**Respiration and Acid-Base Balance BIOL 131 Handout**

Carbon dioxide in plasma can combine with water to produce carbonic acid, which in turn may dissociate to produce protons (H+) and bicarbonate ions (HCO3-). Ventilation regulates the carbon dioxide concentration of the plasma and thus plays an important role in acid-base balance.

Objectives

1. Describe the pH scale, and define the terms acid and base
2. Explain how carbonic acid and bicarbonate ion are formed in the blood and the functions they serve.
3. Define the terms acidosis and alkalosis, and explain how they relate to hypoventilation and hyperventilation.
4. Explain how ventilation is adjusted to help maintain acid-base balance.

Materials

1. pH meter, droppers, 50 and 200 ml beakers, straws
2. Buffer pH=7; 6M HCL, 6M NaOH, phenolphthalein solution

Ventilation accomplishes two different but related functions: (1) oxygenation of the blood- accomplished by bringing new air into the alveoli during the inhalation phase; and (2) the elimination of carbon dioxide from the blood- accomplished by the diffusion of CO2 from the blood into the alveoli and the exhalation of this CO2 rich air out of the body. The former function is required to maintain aerobic cell respiration, and the latter function is needed to maintain the normal pH of the blood.

The pH indicates the concentration of free or unbound H+ (hydrogen ion) in a solution and is defined by the following formula:

pH = log

where [H+] is the concentration of free H+ in moles (atomic weight in grams) per liter.

Some water molecules ionize to produce equal amounts of H+  and OH- (hydroxyl ion). In pure water, the free H+ concentration is 10-7 moles/liter. Since hydrogen has an atomic weight of 1, this is the same as 10-7 g/L. This is equal to a pH of 7.0 and is called a neutral solution. An acidic solution has a higher H+  concentration and a pH less than 7; a basic solution has a lower H+ concentration and a pH greater than 7 (table 1).

An acid is a molecule that can donate a free H+ to a solution and thus lower its pH. Carbonic acid (H2CO3) is formed from the combination of CO2 and water within the red blood cells. This reaction is catalyzed by an enzyme called carbonic anhydrase

carbonic anhydrase

CO2 + H2 H2CO3

Some of the carbonic acid thus formed can dissociate to yield H+ and bicarbonate ion (HCO3-). The free or unbound H+ derived from carbonic acid and other acids in the blood gives normal arterial blood a pH of 7.40 ± 0.05 (table 2).

H2CO3 HCO3- + H+

**The Ability of Buffers to Stabilize the pH of Solutions- Acidosis and alkalosis**

Plasma contains a particular concentration of bicarbonate ion from the dissociation of carbonic acid. Bicarbonate serves as the major buffer of the blood, helping to stabilize the pH of plasma despite the donation of H+  from molecules such as lactic acid, fatty acids, ketone bodies, and other metabolic products. When combined with bicarbonate, the H+ released by these acids is bound and does not lower the blood pH. Although a new acid molecule (carbonic acid) is formed, this reaction prevents a rise in the free H+ concentration and thus buffers the potential pH change in the plasma.

H+ + HCO3- H2CO3

Carbonic acid formed in this way can provide a source of new H+ should the blood pH begin to rise above normal levels (e.g., from a loss of blood H+). The carbonic acid/bicarbonate buffer system thus helps to stabilize the blood pH under normal conditions. Disease states, however, may drive the blood pH below 7.35 (acidosis), or above 7.45 (alkalosis).

Normally, the rate of ventilation matches the rate of CO2 production by the tissues, so that the carbonic acid, bicarbonate, and H+ concentrations in the blood remain within the normal range. If hypoventilation occurs, however, the carbonic acid levels will rise above normal and the pH will fall below 7.35. This condition is called respiratory acidosis. Hyperventilation, conversely, causes an abnormal decrease in carbonic acid and a corresponding rise in blood pH. This condition is called respiratory alkalosis. Respiratory acidosis or alkalosis thus occurs when the blood CO2 level (as measured by its partial pressure or PCO2, in millimeters of mercury) is different from the normal value (40 mm Hg) as a result of abnormal breathing patterns (table 2).

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| **Table 1: The pH Scale** | | | |
|  | H+ Concentration (molar) | pH | OH- Concentration (molar) |
| Acids | 1.0 | 0 | 10-14 |
|  | 0.1 | 1 | 10-13 |
|  | 0.01 | 2 | 10-12 |
|  | 0.001 | 3 | 10-11 |
|  | 0.0001 | 4 | 10-10 |
|  | 10-5 | 5 | 10-9 |
|  | 10-6 | 6 | 10-8 |
| Neutral | 10-7 | 7 | 10-7 |
| Bases | 10-8 | 8 | 10-6 |
|  | 10-9 | 9 | 10-5 |
|  | 10-10 | 10 | 0.0001 |
|  | 10-11 | 11 | 0.001 |
|  | 10-12 | 12 | 0.01 |
|  | 10-13 | 13 | 0.1 |
|  | 10-14 | 14 | 1 |

**Procedure**

1. Obtain a pH meter. Be sure the pH electrodes are immersed in buffer and not allowed to dry. Turn the meter on.
2. Obtain five 50 ml beakers. In the first two beakers and add 25 ml pH 7 buffer solution. Label the beakers with buffer solution 1 and 2. Add 25 ml distilled water in each of the other three beakers. Label the distilled water beakers 3 and 4 and 5.
3. Take a reading of the buffer in beaker 1. It should read approximately 7.0 (there will be some variation among pH checkers).
4. Now transfer the pH meter to beaker 3 of distilled water and record the pH of distilled water in your laboratory report. Return the pH meter back to the buffer solution.

Note: After recording the pH of a solution, always rinse the electrodes thoroughly using distilled water in beaker 3. Wipe the electrodes with a paper towel and return them to the buffer solution. Check the pH of the buffer solution after the cleaning procedure to make sure the electrodes have been adequately cleaned. For the following steps: record the pH of each solution tested in your laboratory report.

1. Add 1 drop of 6M hydrochloric acid (HCl) to beaker 4 of distilled water, and mix thoroughly. Record the pH
2. Add 1 drop of 6M NaOH to beaker 5 of distilled water, mix and record pH.
3. Add 1 drop of 6M HCl to beaker 1 containing pH 7 buffer solution.
4. Add 2 more drops of 6M HCl to beaker 1 and record pH.
5. Add 1 drop of 6M NaOH to beaker 2 containing pH 7 buffer solution
6. Add 2 more drops of 6M NaOH to beaker 2 and record pH.

Enter your date in the spaces below:

pH of Distilled Water \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Beaker 3

pH of Water + 1 drop HCl \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Beaker 4

pH of Water + 1 drop NaOH \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Beaker 5

pH of Buffer \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Beaker 1

pH of Buffer + 1 drop HCl \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Beaker 1

pH of Buffer + 3 drops HCl \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Beaker 1

pH of Buffer + 1 drop NaOH \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Beaker 2

pH of Buffer + 3 drops NaOH \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Beaker 2

Does your data support the statement that buffers help to stabilize the pH of solutions? Explain.

**The Effect of Exercise on the Rate of CO2 Production**

Increased muscle metabolism during exercise results in an increase in CO2 production. Nevertheless, the CO2 levels and pH of arterial blood do not normally change during exercise. This is because the increased rate of CO2 production is matched by an increased rate of CO2 elimination through ventilation. The mechanisms responsible for exercise hyperpnoea (increased breathing) are complex and incompletely understood.

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| **Table 2: The Effect of Respiration on Blood pH** | | | | | |
| PCO2(mmHg) | H2CO3(mEq/L)1 | HCO3-(mEq/L)1 | HCO3-/H2CO3 | Blood pH | Condition |
| 20 | 0.6 | 24 | 40/1 | 7.70 | Respiratory alkalosis |
| 30 | 0.9 | 24 | 26.7/1 | 7.53 | Respiratory alkalosis |
| 40 | 1.2 | 24 | 20/1 | 7.40 | Normal |
| 50 | 1.5 | 24 | 16/1 | 7.30 | Respiratory acidosis |
| 60 | 1.8 | 24 | 13.3/1 | 7.22 | Respiratory acidosis |

Procedure

1. Fill a beaker with 200 ml of distilled water, and add 5.0 ml of 0.1M NaOH and a few drops of phenolphthalein indicator. This indicator is pink in alkaline solutions and clear in neutral or acidic solutions. Divide this solution into two beakers.
2. While sitting quietly, exhale only through a straw into the solution in the first beaker. Note the time it takes to turn the solution from pink to clear, and record this time in your laboratory report.
3. Exercise vigorously for 2 to 5 minutes by running up and down stairs or by doing jumping jacks. Exhale through a straw into the second beaker. Note the time it takes to clear the pink solution and record this time in your laboratory report.

Enter your data in the spaces below:

Time for color change at rest: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Time for color change after exercise: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Explain your results in the space below:

**Questions for Acid Base Exercise:**

1. Define the following terms:

Acid

Base

Acidosis

Alkalosis

1. A solution with a H+ concentration of 10-9 molar has a pH of \_\_\_\_\_\_\_\_\_\_\_\_\_; its OH-concentration is \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.
2. Hypoventilation produces respiratory \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_, whereas hyperventilation produces respiratory\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.
3. Draw equations to show how hypoventilation affects the blood concentration of carbon dioxide, carbonic acid, H+, and bicarbonate.
4. Intravenous infusions of sodium bicarbonate are often given to acidotic patients and relieve the strain of rapid breathing. Write an equation and describe the reason why bicarbonate is helpful in this situation.