**Pre-module Homework Assignment**

*To prepare, read the chapter on Cellular Respiration in your textbook first. Then read and complete this prework.*

Cellular Respiration background

All organisms need to convert chemical fuels into a usable form, such as ATP. Most organisms carry out aerobic respiration, which uses oxygen gas (O2) while some others go through fermentation (without oxygen). Aerobic respiration is a longer biochemical pathway that completely breaks down the fuel molecule to carbon dioxide, generating around 32 molecules of ATP from one glucose molecule (figure 1). Fermentation, a much shorter pathway, produces only two ATP and only partially breaks down glucose. A simple diagram of the aerobic and fermentation (anaerobic) pathways is shown here:



**Figure 1:** “Anaerobic vs Aerobic Metabolism” by Allison Calabrese (CC BY 4.0)

Aerobic Respiration has four stages (figure 2):

1. **Glycolysis: breaks down glucose to 2 molecules of pyruvate, releasing electrons in the form of 2 NADH, and energy in the form of 2 ATP. This pathway consists of 10 chemical steps, it is anaerobic, and happens in the cytoplasm. The 2 pyruvate and the 2 NADH molecules are transported into the matrix of the mitochondria to be used in the next stages. A net total of 2 ATP is generated by substrate- level phosphorylation.
2. Pyruvate Oxidation: in the mitochondrial matrix, the 2 pyruvate molecules are oxidized to produce 2 acetyl-CoA molecules and 2 NADH molecules. Two CO2 molecules are released.
3. Krebs Cycle: this is a cyclical pathway of 8 chemical steps, and it happens in the mitochondrial matrix. It completes the oxidation of the 2 acetyl-CoA molecules to 4 CO2, releasing lots of electrons in the form of 6 NADH and 2 FADH2 molecules. It also generates a total of 2 ATP by substrate-level phosphorylation.

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**Figure 2**: Aerobic Respiration pathway. This diagram represents the major events, but does not represent their locations.

1. Oxidative Phosphorylation: it is performed by a series of large protein complexes (I-IV), associated with the inner mitochondrial membrane (see figure 3). Protein complex I receives electrons from NADH molecules and passes them on to complexes II, III, and IV. Protein complex IV passes the electrons to oxygen, the final electron acceptor, which is reduced to water at this step. Complexes I, III, and IV are proton pumps and use some of the energy of the electrons to pump protons into the intermembrane space, creating a proton gradient.

Electrons from FADH2 begin electron transport at complex II which passes them to complex III and IV and then to oxygen. Since complex I is bypassed, and complex II is not a proton pump, the proton gradient generated from FADH2 electrons is lower than from NADH electrons. This explains why more ATP is generated from NADH than from FADH2.



**Figure 3:** Oxidative Phosphorylation and Chemiosmosis

<https://upload.wikimedia.org/wikipedia/commons/4/46/ElectronTransportChainDw001.png>

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ATP is synthesized by the enzyme ATP synthase, also embedded in the inner membrane. This remarkable enzyme acts as a molecular motor, powered by the proton gradient built in the intermembrane space to make ATP in the matrix. Protons enter the rotor part of ATP synthase (part that is transmembrane) from the intermembrane space and cause it to spin around, letting the protons diffuse into the matrix. This rotation causes the catalytic sites for ATP synthesis (found in the knob-like structure facing the matrix) to change shape, become activated, and convert ADP and inorganic phosphate to ATP.

Introduction to pH:

*Cellular respiration causes pH changes in mitochondrial compartments. An explanation of pH and how to calculate it is useful here.*

pH is a measure of the acidity or basicity of a solution. It was first introduced by the Danish chemist Soren Sorensen who was looking for an easier way to denote the acidity of solutions given technological advances that resulted in far more sensitive equipment for measuring pH.

Acids are substances which donate hydrogen ions (H+), also called protons, while bases are substances that accept protons.

***Question:*** Can you think of the chemical reason why substances donate or accept protons?

Water can act as both a weak acid and a weak base, which means that a small proportion of water molecules can donate or accept protons to produce hydroxyl (OH−) and hydronium (H3O+) ions respectively, as shown below:

H2O + H2O ⇌ H3O+ + OH−

Hydronium is a proton carried around by a water molecule, so from now on we will use the term proton (H+), instead of hydronium ion. A very small amount of water will dissociate as indicated above, such that the concentration of H+ and OH− in pure water at room temperature is:

[H+] = [OH−] = 10-7 M

The pH of a solution is pH = -log[H+] where log is the common logarithm (base 10). The common logarithm is the inverse of the exponential function with base 10. This means that:

[H+] = 10-pH

So, we can see that a change in pH of 1 unit would be a ten-fold increase in the hydrogen ion concentration. Generally logarithmic scales are used when the input has wide variability in scale. Since the [H+] can vary from numbers such as 0.1 M (strong acid) to 0.0000000000001 M (strong base) the logarithmic scale converts these two to more reasonable 1 (strong acid) and 13 (strong base).

Example: log (0.01) = −2 because 0.01 = 10-2

Example: log (75) ≈ 1.875 because 101.875 ≈ 75

Similarly, we can define pOH = -log [OH-]

For pure water at room temperature pH = -log (10-7 M) which means the pH is 7, which indicates that pure water is neither acidic nor basic, but neutral. The pH scale typically ranges from 0 to 14 and any substance with a pH lower than 7 is characterized as an acid, whereas any substance with a pH higher than 7 is characterized as a base.



Here is how a change in concentration of H+ affects the pH. Complete all rows until you get to pH 14:

**Figure 4: pH scale**

[https://commons.wikimedia.org/wiki/File:216\_pH\_Scale-01.jpg](https://commons.wikimedia.org/wiki/File%3A216_pH_Scale-01.jpg)

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|  |  |
| --- | --- |
| **[H+] (M)** | **pH** |
| 1 = 100 | 0 |
| 0.1 = 10-1 | 1 |
| 0.01 = 10-2 | 2 |
|  | 3 |
|  | 4 |
|  | 5 |
|  | 6 |
|  | 7 |
|  | 8 |
|  | 9 |
|  | 10 |
|  | 11 |
|  | 12 |
|  | 13 |
|  | 14 |

What is the relationship between the change in [H+] and the change in pH?

Practice problems:

1. Gastric juice has a H+ concentration of 1.0 x 10-3 M. What is the pH of gastric juice?
2. The pH of the small intestine is 8. What is the [H+] in the small intestine?
3. Compare the [H+] in the stomach and the small intestine; in which of the two organs is the concentration higher and how much higher is it? (*Hint: find the ratio*)
4. HCl is a strong acid, which means that nearly every molecule of HCl in solution has dissociated into one H+ ion and one Cl‑ ion. If an HCl solution is 1 x 10‑1 M, then the hydrogen ion concentration is also 1 x 10-1 M. What is the pH of the solution?
5. Imagine you have a test tube with 10 mL of a 0.1 M HCl solution.
	1. What is the pH of the 0.1 M HCl solution?
	2. You want to dilute the 0.1 M HCl solution by 10-fold. You take another test tube (test tube #2) and fill it with 9 mL of water. You take 1 mL of the original 0.1 M HCL solution and add it to the water in test tube #2. What is the concentration of the diluted HCl solution in test tube #2?
	3. What is the theoretical pH of the diluted HCl solution in test tube #2?