leading to decreased reflexes, lethargy, and cardiac arrhythmias.

Phosphate

Phosphate ions (HPO_4^{--} and $H_2PO_4^-$), are located primarily in the bone but circulate in both the intracellular and extracellular fluids. The serum level is normally 0.85 to 1.45 mmol per liter.

Phosphate is important:

- In bone and tooth mineralization
- In many metabolic processes, particularly those involving the cellular energy source, adenosine triphosphate (ATP)
- As the phosphate buffer system for acid-base balance, and it has a role in the removal of hydrogen ions from the body through the kidneys
- As an integral part of the cell membrane
- In its reciprocal relationship with serum calcium

Hypophosphatemia

Low serum phosphate levels may result from malabsorption syndromes, diarrhea, or excessive use of antacids. Alkalosis and hyperparathyroidism are other causes.

Neurologic function is impaired with low serum phosphate, causing tremors, weak reflexes (hyporeflexia), paresthesias, confusion and stupor, anorexia, and difficulty in swallowing (dysphagia).

The blood cells function less effectively—oxygen transport decreases, and clotting and phagocytosis decrease.

> **THINK ABOUT 2-17**
>
> Explain how serum calcium levels are affected by low phosphate levels.

Hyperphosphatemia

High serum phosphate often results from renal failure. Dialysis patients often take phosphate binders with meals to control their serum phosphate levels. Tissue damage or cancer chemotherapy may cause the release of intracellular phosphate. The manifestations of hyperphosphatemia are the same as those of hypocalcemia.

Chloride

Chloride ion (Cl^-) is the major extracellular **anion** with a normal serum level of 98 to 106 mmol per liter. Chloride ions tend to follow sodium because of the attraction between the electrical charge on the ions; therefore high sodium levels usually lead to high chloride levels.

Chloride and bicarbonate ions, both negatively charged, can exchange places as the blood circulates through the body to assist in maintaining acid-base balance (see Acid-Base Imbalance). As bicarbonate ions are used up in binding with metabolic acids, chloride ions diffuse out of the red blood cells into the serum to maintain the same number of negative ions in the blood (Fig. 2-9). The reverse situation can also occur when serum chloride levels decrease, and bicarbonate ions leave the erythrocytes to maintain electrical neutrality. Thus, low serum chloride leads to high serum bicarbonate, or alkalosis. This situation is referred to as a *chloride shift*.

Hypochloremia

Low serum chloride is usually associated with alkalosis in the early stages of vomiting when hydrochloric acid is lost from the stomach.

Excessive perspiration associated with fever or strenuous labor on a hot day can lead to loss of sodium chloride, resulting in hyponatremia and hypochloremia, and ultimately, dehydration.

Hyperchloremia

Excess chloride ion may develop with the excessive intake of sodium chloride, orally or intravenously, or hypernatremia due to other causes, leading to edema and weight gain.

> **THINK ABOUT 2-18**
>
> a. State one cause of hypomagnesémia.
> b. State one cause of hyperphosphatemia.
> c. List and describe two signs of hypophosphatemia.

Acid-Base Imbalance

Review of Concepts and Processes

Acid-base balance is essential to homeostasis because cell enzymes can function only within a very narrow pH range. *The normal serum pH range is 7.35 to 7.45.* Death usually results if serum pH is below 6.8 or above 7.8 (Fig. 2-10). For example, a pH of less than 7.35 depresses central nervous system function and decreases all cell enzyme activity.

When serum pH is less than 7.4, more hydrogen ions (H^+) are present, and acidosis results. A serum pH of greater than 7.4 is more basic, indicating alkalosis or the presence of fewer **hydrogen ions**. The body normally has a tendency toward acidosis, or a lower pH, because cell metabolism is constantly producing carbon dioxide (CO_2) or carbonic acid (H_2CO_3) and **nonvolatile metabolic acids** such as lactic acid, ketoacids, sulfates, or phosphates. Lactic acid results from the *anaerobic* (without oxygen) metabolism of glucose, ketoacids result from incomplete oxidation of fatty acids, and protein metabolism may produce sulfates or phosphates.

> **THINK ABOUT 2-19**
>
> a. When hydrogen ions are decreased, is the pH higher or lower?
> b. State the optimal range of serum pH and effects on normal cell function if serum pH is not in the optimal range.

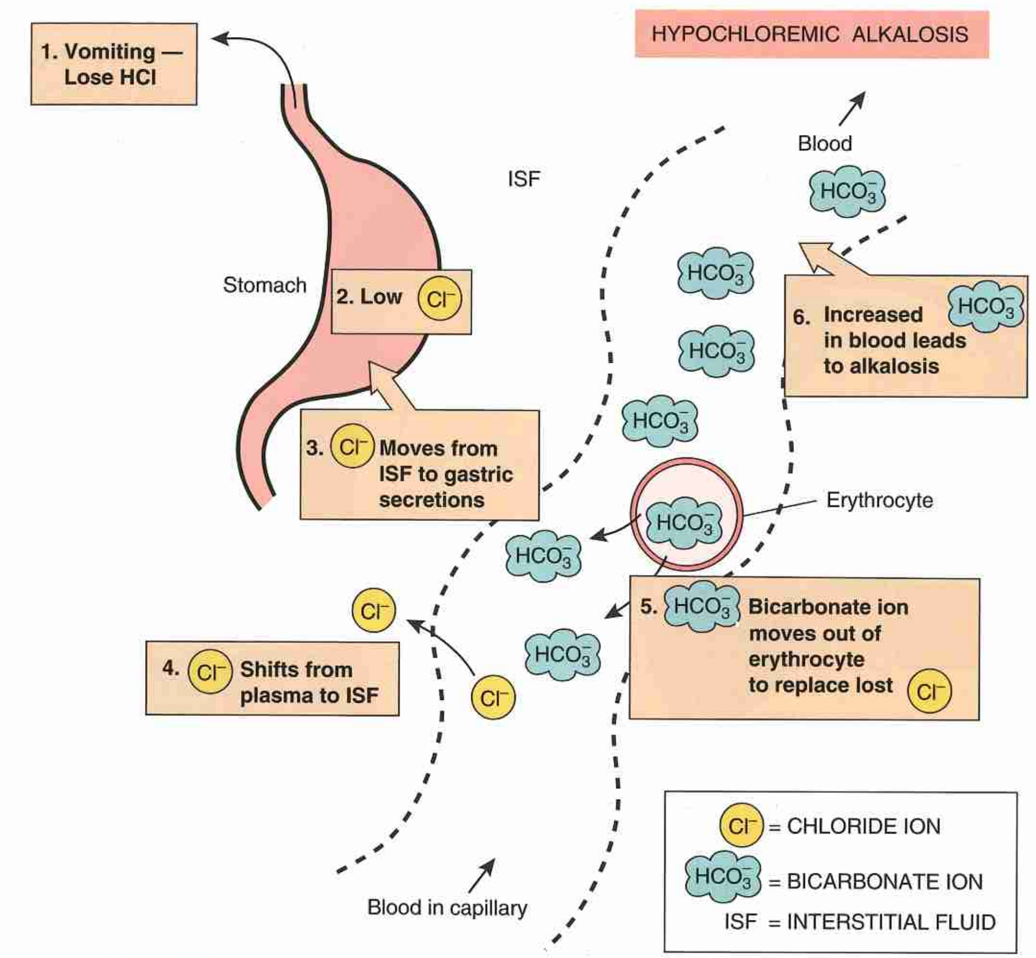

FIGURE 2-9 Schematic representation of chloride-bicarbonate shift with vomiting.

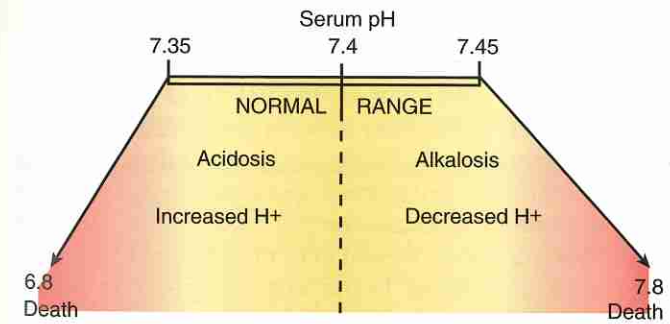

FIGURE 2-10 The hydrogen ion and pH scale.

Control of Serum pH

As the blood circulates through the body, nutrients diffuse from the blood into the cells, various metabolic processes take place in the cells using these nutrients, and metabolic wastes, including acids, diffuse from the cells into the blood (Fig. 2-11).

Three mechanisms control or compensate for pH:

1. The buffer pairs circulating in the blood respond to pH changes immediately.
2. The respiratory system can alter carbon dioxide levels (carbonic acid) in the body by changing the respiratory rate (see Chapter 13).
3. The kidneys can modify the excretion rate of acids and the production and absorption of bicarbonate ion (see Chapter 18).

Note that the lungs can change only the amount of carbon dioxide (equivalent to the amount of carbonic acid) in the body. The kidneys are slow to compensate for a change in pH but are the most effective mechanism because they can excrete all types of acids (volatile or gaseous and nonvolatile) and can also adjust serum bicarbonate levels.

> **THINK ABOUT 2-20**
>
> How does the respiratory rate change when more hydrogen ions enter the blood, and how does this change affect acid levels in the body?

Buffer Systems

To control serum pH, several buffer systems are present in the blood. A buffer is a combination of a weak acid and its alkaline salt. The components react with any acids or alkali added to the blood, neutralizing them and thereby maintaining a relatively constant pH.

The body has four major buffer pairs:

1. The sodium bicarbonate-carbonic acid system
2. The phosphate system

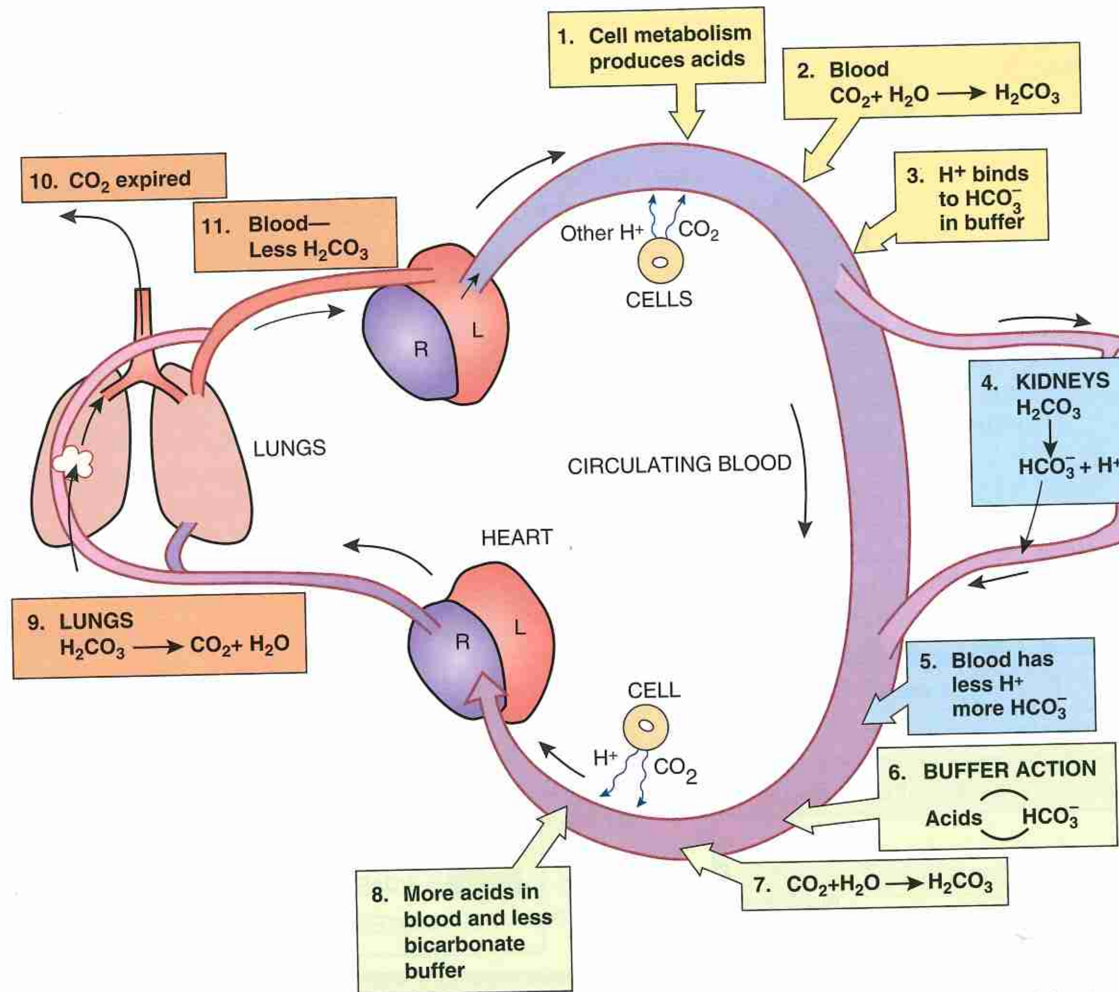

FIGURE 2-11 Changes in acids, bicarbonate ion, and serum pH in circulating blood.

3. The hemoglobin system
4. The protein system

The bicarbonate system is the major extracellular fluid buffer and is used clinically to assess a client's acid-base status. The principles of acid-base balance are discussed here using the bicarbonate pair. Specific numbers are not used because the emphasis is on understanding basic concepts and recognizing trends. Laboratory tests will report the specific values and state the implications of those values.

APPLY YOUR KNOWLEDGE 2-2

Predict three ways by which control of serum pH could be impaired.

The Bicarbonate-Carbonic Acid Buffer System and Maintenance of Serum pH

The bicarbonate buffer system is composed of carbonic acid, which arises from the combination of carbon dioxide with water, and bicarbonate ion, which is present as sodium bicarbonate. The balance of bicarbonate ion (HCO_3^-), a *base*, and carbonic *acid* (H_2CO_3) levels is controlled by the respiratory system and the kidneys (see Fig. 2-11). Cell metabolism produces carbon dioxide, which diffuses into the interstitial fluid and blood, where it reacts with water to form carbonic acid, which then dissociates immediately under the influence of the enzyme carbonic anhydrase to form three hydrogen ions and one bicarbonate ion per molecule of carbonic acid. This enzyme is present in many sites, including the lungs and the kidneys. In the *lungs*, this reaction can be reversed to form carbon dioxide, which is then expired along with water, thus reducing the total amount of carbonic acid or acid in the body. In the *kidneys*, the reaction needed to form more hydrogen ions is promoted by enzymes; the resultant hydrogen ions are excreted in the urine, and the bicarbonate ions are returned to the blood to restore the buffer levels.

To maintain serum pH within the normal range, 7.35 to 7.45, the *ratio* of bicarbonate ion to carbonic acid (or carbon dioxide) must be *20:1*. A 1:1 ratio will not maintain a pH of 7.4! The ratio is always stated with the H^+ component as one.

As one component of the ratio changes, the other component must change *proportionately* to maintain the 20:1 ratio and thus serum pH. For instance, if respiration is impaired, causing an increase in carbon dioxide in the blood, the kidneys must increase serum bicarbonate levels to compensate for the change. The actual concentrations are not critical as long as the proportions are sustained. It may help to remember that the bicarbonate part or alkali part of the buffer ratio is 20, the higher figure, because more bicarbonate base is required to neutralize the acids constantly being produced by the body cells.

THINK ABOUT 2-21

If bicarbonate ion is lost from the body, how will carbonic acid levels change?

Respiratory System

When serum carbon dioxide or hydrogen ion levels increase, chemoreceptors stimulate the respiratory control center to increase the respiratory rate, thus removing more carbon dioxide or acid from the body. When alkalosis develops, the respiratory rate decreases, thus retaining more carbon dioxide and increasing acid levels in the body.

Renal System

The kidneys can also reduce the acid content of the body by exchanging hydrogen for sodium ions under the influence of aldosterone and can remove H^+ by combining them with ammonia and other chemicals. The kidneys also provide the bicarbonate ion for the buffer pair as needed. Urine pH may range from 4.5 to 8.0 as the kidneys compensate for metabolic conditions and dietary intake.

lungs: $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$: *kidneys*

lungs: carbon dioxide + water ↔ carbonic acid ↔ hydrogen ions + bicarbonate ions: *kidneys*

THINK ABOUT 2-22

a. Reduced blood flow through the kidneys for a long time will have what effect on serum pH? Why?
b. How would the lungs and kidneys respond to the ingestion of large quantities of antacids?
c. How is the kidney more effective in maintaining serum pH than the lungs?

A number of laboratory tests can determine acid-base balance. These tests include arterial blood gases (ABGs), base excess or deficit, or anion gap, and details about them may be found in laboratory manuals. Some normal values are listed inside the front cover of this book.

Acid-Base Imbalance

There are four basic types of acid-base imbalance (Table 2-8). An increase in hydrogen ions or a decrease in serum pH results in acidosis, which can result either from an increase in carbon dioxide levels (acid) due to respiratory problems or from a decrease in bicarbonate ions (base) because of metabolic or renal problems. The first category is termed respiratory acidosis (increased carbon dioxide), and the second is called metabolic acidosis (decreased bicarbonate ions).

Alkalosis refers to an increase in serum pH or decreased hydrogen ions. It may be respiratory alkalosis if increased respirations cause a decrease in carbon dioxide (less acid), or metabolic alkalosis if serum bicarbonate increases.

Imbalances may be acute or chronic. In some situations, combinations of imbalances may occur; for example, metabolic acidosis and respiratory alkalosis can occur simultaneously.

THINK ABOUT 2-23

Name or state the category of the imbalance resulting from each of the following: (1) increased respiratory rate, (2) renal failure, and (3) excessive intake of bicarbonate, and state resulting change in the 20:1 ratio.

Compensation

The *cause* of the imbalance determines the first change in the ratio (Figs. 2-12 to 2-15). Respiratory disorders are always represented by an initial change in carbon dioxide. All other problems are metabolic and result from an initial change in bicarbonate ions.

The *compensation* is assessed by the subsequent change in the second part of the ratio (Table 2-9) and requires function by body systems *not* involved in the cause. For example, if a patient has a respiratory disorder causing acidosis, the lungs cannot compensate effectively, but the kidneys can. As long as the ratio of bicarbonate to carbonic acid is maintained at 20:1 and serum pH is normal, the imbalance is considered to be compensated. Compensation is limited and the patient must be monitored carefully if there is an ongoing threat to homeostasis.

Decompensation

If the kidneys and lungs cannot compensate adequately, the ratio changes, and serum pH moves out of the normal range, thus affecting cell metabolism and function. At this point, the imbalance is termed decompensation. Intervention is essential if homeostasis is to be regained. Examples of acid-base imbalance are given in Table 2-8.

THINK ABOUT 2-24

a. In an individual with very low blood pressure or circulatory shock, blood flow to the cells is very poor, resulting in increased lactic acid. Briefly describe the compensations that will take place.
b. What changes in the bicarbonate ratio and serum pH indicate that decompensation has occurred?

TABLE 2-8 Acid-Base Imbalances

	Acidosis	Alkalosis
Respiratory		
Causes	Slow shallow respirations (e.g., drugs) Respiratory congestion	Hyperventilation (anxiety, aspirin overdose)
Effect	Increased PCO_2	Decreased PCO_2
Compensation	Kidneys excrete more hydrogen ion and reabsorb more bicarbonate	Kidneys excrete less hydrogen ion and reabsorb less bicarbonate
Laboratory	Elevated PCO_2 Elevated serum bicarbonate Compensated—serum pH = 7.35 to 7.4 Decompensated—serum pH < 7.35	Low PCO_2 Low serum bicarbonate Compensated—serum pH = 7.4 to 7.45 Decompensated—serum pH > 7.45
Metabolic		
Causes	Shock Diabetic ketoacidosis Renal failure Diarrhea	Vomiting (early stage) Excessive antacid intake
Effect	Decreased serum bicarbonate ion	Increased serum bicarbonate ion
Compensation	Rapid, deep respirations Kidneys excrete more acid and increase bicarbonate absorption	Slow, shallow respirations Kidneys excrete less acid and decrease bicarbonate absorption
Laboratory	Low serum bicarbonate Low PCO_2 Compensated—serum pH = 7.35 to 7.4 Decompensated—serum pH < 7.35	Elevated serum bicarbonate Elevated PCO_2 Compensated—serum pH = 7.4 to 7.45 Decompensated—serum pH > 7.45

Acidosis

Causes of Acidosis

Respiratory acidosis, in which there is an increase in carbon dioxide levels, may occur under several conditions:

- Acute problems such as pneumonia, airway obstruction (aspiration or asthma), or chest injuries, and in those taking drugs such as opiates, which depress the respiratory control center
- Chronic respiratory acidosis, common in people with chronic obstructive pulmonary diseases (COPD) such as emphysema
- Decompensated respiratory acidosis, which may develop if the impairment becomes severe or if, for example, a patient with a chronic problem develops an additional infection

Metabolic acidosis is associated with a decrease in serum bicarbonate resulting from:

- Excessive loss of bicarbonate ions; for example, from diarrhea and loss of bicarbonate in the intestinal secretions
- Increased utilization of serum bicarbonate to buffer increased acids, when large amounts of acids are produced in the body because the buffer bicarbonate binds with such acids until they can be removed by the kidneys; for example, lactic acid may accumulate if blood pressure decreases and insufficient oxygen is available to the cells, or diabetic patients may produce large amounts of ketoacids that use up bicarbonate ions (see Chapter 16)
- Renal disease or failure, in which both decreased excretion of acids and decreased production of bicarbonate ion occur (see Chapter 18). In people with renal failure, compensation by the lungs is inadequate because the lungs can only remove carbon dioxide, not other acids, nor can they produce bicarbonate; therefore a treatment such as dialysis is required to maintain serum pH.
- Decompensated metabolic acidosis, which may develop when an additional factor interferes with compensation. For example, a person with severe diarrhea may become so dehydrated that the kidneys receive little blood and cannot function adequately, causing decompensation. The same result is seen with cardiac arrest.

Effects of Acidosis

The direct effects of acidosis are manifested by the nervous system, in which function is impaired, leading to inadequate responses. Headache, lethargy, weakness, and confusion develop, leading eventually to coma and

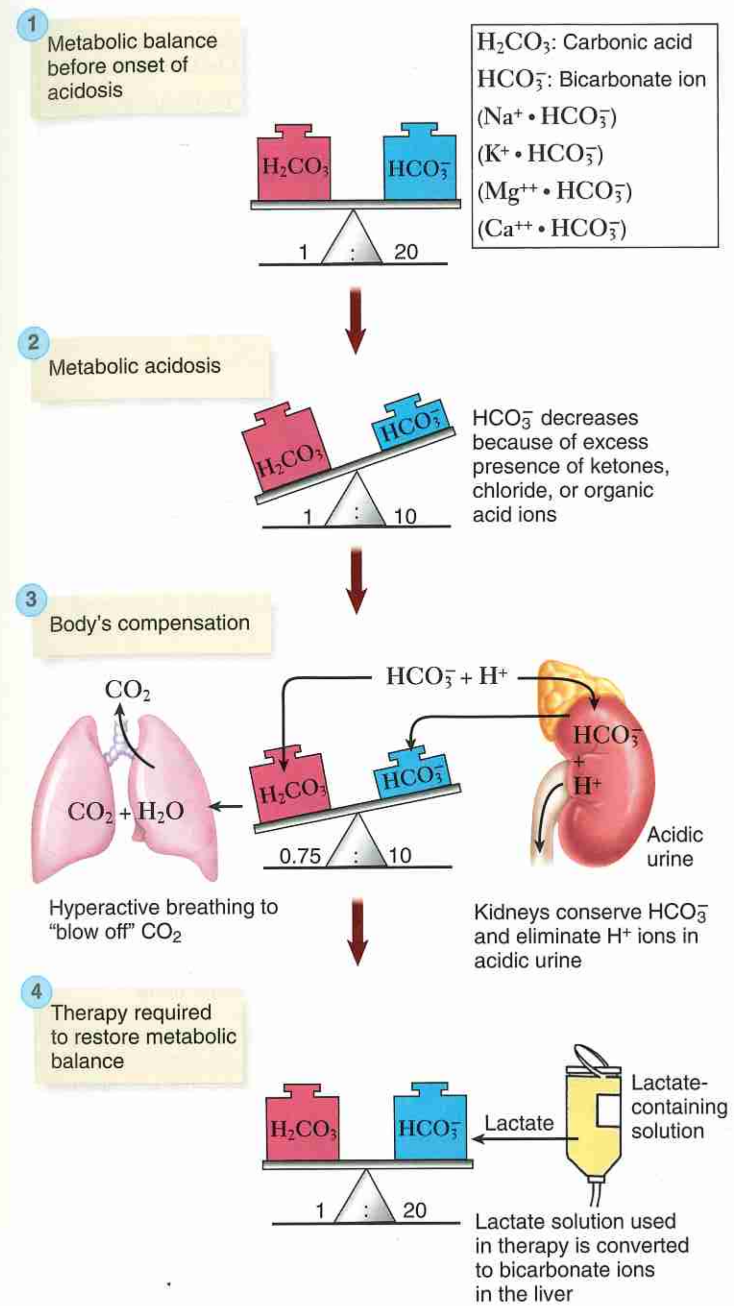

FIGURE 2-12 Metabolic acidosis. *(From Patton KT, Thibodeau GA: Anatomy & Physiology, ed 8, St. Louis, 2013, Mosby.)*

death. Compensations are manifested by deep, rapid breathing (Kussmaul's respirations) and secretion of urine with a low pH (e.g., 5).

Alkalosis

Alkalosis does not occur as frequently as acidosis. *Respiratory alkalosis* results from hyperventilation, usually caused by anxiety, high fever, or an overdose of aspirin (ASA). Head injuries or brainstem tumors may lead to hyperventilation. Stress-related alkalosis may develop rapidly. If the individual cannot quickly be calmed enough to hold his or her breath repeatedly, then it is best treated by rebreathing exhaled air containing excreted carbon dioxide from a paper bag placed over the face. Even if renal compensation is not impaired it is slow to take place.

Metabolic alkalosis, in which there is an increase in serum bicarbonate ion, commonly follows loss of hydrochloric acid from the stomach either in the early stages of vomiting or with drainage from the stomach. Other potential causes are hypokalemia (see Electrolyte Imbalances) and excessive ingestion of antacids.

Effects of Alkalosis

Alkalosis increases the irritability of the nervous system, causing restlessness, muscle twitching, tingling and

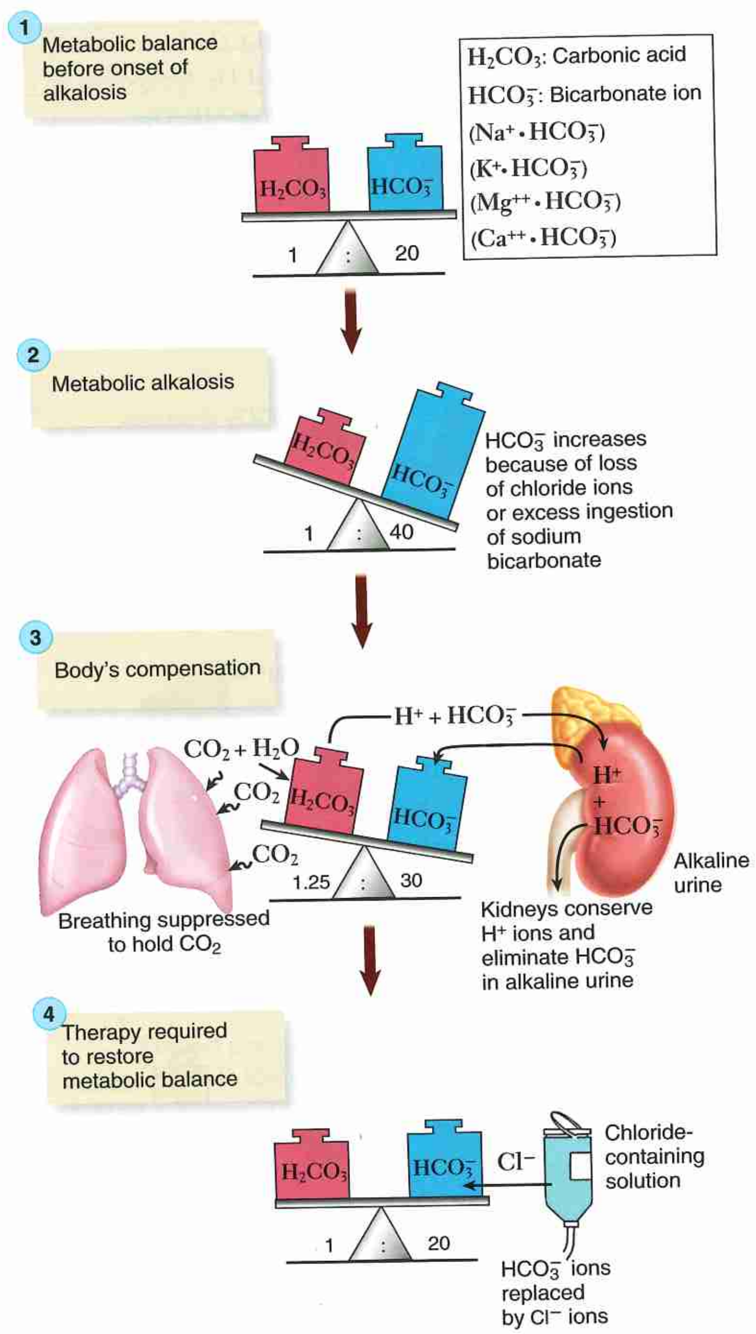

FIGURE 2-13 Metabolic alkalosis. *(From Patton KT, Thibodeau GA: Anatomy & Physiology, ed 8, St. Louis, 2013, Mosby.)*

numbness of the fingers, and eventually tetany, seizures, and coma.

Treatment of Imbalances

The underlying cause of the imbalance must be diagnosed and treated in addition to more immediate corrective measures such as fluid/electrolyte replacement or removal.

- Deficits can be reversed by adding fluid or the particular electrolyte to the body fluids. Excess amounts of either fluid or electrolytes must be removed. For example, a fluid deficit is returned to normal by the increased intake of fluid. Excess fluid is removed, perhaps by taking diuretic drugs to increase the excretion of fluid through the kidneys.
- Caution is required when adjusting fluid levels, to ensure that electrolyte balance is maintained. For example, when adding fluid to the body, it is

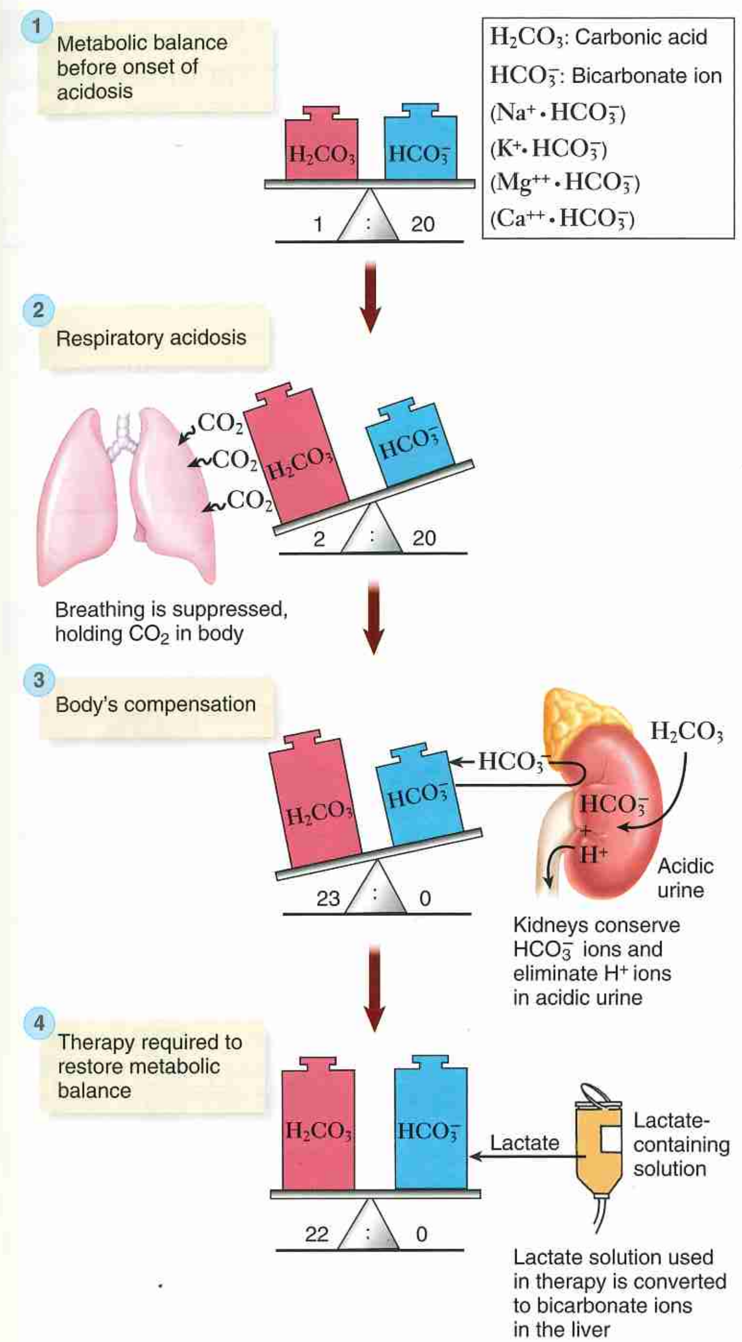

FIGURE 2-14 Respiratory acidosis. *(From Patton KT, Thibodeau GA: Anatomy & Physiology, ed 8, St. Louis, 2013, Mosby.)*

necessary to check electrolyte levels and perhaps add sodium or other electrolytes, to achieve normal levels of all components.

- Addition of bicarbonate to the blood will reverse acidosis; levels of bicarbonate need to be monitored because excess bicarbonate levels may occur.
- In some cases, diet may be modified to maintain better electrolyte balance.
- Other factors such as respiratory or kidney disorders and hormonal imbalances can have dramatic effects on the fluid/electrolyte balance.

THINK ABOUT 2-25

a. For each of the following situations, list the kind of acid-base imbalance likely to occur: (1) chest injury with fractured ribs, (2) infection with high fever, (3) diarrhea.
b. Describe the effect of metabolic acidosis on respiration and on the central nervous system.
c. In an elderly person with respiratory acidosis due to chronic respiratory congestion, why would decreased kidney function be so dangerous?
d. If serum pH decreases to 7.1 because of severe renal disease, explain the change that has occurred in the buffer pair and the effect of this change on the central nervous system.

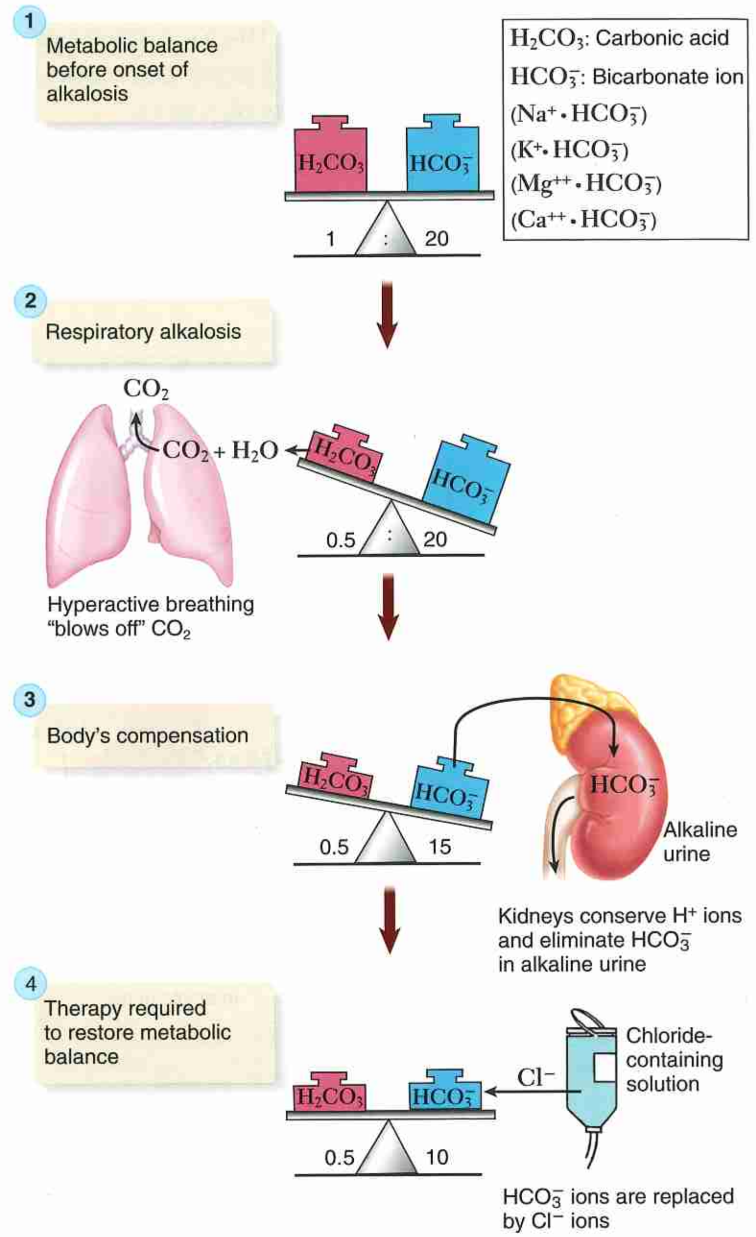

FIGURE 2-15 Respiratory alkalosis. *(From Patton KT, Thibodeau GA: Anatomy & Physiology, ed 8, St. Louis, 2013, Mosby.)*

TABLE 2-9 Examples of Acidosis

Respiratory Acidosis—Individual with Emphysema Retaining CO_2

Stage 1:	Kidneys compensate for slight increase in P_{CO_2} by increasing excretion of acids and production of bicarbonate	No change in serum levels
Stage 2:	Increased retention of CO_2. Respiratory acidosis	Elevated P_{CO_2}
Stage 3:	Compensation. Kidneys reabsorb more bicarbonate	Elevated serum ions. bicarbonate
Stage 4:	Compensated respiratory acidosis: Abnormal serum values indicate problem and compensation adequate to maintain ratio and normal serum pH.	Serum pH = 7.35
Stage 5:	Decompensated respiratory acidosis: Patient acquires pneumonia, and much more CO_2 is retained. Also, kidneys cannot maintain compensation. Ratio is no longer normal, CNS depression, coma, and serum pH drops below the normal range.	Serum pH = 7.31

TABLE 2-9 Examples of Acidosis—cont'd

Metabolic Acidosis—Individual with Diabetic Ketoacidosis Owing to Insulin Deficit

Stage 1:	Slight increase in production of ketoacids. Kidneys increase excretion of acids.	No change in serum values
Stage 2:	Metabolic acidosis: More ketoacids produced than kidneys can excrete quickly, and acids bind with or "use up" buffer bicarbonate.	Low serum bicarbonate
Stage 3:	Respirations become rapid and deep to remove CO_2. Kidneys compensate by excreting more acids and reabsorbing more bicarbonate but cannot keep up with the increasing ketoacids added to the blood.	Low P_{CO_2}
Stage 4:	Compensated metabolic acidosis: Abnormal serum values indicate the problem and compensation adequate to maintain ratio and normal serum pH.	Serum pH = 7.35
Stage 5:	Decompensated metabolic acidosis: Ketoacids continue to increase in the blood at a faster rate, and the kidneys have decreased function owing to dehydration. Therefore, the problem becomes more severe and compensation is inadequate. The ratio is not maintained, and serum pH drops below the normal range.	Serum pH = 7.31

CASE STUDY A

Vomiting

Mr. K.B. is age 81 and has had gastritis with severe vomiting for 3 days. He has a history of heart problems and is presently feeling dizzy and lethargic. His eyes appear sunken, his mouth is dry, he walks unsteadily, and he complains of muscle aching, particularly in the abdomen. He is thirsty but is unable to retain food or fluid. A neighbor has brought Mr. K.B. to the hospital, where examination shows that his blood pressure is low, and his pulse and respirations are rapid. Laboratory tests demonstrate elevated hematocrit, hypernatremia, decreased serum bicarbonate, serum pH 7.35, and urine of high specific gravity (highly concentrated).

This case study illustrates a combination of fluid, electrolyte, and acid-base imbalances. Specific laboratory values are not given so as to focus on the basic concepts. For clarity, this case study is discussed in three parts, the early stage, middle stage, and advanced stage of the imbalances. Further information about the specific problems involved is given in each part and is followed by a series of questions.

Part A: Day 1

Initially, Mr. K.B. lost water, sodium in the mucus content, and hydrogen and chloride ions in the hydrochloric acid portion of the gastric secretions.

Alkalosis develops for two reasons, the first being the direct loss of hydrogen ions and the second being the effects of chloride ion loss. When chloride ion is lost in the gastric secretions, it is replaced by chloride from the serum (see Fig. 2-9). To maintain equal numbers of cations and anions in the serum, chloride ion and bicarbonate ion can exchange places when needed. Therefore more bicarbonate ions shift into the serum from storage sites in the erythrocytes to replace the lost chloride ions. More bicarbonate ions in the serum raise serum pH, and the result is "hypochloremic alkalosis."

1. Which compartments are likely to be affected in this case by early fluid loss?
2. Explain how a loss of sodium ions contributes to dehydration.
3. Describe the early signs of dehydration in Mr. K.B.
4. What serum pH could be expected in Mr. K.B. after this early vomiting?
5. Describe the compensations for the losses of fluid and electrolytes that should be occurring in Mr. K.B.
6. Explain why Mr. K.B. may not be able to compensate for losses as well as a younger adult.

Part B: Days 2 to 3

As Mr. K.B. continues to vomit and is still unable to eat or drink any significant amounts, loss of the duodenal contents, which include intestinal, pancreatic, and biliary secretions, occurs. No digestion and absorption of any nutrients occurs.

Losses at this stage include water, sodium ions, potassium ions, and bicarbonate ions. Also, intake of glucose and other nutrients is minimal. Mr. K.B. shows elevated serum sodium levels.

7. Explain why serum sodium levels appear to be high in this case.
8. Explain how high serum sodium levels might affect the intracellular fluid.
9. Using your knowledge of normal physiology, explain how continued fluid loss is likely to affect:
   a. blood volume
   b. cell function
   c. kidney function
10. Given Mr. K.B.'s history, why might potassium imbalance have more serious effects on him?

Part C: Day 3: Admission to the Hospital

After a prolonged period of vomiting, metabolic acidosis develops. This change results from a number of factors:

- Loss of bicarbonate ions in duodenal secretions
- Lack of nutrients leading to catabolism of stored fats and protein with production of excessive amounts of ketoacids
- Dehydration and decreased blood volume leading to decreased excretion of acids by the kidney
- Decreased blood volume leading to decreased tissue perfusion, less oxygen to cells, and increased anaerobic metabolism with increased lactic acid
- Increased muscle activity and stress leading to increased metabolic acid production

These factors lead to an increased amount of acids in the blood, which bind with bicarbonate buffer and result in decreased serum bicarbonate and decreased serum pH or metabolic acidosis.

11. List several reasons why Mr. K.B. is lethargic and weak.
12. Predict the serum level of carbon dioxide or carbonic acid in this case.
13. If Mr. K.B. continues to lose body fluid, why might serum pH decrease below 7.35?
14. If serum pH drops below 7.35, what signs would be observed in Mr. K.B.?
15. Describe the effect of acidosis on serum potassium levels.
16. Mr. K.B. will be given replacement fluid therapy. Why is it important that sodium and potassium be given as well as water?

CASE STUDY B

Diarrhea

Baby C., 3 months old, has had severe watery diarrhea accompanied by fever for 24 hours. She is apathetic and responds weakly to stimulation. The condition has been diagnosed as viral gastroenteritis.

1. List the major losses resulting from diarrhea and fever.
2. List other signs or data that would provide helpful information.
3. Explain several reasons why infants become dehydrated very quickly.

CASE STUDY C

Nephrotic Syndrome

S.K., age 5, has idiopathic nephrotic syndrome (nephrosis). He has generalized edema with a puffy face, distended abdomen, and edematous legs. He has gained weight but has eaten very little during the past week and has been quite irritable and lethargic. His blood pressure is normal. Laboratory tests indicate high levels of albumin, lipids, and hyaline (protein) casts in the urine, which has a high specific gravity. Blood tests show hypoalbuminemia and elevated cholesterol levels.

1. State the cause of idiopathic nephrotic syndrome.
2. Describe the change in the nephron that leads to albuminuria.
3. Describe the characteristics of the blood and urine that distinguish nephrotic syndrome.
4. Explain how hypoalbuminemia causes generalized edema.
5. Explain why S.K. is retaining sodium and water.
6. Explain why skin breakdown is common in patients with prolonged edema.

CHAPTER SUMMARY

Water, electrolytes, and acids are constantly moving between compartments in the body, depending on intake, output, and variations in cell metabolism. Numerous mechanisms work to maintain a constant internal environment.

- Edema, local or general, results from excess fluid in the interstitial compartment due to increased capillary hydrostatic pressure, increased sodium ion concentration in ECF, decreased plasma osmotic pressure related to decreased plasma proteins, obstructed lymphatic circulation, or increased capillary permeability.
- Dehydration or fluid deficit in the body may be caused by decreased intake or excessive loss of water. Infants and elderly persons exhibit the greatest risk for dehydration.
- The signs of dehydration include thirst, dry oral mucous membrane and decreased skin turgor, fatigue, decreased urine output, and low blood pressure with rapid, weak pulse.
- Third-spacing refers to the movement of fluid out of the vascular compartment into a body cavity or tissue where it cannot circulate.
- Hyponatremia impairs conduction of nerve impulses, muscle contraction, and distribution of body fluids.
- Hypernatremia causes fluid to shift out of cells, affecting cell function.
- Both hyperkalemia and hypokalemia lead to cardiac arrhythmias and possible cardiac arrest.
- Calcium ion levels in the blood are affected by parathyroid hormone, calcitonin, vitamin D, phosphate ion levels, diet, digestive tract, and renal function.
- Hypocalcemia causes muscle twitching and tetany related to increased permeability and excitability of nerve fibers, but leads to weaker cardiac muscle contractions.
- Excessive parathyroid hormone leads to hypercalcemia and bone demineralization that may cause spontaneous fractures.
- Chloride and bicarbonate ions are important in acid-base balance.
- The buffer ratio of 20 parts bicarbonate ion (base) to 1 part CO_2 (carbonic acid) is essential to maintain serum pH in the normal range of 7.35 to 7.45.
- Respiratory acidosis or alkalosis is caused by respiratory impairment increasing PCO_2, or hyperventilation decreasing PCO_2, respectively. The kidneys compensate by altering bicarbonate ion levels to maintain the required ratio.
- Metabolic acidosis results from a deficit of bicarbonate ion, either due to excessive loss of acids (e.g., from diarrhea) or to excessive accumulated acids (e.g., diabetic ketoacidosis). Metabolic alkalosis is caused by increased bicarbonate ion levels, perhaps from increased antacid ingestion. The respiratory and renal systems compensate for these changes.
- Decompensation develops when serum pH moves outside the normal range, preventing the cell enzymes from functioning. This can happen when the kidneys are damaged or when dehydration prevents adequate kidney function.
- Initially, vomiting causes loss of hydrochloric acid from the stomach and metabolic alkalosis. If vomiting is prolonged and severe, dehydration and metabolic acidosis develop.
- Diarrhea causes loss of fluid and bicarbonate ions, leading to metabolic acidosis.
- Generalized edema results from low levels of plasma proteins related to kidney or liver disease or malnutrition.

STUDY QUESTIONS

1. Describe the locations of intracellular and extracellular fluids.
2. Which makes up the higher proportion of body fluid, intracellular fluid or extracellular fluid?
3. How does the proportion of fluid in the body change with age?
4. Why does dehydration affect cell function?
5. What is the function of sodium ion in the body?
6. Describe the effect of hypernatremia on extracellular fluid volume and on intracellular fluid volume.
7. State the primary location (compartment) of potassium.
8. How are sodium and potassium levels controlled in the body?
9. Describe the signs and symptoms of hypocalcemia.
10. Describe how a deficit of vitamin D would affect:
    a. bones
    b. serum calcium level
11. Explain how hypochloremia affects acid-base balance.
12. State the normal range of pH for:
    a. blood
    b. urine
13. Describe how very slow, shallow respirations are likely to affect:
    a. PCO_2
    b. serum pH
14. State three possible causes of metabolic acidosis.
15. A diabetic client is producing excess amounts of ketoacids.
    a. Describe the effects of this excess on serum bicarbonate levels and serum pH.
    b. Explain the possible compensations for this imbalance.
    c. Describe the signs of this compensation.
16. The respirations that accompany metabolic acidosis are frequently called Kussmaul's respirations or "air hunger." What is the purpose of such respirations?
17. A person is found unconscious. He is wearing a Medic-Alert bracelet for diabetes and his breath has the typical odor of acetone (ketoacids).
    a. Predict his serum pH and the rationale for this prediction.
    b. Predict his serum potassium level.
18. How does insulin administration affect serum potassium?
19. A person will probably become very dehydrated as ketoacidosis develops. What heart rate and pulse characteristics would you expect to be present in this dehydrated condition?
20. Prolonged strenuous exercise usually leads to an increase in lactic acid. Given your knowledge of normal circulation, explain why it is helpful to have a cool-down period with mild exercise rather than total rest immediately after strenuous exercise.
21. General anesthetics, presence of pain, and narcotic analgesics for pain often lead to slow, shallow respirations after surgery, circulation is frequently slow, and oxygen levels are somewhat reduced. Predict the effects on the partial pressure of carbon dioxide and, how this would affect serum pH.

ADDITIONAL RESOURCES

Copstead LC, Banasik JL: *Pathophysiology*, ed 4, St. Louis, 2010, Saunders.

Damjanov I: *Pathology for the Health Professions*, ed 4, St Louis, 2011, Elsevier Saunders.

Guyton AC, Hall JE: *Textbook of Medical Physiology*, ed 11, Philadelphia, 2006, WB Saunders.

McCance KL, Huether SE: *Pathophysiology: The Biologic Basis for Disease in Adults and Children*, ed 5, St. Louis, 2005, Mosby.

Patton KT, Thibodeau GA: *Anatomy & Physiology*, ed 8, St Louis, 2013, Mosby.