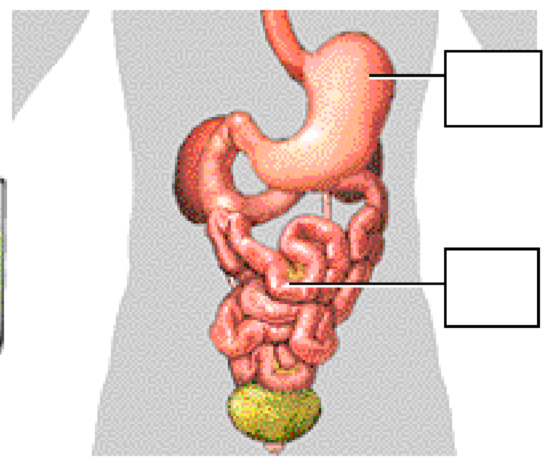
- Let's take the pH of some fluids in the body.
- The pH of arterial blood fluctuates within a normal range of 7.35-7.45.
- The pH of venous blood is slightly lower than that of arterial blood, about 7.35, caused by the presence of more carbonic acid.
- In addition the pH of interstitial fluid is about the same as for venous blood, 7.35.
- In the cell, pH will register about 7.0. Organelles within the cell also have different pH's.
- Which is the most acidic fluid compartment.

____

- The lower the pH, the more acid is present.
- We have just checked the pH of the intracellular and extracellular fluids which are carefully regulated with respect to pH. Now lets check the pH of some exocrine secretions whose pH vary widely .

6. pH of Exocrine Secretions

- The pH of the gastric juice typically varies from 1.2 to 3.0. However the pH typically increases after eating a large meal as a result of the buffering effect of the food.
- The pH of the small intestine is slightly basic because of the presence of bicarbonate ions.
- In each container is a urine sample from the same individual at different times. The pH of urine will vary between 4.5 and 8.0 based on diet and metabolic state.
- Later we will see how the kidney helps to maintain the pH of body fluids by releasing acids and bases into the urine.
- Indicate the pH of the following body fluids:



7. Strong Acid: Hydrochloric Acid

- When the body is in acid/base homeostasis, the pH of the arterial blood is 7.35-7.45 and the proportion of acid and base is correct for normal body function.
- Let's look at the difference between strong and weak acids. Acids are substances that release hydrogen ion and are therefore hydrogen ion donors. Strong acids, such as hydrochloric acid, release all their hydrogen ion in water.

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

Hydrochloric acid — Hydrogen ion — Chloride ion

Continue to Acid/Base Homeostasis – Part II
(Separate Document)

Acid/Base Homeostasis (Part 2)

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- The stomach contains an aqueous solution of hydrochloric acid, which is the only example of a strong acid found in the body.
- Note that as soon as this strong acid hits the water, it completely dissociates into hydrogen ion and chloride ion which are found in the stomach.
- Remember that strong acids are substances that release all their hydrogen ion. The pink color is from an indicator which has been added.

8. Weak Acid: Carbonic Acid

- Unlike strong acids, when weak acids, such as carbonic acid, are added to water it does not completely dissociate. Carbonic acid is formed when we bubble carbon dioxide through water.

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

Carbonic acid — Hydrogen ion — Bicarbonate

- Remember that pH measures of the free hydrogen ion in solution. Because not much hydrogen ion is released when carbonic acid is added to water, this acid is weak, and hit has a higher pH than a strong acid. The pink color is from an indicator which has been added.

9. Weak Acid: Lactic Acid

- When you exercise, your muscles may generate lactic acid.

$$CH_3CHOHCO_2H \rightleftharpoons H^+ + CH_3CH_2OHCO_2^-$$

Lactic acid — Hydrogen ion

Lactate

- Notice that more hydrogen ions are released from the lactic acid than were released from the carbonic acid. Again, the pink color is from an indicator which has been added to show that this is a weak acid.
- Although both carbonic acid and lactic acid are weak acids, lactic acid releases more hydrogen ion and is therefore a stronger weak acid.

10. Weak Base: Bicarbonate

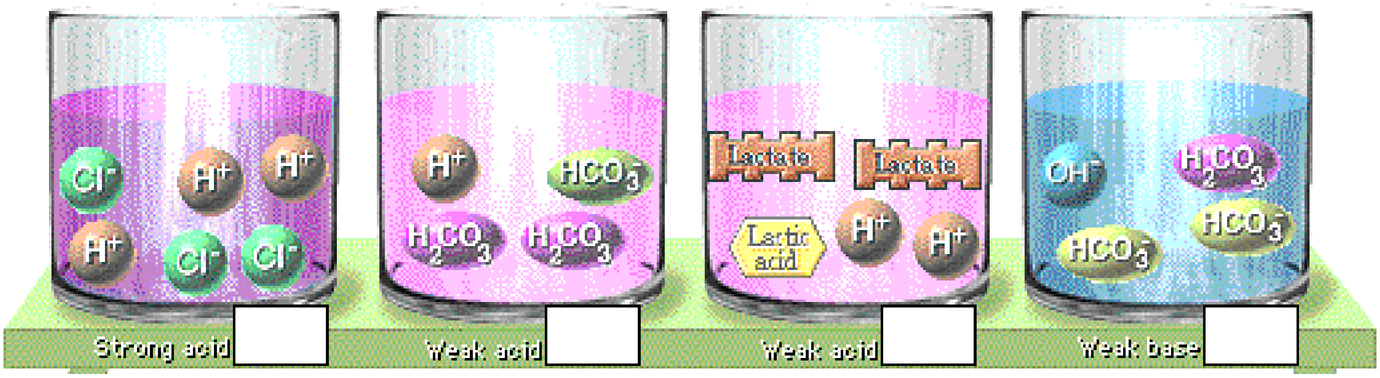
- Bases take up hydrogen ion. While there are both strong and weak bases, only weak bases are found in the body.

$$HCO_3^- \rightleftharpoons OH^- + H_2CO_3$$

Bicarbonate — Hydroxide ion — Carbonic acid

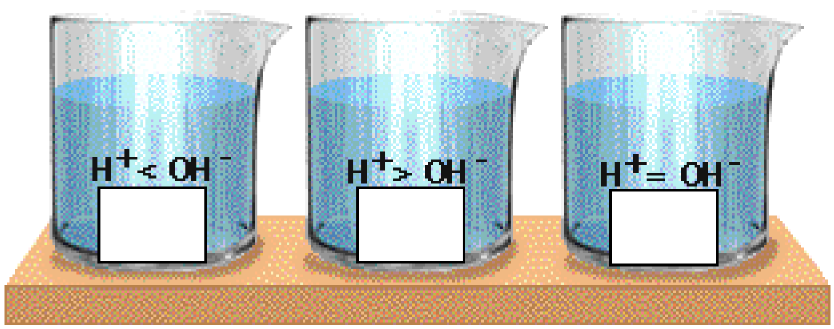
- Sometimes basic solutions are called alkaline solutions.

- Note that there would have to be a positive ion, such as sodium, with the bicarbonate on the shelf.
- A small percentage of the bicarbonate ions take up hydrogen ions from the water. When water molecules lose hydrogen ion, hydroxide ion remains, which increases the pH. Again, the pink color is from an indicator which has been added.
- Indicate the pH's of these solutions:



11. Match the pH to the Beaker

- A neutral solution has a pH of 7 because the hydrogen ion and hydroxide ion concentrations are equal.
- Indicate the pH's on the appropriate beakers.



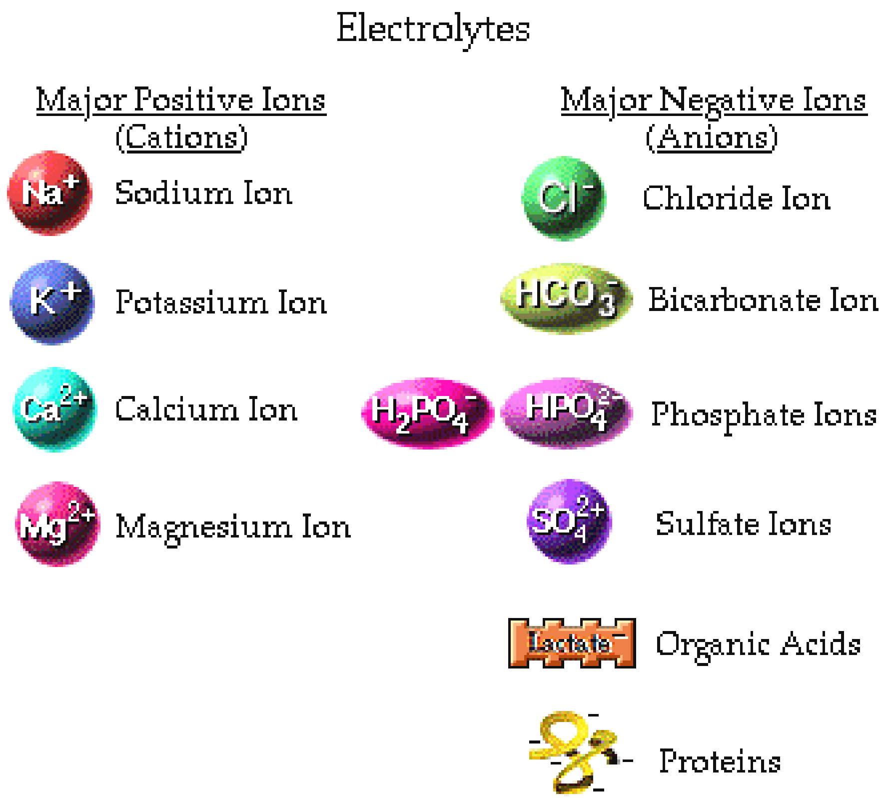
pH 3 pH 7 pH 10

- At pH 7 the concentrations of hydrogen ion and hydroxide ion are equal and the solution is neutral.
- At pH 3 the concentrations of hydrogen ion is greater than hydroxide ion and the solution is acidic.
- At pH 10 the concentrations of hydrogen ion is less than hydroxide ion and the solution is basic.

*Now is a good time to go to quiz question 1:
- Click the Quiz button on the left side of the screen.
- Work through all parts of question 1.
- After answering question 1, click on the Back to Topic button on the left side of the screen.
- To get back to where you left off, click on the scrolling page list at the top of the screen.
- Choose "12. Electrolytes as Weak Acids and Bases."

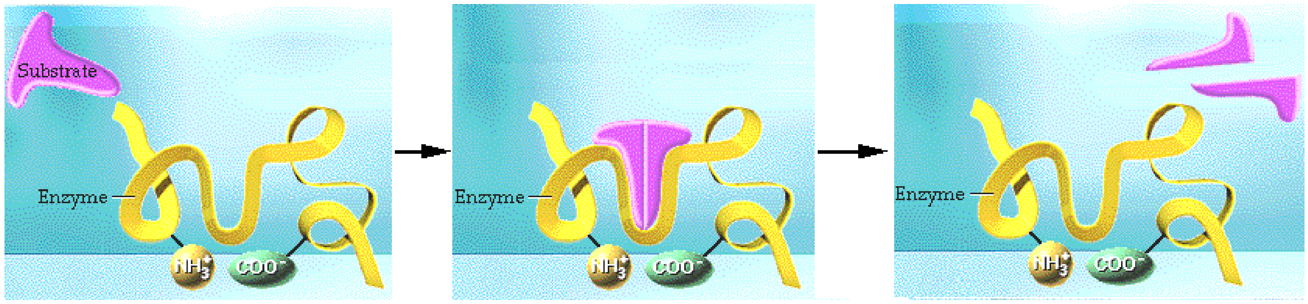
12. Electrolytes as Weak Acids and Bases

- Some electrolytes normally found in plasma can act as weak acids and bases.
- Bicarbonate, hydrogen phosphate, sulfate, and anions of organic acids all serve as bases in the body.
- Dihydrogen phosphate is an acid in the body.
- In addition proteins have acidic and basic side groups.
- Indicate the acids and bases on the chart below:



13. Normal Globular Protein

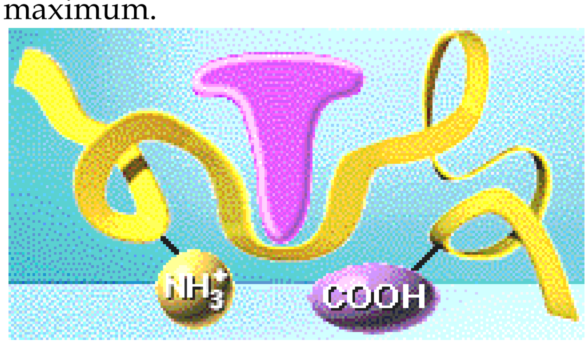
- Maintaining the pH of body fluids is very important because many proteins cannot function at an altered pH. Many globular proteins have specific functions in the body and their shape is crucial for their function.
- The protein shown is an enzyme. Enzymes have active sites with a specific shape. If for some reason the shape of the protein changes, this enzyme would no longer be able to function.
- Because this enzyme functions within the cytoplasm of the cell, it operates best at pH 7.0.



- Proteins have positive and negative charges that will determine, to some extent, the shape, or tertiary structure, of the protein. These positive and negative charges are present because of acidic and basic amino acid side chains.
- This protein is shown with only one positive and negative charge, but remember that proteins have many charges.

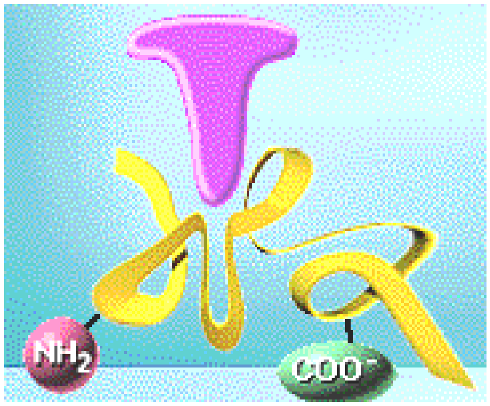
14. Effect of Acid on Globular Protein

- If pH is altered, globular proteins lose their shape or denature and cannot function properly. Clinical symptoms will result. For example, when lactic acid is generated in large quantities by muscle, muscles can no longer perform to their maximum.



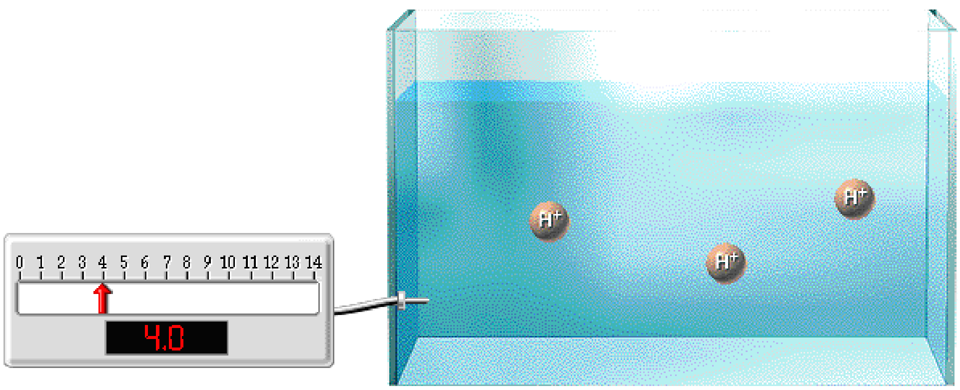
15. Effect of Base on Globular Protein

- Now let's see what happens when we add base to this enzyme.
- Again, if base is added, globular proteins denature and cannot function properly.
- To summarize, proteins can release and accept hydrogen ion. however, If the pH of the body fluid changes too much, proteins, such as enzymes and hormones, will no longer function.



16. Buffers

- The body has three ways of maintaining a normal pH range:
  Chemical buffer systems
  Respiratory controls
  Renal mechanisms
- First we'll describe chemical buffers. They act within seconds to help the body control pH.
- Notice the large drop in pH, which is typical when acid is added to an unbuffered solution.



- Most buffers are composed of weak acid and weak base pairs which are sometimes called conjugate acid/base pairs. The purpose of a buffer is to help the body maintain a relatively constant pH.
- There are three important buffer systems in the body:
  Carbonic acid/bicarbonate buffer system
  Phosphate buffer system
  Protein buffers

17. Carbonic Acid/Bicarbonate Buffer

- First let's discuss the carbonic acid/bicarbonate buffer system. The weak acid is carbonic acid, H_2CO_3, and the weak base is bicarbonate, HCO_3^-.
- When acid is added, the hydrogen ion attaches to the weak base, bicarbonate, to form a weak acid, carbonic acid:

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

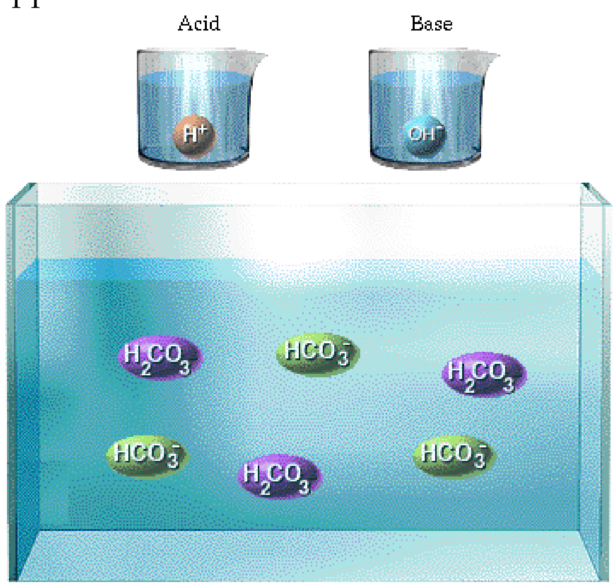
Bicarbonate Hydrogen ion Carbonic acid

- Because the hydrogen ion attaches and is not free in solution, the pH will not change dramatically. The weak acid that forms will not dissociate into hydrogen ions to any great extent.
- When base is added, the hydroxide pulls a hydrogen ion off of carbonic acid, forming water and bicarbonate:

$$H_2CO_3 + OH^- \rightleftharpoons HCO_3^- + H_2O$$

Carbonic acid Hydroxide ion Bicarbonate Water

- Because the hydroxide pulled a hydrogen ion off of the carbonic acid and formed water, the hydroxide did not significantly increase the pH of the solution.
- Show what happens when both acid and base are added to this solution:



18. Phosphate Buffer

- Now let's take what we learned about the carbonic acid/bicarbonate buffer system and apply it to the phosphate buffer system.
- Which of these is the weak acid? ____ $H_2PO_4^-$ or ____ $HPO_4^=$
- Dihydrogen phosphate is the weak acid. You can tell because it contains more hydrogen ion.
- When acid is added: The hydrogen ion adds to the weak base, hydrogen phosphate.

$$HPO_4^= + H^+ \rightleftharpoons H_2PO_4^-$$

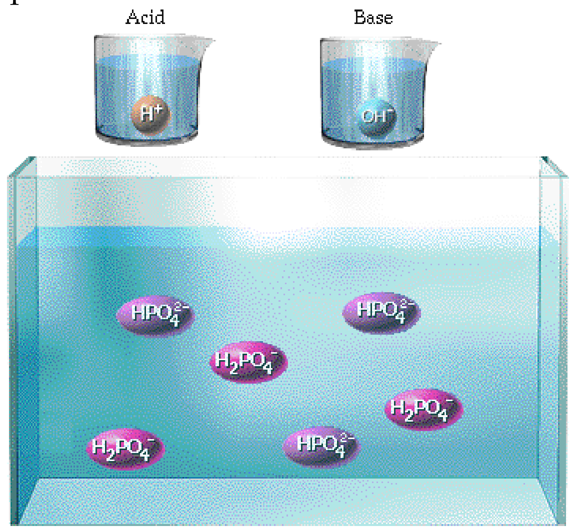
hydrogen phosphate hydrogen ion dihydrogen phosphate

- When base is added: The hydroxide ion pulls a hydrogen ion off of dihydrogen phosphate to form water and hydrogen phosphate.

$$H_2PO_4^- + OH^- \rightleftharpoons HPO_4^{=}$$

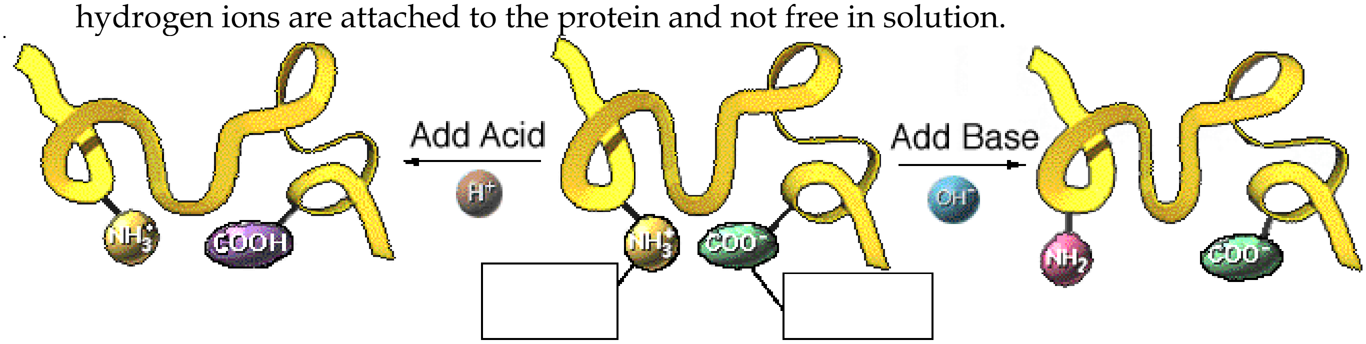
dihydrogen phosphate hydroxide ion hydrogen phosphate

- Show what happens when both acid and base are added to this solution:



19. Protein Buffers

- Remember that proteins have side chains which can act as weak acids or weak bases, allowing proteins to serve as buffers.
- When acid is added when there is excess hydrogen ion in the body fluids.
- When there is too much acid in the body, proteins take up hydrogen ion onto side chains that are weak bases. pH does not change much because the hydrogen ions are attached to the protein and not free in solution.



- Now let's see what happens when base is added to the protein.
- When there is excess base in the body, proteins release hydrogen ion from side chains that are weak acids.

- Notice that the shape of the protein did not change much here because only small amounts of acid or base were added. If the pH increases or decreases too much, the proteins may become denatured and not function properly.

*Now is a good time to go to quiz question 2:

- Click the Quiz button on the left side of the screen.
- Work through all parts of question 2.
- After answering question 2, click on the Back to Topic button on the left side of the screen.
- To get back to where you left off, click on the scrolling page list at the top of the screen.
- Choose "20. Dynamic Equilibrium."

20. Dynamic Equilibrium

- This chemical equation expresses the relationship between the weak acid and weak base of a buffer.

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

Carbonic acid   Hydrogen ion   Bicarbonate

- Many reactions that occur in the body, such as this one, are reversible.
- The reaction can go either in the forward direction or the reverse direction.
- The double arrows indicate that reaction can go either in the forward direction or the reverse direction.
- When the body is in acid/base homeostasis, carbonic acid is constantly forms bicarbonate and hydrogen ion.
- Bicarbonate and hydrogen ion constantly come back together again to reform carbonic acid.
- This is a dynamic equilibrium reaction since both the forward and reverse reactions are occurring simultaneously but there is no change in the concentrations of the weak acid and weak base.

21. Adding Carbonic Acid

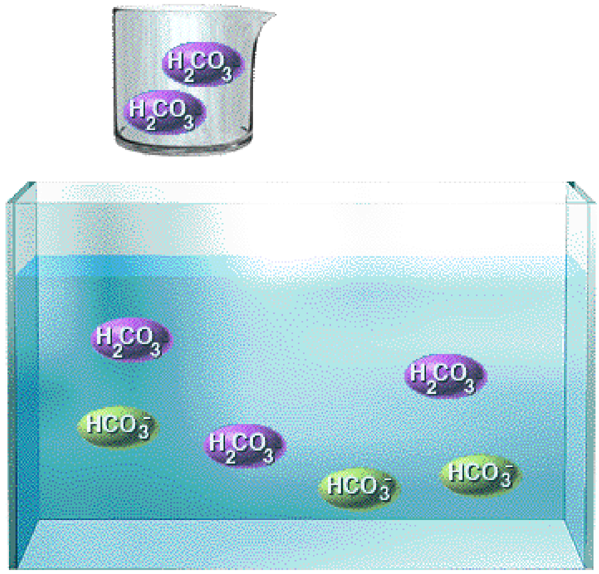
- Now lets use this equation to explain what happens when the body is not in homeostasis and there is too much carbonic acid in the body fluids.

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

Carbonic acid   Hydrogen ion   Bicarbonate

- Adding more carbonic acid forces the reaction to form more bicarbonate and hydrogen ion.
- What is this change in equilibrium called?
  - ___ shift to the right
  - ___ shift to the left
- Because we have added more carbonic acid the reaction proceeds to the right.

- Show what happens when the carbonic acid is added:



22. Adding Hydrogen Ion

- Now let's consider what happens if we add more bicarbonate or hydrogen ion to the right side of the equation. Which direction will the reaction proceed?

  ___ Reaction will shift to the right.

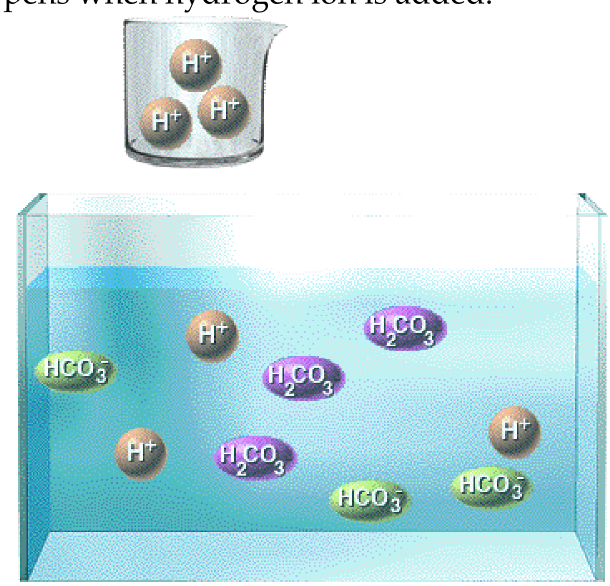
  ___ Reaction will shift to the left

- The reaction will shift to the left and most of the excess acid will be taken up, allowing the pH to remain fairly constant.

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

Carbonic acid Hydrogen ion Bicarbonate

- Show what happens when hydrogen ion is added:



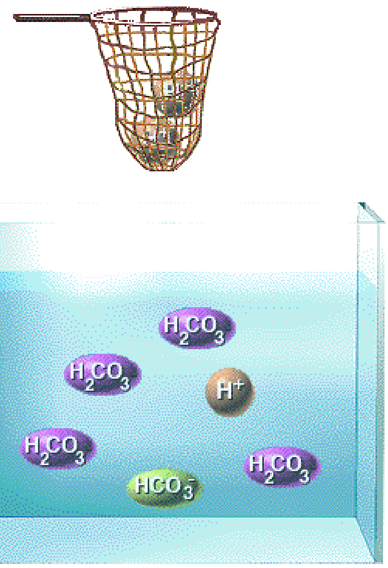
23. Removing Hydrogen Ion

- Now let's show what happens when there's not enough acid in the body.
- As hydrogen ion is taken away, more hydrogen ion is generated by the buffer system, allowing the pH to remain fairly constant.

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

Carbonic acid Hydrogen ion Bicarbonate

- What do you think we call this change in equilibrium?
  - ___ shift to the right
  - ___ shift to the left
- It is a shift to the right because the reaction proceeds to the right.
- Show what happens when hydrogen ion is removed:



24. Introduction to Respiratory Control

- We have looked at the role of chemical buffers in acid/base balance, now let's look at the role of the respiratory system in regulation of acid/base balance.
- Note that respiratory control occurs rapidly, but not as rapidly as chemical buffering.
- Cell metabolism generates carbon dioxide which is eliminated from the body by the lungs.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

- When we breathe more deeply and quickly, more carbon dioxide leaves the body.
- When we breathe more slowly or more shallowly, less carbon dioxide leaves the body.

25. Role of Bicarbonate Buffer

- Within the body fluids carbon dioxide and water are constantly coming together to form carbonic acid.
- Bicarbonate and hydrogen ion are also constantly forming carbonic acid.
- Inside red blood cells and other cells the enzyme carbonic anhydrase, combines the carbon dioxide with water to form carbonic acid.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

Carbon dioxide Water Carbonic acid

- This is a reversible reaction and carbonic acid will break down to carbon dioxide and water.
- Note that this reaction can occur outside of cells without the enzyme, but the reaction time is slower.
- Bicarbonate and hydrogen ion are also constantly forming carbonic acid:

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

Hydrogen ion Bicarbonate Carbonic acid

26. Role of Carbon Dioxide/Carbonic Acid Equilibrium

- As you remember, this is the equation for the carbonic acid/bicarbonate buffer.

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

Carbonic acid Bicarbonate Hydrogen ion

- Now let's expand the equation to see how the entire respiratory system works to regulate pH. Carbonic acid can break down into carbon dioxide and water.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

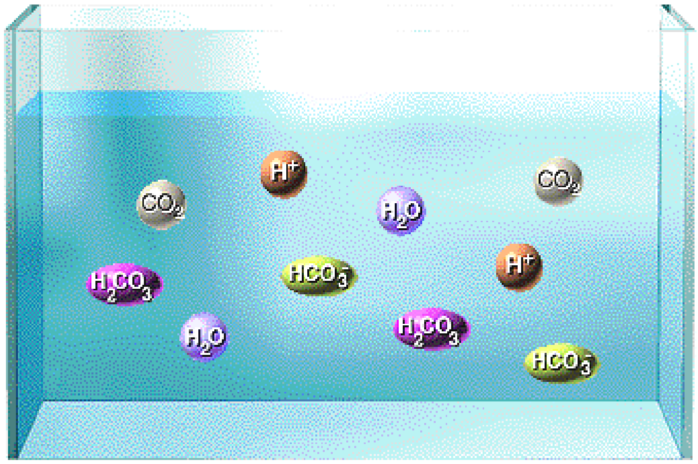
Carbon dioxide Water Carbonic acid

- Carbon dioxide and water can also combine together to form carbonic acid, which breaks down into bicarbonate and hydrogen ion.

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

Carbon dioxide Water Carbonic acid Bicarbonate Hydrogen ion

- Show what happens in this tank:



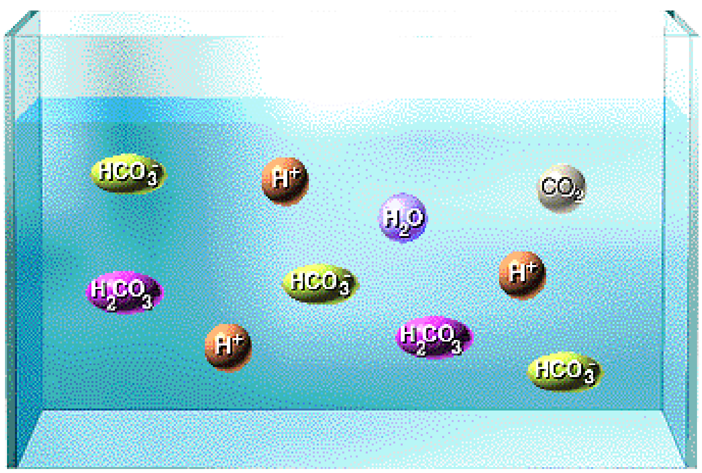
- Bicarbonate and hydrogen ion can also coming together to form carbonic acid which splits into carbon dioxide and water.

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

Hydrogen ion Bicarbonate Carbonic acid

Carbon dioxide Water

- Show what happens in this tank:



Continue to Acid/Base Homeostasis – Part III
(Separate Document)

Acid/Base Homeostasis (Part 3)

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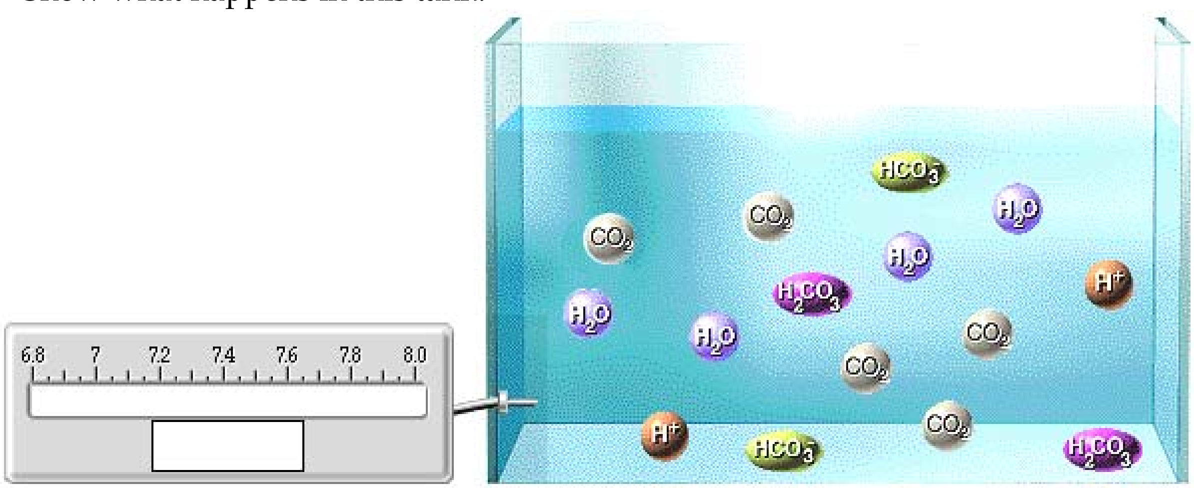
27. Effect of Hypoventilation

- Now let's look at how the rate of respiration affects this reaction.
- If the rate of respiration decreases or if the exchange of gases in the lungs is impaired, what happens to the carbon dioxide in the plasma?
  ___ CO_2 increases
  ___ CO_2 decreases
- If the rate of respiration decreases, then carbon dioxide can't leave the plasma and the carbon dioxide to builds up.

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

Carbon dioxide   Water   Carbonic acid
Bicarbonate   Hydrogen ion

  ___ Equilibrium shifts to the right and H^+ increases
  ___ Equilibrium shifts to the left and H^+ decreases
- If the rate of respiration decreases, what will happen to the equilibrium of this reaction?
- A carbon dioxide build-up in the plasma causes the reaction to proceed to the right and hydrogen ion increases.
- Show what happens in this tank:



- If the rate of respiration decreases, what will happen to the pH of the plasma?
  ___ pH increases
  ___ pH decreases
- Because H^+ is being generated, the plasma becomes more acidic and the pH decreases.

28. Effect of Hyperventilation

- If the respiration rate increases to above normal, what happens to the carbon dioxide in the plasma.

  ___ CO_2 increases ___ CO_2 decreases

- If the rate of respiration increases, then carbon dioxide readily leaves the plasma and is exhaled.
- What will happen to the equilibrium of this reaction if the rate of respiration increases?

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

Carbon dioxide Water Carbonic acid

Bicarbonate Hydrogen ion

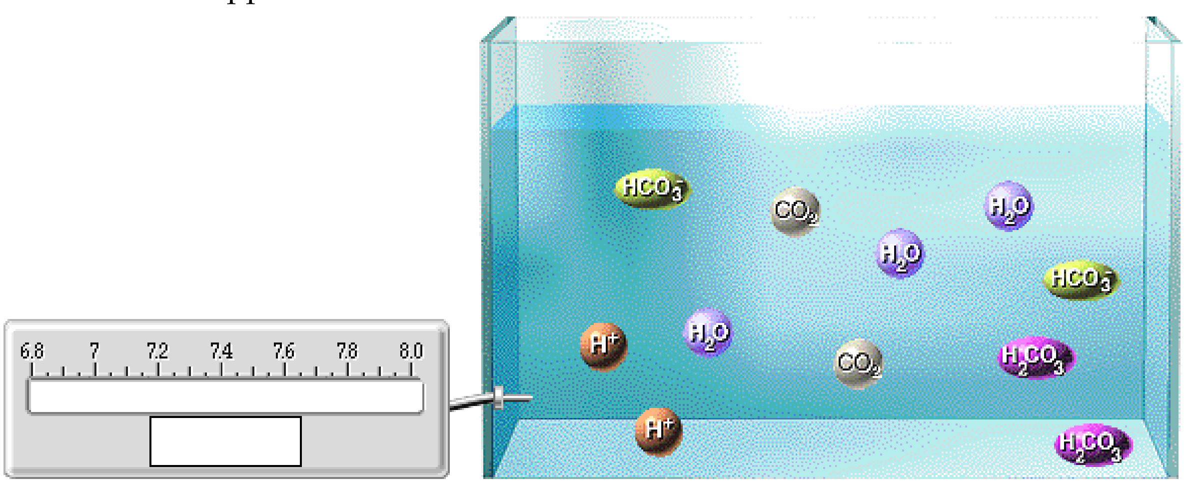
___ Equilibrium shifts to the right and H^+ increases ___ Equilibrium shifts to the left and H^+ decreases

- Because carbon dioxide is leaving the plasma, more H^+ combines with bicarbonate to make more carbon dioxide and the reaction proceeds to the left.
- If the rate of respiration increases, what will happen to the pH of the plasma?

  ___ pH increases ___ pH decreases

- Because H^+ is being used up to form more CO2, the plasma becomes more basic and the pH increases.
- You can see how the increased rate of respiration has an effect on the pH of the plasma.
- Because carbonic acid can freely turn into carbon dioxide and can be eliminated through the lungs, it is a volatile acid.

- Show what happens in this tank:



*Now is a good time to go to quiz question 3:

- Click the Quiz button on the left side of the screen.
- Work through all parts of question 3.
- After answering question 3, click on the Back to Topic button on the left side of the screen.
- To get back to where you left off, click on the scrolling page list at the top of the screen.
- Choose "29. Renal Processes."

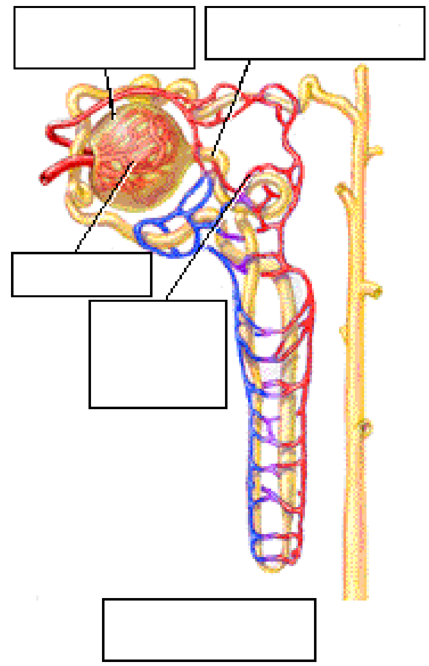
29. Renal Processes

- We will now discuss how renal mechanisms adjust the acid/base balance in the body.

- As you remember, there are three renal processes:
  1. Filtration
  2. Reabsorption
  3. Secretion

- First let's examine what happens during filtration with respect to acid/base balance.

- Label this diagram:



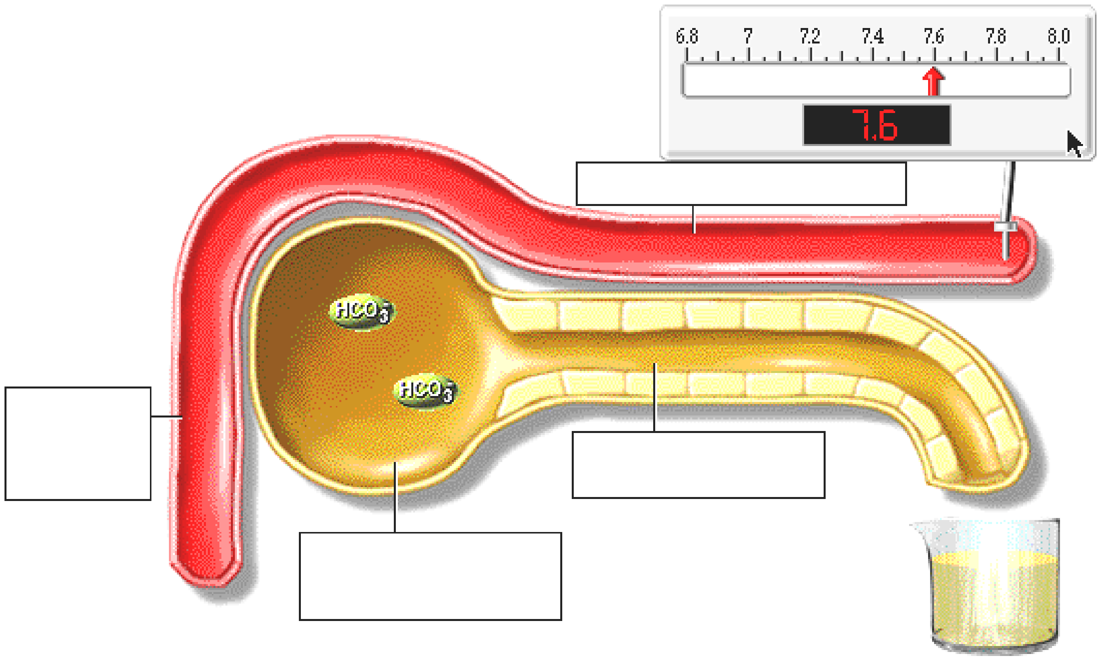
30. Renal Control of pH

- This simplified diagram allows you to observe the non selective filtration of several substances that affect the pH of body fluids from the glomerular capillaries into the glomerular capsule:
  - hydrogen ions, H^+
  - bicarbonate ions, HCO_3^-
  - carbon dioxide, CO_2
  - phosphate ions, HPO_4^{-2}, $H_2PO_4^{-2}$
  - other fixed acids
- Renal tubules selectively reabsorb and secrete these acids and bases to fine-tune the pH of the plasma.

31. Renal Control of Alkalosis

- Now let's consider what happens when the amount of base increases in the body.

- If the plasma pH is too high, bicarbonate is filtered at the glomerulus, but it is not reabsorbed. Bicarbonate goes into the urine and is eliminated from the body.
- Label this diagram and show what happens to the bicarbonate during alkalosis:



- As bicarbonate is eliminated from the body, what happens to the pH of the plasma?
  ___ pH increases
  ___ pH decreases
- Bicarbonate is a base, and as more is eliminated, acid will increase and the pH will decrease.

32. Renal Control of Acidosis

- Now let's consider what happens when the acid in the body increases.
- When acid increases, there are three major ways that the kidney tubules regulate the pH of the body fluids:

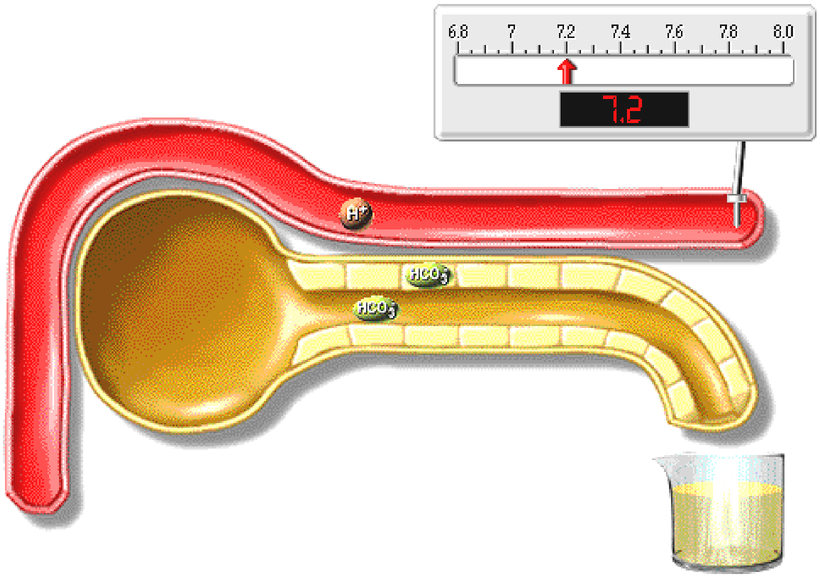
  1. Reabsorption of HCO_3^-

  2. Generation of HCO_3^- by the kidney tubule cells.
     - By adding new bicarbonate to the blood the pH increases and new buffering power is added to the blood.

  3. Secretion of H^+
- Renal mechanisms are the slowest mechanism and may take hours or days to complete.

- Renal mechanisms are important in the elimination of fixed acids from the body. Fixed acids, are constantly being generated in metabolic reactions and many must be removed from the body in the urine.
- We have just looked at the major functions of the kidney in regulating acid/base balance. The next page will describe these mechanisms in more detail.

- Show what happens to the bicarbonate and hydrogen ion in this diagram:



33. How the Kidneys Combat Acidosis

- Major ways that the kidneys combat acidosis:

  1. Conserving (Reabsorption) of $HCO3^{-}$

  2. Generation of $HCO3^{--}$

  3. Secretion of H^{+}

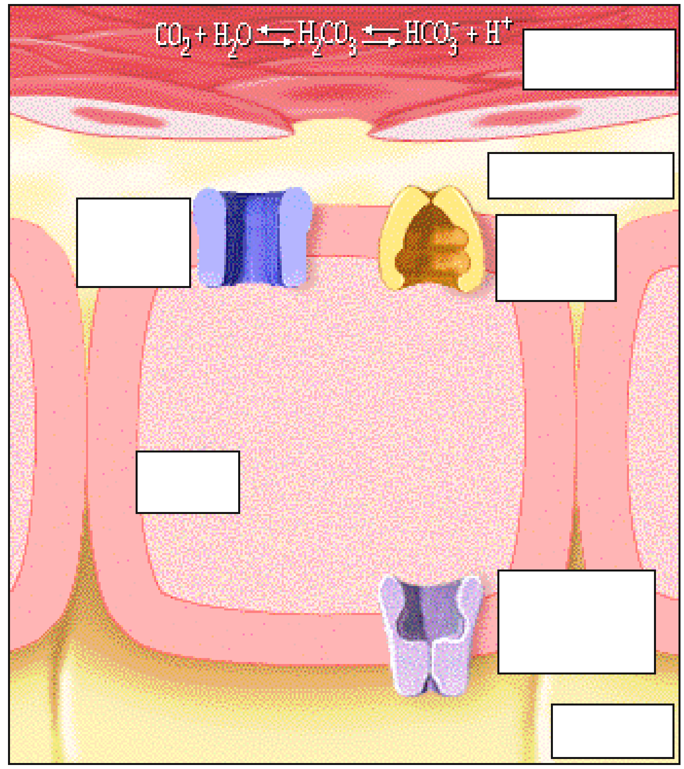
- First let's take a closer look at how the kidneys combat acidosis by conserving (reabsorbing) bicarbonate ions in the proximal convoluted tubule or PCT.

34. Reabsorption of Bicarbonate

1. Carbon dioxide arrives at the kidney tubule cell in the proximal convoluted tubule from the:
   1. filtrate
   2. plasma
   3. from metabolic reactions within the cell.

- The more carbon dioxide in the blood, as in the case of respiratory acidosis, the more enters the cell.

- Label this diagram and show how the carbon dioxide enters the cell:



2. Within the proximal tubule cell, carbon dioxide and water form carbonic acid. This reaction is catalyzed by carbonic anhydrase, shown here as CA.

$CO_2 + H_2O \rightarrow H_2CO_3$

Carbon dioxide Water

Carbonic acid

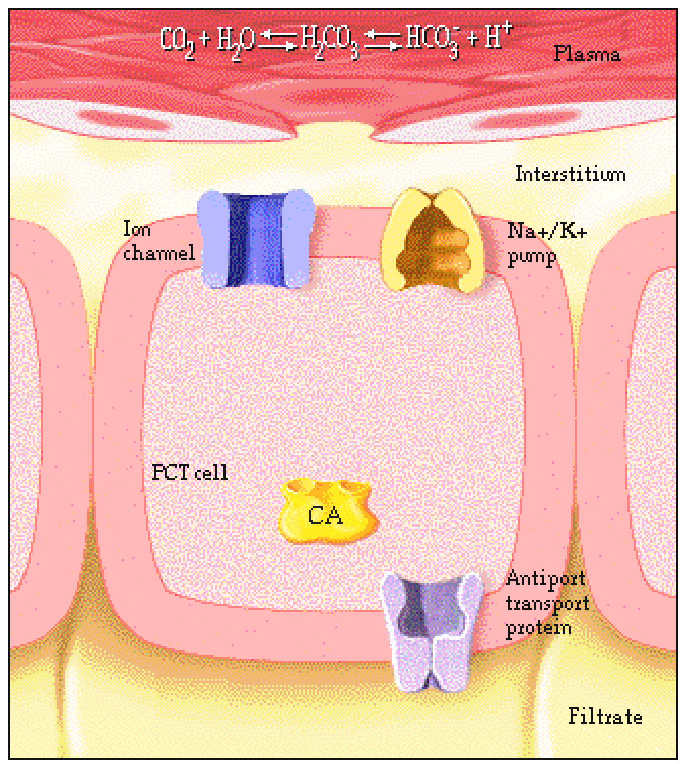
- Then the carbonic acid splits into hydrogen ions and bicarbonate.

$H_2CO_3 \rightarrow H^+ + HCO_3^-$

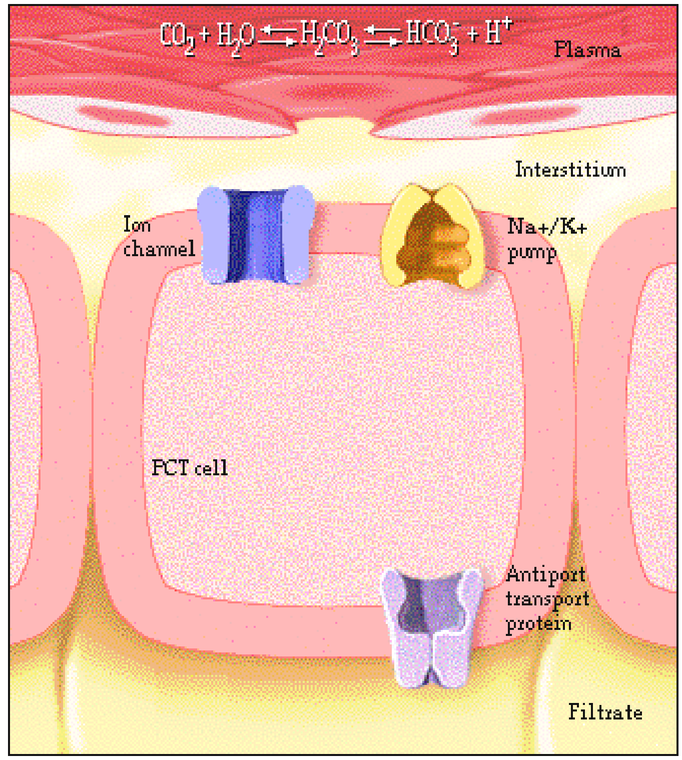
Carbonic acid Hydrogen ion

Bicarbonate

- Show what happens to the carbon dioxide:



3. The hydrogen ion moves into the filtrate in exchange for Na^+, to maintain electrical neutrality, through a sodium ion/hydrogen ion antiport transport protein, or countertransport, which is a type of secondary active transport.



- The concentration of sodium ion inside the cell is kept low by the sodium/potassium pump on the surface of the cell facing the plasma.

- This low concentration of sodium ion inside the cell drives the sodium ion/hydrogen ion antiport system.

- Show what happens to the hydrogen ion and how the sodium ion concentrations remain low within the cell:

4. In the filtrate, H^+ combines with filtered bicarbonate to form carbonic acid.

H^+ + HCO_3^- → H_2CO_3

Hydrogen ion Bicarbonate Carbonic acid

- Carbonic anhydrase then breaks apart the carbonic acid into carbon dioxide and water.

H_2CO_3 → CO_2 + H_2O

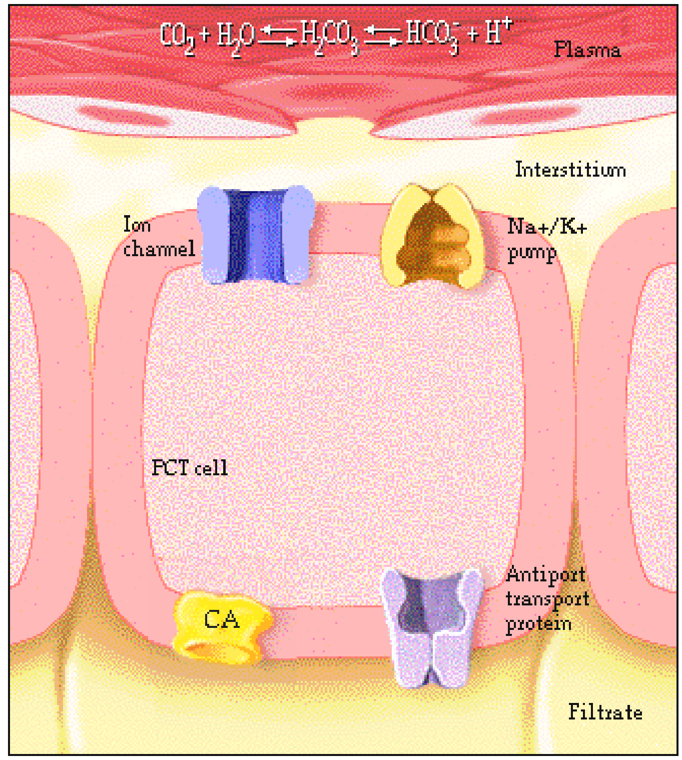
Carbonic acid Carbon dioxide Water

- The carbonic anhydrase may be attached to the brush border (microvilli) of the PCT cell.

- The carbon dioxide diffuses into the kidney tubule cell, removing bicarbonate from the filtrate. Note that bicarbonate can't move back to the filtrate itself, it must be moved back in the form of carbon dioxide.

- This carbon dioxide can reform bicarbonate within and the process repeats.

- Show what happens to the hydrogen ion within the filtrate on this diagram:

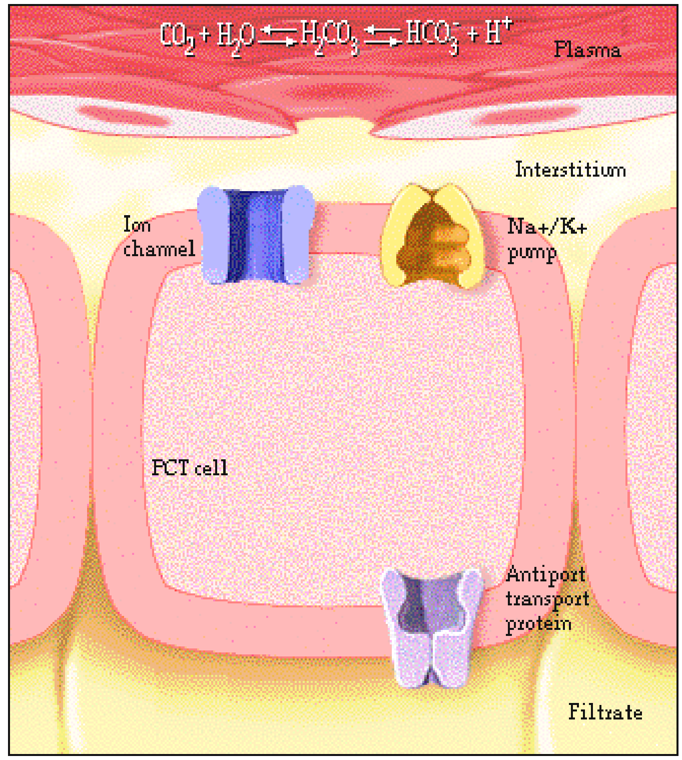


5. Much of the water generated also gets reabsorbed.

• The bicarbonate generated within the cells of the proximal convoluted tubule diffuses into the plasma.

• Sodium ion also moves out of the cell to maintain electrical neutrality.

• Show what happens to the water, sodium, and bicarbonate ions in this diagram:



• What is the result of this whole process?

1. HCO_3^- is reabsorbed into the plasma. Typically 80-90% of filtered bicarbonate is reabsorbed in the PCT.

2. You end up with more sodium ions getting reabsorbed back into the plasma.

In severe acidosis, this process continues until all the bicarbonate is reabsorbed from the filtrate.

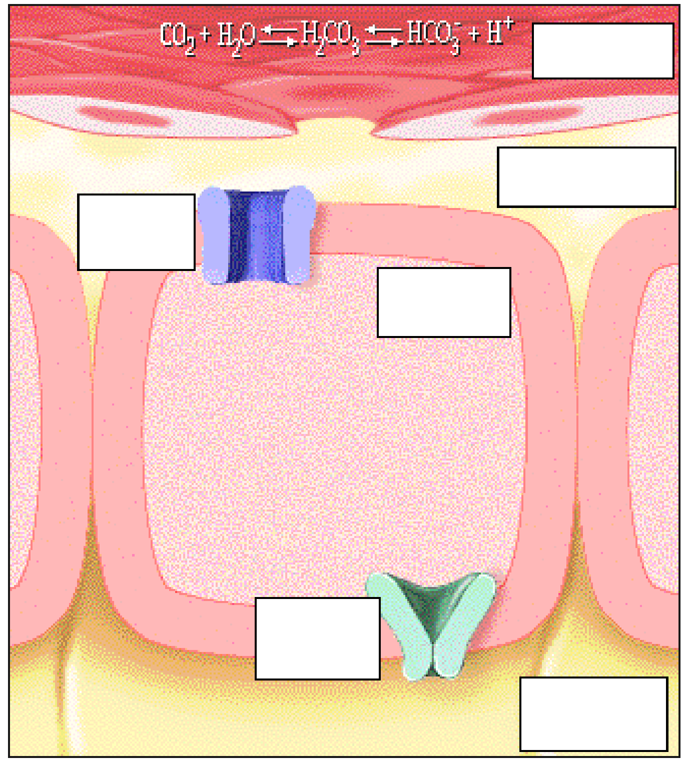
• Now let's see how additional bicarbonate can be generated in the intercalated cells of the cortical collecting duct.

35. Generation of Bicarbonate

• In order to combat acidosis, the cells of the cortical collecting duct will generate bicarbonate which is taken back up into the plasma.
• At the same time hydrogen ions are secreted into the filtrate.
• The hydrogen ions attach to buffers and are eliminated from the body. Let's see how this process occurs.

1. Carbon dioxide arrives at the kidney tubule cell in the collecting duct from the plasma or from metabolic reactions within the cell.

- Label this diagram and show this process on the diagram to the right:



2. In the kidney tubule cell carbon dioxide and water form carbonic acid. The reaction is catalyzed by carbonic anhydrase:

CO_2 + H_2O ➞ H_2CO_3

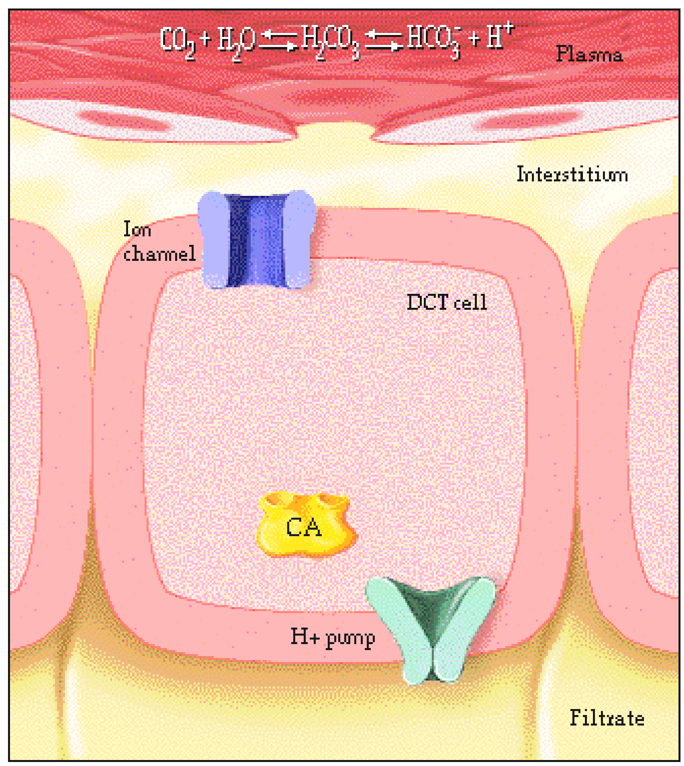
Carbon dioxide Water Carbonic acid

- Then the carbonic acid splits into hydrogen ions and bicarbonate.

H_2CO_3 ➞ H^+ + HCO_3^-

Carbonic acid Hydrogen ion Bicarbonate

- Show this process on the diagram to the right:

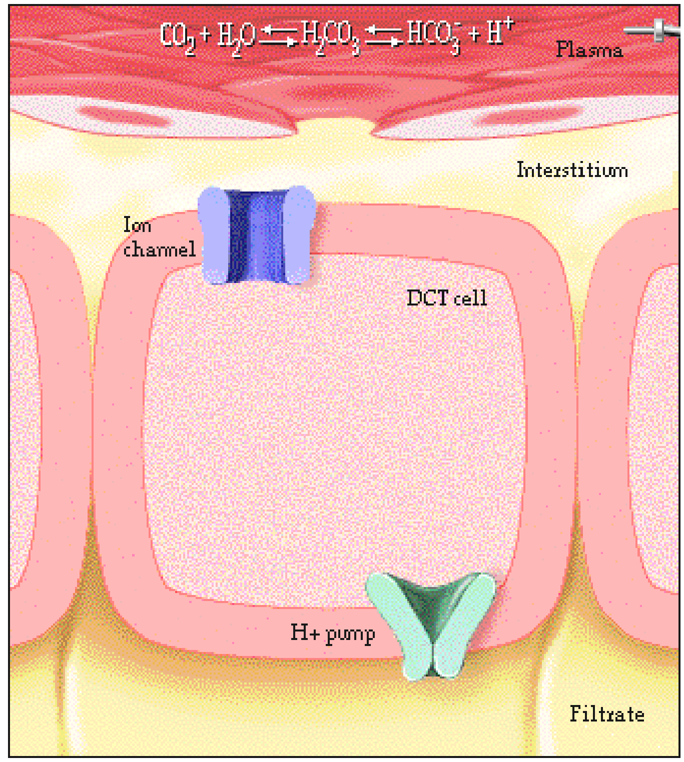


3. The hydrogen ion goes into the filtrate via primary active transport.

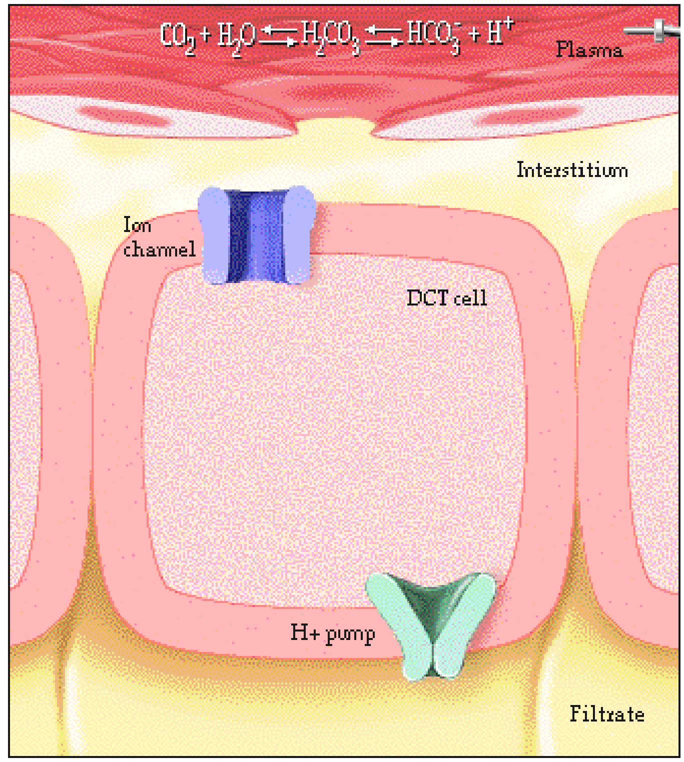
• ATP is used up.

• Hydrogen ion is secreted against the gradient and there can be a thousand times more hydrogen ion in the filtrate than in the plasma.

• Show this process on the diagram to the right:



4. Bicarbonate is scarce in the filtrate at this point because it is reabsorbed in the proximal convoluted tubule, so the hydrogen ion will combine with a buffer such as hydrogen phosphate, which is the most important buffer in the urine.



$HPO_4^{-2} + H^+ \longrightarrow H_2PO_4^{-1}$

Dihydrogen Hydrogen
Hydrogen
phosphate ion
phosphate

- The resulting dihydrogen phosphate is unable to go back into the cell and is trapped in the filtrate and excreted.

- By attaching the hydrogen ion to hydrogen phosphate the pH of the filtrate is kept above 4.5. In fact, hydrogen ion secretion will stop if the pH of the filtrate goes below 4.5.

- Show this process on the diagram to the right:

Continue to Acid/Base Homeostasis – Part IV
(Separate Document)

Acid/Base Homeostasis (Part 4)

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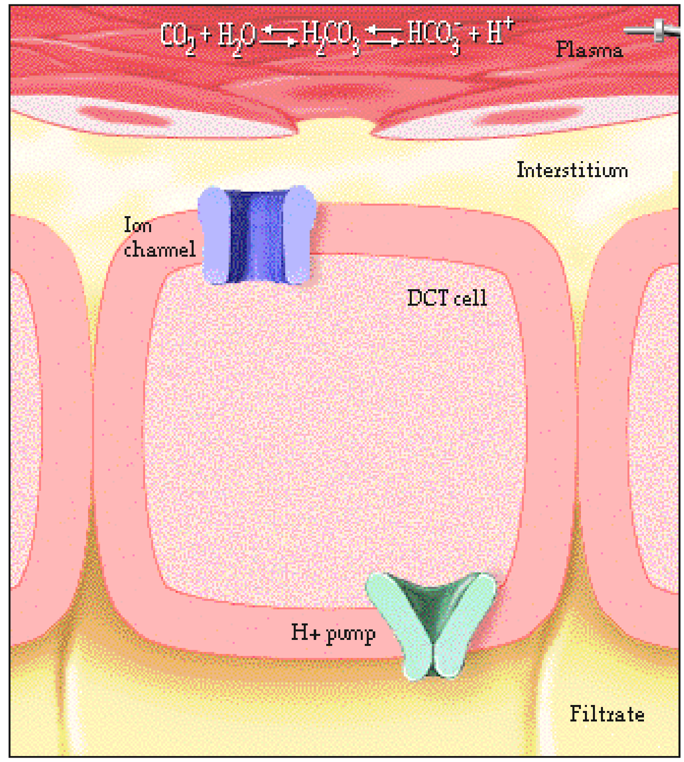
5. The newly formed bicarbonate moves into the plasma.

- Chloride ion moves into the cell at the same time to maintain electrical neutrality.

- What effect does the increase in bicarbonate in the blood have on the pH of the plasma?
  __ pH increases
  __ pH decreases

- By adding newly generated bicarbonate to the plasma, hydrogen ion is used up and the pH increases.

- Show this process on the diagram to the right:



Here are our results:

- Newly generated bicarbonate is added to the plasma, increasing the pH of blood and adding new buffering power to the plasma.
- Hydrogen ion is secreted into the filtrate, attaches to buffers, and is eliminated from the body.

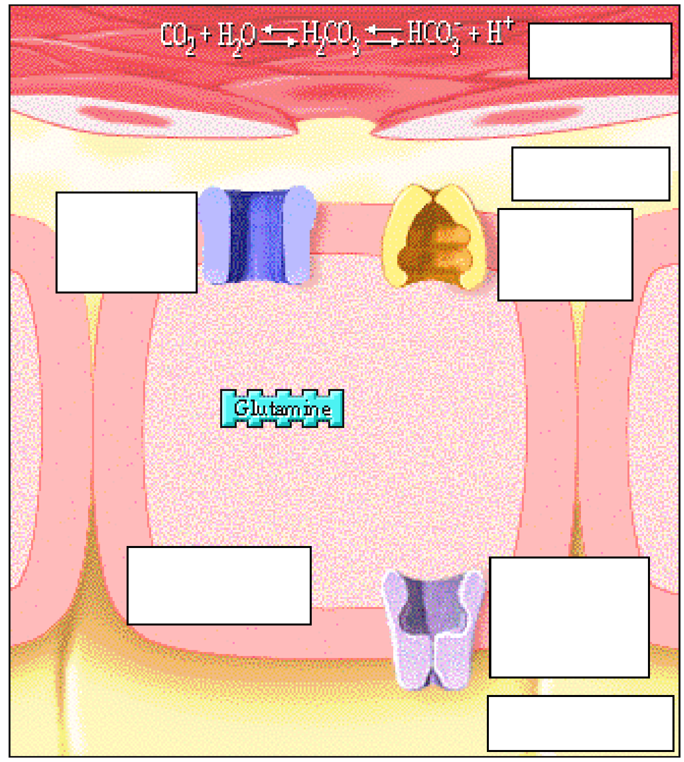
36. Glutamine Metabolism

1. A second and more important process for generating bicarbonate and secreting hydrogen ion occurs within the cells of the proximal convoluted tubule.

- Glutamine is an amino acid that is metabolized in the tubule cells of the kidney. The products of its metabolism are ammonia and bicarbonate.

- The ammonia, which is a base combines with a hydrogen ion inside the cell to form ammonium.

- Label this diagram and show this process on the diagram to the right:

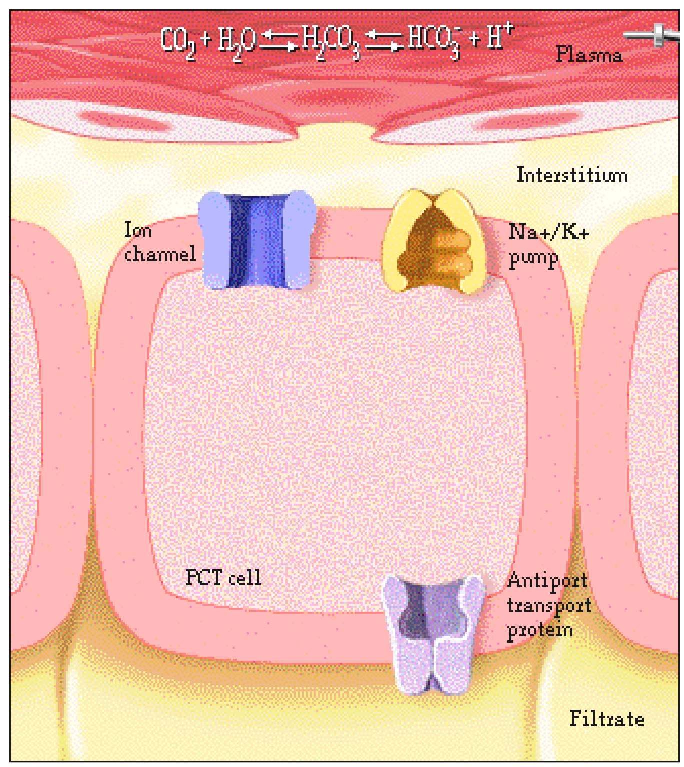


2. The ammonium then travels from the kidney tubule cell to the filtrate in exchange for sodium via an antiport transport protein, or countertransport, which is a type of secondary active transport.

- The sodium ion concentration is kept low inside the cells by the sodium/potassium pump.

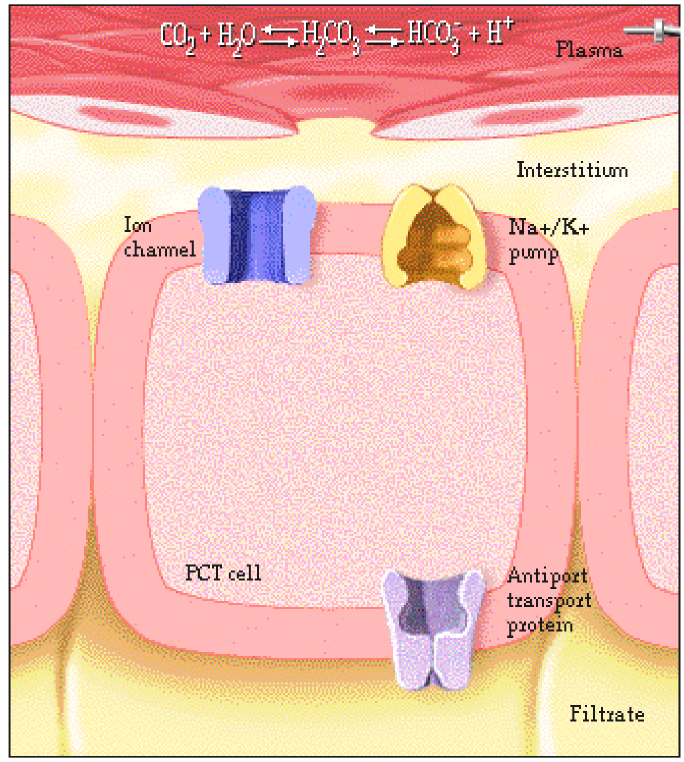
- This ammonium is eliminated in the urine. This ion is unable to diffuse back into the cell, therefore trapping the H^+ in the filtrate for excretion.

- Show this process on the diagram to the right:



3. The bicarbonate leaves the kidney tubule cell together with sodium and goes into the plasma.

- Show this process on the diagram to the right:

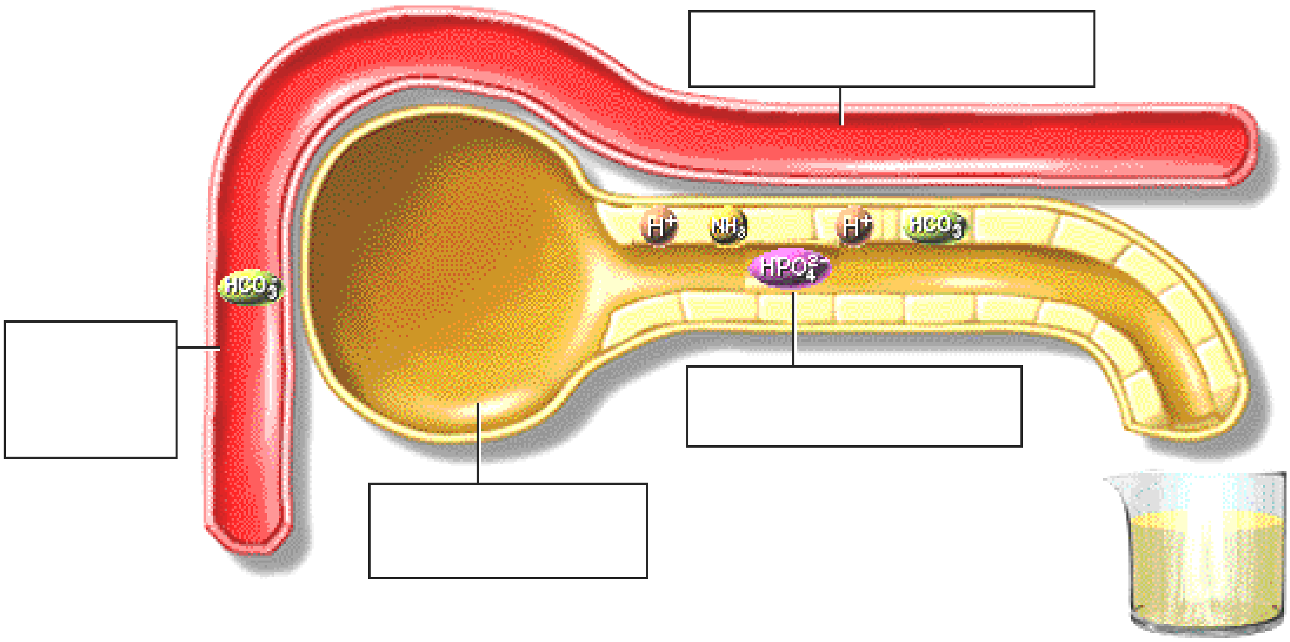


- Result:
  1. Newly generated bicarbonate is added to the blood, increasing the pH of plasma and adding new buffering power to the plasma.
  2. Hydrogen ion is eliminated from the body in the form of ammonium.

37. Summary: Renal Control of Acidosis

- Summary: Three mechanisms for renal control of acidosis:
  1. Conserving (reabsorption) of $HCO3^-$.
  2. Generating $HCO3^-$ by the kidney tubule cells increases the pH of the plasma and adds new buffering power to the plasma.
  3. Secreting buffered H^+ into the urine eliminates H^+ from the body and increases the pH of the plasma.

- Illustrate the three mechanisms for renal control of acidosis on this diagram:



*Now is a good time to go to quiz question 4:

- Click the Quiz button on the left side of the screen.
- Work through all parts of question 4.
- After answering question 4, click on the Back to Topic button on the left side of the screen.
- To get back to where you left off, click on scrolling page list at the top of the screen.
- Choose "38. Mechanisms the Body Uses to Maintain pH."

38. Mechanisms the Body Uses to Maintain pH

Let's review the mechanisms the body uses to maintain pH.

1. Chemical Buffers
   - Chemical buffers act within seconds to correct abnormalities in pH within the body fluids.
2. Respiratory Control
   - The respiratory control mechanism is slower than the buffers mechanism and may take minutes to begin.
   - This mechanism is important in compensating for metabolic acidosis or alkalosis.
   - Via the respiratory mechanism, the volatile acid, carbonic acid is eliminated from the body as carbon dioxide.
3. Renal Mechanisms
   - Renal mechanisms are the slowest mechanisms may take hours or days to complete.
   - Renal mechanisms are important in compensating for respiratory acidosis or alkalosis.
   - These mechanisms are important in the elimination of fixed acids from the body.

39. Effect of Plasma Proteins on pH

- The normal arterial plasma pH is between 7.35 and 7.45.
- Remember, most proteins in the plasma have an optimum pH of 7.4.
- Which of these conditions is associated with a pH greater than 7.45?
  ___ Acidosis
  ___ Alkalosis
- Alkalosis occurs when the pH of the blood rises above 7.45. There are two major types of alkalosis:
  - Metabolic alkalosis
  - Respiratory alkalosis
- Acidosis occurs when the pH of the plasma falls below 7.35. There are two major types of acidosis:
  - Metabolic acidosis
  - Respiratory acidosis

40. Compensation for Acidosis and Alkalosis

The body compensates for acidosis and alkalosis with three major mechanisms:

- Chemical buffers
- Respiratory system
- Urinary System

- Chemical buffers work quickly and immediately, but they have a limited capacity. When the buffer systems become overwhelmed, as in acidosis or alkalosis, the respiratory and urinary systems compensate.
- Note that compensatory mechanisms help return the pH to normal or near normal levels, but do not correct the underlying problem.
- When metabolic acidosis or alkalosis occurs, the respiratory system will compensate by changing the rate of respiration.
- When respiratory acidosis or alkalosis occurs, the problem lies within the respiratory system. Because the respiratory system is not able to correct the condition, the urinary system compensates for the problem.
- On the next four pages we will examine the four major acid/base disturbances and the compensatory mechanisms that help to restore pH to normal levels.

41. Causes of Metabolic Acidosis

- Metabolic acidosis occurs when there is an excess of any body acid, except carbonic acid.
- Metabolic acidosis occurs if there is too much acid production in the body, or if there is loss of base.
- An excess of metabolic acids can occur as a result of many conditions including ketoacidosis from total absence of insulin in the body, or starvation, lack of oxygen in the tissues which causes the production of

lactic acid, and some types of kidney disease, which prevent elimination of acid from the body.

- Fill out this chart:

Excess Acid Production	Loss of Base

- Excess acid can also appear in the extracellular fluids due to a high potassium ion concentration in the extracellular fluid. As the excess potassium moves into the cells, hydrogen ion comes out.
- Loss of base can occur as a result of excessive diarrhea, which causes the loss of bicarbonate that is plentiful in interstitial fluid.
- Let's look at a specific example of metabolic acidosis, diabetic ketoacidosis.

42. Symptoms of Diabetic Ketoacidosis

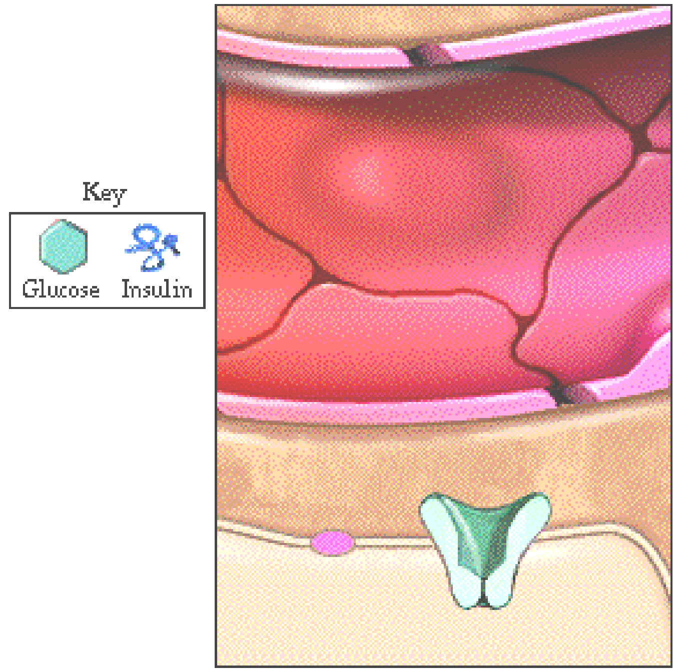
- Jennifer Smith, age 14, has been brought to the emergency room. Her parents were unable to awaken her for school this morning.
- Mr. and Mrs. Smith report to the ER physician that Jennifer has been eating a lot but still losing weight for the past month. She has also been thirsty, drinking large amounts of water, and going to the bathroom frequently.
- The physician notices that Jennifer is difficult to awaken, her skin is warm, dry, and flushed, and she is breathing deeply and rapidly.
- You've seen the effect that altered pH has on proteins in the body. The systemic effects of ketoacidosis can be dramatic.
- The individual with ketoacidosis may experience central nervous system depression, heart dysrhythmias, and decreased cardiac contractility as a result of increased intracellular acidity.
- In Jennifer's case she is also experiencing the effects of dehydration from increased blood glucose and increased osmolarity.
- When the blood pH reaches approximately 6.9 brain stem dysfunction occurs, closely followed by death.
- Fortunately Jennifer is in a health care facility where she will be treated.
- After some laboratory tests the physician determines that Jennifer has developed Type I diabetes. As sometimes happens, ketoacidosis is the first indication of the presence of Type I diabetes.
- Let's look more closely at what is happening with Jennifer.

43. Role of Insulin

- In normal cell metabolism, the hormone insulin is released from beta cells in the pancreas when a person eats and allows glucose transport across the cell membrane of some cells.

- When insulin is absent, as in Type I diabetes for example, fat breakdown occurs and production of keto acids by the liver increases until the body's buffer systems become overwhelmed and ketoacidosis ensues.

- Illustrate the role of insulin on the diagram to the right:



- Would you expect Jennifer's blood pH to be high or low?

- Because Jennifer has developed ketoacidosis, her pH will fall.

44. Compensation for Metabolic Acidosis

<u>Compensation for Metabolic Acidosis</u>

- Once an individual has metabolic acidosis, the carbonic acid/bicarbonate buffer system will come into action. Which direction will the equilibrium reaction go ?

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

Carbon dioxide Water Carbonic acid

Bicarbonate Hydrogen ion

___ Equilibrium shifts to the right

___ Equilibrium shifts to the left

- Because more H^+ is being generated in the body, the excess H^+ will combine with $HCO3^-$ to form CO_2.
- As a result of metabolic acidosis, will the level of $HCO3^{-1}$ increase or decrease?

  ___ $HCO3^-$ increases

  ___ $HCO3^-$ decreases
- Because there is an excess amount of H^+, the H^+ will react with $HCO3^{-1}$ as a result of metabolic acidosis, and the $HCO3^-$ will decrease.

- Which body system will respond to compensate for this acid/base imbalance? Click the correct answer.
  __Urinary system
  __Respiratory system
- The respiratory system will compensate in an effort to bring the pH back toward normal.
- Predict how the Jennifer will compensate for metabolic acidosis.
  __Breathe faster
  __Breathe slower
- Because of the increased CO2, the respiratory centers in the brain and large arteries are stimulated. The patient will begin to breathe faster and deeper. This response is called hyperventilation.
- Hyperventilation allows the body to reduce the overall amount of acid by exhaling H_2CO_3 in the form of CO2 and H_2O.
- Although the respiratory system is the primary compensatory mechanism for metabolic acidosis, the kidneys are not idle.
- The kidneys will respond to the decreased pH by excreting more H^+. This response may take several days to occur.

- Respiratory compensation is much faster.
- The body's compensatory mechanisms serve to return the pH to normal or near normal levels, but they do not correct the underlying problem.
- In the case of diabetic ketoacidosis, insulin must be administered to restore normal cell metabolism .

45. Causes of Metabolic Alkalosis

Causes of Metabolic Alkalosis

- Metabolic alkalosis is caused by a relative deficit of any acid in the body, except carbonic acid.
- Metabolic alkalosis can occur from an excess of base in the body. Ingestion of too much bicarbonate, or baking soda, would produce an excess of base.
- Metabolic alkalosis can also occur as a result of too little acid in the body . Vomiting of stomach contents containing hydrochloric acid would deplete the acid in the body.
- Metabolic alkalosis can occur when there is too little potassium in extracellular fluid. Hypokalemia causes potassium to come out of cells in exchange for hydrogen ion.
- List the causes of metabolic alkalosis here:

Loss of acid	Too much base

46. Stomach Flu

- Let's look at an example to see how alkalosis occurs.
- Jose Fuentes has caught the stomach flu that's been going around the office, and is vomiting.
- As a result of vomiting, Jose is losing a lot of stomach acid. What would you expect to happen to his blood pH ?
- His pH will rise indicating he is becoming alkalotic from loss of hydrogen ion.
- As alkalosis progresses, Jose will experience the effects of rising pH on interstitial fluid.
- Initially nerve cell membranes become irritable and muscle spasm and convulsions may occur.
- With severe alkalosis, central nervous system depression occurs, and confusion, lethargy, and coma ensue.
- Death occurs when the blood pH reaches about 7.8.
- Fortunately, Jose has a 24 hour flu. Let's see how his body compensates to keep his pH from getting too high.

47. Compensation for Metabolic Alkalosis

<u>Compensation for Metabolic Alkalosis</u>

- Once an individual has metabolic alkalosis, the carbonic acid/bicarbonate buffer system will come into action. Now which direction will the equilibrium reaction go ?

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

Carbon dioxide Water Carbonic acid

Bicarbonate Hydrogen ion

___ Equilibrium shifts to the right

___ Equilibrium shifts to the left

- Because there is less H^+ in the body, the reaction will shift to the right and more H^+ and $HCO3^-$will form.
- Predict how Jose's body will compensate for metabolic alkalosis.

  __Hypoventilate

  __Hyperventilate
- As the equation shifts to the right, CO2 decreases. The respiratory centers in the brain are inhibited and Jose hypoventilates.

- Jose has lost chloride and fluid volume as well as acid. These combined losses prevent the kidneys from excreting excess base.
- As with the other acid/base disturbances, compensatory mechanisms help keep the pH in a range appropriate for body function but they do not correct the underlying problem. Within 24 hours, Jose will be feeling a lot better.

48. Causes of Respiratory Acidosis

Causes of Respiratory Acidosis

- Respiratory acidosis occurs when there is an excess of carbon dioxide, and therefore an increase in carbonic acid in the body.
- Because carbonic acid is excreted by the lungs in the form of carbon dioxide and water, any condition that impairs the elimination of CO_2 may result in respiratory acidosis.
- Causes of respiratory acidosis include conditions that impair exchange of gases in the lungs, activity of the diaphragm muscle, or respiratory control in the brain stem.

49. Emphysema

- Patrick O'Shea has smoked cigarettes for 45 years and has emphysema.
- In emphysema, alveolar walls disintegrate over time, producing large air spaces that remain filled with gases during expiration. This condition reduces the surface area in the lung available for exchange of oxygen and carbon dioxide.
- As a result of this destructive process, carbon dioxide becomes trapped in the alveoli and blood levels of carbon dioxide rise.

50. Symptoms of Respiratory Acidosis

Symptoms of Respiratory Acidosis

Headache
Cardiac dysrhythmias
Blurred vision
Dizziness
Disorientation
Lethargy

- The neurologic symptoms of respiratory acidosis are sometimes more severe than those of metabolic acidosis because carbon dioxide crosses the blood-brain barrier more readily than many metabolic acids.
- Because emphysema is a long term process the cumulative effects of respiratory acidosis may not be seen for many years.
- If Patrick were to develop an acute episode of pneumonia, further reducing the lung's ability to exchanges gases, symptoms would become evident more rapidly.

- As a result of respiratory acidosis from emphysema, which direction will this equation go?
- As a result of emphysema, which direction will this equation go?

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

Carbon dioxide Water Carbonic acid

Bicarbonate Hydrogen ion

___ Equilibrium shifts to the right

___ Equilibrium shifts to the left

- The build-up of carbon dioxide in the blood causes the equilibrium to shift to the right.
- What happens to acid levels in the blood ?

___ Acid levels rise

___ Acid levels fall

- Acid levels rise.

51. Compensation for Respiratory Acidosis

Compensation for Respiratory Acidosis

- Now predict how the body compensates for respiratory acidosis. Click all that apply.

___ Hypoventilation

___ Hyperventilation

___ Kidneys retain bicarbonate

___ Kidneys excrete bicarbonate

___ Kidneys excrete H^+

- The kidneys will reabsorb and generate bicarbonate to maintain acid/base balance. The kidneys will also excrete excess hydrogen ion in the urine.

- Patrick may survive for many years without obvious symptoms of respiratory acidosis, however because he has smoked for so many years, other respiratory conditions such as pneumonia may cause serious problems for him.

52. Causes of Respiratory Alkalosis

Causes of Respiratory Alkalosis

- Respiratory alkalosis is a deficit of carbon dioxide and occurs as a result of hyperventilation.
- When respirations are excessively deep and rapid, carbonic acid is excreted rapidly from the lungs in the form of carbon dioxide and water. The result is a deficit of both carbon dioxide and carbonic acid.
- What causes an individual to hyperventilate to the point of carbonic acid deficit? Low levels of oxygen in the blood, may cause

hyperventilation. Stimulation of the brain stem in the case of meningitis may cause hyperventilation. Head injury may also cause hyperventilation.

- For Sally, however, hyperventilation appears to be caused by severe anxiety over a visit to the dentist. Let's see how this works.

53. Symptoms of Respiratory Alkalosis

Symptoms of Respiratory Alkalosis

- Sally is nervous about her visit to the dentist and begins to breathe much more rapidly than usual.
- The symptoms of respiratory alkalosis reflect the irritation to the central and peripheral nervous system that occurs when pH rises too high. The individual may exhibit numbness and tingling in the fingers and around the mouth, dizziness, and confusion.
- As a result of hyperventilation, which direction will this equation go?

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

Carbon dioxide Water Carbonic acid

Bicarbonate Hydrogen ion

___ Equilibrium shifts to the right

___ Equilibrium shifts to the left

- With each exhalation, more carbonic acid is eliminated from the lungs as CO2. The reaction proceeds to the left.
- What will happen to the concentration of H^+ in the blood?

___H^+ increases

___ H^+ decreases

- H^+ will decrease because the H^+ is combining with HCO_3^- to form more CO_2.

54. Compensation for Respiratory Alkalosis

Compensation for Respiratory Alkalosis

- How will Sally's body compensate for respiratory alkalosis. Click the correct answer.

____Retain bicarbonate

___Excrete bicarbonate

__ Hyperventilate

__ Hypoventilate

- Because this is an acid/base disturbance of respiratory origin, the kidneys will excrete bicarbonate, the base, to compensate for the loss of acid.
- In reality renal compensation occurs relatively slowly.

- Because the underlying cause of Sally's alkalosis is short lived, renal compensation may not in fact occur.
- Sally will probably return to acid/base homeostasis as soon as her visit to the dentist is over and her respiratory rate returns to normal.

55. Metabolic Acidosis Review

You have just been introduced to the four major acid/base disturbances and their corresponding compensatory mechanisms. Let's review this information.

Continue to Acid/Base Homeostasis – Part V
(Separate Document)

Acid/Base Homeostasis (Part 5)

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Metabolic Acidosis

- What is the cause of metabolic acidosis? Click all that apply.
  ___ Excess H+ generated within the body
  ___ Loss of base from the body
  ___ Deficit of H+ within the body
  ___ Gain of base in the body
- Metabolic acidosis can be caused by either a gain of acid or a loss of base from the body.
- Which of the following would be observed in simple, uncompensated metabolic acidosis?
  ___ CO_2 rises
  ___ CO_2 falls
  ___ HCO_3^- rises
  ___ HCO_3^- falls
- HCO_3^- levels fall due to loss of HCO_3^- from the body or increased acid reacting with HCO_3^-.
- What system will compensate for respiratory acidosis?
  ___ Respiratory system
  ___ Renal system
- Because the problem is metabolic in origin, the respiratory system compensates.
- Will this individual hyperventilate or hypoventilate?
  ___ Hyperventilate
  ___ Hypoventilate
- The individual hyperventilates to blow off the excess carbon dioxide which is generated.
- As a result of compensation, which direction will this reaction go?

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

Carbon dioxide   Water   Carbonic acid
Bicarbonate   Hydrogen ion

- The increased hydrogen ion stimulates the respiratory centers, increasing ventilation, decreasing carbon dioxide, and shifting the reaction to the left.
- Fill out this chart as you go through the next few pages:

	Acidosis	Alkalosis
Metabolic	**Cause:**	**Cause:**
	Compensation: $CO_2 + H_2O$ H_2CO_3 $HCO_3^- + H^+$	**Compensation:** $CO_2 + H_2O$ H_2CO_3 $HCO_3^- + H^+$
Respiratory	**Cause:** $CO_2 + H_2O$ H_2CO_3 $HCO_3^- + H^+$	**Cause:** $CO_2 + H_2O$ H_2CO_3 $HCO_3^- + H^+$
	Compensation:	**Compensation:**

56. Metabolic Alkalosis Review

<u>Metabolic Alkalosis</u>

- What is the cause of metabolic alkalosis? Click all that apply.
  - ___ Excess H+ generated within the body
  - ___ Loss of base from the body
  - ___ Deficit of H+ within the body
  - ___ Gain of base in the body
- Metabolic alkalosis can be caused by either a loss of acid or a gain of base in the body
- Which of the following would be observed in simple, uncompensated metabolic alkalosis?
  - ___ CO_2 rises
  - ___ CO_2 falls
  - ___ HCO_3^- rises
  - ___ HCO_3^- falls
- HCO_3^- levels rise due to gain of HCO_3^- or decreased acid reacting with HCO_3^-.
- What system will compensate for metabolic alkalosis?
  - ___ Respiratory system
  - ___ Renal system
- Because the problem is metabolic in origin, the respiratory system compensates.
- Will this individual hyperventilate or hypoventilate?
  - ___ Hyperventilate
  - ___ Hypoventilate
- The individual hypoventilates to conserve CO_2.
- As a result of compensation, which direction will this reaction go?

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

Carbon dioxide Water Carbonic acid

Bicarbonate Hydrogen ion

- The decreased H^+ causes the equilibrium reaction of this reaction to shift to the right.
- Notice that the equilibrium reaction illustrates how the respiratory system compensates for metabolic acidosis and alkalosis. The respiratory system is not the cause of the condition.

57. Respiratory Acidosis Review

Respiratory Acidosis

- What is the cause of respiratory acidosis?
  - ___ Excess H^+ generated in the body
  - ___ Loss of base from the body
  - ___ Deficit of H^+ from the body
  - ___ Gain of base from the body
  - ___ Increased H_2CO_3
  - ___ Decreased H_2CO_3
- Respiratory acidosis occurs because CO_2 is not eliminated from the body.
- As a result of respiratory acidosis, which direction will this reaction go?

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

Carbon dioxide Water Carbonic acid

Bicarbonate Hydrogen ion

- Yes, the increased CO_2 in the blood will cause the reaction to shift to the right.
- Which of the following would be observed in simple, uncompensated respiratory acidosis?
  - ___ CO_2 rises
  - ___ CO_2 falls
  - ___ HCO_3^- rises
  - ___ HCO_3^- falls
- CO_2 rises because the individual is unable to blow off this gas.
- What system will compensate for respiratory acidosis?
  - ___ Respiratory system
  - ___ Renal system
- Over time, the renal system will compensate by generating or reabsorbing HCO_3, or excreting H+, but it may take hours or days for complete compensation to occur.

- Fill out this chart with the virtual professor:

NORMAL	ABOVE	BELOW

58. Respiratory Alkalosis Review

Respiratory Alkalosis

- What is the cause of respiratory alkalosis? Click all that apply.
  - ___ Excess H^+ generated in the body
  - ___ Loss of H^+ from the body
  - ___ Loss of CO_2 from the body
  - ___ Buildup of CO_2 in the body
- Respiratory alkalosis occurs when too much carbon dioxide is eliminated from the body because of hyperventilation.
- As a result of respiratory alkalosis, which direction will this reaction go?

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

Carbon dioxide Water Carbonic acid

Bicarbonate Hydrogen ion

- The equilibrium reaction shifts to the left as acid is used up.
- As carbon dioxide is blown off, which direction will the reaction go?
- Which of the following would be observed in simple, uncompensated respiratory alkalosis
  - ___ CO_2 rises
  - ___ CO_2 falls
  - ___ HCO_3^- rises
  - ___ HCO_3^- falls
- Yes, CO_2 falls due to hyperventilation.
- What system will compensate for respiratory alkalosis?
  - ___ Respiratory system
  - ___ Renal system
- Over time, the renal system will compensate by excreting excess base.

59. Summary

Here's a summary of what we've covered:

- Chemical buffers quickly adjust small changes in pH
- By altering the rate of respiration, the respiratory system can eliminate carbonic acid, a volatile acid, in the form of carbon dioxide.
- By retaining, generating, or eliminating bicarbonate, or secreting hydrogen ion, the urinary system can regulate the pH of body fluids.
- Respiratory acidosis, respiratory alkalosis, metabolic acidosis, and metabolic alkalosis are the four most common disturbances of acid/base balance.
- Compensation for respiratory acidosis and respiratory alkalosis involve renal mechanisms. Compensation for metabolic acidosis and metabolic alkalosis involve respiratory mechanisms.

*Now is a good time to go to quiz questions 5-6:

- Click the Quiz button on the left side of the screen.
- Work through all parts of questions 5-6.

<u>Notes on Quiz Questions:</u>

Quiz Question #1: Weak and Strong Acids and Bases

- This question has you predict if acids or bases are strong or weak.

Quiz Question #2: Buffers

- This question has you predict what happens when acid is added to water vs. adding acid to a buffer.

Quiz Question #3: Respiratory Control

- This question has you predict what happens during hypoventilation and hyperventilation.

Quiz Question #4: Renal Control

- This question asks you to predct what will happen in the kideny during acidosis.

Quiz Question #5: Reabsorption of Bicarbonate

- This question asks you to list the steps in the reabsorption of bicarbonate.

Quiz Question #6: Acid/Base Game

- This question asks you to predict the type of acid/base disturbance.

Quiz Question #7: Name that Acid/Base Disturbance

- This question asks you to predict the type of acid/base disturbance.

Study Questions on Acid/Base Homeostasis:

1. (Page 1.) What three systems work together to ensure that the pH of body fluids remain within a specific narrow limit?

2. (Page 3.) How do we measure the acidity or basicity of a solution?

3. (Page 3.) What does pH measure?
4. (Page 3.) Where do acids and bases in our bodies come from?

5. (Page 4.) Which pH is the most acidic, pH 4 or 8?

6. (Page 4.) The lower the pH, the more ______ the solution is. The higher the pH, the more ______ the solution is.

7. (Page 4.) When H^+ increases, acidity ________, and pH _________.

8. (Page 4.) When H^+ decreases, acidity ________, and pH _________.

9. (Page 4.) When we increase or decrease the pH by one pH unit, we are changing the concentration of H^+ by a factor of ___.

10 (Page 4.) Label the diagram on page 4.

11. (Page 5.) Label the diagram on page 5 with the pH's.

12. (Page 5.) Which of the compartments in the diagram on page 5 is the most acidic?

13. (Page 6.) Label the diagram on page 6 with the pH's.

14. (Page 7.) Define acid.

15. (Page 7.) What is a strong acid?

16. (Page 7.) Write an equation for what happens when the strong acid, HCl dissolves in water.

17. (Page 8.) What's the difference between a strong and a weak acid?

18. (Page 8.) Give the equation for what happens when carbonic acid is dissolved in water.

19. (Page 9.) Do all weak acids have the same acidity?

20. (Page 10.) Define base.

21. (Page 10.) What is another name for a basic solution?

22. (Page 10.) Give an equation that shows what happens when bicarbonate is dissolved in water.

23. (Page 10.) Label the diagram on page 10 with the pH's.

24. (Page 11.) What pH is neutral?

25. (Page 11.) Indicate the pH's on the appropriate beakers on the diagram on p. 11.

26. (Page 12.) Consider the electrolyte chart on p. 12.
   a. Which electrolytes can serve as weak bases?
   b. Which electrolytes can serve as weak acids?

27. (Page 13.) Why is maintaining the pH of body fluids is very important?

28. (Page 14.) What happens when acid is added to a globular protein?

29. (Page 15.) What happens when base is added to a globular protein?

30. (Page 16.) What are the three mechanisms the body uses to maintain a normal pH range?

31. (Page 16.) What happens when acid is added to an unbuffered solution, such as water?

32. (Page 16.) What are buffers composed of?

33. (Page 16.) What is the purpose of a buffer?

34. (Page 16.) What are the three important buffer systems in the body?

35. (Page 17.) Consider the carbonic acid/bicarbonate buffer system. Which is the weak acid and which is the weak base? H_2CO_3, HCO_3^-

36. (Page 17.) When acid is added to the carbonic acid/bicarbonate buffer system, what happens.

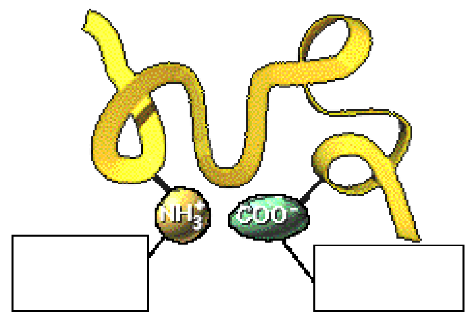
37. (Page 17.) When base is added to the carbonic acid/bicarbonate buffer system, what happens.

38. (Page 18.) Consider the dihydrogen phosphate/hydrogen phosphate buffer system. Which is the weak acid and which is the weak base? $H_2PO_4^-$, $HPO_4^=$

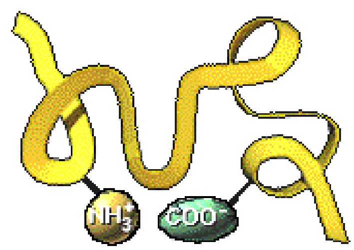
39. (Page 18.) When acid is added to the dihydrogen phosphate/hydrogen phosphate buffer system, what happens.

40. (Page 18.) When base is added to the dihydrogen phosphate/hydrogen phosphate buffer system, what happens.

41. (Page 19.) Label the side chains in this protein.



42. (Page 19.) What happens to the COO^- group when acid is added?



43. (Page 19.) What happens to the NH_3^+ group when acid is added?

44. (Page 20.) Explain dynamic equilibrium in terms of the carbonic acid/bicarbonate buffer system.

45. (Page 21.) When the body is not in homeostasis and there is too much carbonic acid in the body fluids, which way will the reaction go, to the left or to the right?

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

Carbonic acid Hydrogen ion Bicarbonate

46. (Page 22.) When the body is not in homeostasis and there is too much hydrogen ion in the body fluids, which way will the reaction go, to the left or to the right?

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

Carbonic acid Hydrogen ion Bicarbonate

47. (Page 23.) When the body is not in homeostasis and there is not enough hydrogen ion in the body fluids, which way will the reaction go, to the left or to the right?

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

Carbonic acid Hydrogen ion Bicarbonate

48. (Page 24.)What is the equation for cell metabolism that occurs within the cells of the body?

49. (Page 24.)What happens to the carbon dioxide generated by this equation?

50. (Page 24.) When we breathe more deeply and quickly, what happens to the carbon dioxide leaving the lungs?

51. (Page 24.)When we breathe more slowly or more shallowly, what happens to the carbon dioxide leaving the lungs?

52. (Page 25.) What is the relationship between carbonic acid and carbon dioxide and water?

53. (Page 25.) What enzyme catalyses the reaction between carbonic acid and carbon dioxide and water?

54. (Page 26.) This is the equation for the carbonic acid/bicarbonate buffer.

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

Carbonic acid Bicarbonate Hydrogen ion

This is the equation for the breakdown of carbonic acid into carbon dioxide and water.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

Carbon dioxide Water Carbonic acid

Put together these two equations to show the dynamic equilibrium between carbon dioxide and bicarbonate.

55. (Page 27.) If the rate of respiration decreases or if the exchange of gases in the lungs is impaired, what happens to the carbon dioxide in the plasma, will it increase or decrease?

56. (Page 27.) If the rate of respiration decreases or if the exchange of gases in the lungs is impaired, what happens to the direction of this equation, will it shift to the left or to the right?

$$CO_2 \quad + \quad H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3 \; + \; H^+$$

Carbon dioxide Water Carbonic acid
Bicarbonate Hydrogen ion

57. (Page 27.) If the rate of respiration decreases, what will happen to the pH of the plasma, will it increase or decrease?

58. (Page 28.) If the respiration rate increases to above normal, what happens to the carbon dioxide in the plasma, will it increase or decrease?

59. (Page 28.) If the rate of respiration increases, what happens to the direction of this equation, will it shift to the left or to the right?

$$CO_2 \quad + \quad H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3 \; + \; H^+$$

Carbon dioxide Water Carbonic acid
Bicarbonate Hydrogen ion

60. (Page 28.) If the rate of respiration increases, what will happen to the pH of the plasma, will it increase or decrease?

61. (Page 28.) Why is carbonic acid considered to be a volatile acid?

62. (Page 29.) Label the diagram on page 29.

63. (Page 29.) What are three renal processes?

64. (Page 30.) List some of the important ions and molecules that will affect the pH of the urine.

65. (Page 30.) How do the renal tubules fine-tune the pH of the plasma?

66. (Page 31.) Label the diagram on page 31.

67. (Page 31.) What happens in the kidney when the amount of base increases in the body?

68. (Page 31.) As bicarbonate is eliminated from the body, what happens to the pH of the plasma, will it increase or decrease?

69. (Page 32.) Use the diagram on page 32 to illustrate the three mechanisms the kidney uses to rid the plasma of excess acid?

70. (Page 32.) How does the generation of bicarbonate by kidney tubule cells add new buffering power to the blood?

71. (Page 32.) How fast are renal mechanisms compared to chemical buffers and the respiratory system?

72. (Page 32.) What is a fixed acid and how is the kidney responsible for removing fixed acids?

73. (Page 34.) Label the diagram on page 34.

74. (Page 34.) Using the diagrams on page 34, list the steps in the conserving or reabsorption of bicarbonate.

75. (Page 34.) What is the result of this whole process of the conserving or reabsorption of bicarbonate?

76. (page 35.) Label the diagram on page 35.

77. (Page 35.) Using the diagrams on page 35, list the steps in the generation of bicarbonate.

78. (Page 35.) What is the result of this whole process of the generation of bicarbonate?

79. (page 36.) Label the diagram on page 36.

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Acid/Base Homeostasis (Part 6)

80. (Page 36.) Using the diagrams on page 36, list the steps in the secretion of H^+.

81. (Page 36.) What is the result of this whole process of the secretion of H^+ ?

82. (Page 37.) Label the diagram on p. 37 and show the three mechanisms that occur during acidosis.

83. (Page 38.) Contrast the amount of time it takes for chemical buffers, the respiratory system and the urinary system to work.

84. (Page 38.) The respiratory mechanism is important for compensation for what type of acidosis and alkalosis?

85. (Page 38.) The urinary mechanism is important for compensation for what type of acidosis and alkalosis?

86. (Page 38.) What types of acids are eliminated via the respiratory system?

87. (Page 38.) What types of acids are eliminated via the urinary system?

88. (Page 39.) Alkalosis occurs when the pH of the blood rises above 7.45. What are two major types of alkalosis?

89. (Page 39.) Acidosis occurs when the pH of the plasma falls below 7.35. What are two major types of acidosis?

90. (Page 40.) Summarize how the body compensates for acidosis and alkalosis with three major mechanisms.

91. (Page 40.) Why can't the buffer systems take care of acidosis and alkalosis?

92. (Page 41.) When does metabolic acidosis occur?

93. (Page 42.) Why did Jennifer experience dehydration in her ketoacidosis?

94. (Page 43.) When ketoacidosis occurs, is the pH of the plasma high or low?

95. (Page 44.) Once an individual has metabolic acidosis, the carbonic acid/bicarbonate buffer system will come into action. Which direction will the equilibrium reaction go , to the left or to the right?

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

Carbon dioxide Water Carbonic acid
Bicarbonate Hydrogen ion

96. (Page 44.) As a result of metabolic acidosis, will the level of bicarbonate increase or decrease?

97. (Page 44.) Which body system will respond to compensate for this acid/base imbalance, the urinary system or the respiratory system?

98. (Page 44.) Predict how the respiratory system will compensate for metabolic acidosis, will you breathe faster or slower?

99. (Page 45.) What causes metabolic alkalosis?

100. (Page 46.) When vomiting from the stomach occurs, what is lost from the body?

101. (Page 46.) What would you expect to happen to the pH when vomiting from the stomach occurs?

102. (Page 47.) Once an individual has metabolic alkalosis, the carbonic acid/bicarbonate buffer system will come into action. Now which direction will the equilibrium reaction go, will it shift to the right or to the left?

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

Carbon dioxide Water Carbonic acid
Bicarbonate Hydrogen ion

103. (Page 47.) Predict how the body will compensate for metabolic alkalosis. Will hypoventilation or hyperventilation occur?

104. (Page 48.) When does respiratory acidosis occur?

105. (Page 49.) What is the defect in emphysema?

106. (Page 50.) Why would the neurologic symptoms of respiratory acidosis be sometimes more severe than those of metabolic acidosis?

107. (Page 50.) As a result of respiratory acidosis from emphysema, which direction will this equation go, would it shift to the left or to the right?

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

Carbon dioxide Water Bicarbonate Hydrogen ion Carbonic acid

108. (Page 51.) What happens to acid levels in the blood, will they rise or fall?

109. (Page 51.) How the body compensates for respiratory acidosis.

110. (Page 52.) What causes respiratory alkalosis?

111. (Page 53.) As a result of hyperventilation, which direction will this equation go, will it shift to the right or left?

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

Carbon dioxide Water Bicarbonate Hydrogen ion Carbonic acid

112. (Page 54.) What will happen to the concentration of H^+ in the blood, will it increase or decrease?

113. (Page 54.) How will the body compensate for respiratory alkalosis?

114. (Page 41, 45, 48, & 52.) Would the following cause metabolic acidosis, metabolic alkalosis, respiratory acidosis or respiratory alkalosis?

a. Excessive diarrhea, caused by loss of bicarbonate which is plentiful in intestinal fluid.
b. Vomiting of stomach contents containing hydrochloric acid would deplete the acid in the body.
c. Severe anxiety over a visit to the dentist.
d. Some types of kidney disease, which prevent elimination of acid from the body.
e. Stimulation of the brain stem in the case of meningitis may cause hyperventilation.
f. Ketoacidosis from total absence of insulin in the body, or starvation.
g. Decreased activity of the diaphragm muscle.
h. Low levels of oxygen in the blood, may cause hyperventilation.
i. Lack of oxygen in the tissues which causes the production of lactic acid.
j. Ingestion of too much bicarbonate, or baking soda, would produce an excess of base.
k. Vomiting of intestinal contents.

l. Head injury may also cause hyperventilation.
m. Excess acid can also appear in the extracellular fluids due to a high potassium ion concentration in the extracellular fluid.
n. Metabolic alkalosis can occur when there is too little potassium in extracellular fluid.
o. Conditions that impair exchange of gases in the lungs.
p. Lack of respiratory control in the brain stem.

115. (Pages 55-58.) Fill out this diagram:

	Acidosis	Alkalosis
Metabolic	**Cause**:	**Cause**:
	Compensation: $CO_2+H_2O \quad H_2CO_3 \quad HCO_3^-+H^+$	**Compensation**: $CO_2+H_2O \quad H_2CO_3 \quad HCO_3^-+H^+$
Respiratory	**Cause**: $CO_2+H_2O \quad H_2CO_3 \quad HCO_3^-+H^+$	**Cause**: $CO_2+H_2O \quad H_2CO_3 \quad HCO_3^-+H^+$
	Compensation:	**Compensation**:

116. (Page 55.) What is the cause of metabolic acidosis? (Check all that apply.)
___ Excess H^+ generated within the body
___ Loss of base from the body
___ Deficit of H+ within the body
___ Gain of base in the body

117. (Page 55.) Which of the following would be observed in simple, uncompensated metabolic acidosis?
___ CO_2 rises
___ CO_2 falls
___ HCO_3^- rises
___ HCO_3^- falls

118. (Page 55.) What system will compensate for respiratory acidosis, the respiratory system or the renal system?

119. (Page 55.) As a result of compensation, which direction will this reaction go, to the right or to the left?

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

Carbon dioxide Water Carbonic acid

Bicarbonate Hydrogen ion

120. (Page 55.) Will this individual hyperventilate or hypoventilate?

121. (Page 56.)What is the cause of metabolic alkalosis? (Check all that apply.)
 ___ Excess H+ generated within the body
 ___ Loss of base from the body
 ___ Deficit of H+ within the body

122. (Page 56.) Which of the following would be observed in simple, uncompensated metabolic alkalosis?
 ___ CO_2 rises
 ___ CO_2 falls
 ___ HCO_3^- rises
 ___ HCO_3^- falls

123. (Page 56.) What system will compensate for metabolic alkalosis, the respiratory system or the renal system?

124. (Page 56.) As a result of compensation in metabolic alkalosis, which direction will this reaction go?

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

Carbon dioxide Water Carbonic acid

Bicarbonate Hydrogen ion

125.(Page 56.) Will the individual in metabolic alkalosis hyperventilate or hypoventilate?

126. (Page 57.) What is the cause of respiratory acidosis? (Check all that apply.)
 ___ Excess H+ generated in the body
 ___ Loss of H+ from the body
 ___ Loss of CO_2 from the body
 ___ Buildup of CO_2 in the body

127. (Page 57.) As a result of respiratory acidosis, which direction will this reaction go?

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

Carbon dioxide Water Carbonic acid
Bicarbonate Hydrogen ion

128.(Page 57.) Which of the following would be observed in simple, uncompensated respiratory acidosis?

___ CO_2 rises
___ CO_2 falls
___ HCO_3^- rises
___ HCO_3^- falls

129. (Page 57.) What system will compensate for respiratory acidosis, the respiratory system or the renal system?

130. (Page 57.) Complete this chart:

NORMAL	ABOVE	BELOW

131. (Page 58.) What is the cause of respiratory alkalosis? (Check all that apply.)

___ Excess H+ generated in the body
___ Loss of H+ from the body
___ Loss of CO_2 from the body
___ Buildup of CO_2 in the body

132. (Page 58.) As a result of respiratory alkalosis, which direction will this reaction go?

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

Carbon dioxide Water Carbonic acid
Bicarbonate Hydrogen ion

133. Which of the following would be observed in simple, uncompensated respiratory alkalosis

___ CO_2 rises
___ CO_2 falls

___ HCO_3^- rises

___ HCO_3^- falls

134. What system will compensate for respiratory alkalosis, the respiratory system, or the renal system?

Continue to Acid/Base Homeostasis – Part VII
(Separate Document)

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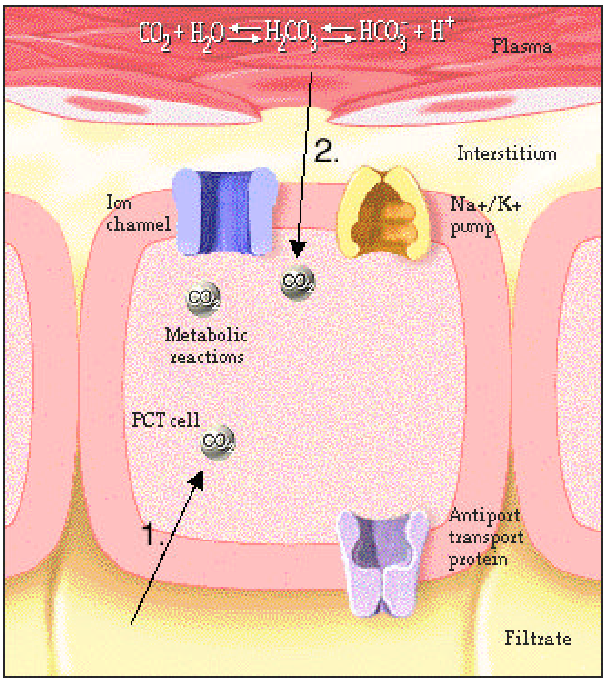
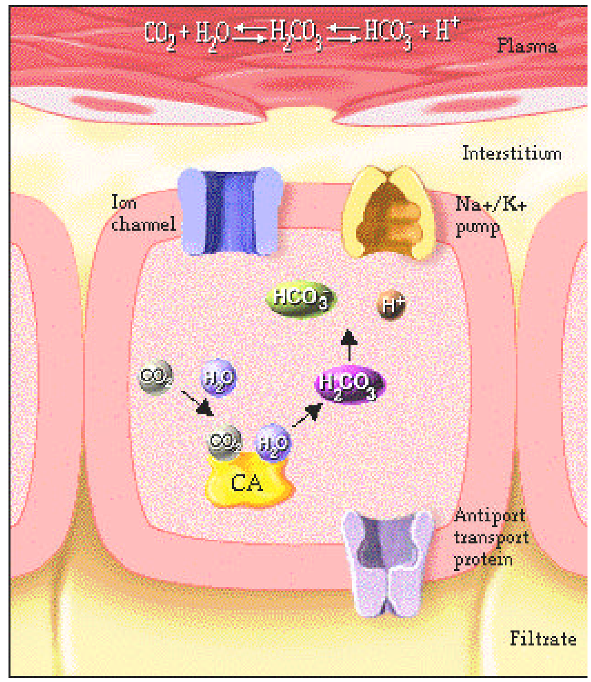
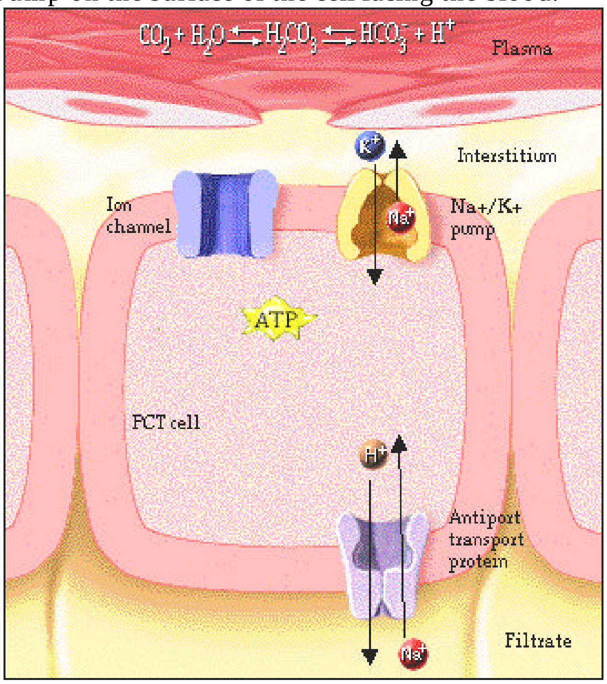
74. (1) Carbon dioxide arrives at the kidney tubule cell in the proximal convoluted tubule from the filtrate, plasma, or from metabolic reactions within the cell.



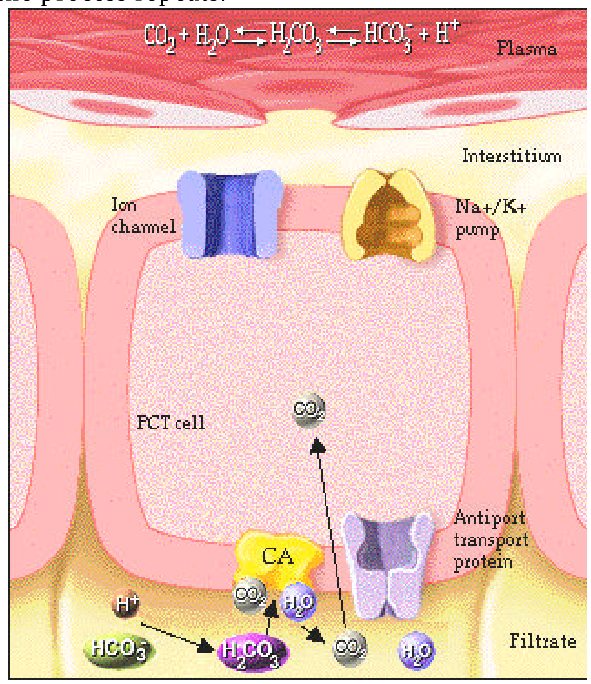
(2) Within the proximal tubule cell, carbon dioxide water form carbonic acid. This reaction is catalyze carbonic anhydrase, shown here as CA. Then t carbonic acid splits into hydrogen ions and bicarbonate.



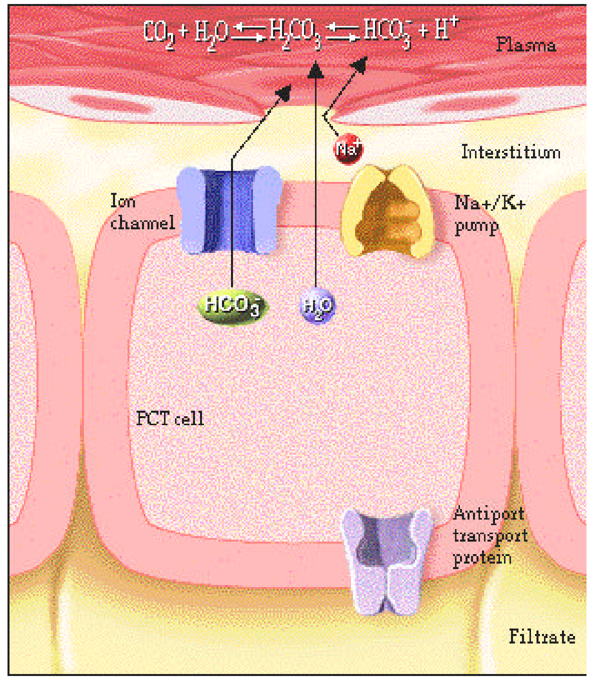
(3) The hydrogen ion moves into the filtrate in exchange for Na^+, to maintain electrical neutrality, through a sodium ion/hydrogen ion antiport transport protein, or countertransport, which is a type of secondary active transport. The concentration of sodium ion inside the cell is kept low by the sodium/potassium pump on the surface of the cell facing the blood.



(4) In the filtrate, H^+ combines with fil
bicarbonate to form carbonic acid. Carbonic anhy
then breaks apart the carbonic acid into carbon dic
and water. The carbon dioxide diffuses into the ki
tubule cell, removing bicarbonate from the fil
This carbon dioxide can reform bicarbonate withir
the process repeats.

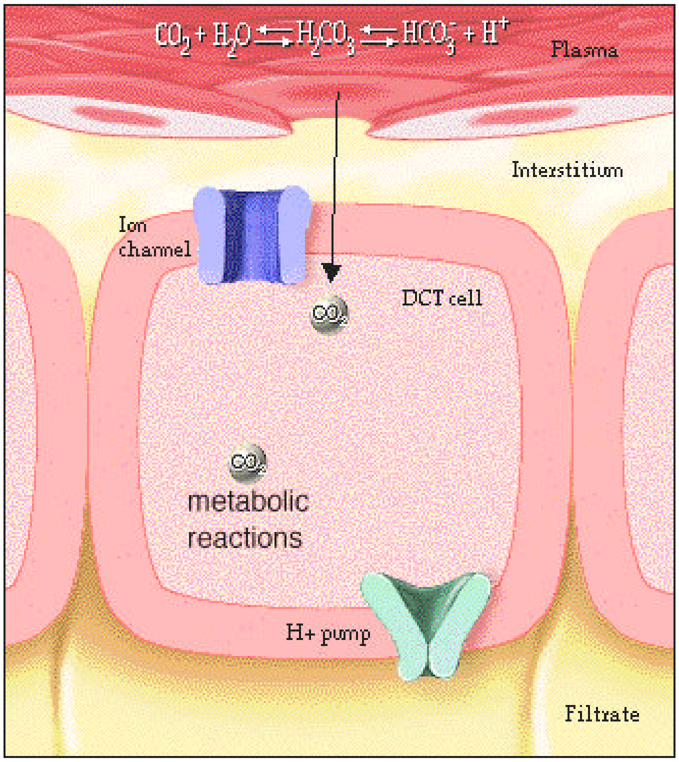


(5) Much of the water generated also gets reabsorbed. The bicarbonate generated within the cells of the proximal convoluted tubule diffuses into the plasma. Sodium ion also moves into the plasma via the sodium/potassium pump to maintain electrical neutrality.

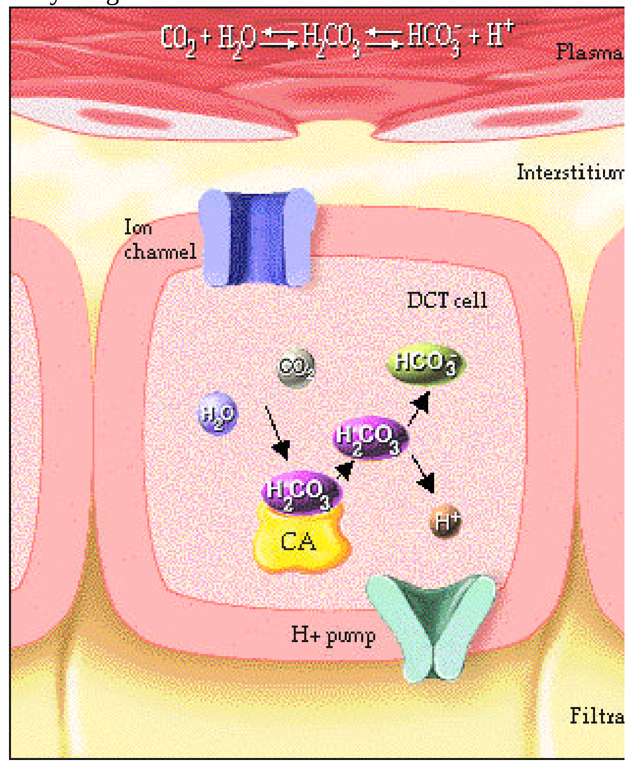


75. (1) HCO_3^- is reabsorbed into the plasma. Typically 80-90% of filtered bicarbonate is reabsorbed in the PCT. (2) You end up with more sodium ions getting reabsorbed back into the plasma.
76. Right side of page from top to bottom: Plasma, interstitium, DCT cell, filtrate Left side of page from top to bottom: Ion channel, H^+ pump

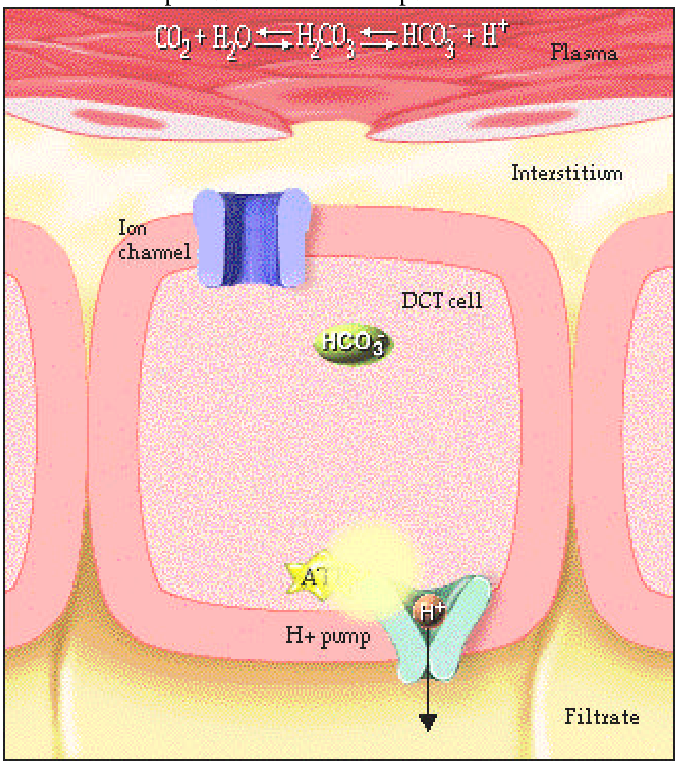
77. (1) Carbon dioxide arrives at the kidney tubule cell in the late distal convoluted tubule and cortical collecting duct from the plasma or from metabolic reactions within the cell.



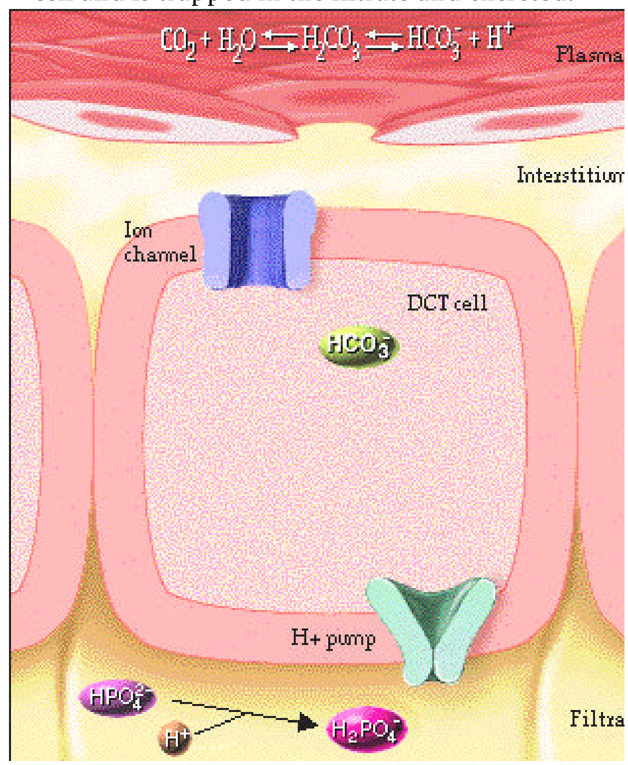
(2) In the kidney tubule cell carbon dioxide and v
form carbonic acid. The reaction is catalyze
carbonic anhydrase. Then the carbonic acid splits
hydrogen ions and bicarbonate.



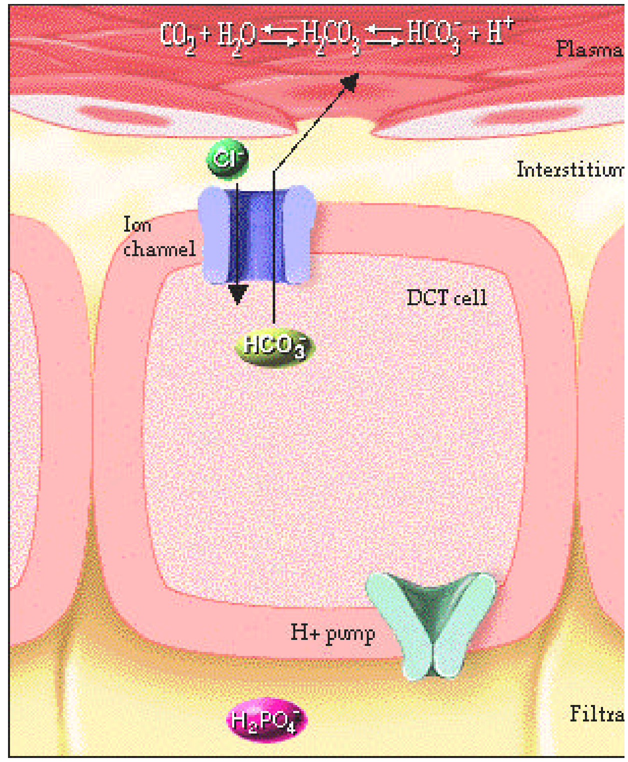
(3) The hydrogen ion goes into the filtrate via primary active transport. ATP is used up.



(4) Bicarbonate is scarce in the filtrate at this because it is reabsorbed in the proximal convo tubule, so the hydrogen ion will combine with a b such as hydrogen phosphate, which is the important buffer in the urine. The resu dihydrogen phosphate is unable to go back into cell and is trapped in the filtrate and excreted.



(5) The newly formed bicarbonate moves into the plasma. Chloride ion moves into the cell at the same time to maintain electrical neutrality. The pH of the plasma increases.

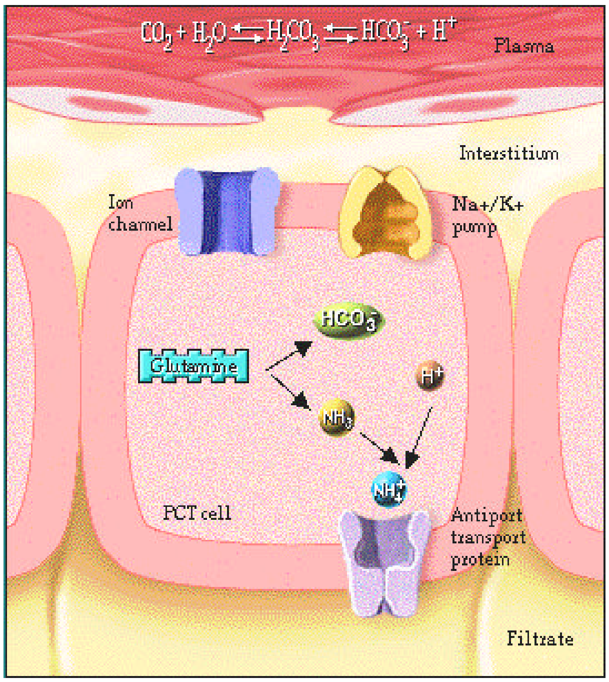


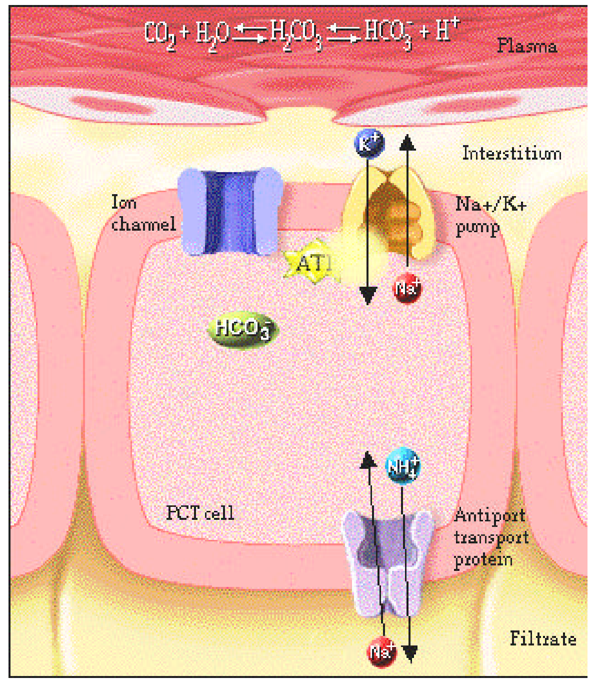
78. (1) Newly generated bicarbonate is added to the plasma, increasing the pH of blood and adding new buffering power to the plasma. (2) Hydrogen ion is secreted into the filtrate, attaches to buffers, and is eliminated from the body.

79. Right side of page from top to bottom: Plasma, interstitium, Na+/K+ pump, antiport transport protein, filtrate   Left side of page from top to bottom: Ion channel, PCT cell

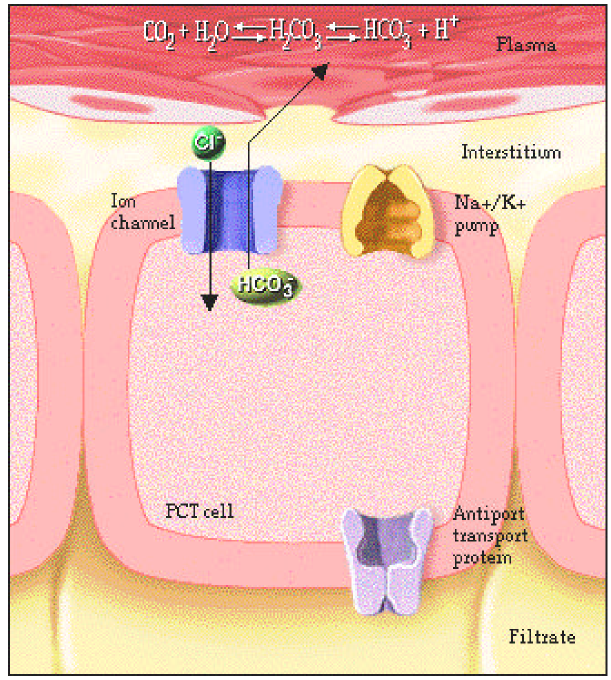
80. (1) In severe acidosis, another process will occur within the cells of the proximal convoluted tubule. Glutamine is an amino acid that is metabolized in the tubule cells of the kidney. The products of its metabolism are ammonia and bicarbonate. The ammonia, which is a base combines with a hydrogen ion inside the cell to form ammonium.

(2) The ammonium then travels from the kidney tu cell to the filtrate in exchange for sodium vi antiport transport protein, or countertransport, w is a type of secondary active transport. The so ion concentration is kept low inside the cells by sodium/potassium pump. This ammoniun eliminated in the urine.





(3) The bicarbonate leaves the kidney tubule cell in exchange for chloride and goes into the plasma.



81. (1) Newly generated bicarbonate is added to the blood, increasing the pH of plasma and adding new buffering power to the plasma. (2) Hydrogen ion is eliminated from the body in the form of ammonium.
82. Clockwise from upper right: Peritubular capillary, renal tubule, glomerular capsule, glomerular capillary

(1) Conserving (reabsorption) of HCO_3^-. (2) Generating HCO_3^- by the kidney tubule cells increases the pH of the plasma and adds new buffering power to the plasma. (3) Secreting buffered H^+ into the urine eliminates H^+ from the body and increases the pH of the plasma.

83. Chemical buffers act within seconds to correct abnormalities in pH within the body fluids. The respiratory control mechanism is slower than the buffers mechanism and may take minutes to begin. Renal mechanisms are the slowest mechanisms may take hours or days to complete.
84. Th respiratory mechanism is important in compensating for metabolic acidosis or alkalosis.
85. Renal mechanisms are important in compensating for respiratory acidosis or alkalosis.
86. Carbonic acid is released as carbon dioxide and water.
87. The urinary system eliminates fixed acids from the body.
88. Metabolic alkalosis and respiratory alkalosis
89. Metabolic acidosis and respiratory acidosis
90. Chemical buffers, respiratory system, urinary system
91. Chemical buffers work quickly and immediately, but they have a limited capacity. When the buffer systems become overwhelmed, as in acidosis or alkalosis, the respiratory and urinary systems compensate.
92. Metabolic acidosis occurs when there is an excess of any body acid, except carbonic acid. It occurs when there is too much acid production in the body, or if there is loss of base.
93. Dehydration occurred from increased blood glucose and increased osmolarity.
94. Low
95. Because more H^+ is being generated in the body, the excess H^+ will combine with HCO_3^- to form CO_2. and the reaction will shift to the left.
96. Because there is an excess amount of H^+, the H^+ will react with HCO_3^{-1} as a result of metabolic acidosis, and the HCO_3^{-1} will decrease.
97. The respiratory system will compensate in an effort to bring the pH back toward normal.
98. Because of the increased CO_2, the respiratory centers in the brain and large arteries are stimulated. The patient will begin to breathe faster and deeper. This response is called hyperventilation.
99. Metabolic alkalosis is caused by a relative deficit of any acid in the body, except carbonic acid. Metabolic alkalosis can occur from an excess of base in the body. Metabolic alkalosis can also occur as a result of too little acid in the body.
100. Hydrogen ion, from the hydrochloric acid in the stomach.
101. The pH will rise indicating the individual is becoming alkalotic from loss of hydrogen ion.
102. Because there is less H^+ in the body, the reaction will shift to the right and more H^+ and HCO_3^- will form.
103. As the equation shifts to the right, CO_2 decreases. The respiratory centers in the brain are inhibited hypoventilation occurs.
104. Respiratory acidosis occurs when there is an excess of carbon dioxide, and therefore an increase in carbonic acid in the body.
105. Alveolar walls disintegrate over time, producing large air spaces that remain filled with gases during expiration. Carbon dioxide becomes trapped in the alveoli and blood levels of carbon dioxide rise.
106. Because carbon dioxide crosses the blood-brain barrier more readily than many metabolic acids.

107. The build-up of carbon dioxide in the blood causes the equilibrium to shift to the right.
108. Acid levels rise and the pH decreases.
109. Kidneys retain bicarbonate and excrete H^+.
110. Respiratory alkalosis is a deficit of carbon dioxide and occurs as a result of hyperventilation.
111. With each exhalation, more carbonic acid is eliminated from the lungs as CO_2. The reaction proceeds to the left.
112. H^+ will decrease and the pH will increase because the H^+ is combining with HCO_3^- to form more CO_2.
113. By excreting bicarbonate through the kidneys.
114. Metabolic acidosis: a,d,f,i,k,m Metabolic alkalosis: b,j,n Respiratory acidosis: g,p,o Respiratory alkalosis: c,e,h,l

115.

	Acidosis	Alkalosis
Metabolic	**Cause**: Generation of H^+ or loss of base from the body. HCO_3^- falls	**Cause**: Loss of H^+ or generation of base in t body. HCO_3^-
	Compensation: Respiratory - Hyperventilation $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$	**Compensation**: Respiratory - Hypoventilat $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$
Respiratory	**Cause**: Defective exchange of gases in the lungs. $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$ CO_2 rises	**Cause**: Hyperventilation $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$ CO_2
	Compensation: Renal Urinary Reabsorption of HCO_3^-	**Compensation**: Renal Urinary Excretion of HCO_3^-

116. Metabolic acidosis can be caused by either a gain of acid or a loss of base from the body.
117. HCO_3^- levels fall due to loss of HCO_3^- from the body or increased acid reacting with HCO_3^- .
118. Because the problem is metabolic in origin, the respiratory system compensates.
119. The increased H^+ causes the equilibrium reaction of this reaction to shift to the left.
120. The individual hyperventilates to blow off the excess carbon dioxide which is generated.
121. Metabolic alkalosis can be caused by either a loss of acid or a gain of base in the body
122. HCO_3^- levels rise due to gain of HCO_3^- or decreased acid reacting with HCO_3^-.
123. Because the problem is metabolic in origin, the respiratory system compensates.
124. The decreased H^+ causes the equilibrium reaction of this reaction to shift to the right.
125. The individual hypoventilates to conserve CO_2.
126. Respiratory acidosis occurs because CO_2 is not eliminated from the body.
127. The increased CO2 in the blood will cause the reaction to shift to the right.
128. CO_2 rises because the individual is unable to blow off this gas.
129. The renal system will compensate by generating or reabsorbing bicarbonate or excreting H^+, but it may take hours or days for complete compensation to occur.
130.

NORMAL	ABOVE	BELOW
BLOOD pH 7.35-7.45	alkalosis	acidosis
pCO_2 35-45 mmHg	respiratory acidosis	respiratory alkalosis
HCO_3^- 22-26 mEq/L	metabolic acidosis	metabolic alkalosis

131. Respiratory alkalosis occurs when too much carbon dioxide is eliminated from the body because of hyperventilation.
132. The equilibrium reaction shifts to the left as acid is used up.
133. CO_2 falls due to hyperventilation.
134. The renal system will compensate by excreting excess base.