Paramedic Resource Manual

ACID-BASE BALANCE

SECTION SIX

2014 Update by
Ontario Base Hospital Group Education Subcommittee

OJECTIVES: ACID-BASE BALANCE

The objectives indicate what you should know, understand and be prepared to explain upon completion of this module. The self-assessment questions and answers will enable you to judge your understanding of the material.

Upon completion of this module, the student should be able to:

1. explain the importance of acid-base balance.

2. explain the role of hydrogen ion excretion.

3. define pH and state the normal pH range of blood.

4. name the four physiological buffering systems and state the role of the most important of these in the maintenance of acid-base balance.

5. explain the role of the complementary mechanisms of the blood, lungs and kidneys in maintaining homeostasis.

6. define and state the prehospital, clinical manifestations of:

   a) Metabolic acidosis
   b) Metabolic alkalosis
   c) Respiratory acidosis
   d) Respiratory alkalosis.

If you have studied this subject previously, you may test your ability using the self-assessment questions. If you are able to obtain 90% or greater, you may choose not to do the unit and merely review the sections, or parts of sections, where weakness may exist. If you obtain less than 90%, it is recommended that the module be done in its entirety, stressing areas where more review is needed.

PREREQUISITE KNOWLEDGE

This module includes the information necessary to meet the objectives. However, in order to successfully complete this module, a prerequisite background knowledge in the following topics is required:

1. A basic knowledge of the concepts of pH, acidity and alkalinity, and of the relationship between pH and hydrogen ion (H^+) concentration. (This information is reviewed in the Glossary of this module.)
2. A familiarity with the theory of buffers.

GLOSSARY

ACIDOSIS	A disturbance of the acid-base balance of the body resulting in a blood pH below 7.35, i.e. acidic compared to normal pH.
ALKALOSIS	A disturbance of the acid-base balance of the body resulting in a blood pH above 7.45, i.e. alkaline compared to normal pH.
BUFFER	A chemical solution which reacts with, and resists changes in pH, when acid or base is added to the solution. In the body, buffers act as a transport system to move excess H^+ ions to the lungs and kidneys for excretion.
COPD	Abbreviation for "Chronic Obstructive Pulmonary Disease".
DEOXYHEMOGLOBIN	The non-oxygenated or reduced form of (reduced Hb) Hemoglobin is symbolized: Hb
EXTRACELLULAR FLUID (ECF)	The body fluid which occupies the area outside the cells. This includes the blood plasma and fluid in the tissue spaces.
FIXED ACIDS	Also called "non-volatile acids". Those acids which cannot be "breathed off" as gases by the lungs, but must be excreted in the urine.
HOMEOSTASIS	The state of equilibrium in the body with respect to various functions and to the chemical compositions of the fluids and tissues. The processes through which such equilibrium is maintained.
HYPERVENTILATION	Ventilations which are increased in depth and/or rate, resulting in a loss of CO_2 from the body.
HYPOVENTILATION	Ventilations which are decreased in rate and/or depth, resulting in a retention of CO_2 in the body.
INTERSTITIAL FLUID (ISF)	That part of the Extracellular fluid that circulates between and around the cells.
INTRACELLULAR FLUID (ICF)	A solution of water and electrolytes which circulates within the cells of the body.

METABOLIC ACIDOSIS	A condition of decreased blood pH (<7.35) resulting from a decrease in HCO^{3-} concentration (due to excessive loss of HCO^{3-} or retention/production of acid).
METABOLIC ALKALOSIS	A condition of increased blood pH (>7.45) resulting from a increase in HCO^{3-} concentration (due to retention of HCO^{3-} or excessive loss of acid).
MIXED ACID-BASE DISTURBANCE	A condition in which more than one type of acid-base disturbance exists simultaneously.
NON-VOLATILE ACIDS	Also called “fixed acids”. Those acids which cannot be “breathed off” as gases by the lungs, but must be excreted in the urine.
OXYHEMOGLOBIN	The oxygenated (oxygen-bound) form of hemoglobin (symbolized: HbO^2).
pH	Symbol used to express the logarithm of the reciprocal of the Hydrogen ion concentration (used to express the degree of acidity or alkalinity.
RBCs	Abbreviation for “red blood cells”.
RESPIRATORY ACIDOSIS	A condition of decreased blood pH (<7.35) due to retention of CO_2 which results in an increase in H_2CO_3 concentration.
RESPIRATORY ALKALOSIS	A condition of increased blood pH (>7.45) due to an excessive loss of CO2 which results in a decrease in H_2CO_3 concentration.
TETANY	A hyperirritability of the muscles leading to tremors and spasms (occurs when the body is in a state of alkalosis).
VOLATILE ACIDS	Those acids which can be excreted from the body as gases, i.e. “breathed off” by the lungs.

pH, ACIDITY AND ALKALINITY

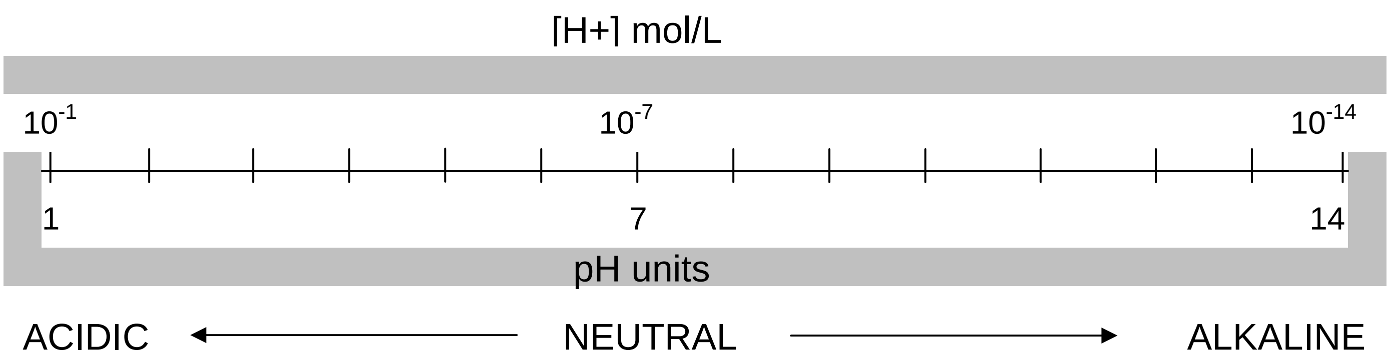
The degree of acidity or alkalinity of a solution is determined by its hydrogen ion (H^+) concentration. An increase in hydrogen ion (H^+) concentration makes a solution more acidic, while a decrease makes it more alkaline. The concentration of free hydrogen ions (H^+) in the body fluids is extremely small, approximately 0.0000001 mol/L, which can be expressed mathematically as 10^{-7} mol/L. Because these small numbers are so cumbersome to work with, the concept of pH was developed to express hydrogen ion (H^+) concentration more compactly. For convenience, acidity and alkalinity is expressed as the negative logarithm of the hydrogen ion (H^+) concentration, which is referred to as pH.

$$pH = -\log [H+]$$

Hydrogen Ion Concentration

in mol/L

To express a hydrogen ion concentration of 10^{-7} mol/L as a pH, the negative sign is dropped and this concentration (10^{-7}) of H = is indicated as pH 7. Thus, a range of hydrogen ion concentrations of 10^{-1} to 10^{-14} (0.1 to 0.00000000000001) mol/L can be represented as a range of pH from 1 to14.



There is an inverse relationship between pH and the hydrogen ion (H+) concentration. That is, as the hydrogen ion concentration increases, the pH decreases, and vice versa. Thus, an acidic solution has a low pH and a high hydrogen ion concentration, while an alkaline solution has a high pH and low hydrogen ion concentration.

IMPORTANCE OF ACID-BASE BALANCE

Normal metabolic function can occur only if the composition of the body cells and their surrounding environment are kept relatively constant. Therefore, one of the most important functions of the body is the careful regulation of both fluid and electrolyte balance, and acid-base balance.*

Disturbances in the acid-base balance of the body lead to cellular dysfunction and can seriously jeopardize a patient's life. Necessary metabolic activities can proceed only if the balance between acidic and basic substances in body fluids is kept within proper limits. The activity of virtually all the thousands of enzymes within the cells are to some extent pH-dependent.**

Even more important, however, is the pH-dependence of the overall functioning of the body, e.g. membrane transport processes, and ionic states of all substances. In an acidic or basic environment, some chemical reactions are accelerated while others are slowed down and can even be stopped completely. It is, therefore, important to understand the mechanisms involved in maintaining the body's normal acid-base balance, and the consequences of acid-base disturbances.

HYDROGEN ION PRODUCTION AND EXCRETION

Acid-base balance at its simplest level refers to the homeostasis (or balance) of the hydrogen ion (H+) concentration in body fluids. Since many end-products of the body's metabolic reactions are acidic, the body produces a large excess of acid under normal physiological conditions (Figure 1).

If this acid were allowed to accumulate, the effect on the blood, tissue fluid and intracellular fluid pH's would be dramatic and lethal. Thus, in the face of continual production of acids, the body must have mechanisms by which it can minimize the pH changes in the body fluids. In addition, since the amount of acid produced continually varies, these mechanisms must be able to respond to pH variations and adapt accordingly.

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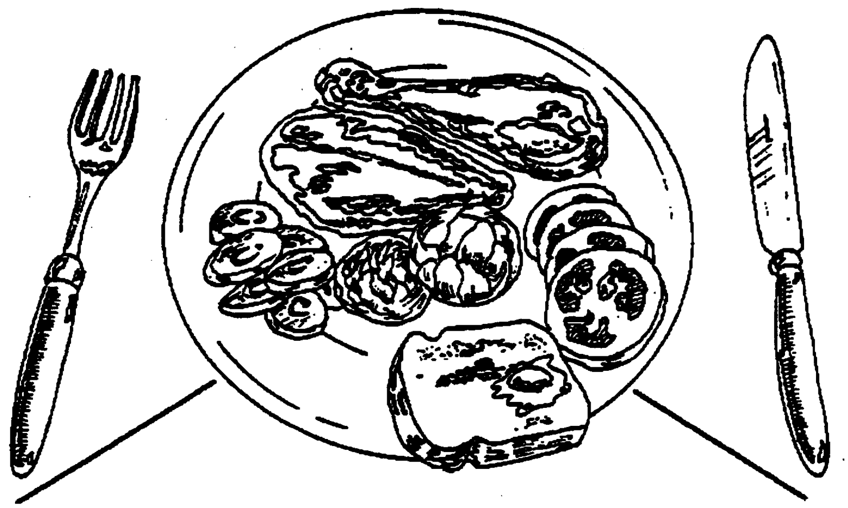
* Water and electrolyte balance and acid-base balance are closely interrelated, and in relation to their disturbance in disease, they must be considered together. However, for convenience, these two topics are presented separately , in different instructional modules.

** The concept of pH and its relationship to acidity and alkalinity is reviewed in the Glossary of this module.

FIGURE 1: ACIDIC END-PRODUCTS OF METABOLISM



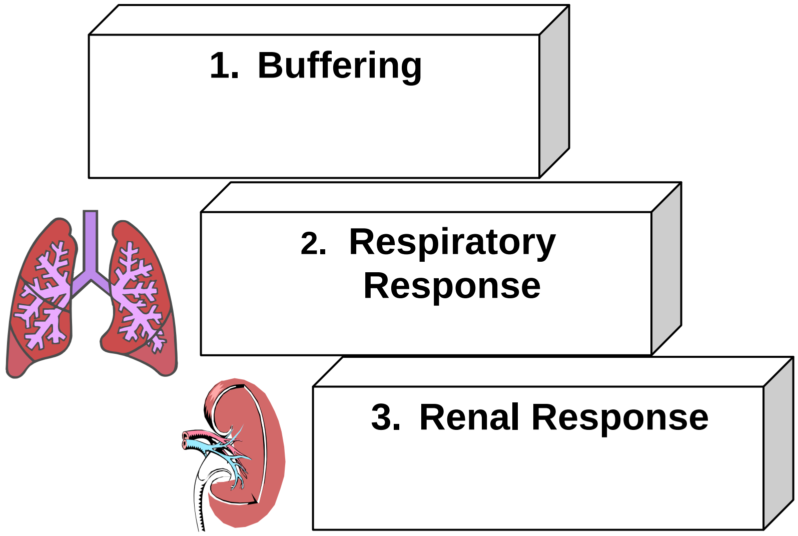
MECHANISMS OF pH REGULATION AND HYDROGEN ION EXCRETION

In counteracting the accumulation of excess acid (H^+ ions), the body faces two distinct tasks:

- elimination of the excess hydrogen ions (H^+) from the body
- prevention of pH changes in the blood while transporting these hydrogen ions to the organs where they will be excreted.

The transportation and elimination of excess hydrogen ions (acid) from the body is accomplished by means of the respiratory system, the renal system and the chemical buffer systems. The respiratory and renal systems are physiological mechanisms by which hydrogen ions (H^+) are excreted from the body, while the chemical buffer systems rely on their physiochemical action to minimize pH changes in the body fluids during hydrogen ion transport to the lungs and kidneys. Each of these mechanisms (Figure 2) shares the responsibility of maintaining the hydrogen ion concentration (and therefore the blood pH) within its normal, narrow limits.

FIGURE 2: MECHANISMS OF pH REGULATION AND HYDROGEN ION EXCRETION



The body has three main mechanisms by which it regulates blood pH. The chemical buffer systems act more or less immediately in response to an upset in the balance of hydrogen ions in the body fluids. These buffers are responsible for maintaining a normal blood pH (7.35 – 7.45) during hydrogen ion transport to the lungs and kidneys. The lungs and kidneys are responsible for the elimination of excess hydrogen ions from the body. The respiratory response is almost immediate, while the renal response is slowest to act.

THE PHYSIOLOGICAL BUFFER SYSTEMS

An acid-base buffer is a chemical solution which prevents excessive change in pH (and H+ concentration) when either acid or base is added to the solution. Specifically, a buffer is a mixture of: either a weak acid and its alkali salt, or a weak base and its acid salt. In the body, the buffers of physiological importance are mixtures of weak acids and their alkali salts.

If excess base is added to the solution, the weak acid part of the buffer reacts to neutralize it. Likewise if excess acid is added to the solution, the alkali salt part of the buffer reacts to neutralize it. In this way, the body's buffers can be regarded as chemical sponges, soaking up surplus hydrogen ions (H^+) or releasing them as required.

All of the base that is available for immediate neutralization of acids produced by cell metabolism is in the form of buffer salts. Thus, it is only by the chemical action of these buffers that hydrogen ions (H^+) can be transported in the blood to the lungs and kidneys for excretion without the blood pH dropping drastically. The chemical action of the buffers occurs within a fraction of a second to prevent excessive changes in hydrogen ion (H^+) concentration and pH. Although there are many buffer systems working within body fluids, four main systems exist.

- The bicarbonate/carbonic acid buffer system
- The phosphate buffer system
- The protein buffer system
- The hemoglobin buffer system.

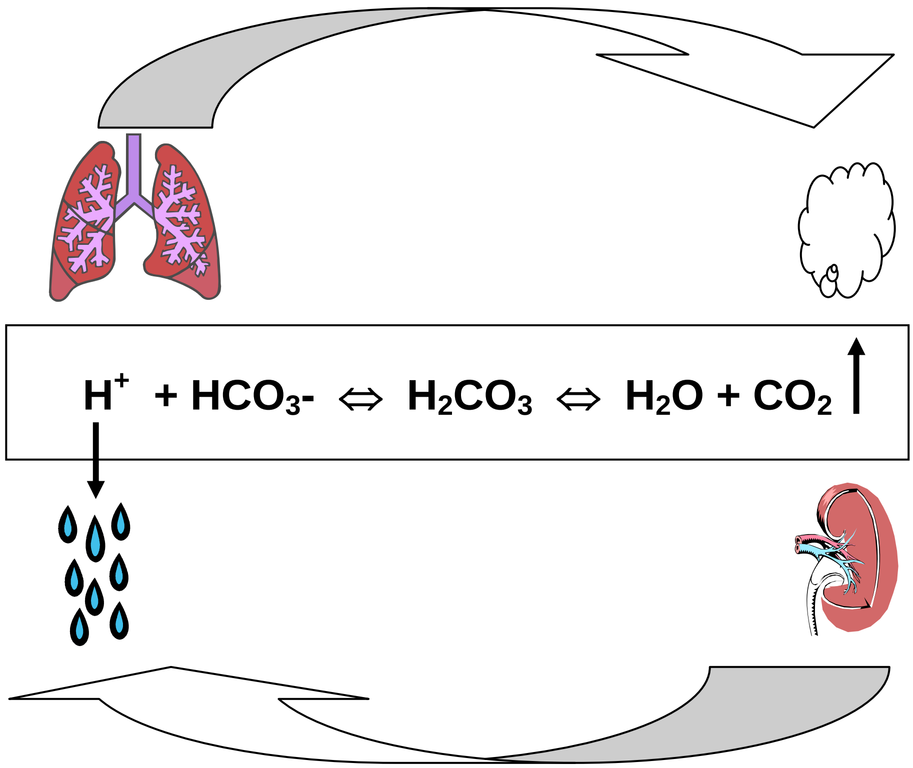
The bicarbonate/carbonic acid buffer system is the major buffer system for fixed acids in the blood. (It buffers $\simeq$ 0.7 (70%) of the fixed acids in the plasma and $\simeq$ 0.3 (30%) of the fixed acids in the RBCs). It is quantitatively the largest buffer system in the body, and is therefore the most important overall in regulating pH. Part of its importance derives from the fact that each of the components of this buffer system can be regulated via the lungs and kidneys:

- carbonic acid (H_2CO_3) can be retained or exhaled as carbon dioxide (CO_2)
- bicarbonate (HCO_3) can be retained or excreted by the kidney tubules as required by the body.

In the blood, the normal ratio of bicarbonate/carbonic acid is 20/1, so this system is heavily weighted towards buffering against excess acid production.

Both components of this important buffer system can be regulated via the lungs and the kidneys (Figure 3). The weak acid component, carbonic acid (H_2CO_3), can be retained or exhaled as carbon dioxide (CO_2) via the lungs, while the salt component, bicarbonate (HCO_3) can be retained or excreted by the kidney tubules according to the body's needs.

FIGURE 3: REGULATION OF THE COMPONENTS OF THE BICARBONATE / CARBONIC ACID BUFFER SYSTEM



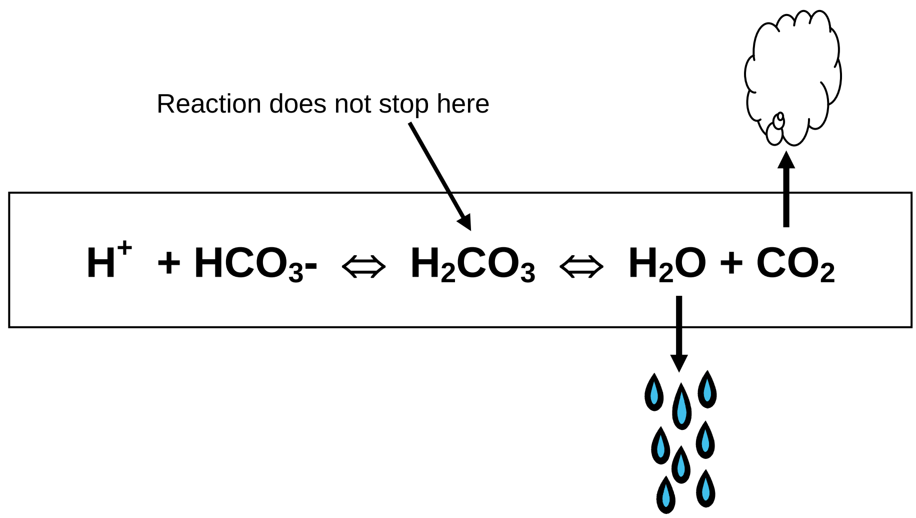
The other buffer systems are of less clinical significance than the bicarbonate/carbonic acid buffer system and will not be discussed here.

THE RESPIRATORY SYSTEM

The lungs are responsible for the regulation of the levels of volatile acids in the body fluids. The term “volatile” indicates that these compounds can be “breathed off”, i.e. excreted as gases.

Carbon dioxide (CO_2), the major end-product of metabolism, is being formed continuously inside the cells. It diffuses out of the cells, through the interstitial fluid, into the bloodstream. Here it forms carbonic acid (H_2CO_3) and dissolves. It is then buffered and transported to the lungs. In the lung tissue, CO_2 is reformed, diffuses into the alveoli and is exhaled (Figure 4).

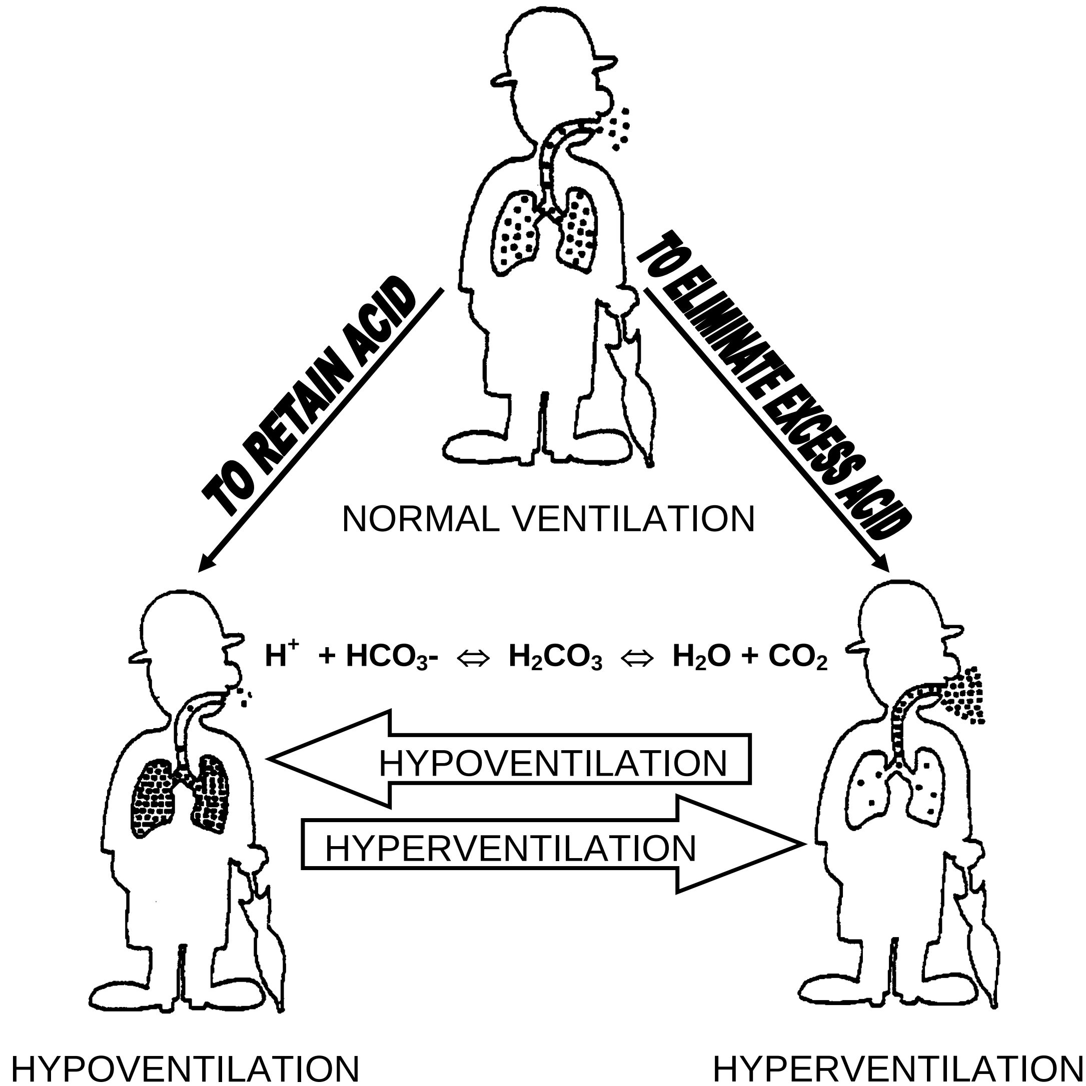
FIGURE 4: EXCRETION OF VOLATILE ACIDS BY THE LUNGS



In the lungs, acid is excreted as carbon dioxide (CO_2), while the water (H_2O) produced by the reaction is dissipated into the general water pool in the body. Note that these equilibrium reactions can be shifted to the left to produce more acid (H^+) or to the right to eliminate acid (as CO_2) as required by the body.

Whenever an imbalance in the hydrogen ion (H^+) concentration exists, the respiratory centre is stimulated. If the body needs to eliminate excess acid (H^+ ions), the lungs respond by increasing the rate of respiration (called **HYPERVENTILATION**) so as to eliminate more acid as CO_2 (Figure 5). If the body needs to retain acid (H^+ ions) to counteract a pH which is too alkaline, the lungs can decrease the rate of respiration (called **HYPOVENTILATION**) so as to retain more CO_2 (Figure 5).

FIGURE 5: HYPERVENTILATION AND HYPOVENTILATION



In the lungs, the equilibrium reaction can be shifted to the left to retain acid by decreasing the role of ventilation (HYPOVENTILATION), or can be shifted to the right to eliminate excess acid by increasing the ventilation rate (HYPERVENTILATION).

The respiratory response to changes in hydrogen ion (H^+) concentration and blood pH is very rapid. Working alone, the lungs can readjust the H^+ concentration within seconds after a sudden change has occurred. However, the respiratory mechanism has only a 50%-75% efficiency rate, i.e. the lungs alone cannot return the pH to its normal level of approximately 7.40. This is because, as the hydrogen ion concentration approaches normal, the stimulus to the respiratory centre is lost. For example, if the blood pH suddenly drops from 7.40 to 7.00, the respiratory system can return the pH to about 7.20-7.30 within a minute. Beyond that, the kidneys and the buffering systems must act to restore the balance. In a case such as this, medical treatment may include attempting to mimic the body's own respiratory response to the acidic pH. For example, the intentional hyperventilation of patients who have been in a state of cardio-respiratory arrest for some time prior to your arrival.

THE RENAL SYSTEM

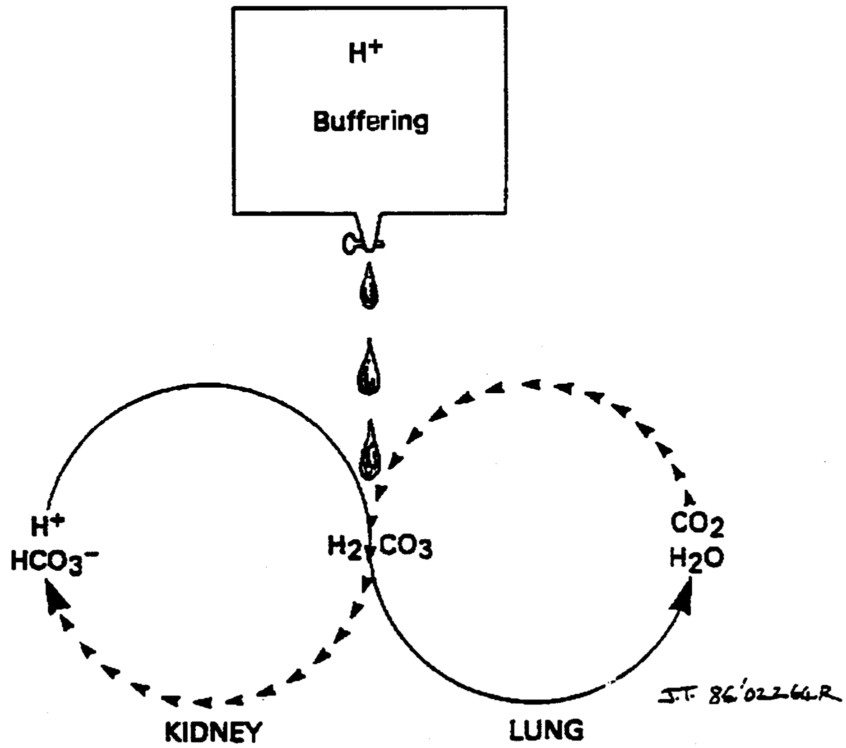
The kidneys are responsible for the regulation of the levels of **non-volatile or fixed acids,** acid which cannot be "breathed off", in the body. These include lactic acid, ketone bodies, phosphoric acid and sulfuric acid. All these acids dissociate in the body fluids to produce free hydrogen ions (H^+) which must then be excreted by the kidneys.

Whenever an imbalance in the hydrogen ion (H^+) concentration occurs, the kidney tubule cells are stimulated to adjust the excretion or reabsorption (retention) of acid (as H^+ ions) or buffer base (as HCO_3^- ions) as required. If the body needs to eliminate excess acid (H^+ ions) when the blood pH is too low, the kidneys respond by excreting more H^+ ions (acid) and retaining more HCO_3^- ions (buffer base to neutralize excess acid). If the blood pH becomes too alkaline, the kidneys respond by retaining H^+ ions (acid) and excreting HCO_3^- ions (buffer base).

The renal response to changes in hydrogen ion (H^+) concentration and blood pH is quire slow in comparison to that of the respiratory system. The kidneys, working alone, would require from several hours to a day or more to readjust the H^+ concentration after a sudden change. However, due to their versatility, the kidneys are the most powerful of the control mechanisms, and have a 100% efficiency rate. The kidneys, by themselves, are able to return the pH completely to normal given adequate time.

The interaction between the lungs, kidneys and chemical buffer systems are summarized in Figure 6.

FIGURE 6: INTERACTION BETWEEN LUNGS, LIDNEYS AND BUFFER SYSTEM IN REGULATING pH



In the blood, the chemical buffers act like a reservoir to "even out" the flow of hydrogen ions (H^+) into the respiratory and renal mechanisms. Excess acid can be eliminated via the kidneys (as H^+) or the lungs (as CO_2).

ACID-BASE DISTURBANCES

In disease, the pH of the blood and other fluids may move outside of normal limits due to an upset in the balance between acids and bases. This condition poses a serious threat to life unless it is remedied without delay. The organs which act to regulate acid-base homeostasis will attempt to restore the balance:

The lungs, by excreting or retaining acid (as CO_2)
The kidneys, by excreting or retaining acid (as H^+) or base (as HCO_3) as required.

Because of the importance of bicarbonate ions (HCO_3^-) and carbon dioxide (CO_2) in the regulation of acid or base excesses or deficits, the pH of the blood is directly dependent on bicarbonate/carbonic acid ration in the blood. The pH of the blood and other body fluids is directly proportional to the ratio of bicarbonate (HCO_3^-) to carbonic acid (H_2CO_3) (Figure 7).

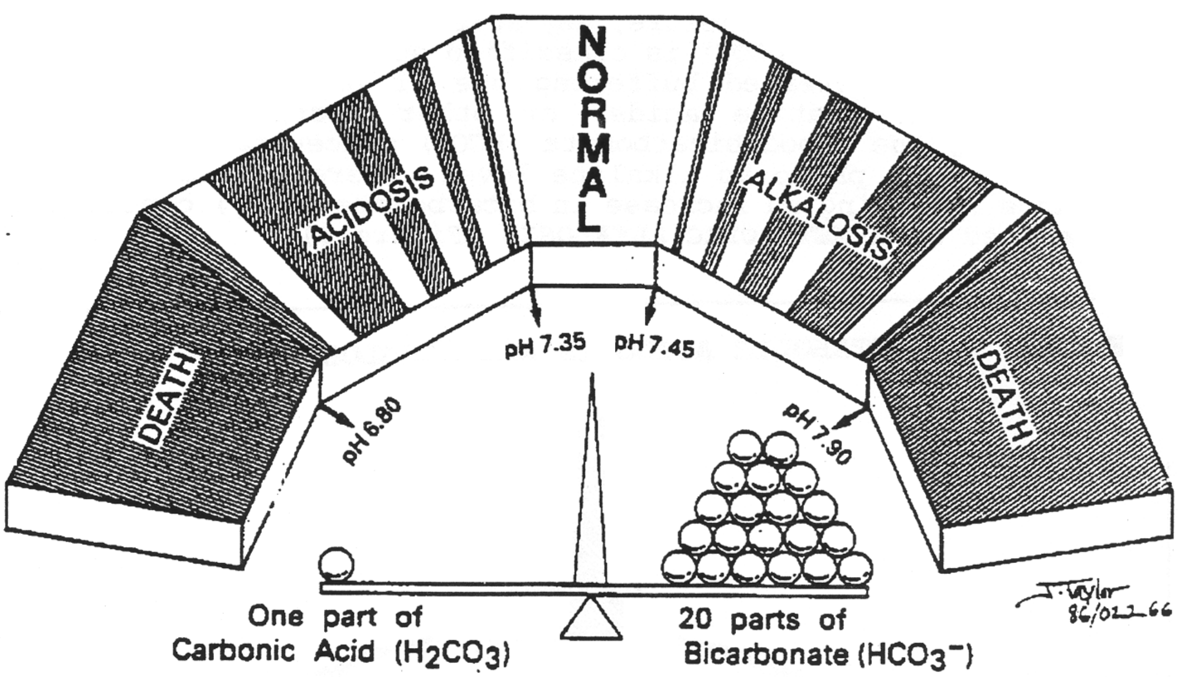
FIGURE 7:

$$\text{pH depends upon} \quad \frac{HCO_3^-}{H_2CO_3}$$

In health, the normal blood pH is 7.40 and the bicarbonate/carbonic acid ratio is 20/1. When the ratio is disturbed, the pH of the blood and body fluids may move outside the normal limits (pH 7.35-7.45). The resulting condition will be either ACIDOSIS, in which the pH is below the lower limit, or ALKALOSIS, when the pH is above the upper limit.

Acidosis can result from the body's failure to excrete excess acid (respiratory disease, kidney failure), the body's overproduction of acid metabolites (diabetes mellitus), or a loss of the body's alkaline reserves (severe diarrhea). Alkalosis can result from excessive loss of acid (hyperventilation, severe vomiting), or the addition of large amounts of alkali (excessive antacid ingestion).

FIGURE 8: NORMAL pH, ACIDOSIS AND ALKALOSIS



When the pH goes below 7.35, there is an excess of hydrogen ions (acid) and a state of ACIDOSIS exists. When the pH goes above 7.45, there is a depletion of hydrogen ions (acid) and a state of ALKAKOSIS exists. The extreme limits that are compatible with life are a blood pH of approximately 6.80-7.90. However, as the pH deviates from the norm of 7.35-7.45, there is a progressive deterioration in enzyme systems and cellular function. The patient's prognosis at such values is very poor and in either extreme, the imbalance may result in death if not corrected. As a point of interest, the body tends to tolerate acidosis much better than alkalosis.

In summary:

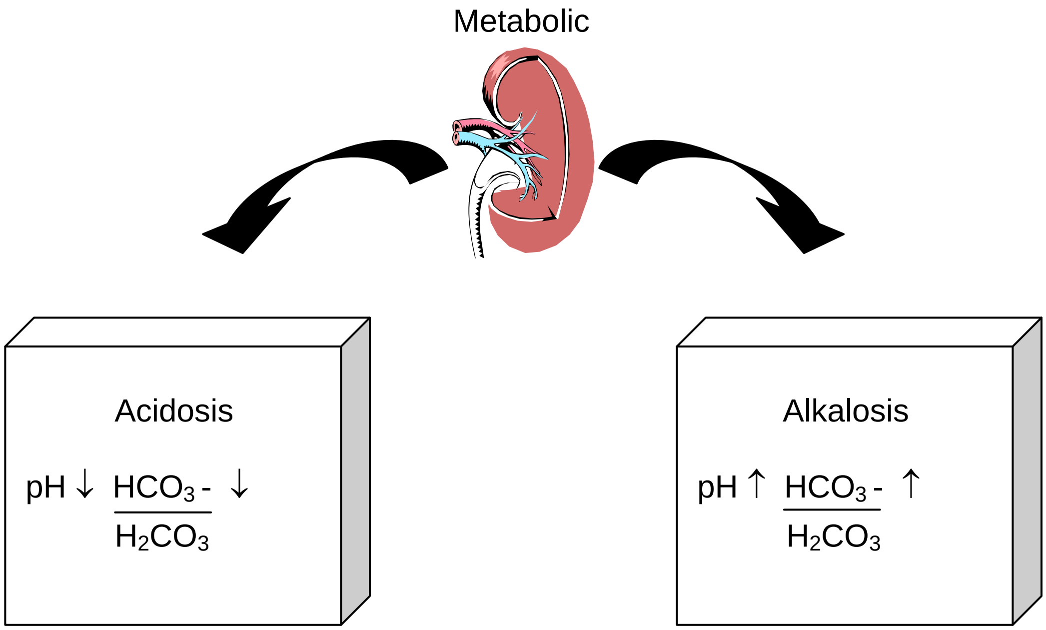
Normal blood pH = 7.35 – 7.45

pH < 7.35 is ACIDOSIS	pH > 7.45 is ALKALOSIS

Since an acidosis or an alkalosis can result from an abnormality in either the bicarbonate or the carbonic acid concentration, acid-base disturbances can be further classified as either "metabolic" or "respiratory". The concentration of bicarbonate ions (HCO_3^-) is affected by the metabolic production of acids and bases and by the activities of the kidneys. Because of this, bicarbonate (HCO_3^-) is referred to as the **METABOLIC** component of the ratio (or sometimes the **"NON-RESPIRATORY"** component).

If there is an excess of non-volatile acids or a loss of base, the blood bicarbonate (HCO_3^-) concentration decreases, causing a drop in pH to an acidic level. Therefore, any acid-base disturbance involving a loss of bicarbonate (HCO_3^-) is classified as – a **METABOLIC ACIDOSIS**. If there is a decreased buffering use of bicarbonate (due to a decrease in non-volatile acids) or other increase in the base concentration, the blood bicarbonate (HCO_3^-) concentration increases, causing a rise in pH to an alkaline level. Therefore, any acid-base disturbance involving an increase in bicarbonate (HCO_3^-) concentration is classified as a **METABOLIC ALKALOSIS** (Figure 9).

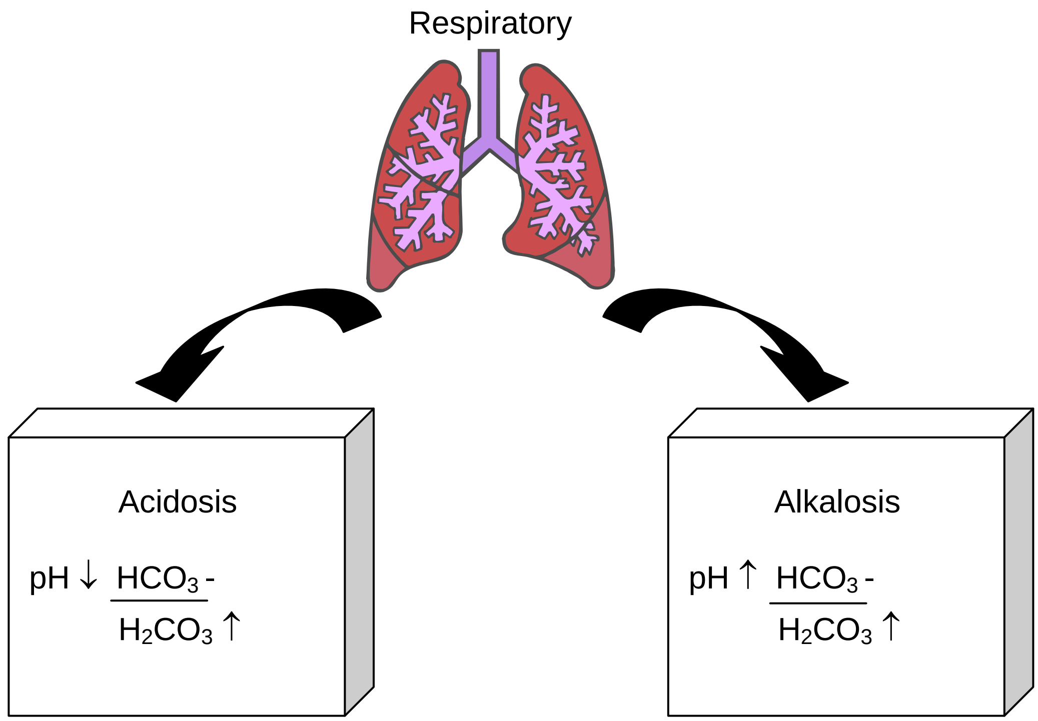
FIGURE 9: METABOLIC ACIDOSIS AND ALKALOSIS



The concentration of carbonic acid (H_2CO_3) is determined by the carbon dioxide (CO_2) concentration, which is in turn controlled by the lungs. Because of this, carbonic acid (H_2CO_3) is referred to as the RESPIRATORY component of the ratio.

If the lungs cannot remove CO_2 (by decreased lung activity), the blood carbonic acid (H_2CO_3) concentration increases, causing a drop in pH to an acidic level. Therefore, any acid-base disturbance associated with an increase in carbonic acid ((H_2CO_3) concentration (as CO_2 retention) is classified as a **RESPIRATORY ACIDOSIS**. If the lungs remove too much CO_2 (by increased lung activity), the blood carbonic acid (H_2CO_3) concentration decreases, causing a rise in pH to an alkaline level. Therefore, any acid-base disturbance associated with a decrease in carbonic acid (H_2CO_3) concentration (as CO_2 loss) is classified as a **RESPIRATORY ALKALOSIS**.

FIGURE 10: RESPIRATORY ACIDOSIS AND ALKALOSIS



These, then, are the four main classifications of acid-base disturbances. In each case, the loss from, or addition to the body of acid or base, causes a shift in blood pH outside the normal range. At this point each disturbance is said to be **UNCOMPENSATED**.

In respiratory disturbances, the lungs are usually compromised, and so the kidneys will attempt to compensate, i.e. restore the acid-base balance, by retaining or excreting H^+ ions (acid) or HCO_3^- ions (base) as needed.

In metabolic disturbances, the lungs will attempt to compensate by retaining or eliminating CO_2 (acid) as required. If the kidneys are not directly involved in the metabolic disturbances, they will also help to restore the acid-base balance.

In addition to the body's own compensatory mechanisms, administration of chemical treatment by a physician may be required in order to restore the acid-base balance. When the pH is brought back within the normal range, the disturbance is said to be **FULLY COMPENSATED**. In most cases however, the action of compensatory mechanisms and medical treatment result in only **PARTIAL COMPENSATION**, i.e. pH improves but remains outside the normal range, until the primary cause of the disturbance can be corrected.

In seriously ill patients, it is not uncommon to have two types of acid-base disturbance present simultaneously – so-called **MIXED DISTURBANCES**. For example, in a case of salicylate (aspirin) overdose, the initial disturbance is a respiratory alkalosis. This occurs due to the stimulation of the respiratory centre by the drug which produces marked hyperventilation. Then, the metabolism of the salicylates results in an accumulation of acids in the body and a metabolic acidosis. Cases of mixed acid-base disturbances are quite complex and difficult, and treatment must be vigorous to prevent death.

TABLE 1

CONDITIONS LEADING TO ACIDOSIS

METABOLIC ACIDOSIS	RESPIRATORY ACIDOSIS
o Uncontrolled diabetes mellitus (+ ketoacids) o Starvation or severe carbohydrate – reduced diet (↑ ketoacids) o Severe exercise (↑ lactic acid) o Severe diarrhea (G.I. loss of HCO_3^-) o Renal failure (failure to excrete H+) o Cardiac failure/arrest (↑ lactic acid) o Acute alcohol intoxication (↑ fixed acids) o Salicylate overdose (↑ fixed acids) o Shock (↑ lactic acid)	o Lung disease – COPD – Pneumonia (impaired gas exchange, retention of CO_2) o Barbiturate overdose (depression of respiratory centre, retention of CO_2) o Overdose of narcotics, or any sedative, tranquilizer or major depressant (same as for barbiturates) o Head injury (brain damage, depression of respiratory centre, retention of CO_2) o Any condition resulting in hypoventilation (retention of CO_2)

TABLE 2

CONDITIONS LEADING TO ALKALOSIS

METABOLIC ALKALOSIS	RESPIRATORY ALKALOSIS
o Excessive administration of sodium bicarbonate during treatment of cardiac arrest (↑ HCO_3^-) o Prolonged volume depletion (excessive diuretic use) o Prolonged vomiting (gastric loss of H^+) o Gastric suction (gastric loss of H^+) o Hyperaldosteronism (i.e. Cushing's Disease) (renal loss of H^+)	o Salicylate overdose – early stages (stimulation of respiratory centre, loss of CO_2) o High fever (stimulation of respiratory centre, loss of CO_2) o Hysteria/voluntary overbreathing (hyperventilation, loss of CO_2) o Passive overventilation by incorrectly adjusting artificial ventilator (loss of CO_2) o Any condition resulting in hyperventilation (excretion of CO_2)

Clinical vignette

The acid-base disturbances that will be most important to you are those of respiratory acidosis and metabolic acidosis.

In respiratory acidosis there is a build up of CO_2 (usually associated with hypoxia) – the causes of which are listed in Table 1. Since the accumulation of CO_2 is not desirable you will have to provide adequate ventilation either by treating the cause and/or assisting the patient's ventilation. This may require manually ventilating the patient and treating the cause later. Hypoxia will be corrected by oxygenating the patient.

Some of the causes of **respiratory acidosis** may be treated in the field promptly and adequately, e.g. narcotic overdose can be reversed with naloxone with immediate correction of the respiratory acidosis and hypoxia. Other causes such as pulmonary edema or a head injury may require assisted ventilation and/or intubation. This is used because the patient's condition is not immediately reversible. It is necessary to lower the CO_2 and increase the oxygen levels in order to return the pH of body fluids to normal. Vital organs are compromised by increased CO_2 and decreased O_2. Increased CO_2 can cause the brain to swell, the heart can become irritable and susceptible to arrhythmias and the blood pressure can drop. Therefore adequately ventilating the patient can be vital to survival.

An example of **metabolic acidosis** that can be treated initially in the field is diabetic ketoacidosis. These patients are usually volume depleted and require large volumes of isotonic saline (normal saline) to correct their volume depletion. Once the patient's volume is restored then perfusion to the tissues is improved. This decreases the build up of lactic acid thus returning the anion gap and the blood pH to normal.

Respiratory alkalosis is a condition in which the patient's respiratory system is stimulated to a degree that the level of CO_2 is lowered below normal. While hyperventilation due to anxiety is one possibility, before you apply the paper bag for rebreathing, consider the possibility of ASA toxicity or diabetic ketoacidosis as the cause of the respiratory pattern. In these instances, rebreathing will do more harm than good.

ADVANCED LIFE SUPPORT
PRECOURSE
ACID-BASE BALANCE

SELF-ASSESSMENT

Marks

[4] 1. Fill in the blanks:

The overall functioning of the body relies heavily on the maintenance of proper acid-base balance. Chemical reaction rates are very pH dependent, as is the activity of the (a) ____________ which catalyze these reactions. The acid-base balance refers specifically to the balance or (b) ____________________ of the hydrogen ion concentration (and therefore, pH) in body fluids.

The end-products of metabolism are mainly (c) ___________________ in nature. Therefore, the body must act to prevent lethal changes in the pH of body fluids. The excess hydrogen ions are excreted via the (d) ________________ and the (e) ________________________ and are "neutralized" during transport in the blood by (f) ______________________. The lungs excrete the (g) __________________ acids, while the kidneys excrete the (h) __________________________ acids. These are the mechanisms by which the body maintains acid-base balance.

[2] 2. Complete the following chart, comparing the response of the lungs vs. the kidneys to acid-base disturbances.

	LUNGS	KIDNEYS
a) Speed of response (fast or slow)		
b) Restores normal pH (partially or completely)		

[4] 3. Complete the following chart, stating the response of the lungs and the kidneys to low blood pH (excess acid) and high blood pH (excess base).

Response to:	LUNGS	KIDNEYS
Low blood pH (excess acid)		
High blood pH (excess base)		

[11] 4. a) $NaHCO2$ is the chemical formula for ____________________.

b) Prepared as a drug for intravenous administration it would be used to (raise/lower) the pH.

c) The effect of hyperventilation of a patient in cardio-respiratory arrest is (raise/lower) the pH.

d) The untreated cardiac arrest patient will have an acid-base disorder of which type? ______________________________________.

[3] Why?

[1] e) You are assessing a patient who is hyperventilating. Define hyperventilation.

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[3] f) Besides anxiety, list 3 other possible etiologies for hyperventilation.

---

[2] 5. a) State the normal range of blood pH.

---

b) Name the main buffer pair which determines blood pH.

---

[6] 6. Complete the following chart by stating:

- The effect on blood pH (increased or decreased)
- The type of acid-base disturbance resulting from each imbalance.

(1/2 mark each for effect; 1 mark each for naming disturbance)

IMBALANCE	EFFECT ON pH	TYPE OF ACID-BASE DISTURBANCE
$\frac{HCO_3^- \uparrow\uparrow}{H_2CO_3}$		
$\frac{HCO_3^- \downarrow\downarrow}{H_2CO_3}$		
$\frac{HCO_3^-}{H_2CO_3 \uparrow\uparrow}$		
$\frac{HCO_3^-}{H_2CO_3 \downarrow\downarrow}$		

[4] 7. a) State two clinical situations which may result in metabolic acidosis, indicating the source of the acidosis.

____

____

____

____

33 TOTAL

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SELF-ASSESSMENT ANSWERS

1. a) enzymes
   b) homeostasis
   c) acidic
   d) lungs
   e) kidneys
   f) (chemical) buffers
   g) volatile
   h) non-volatile or fixed

2.

	LUNGS	KIDNEYS
a) Speed of response (fast or slow)	fast	slow
b) Restores normal pH (partially or completely)	partially	completely

3.

Response to:	LUNGS	KIDNEYS
Low blood pH (excess acid)	Hyperventilation (exhale excess acid as CO_2)	Excrete H^+ ions (acid) Retain HCO_3^- ions (base)
High blood pH (excess base)	Hypoventilation (retain acid as CO_2)	Excrete HCO_3^- ions (base) Retain H^+ ions (acid)

4. a) sodium bicarbonate
   b) raise
   c) raise
   d) mixed acidosis (i.e. both respiratory and metabolic) Why?
   (1 mark each)
      - lack of ventilation causes CO_2 accumulation (respiratory component).
      - Hypoxia and lack of perfusion lead to anaerobic metabolism at the cellular level.
      - Lactic acid production results from anaerobic metabolism. This is the metabolism component.
   e) ventilations that are increased in either rate, depth or both, resulting in loss of CO_2.
   f) ASA toxicity; head injury; diabetic ketoacidosis.

5. a) normal range of blood pH = 7.35 – 7.45

b) Main buffer pair which determines blood pH: bicarbonate/carbonic acid or HCO_3^-/H_2CO_3

6.

IMBALANCE	EFFECT ON pH	TYPE OF ACID-BASE DISTURBANCE
$\frac{HCO_3^- \uparrow\uparrow}{H_2CO_3}$	↑ (increase)	Metabolic Alkalosis
$\frac{HCO_3^- \downarrow\downarrow}{H_2CO_3}$	↓ (decrease)	Metabolic Acidosis
$\frac{HCO_3^-}{H_2CO_3 \uparrow\uparrow}$	↓ (decrease)	Respiratory Acidosis
$\frac{HCO_3^-}{H_2CO_3 \downarrow\downarrow}$	↑ (increase)	Respiratory Alkalosis

7. Any two of:

- diabetic ketoracidosis (↑ ketoacids)
- starvation (↑ ketoacids)
- severe exercise (↑ lactic acid)
- severe diarrhea (loss of HCO_3^-)
- renal failure (↑ H^+)
- cardiac arrest (↑ lactic acid)
- acute alcohol intoxication (↑ fixed acids)
- ASA overdose (↑ fixed acids)
- Shock (↑ lactic acid)

ADVANCED LIFE SUPPORT
PRECOURSE
ACID-BASE BALANCE

EVALUATION

Upon completion of this module, please fill in and return this form to your base hospital co-ordinator.

Your comments will help to ensure that this unit is a useful learning module. Please indicate any problems that you may have encountered. All suggestions for improvement are welcomed.

1. How long did it take to complete this module? Please estimate.

Reading	___________	hours
Self assessment	___________	hours
Total time	___________	hours

2. Were the objectives of the module clearly stated?

   [ ] yes [ ] no
   If no, please comment.

3. Did you see any of the resource materials?

   [ ] yes [ ] no
   If yes, which items ____
   ____
   ____
   Were they helpful? ____

4. Were the reference notes adequate?

   [ ] yes [ ] no
   If no, please comment.

5. Were the reference notes easy to follow?

[ ] yes [ ] no

If no, please comment.

6. Were the examples provided satisfactory?

   [ ] yes [ ] no

   If no, please comment.

7. Were any of the self-assessment questions poorly worded?

   [ ] yes [ ] no

   If yes, please specify.

1. Was the level of the module satisfactory for your program of study?

   [ ] yes [ ] no

   If no, please comment.

Base Hospital ____

9. General comments or suggested improvements.