

Chapters 6 and 7—Energy, Respiration and Fermentation

Week 3 Workshop Questions

- 1) Many people today are hooked on “fat free” or low-fat foods. They believe that if something is fat free, we can eat more of it and still maintain our current weight—or even lose weight. We may even think this means we can lose weight without exercising. Often, they are baffled to find that after ignoring the serving size shown on the packaging of these foods, they find themselves gaining weight. If “fat is stored as fat” and they are not eating any fat, why are they getting fatter?

When ATP (energy) is abundant, cellular respiration slows down; and that intermediates of glycolysis and the Krebs cycle can be enzymatically converted to fatty acids and glycerol and packaged into adipose tissue (even if the original energy source was glucose).

- 2) People are familiar with the muscle “burn” associated with intense exercise. Many of us even know that the burn is caused by lactic acid buildup, but do not know what lactic acid is, or why it causes the burn. Within your workshop group, try to come up with a reason why it causes a burning sensation.

Lactic acid is the by-product of fermentation in our muscle cells. During vigorous exercise, our muscle cells are rapidly using and making ATP. It is not long before the oxygen in the muscle is being used for oxidative phosphorylation faster than our blood can deliver it, so oxygen stores run out. Muscle cells have the enzymes used for lactic acid fermentation, and for short periods of time they can generate ATP via glycolysis in the absence of oxygen. Lactic acid is not good for cells; it is actually toxic in high levels. The “lactic acid burn” is not caused by high levels of lactate in your blood. Subjects who were given high levels of sodium lactate did not suffer the burning sensation. These symptoms result from the drop in pH of the blood that results from increasing acid content. An increase in any acid would cause the same sensation.

- 3) Dinitrophenol (DNP) is a compound that has the ability to separate the flow of electrons and the pumping of H^+ ions for ATP synthesis. This means that the energy from electron transfer cannot be used for ATP synthesis. About 50 years ago, DNP was given as a drug to help patients lose weight. Why does this work? Why would this be dangerous, especially in high doses?

If electron transport doesn't produce ATP, then much more sugar must be metabolized for energy needs. Very low production of ATP would be lethal. In oxidative phosphorylation, the flow of electrons from NADH and FADH₂ to oxygen results in the pumping of H^+ from the matrix to the inner membrane space. This gradient of H^+ can produce ATP by flowing through ATP synthetase in the mitochondrial inner membrane. Dinitrophenol disrupts the H^+ gradient reducing ATP synthesis. Under these conditions, much of our food that we eat could not be used for ATP synthesis are we lose weight. However, too much inhibitor and we could make too little ATP for life. The difference between weight loss and death is only a small concentration change in dinitrophenol, making the drug dangerous.

- 4) Trematol is a poison derived from the roots of the white snake plant. Cows eating this plant concentrate the poison in their milk. The poison inhibits liver enzymes that convert lactic acid to other compounds for metabolism. Why does physical exertion increase symptoms of poisoning by trematol? Why does the pH of the blood decrease in a person who has digested trematol?

Physical exertion would increase the production of lactic acid by fermentation, and the build up of lactic acid decreases blood pH when liver enzymes are blocked. During exertion, our muscles produce lactic acid from pyruvate by fermentation, allowing the regeneration of NAD⁺ for continued ATP production by glycolysis. Because lactic acid metabolism is blocked by tremetol, the acid would build up in our blood, decreasing the pH.

- 5) Explain why in anaerobic cells the ratio of pyruvate/ lactate is much less than 1 while under aerobic conditions the ratio of pyruvate/ lactate is much greater than 1.

Lactate is produced from pyruvate only under anaerobic conditions. The glycolytic pathway produces pyruvate, which in the presence of oxygen will be further metabolized in the citric acid cycle to produce NADH and FADH₂ for oxidative phosphorylation in the mitochondria. Normally, lactic acid will be low under these conditions. In the absence of oxygen (anaerobic), pyruvate must be converted to lactic acid, the only reaction that can regenerate NAD⁺ allowing further glycolysis. The production of lactic acid only under anaerobic conditions explains why pyruvate/lactate is much less than 1 in anaerobic cells and much greater than one in aerobic cells.

- 6) In the first step of glycolysis, the enzyme hexokinase uses ATP to transfer a phosphate to glucose to form glucose-6-phosphate. The product continues to be oxidized forming pyruvate in glycolysis and is a precursor to acetyl-CoA for the citric acid cycle (Kreb's cycle). Suppose that a cell has only glucose available for energy and that the activity of hexokinase is suddenly stopped in this cell. Which of the following conditions will occur and why?
- The cell will continue to produce energy from mitochondrial electron transport.
 - The cell will continue to produce ATP using the citric acid cycle.
 - The cell will ultimately be unable to produce ATP.
 - The cell will be forced to switch to fermentation to produce ATP.
 - The use of oxygen by the cell will increase.

Because energy production requires that glucose first be metabolized in glycolysis, the loss of hexokinase would block ATP production in the cell.

- 7) During a heart attack, blood flowing to the heart muscle is interrupted by blockage of a coronary artery. Which of the following metabolic activities would you expect to change in the heart? Explain why? (there may be more than one)
- oxidative phosphorylation would slow down in the mitochondria
 - the rate of production of lactic acid would be stimulated
 - the use of glucose by the muscle tissue would increase
 - the production of water by mitochondria would be inhibited

All are expected metabolic changes . Arteries carry oxygenated blood. If the flow of blood through the coronary artery to the heart is blocked, the heart is being deprived of oxygen. All of the above answers are expected effects of an insufficient oxygen supply to the cells, and resulting fermentation.

- 8) Hummingbirds and nectar-feeding insects eat a diet that is rich in sugars and extremely low in protein. How are these individuals able to synthesize the amino acids and proteins required for growth?

The sugar consumed by the hummingbirds that is not needed to fuel ATP production can ultimately be converted to amino acids through the Krebs cycle. When ATP is abundant, intermediates can be siphoned from the Krebs cycle to make the amino acids used to build proteins.

- 9) Cyanide (C≡N⁻) blocks complex IV of the electron transport chain. Suggest a hypothesis for what happens to the electron transport chain when complex IV stops working. Your hypothesis should explain why cyanide poisoning is lethal.

When cyanide blocks complex IV of the electron transport chain, all of the upstream components of the electron transport chain become stuck in a reduced state because the next molecule in the pathway/chain is unable to accept its electron. In a very short time, all of the NAD⁺ in the cell becomes reduced to NADH. Without NAD⁺, glycolysis and the Krebs cycle cannot continue. This stops the production of ATP in the cell unless a fermentation pathway is available to the cell. However, cyanide poisoning is fatal because brain cells do not have the enzymes needed for

fermentation. Even in cells that can undergo fermentation, there would not be enough ATP molecules to fuel the cell's energy needs over the long term.

10) When yeast cells are placed in a low-oxygen environment, the mitochondria in these cells become reduced in size and number. Suggest a plausible explanation for this observation.

When yeast cells are placed in a low-oxygen environment, they begin to switch to fermentation instead of cellular respiration. Because the fermentation pathway is predominant in this situation, there is no need for the cell to devote the energy needed for the production and upkeep of the mitochondria.

11) Most agricultural societies have come up with ways to ferment the sugars in barley, wheat, rice corn, or grapes and produce alcoholic beverages. Historians argue that this was an effective way for farmers to preserve the chemical energy in grains and fruits in a form that would not be eaten by rats or spoiled by bacteria or fungi. Why does a great deal of energy remain in the products of fermentation pathways?

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12) Compare and contrast substrate level phosphorylation and oxidative phosphorylation.

Both substrate-level phosphorylation and oxidative phosphorylation result in the formation of ATP by the addition of an inorganic phosphate to a molecule of ADP. Both reactions are catalyzed by enzymes that couple the formation of ATP to an exergonic reaction that provides the energy for the synthesis of ATP. Substrate-level phosphorylation occurs when enzymes involved in glycolysis, the Krebs cycle, or fermentation remove a phosphate from a substrate in the pathway and directly transfer it to ADP. The removal of the phosphate from the substrate is the exergonic reaction that fuels the endergonic synthesis of ATP. Substrate-level phosphorylation during glycolysis and fermentation occurs in the cytoplasm, while substrate-level phosphorylation during the Krebs cycle occurs in the mitochondrial matrix. On the other hand, oxidative phosphorylation refers to the synthesis of ATP by the enzyme ATP synthase. This enzyme couples the energy-releasing diffusion of protons down their concentration gradient to the phosphorylation of ADP to form ATP. It is called oxidative because the energy to create the proton-motive force (the concentration gradient that drives the diffusion through ATP synthase) comes from the movement of electrons through a series of increasingly oxidized molecules, of which oxygen is the final electron acceptor. Many of the molecules in the electron transport chain use the energy released by oxidation to pump protons from the mitochondrial matrix to the inter-membrane space.

13) What is the relationship between cellular respiration and fermentation? Why does cellular respiration produce so much more ATP than fermentation?

Cellular respiration and fermentation are two different catabolic processes that cells can use to harness the chemical energy in glucose to fuel the production of ATP. Both processes begin with glycolysis. But in cellular respiration pyruvate, the product of glycolysis, is further metabolized through the Krebs cycle. Most of the energy in the glucose molecule is transferred (by electrons) to NADH and FADH₂, which goes on to donate electrons to the electron transport chain, which indirectly fuels the production of ATP by chemiosmosis and ATP synthase. Cellular respiration can take place only in the presence of oxygen, because it is the final electron acceptor in the electron transport chain. But in the absence of oxygen there is no final electron acceptor, so all of the members of the electron transport chain become stuck in a reduced state, since the next molecule in the pathway/chain is unable to accept its electron. In a very short time, all the NAD⁺ in the cell becomes reduced to NADH. Without NAD⁺, glycolysis cannot continue. In this situation, pyruvate can be used as an oxidizing agent by the enzymes of fermentation pathway to oxidize NADH to NAD⁺, allowing glycolysis to continue. During these reactions, by-products such as lactate or ethanol are produced from the reduction of pyruvate. Cellular respiration produces substantially more ATP than fermentation, because oxygen is a much stronger

oxidizing agent than pyruvate. This means that the potential energy drop between glucose and oxygen is much greater than the potential energy drop between glucose and pyruvate.