1. An autotroph is an organism that—
   a. extracts energy from organic sources
   b. converts energy from sunlight into chemical energy
   c. relies on the energy produced by other organisms as an energy source
   d. both a and b

The correct answer is d—
   A. Answer a is incorrect. The ability to gain energy from organic sources is a common property of both autotrophs and heterotrophs.

The correct answer is d—
   B. Answer b is incorrect. Autotrophs are uniquely able to convert solar energy into chemical energy; however, they also extract energy from organic sources. Thus they make their own organic sources, but still convert these into ATP.

The correct answer is d—
   C. Answer c is incorrect. Reliance on the energy produced by others is a characteristic of heterotrophs.

The correct answer is d—both a and b
   D. Answer d is correct. Autotrophs can both store the Sun’s energy in the chemical bonds of organic molecules and retrieve that energy from the organic molecules to power the activities of the cell.

2. Which of the following processes is(are) required for the complete oxidation of glucose?
   a. The Krebs cycle
   b. Glycolysis
   c. Pyruvate oxidation
   d. All of the above

The correct answer is d—
   A. Answer a is incorrect. The Krebs cycle is the series of reactions that completes the oxidation of the glucose (now in the form of an acetyl group). This would be a valid answer except that there are other stages listed.

The correct answer is d—
   B. Answer b is incorrect. Pyruvate oxidation links glycolysis with the Krebs cycle. This would be a valid answer except that there are other stages listed.

The correct answer is d—
   C. Answer c is incorrect. Glycolysis is the first stage in the oxidation of glucose. This would be a valid answer except that there are other stages listed.

The correct answer is d—All of the above
   D. Answer d is correct. All of the processes listed are stages in the oxidation of glucose.

3. The energy associated with a molecule of glucose is stored in its—
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Chapter 7 – Answers

a. carbon atoms  
b. chemical bonds  
c. electrons  
d. protons

The correct answer is b—

A. Answer a is incorrect. Glucose is a carbohydrate and as such is composed of six carbon atoms; however, the atoms are not involved in the storage of energy.

The correct answer is b—chemical bonds

B. Answer b is correct. Chemical bonds represent stored, or potential, energy in any molecule.

The correct answer is b—

C. Answer c is incorrect. Electrons are involved in storing and carrying energy as part of redox reactions. Only the electrons participating in chemical bonds contribute to the energy of the molecule.

The correct answer is b—

D. Answer d is incorrect. Protons (hydrogen atoms) are an important part of many redox reactions, but on their own, they are not involved in energy storage.

4. How is ATP produced by glycolysis?
   a. Through the priming reactions  
b. Through the production of glyceraldehyde-3-phosphate  
c. By substrate-level phosphorylation  
d. As a result of the reduction of NAD⁺ to NADH

The correct answer is c—

A. Answer a is incorrect. The priming step of glycolysis requires the consumption of 2 ATP molecules. No ATP is made at this step.

The correct answer is c—

B. Answer b is incorrect. The production of glyceraldehyde-3-phosphate is a result of splitting glucose, but it does not result in ATP production. Two ATPs are consumed to make G3P.

The correct answer is c—By substrate-level phosphorylation

C. Answer c is correct. The oxidation of glyceraldehyde-3-phosphate to pyruvate results in the production of a total of 4 ATP molecules through substrate-level phosphorylation.

The correct answer is c—

D. Answer d is incorrect. NADH is an electron carrier that will transfer its electron to the electron transport chain and ultimately produce ATP, but ATP is not directly produced by glycolysis.
5. Which of the following is NOT a true statement regarding cellular respiration?
   a. Enzymes catalyze reactions that transfer electrons.
   b. Electrons have a higher potential energy at the end of the process.
   c. Carbon dioxide gas is a byproduct.
   d. The process involves multiple redox reactions.

The correct answer is b—
   A. Answer a is incorrect. Cellular respiration can occur because enzymes are present to catalyze the redox reactions found in the process.

The correct answer is b—Electrons have a higher potential energy at the end of the process.
   B. Answer b is correct. The overall process of cellular respiration releases energy for use by the cell. As a consequence, the potential energy at the end of the process will be much lower.

The correct answer is b—
   C. Answer c is incorrect. Carbon dioxide (CO₂) is released as the C-H bonds in glucose are broken and the C is oxidized.

The correct answer is b—
   D. Answer d is incorrect. Cellular respiration involves a complex series of redox reactions. The use of multiple small reactions allows the cell to capture the energy stored in the glucose molecules.

6. The majority of the ATP produced during aerobic respiration is made by—
   a. the electrons carried by NADH
   b. the movement of hydrogen ions through an ATP synthase enzyme
   c. substrate-level phosphorylation
   d. autophosphorylation

The correct answer is b—
   A. Answer a is incorrect. Electrons are associated with the production of ATP via the electron transport chain on the inner membrane of the mitochondria. The synthesis of ATP inside a mitochondrion is the result of oxidative phosphorylation and chemiosmosis and is part of the process of cellular respiration.

The correct answer is b—the movement of hydrogen ions through an ATP synthase enzyme
   B. Answer b is correct. The enzyme ATP synthase uses the energy of the proton gradient to generate ATP by oxidative phosphorylation as part of cellular respiration.

The correct answer is b—
   C. Answer c is incorrect. A single ATP is produced by substrate-level phosphorylation with each turn of the Krebs cycle. This is dwarfed by the amount produced by chemiosmosis.

The correct answer is b—
   D. Answer d is incorrect. Autophosphorylation suggests that ADP is capable of phosphorylating itself. This process is not part of glycolysis.
7. What is the role of NAD$^+$ in the process of cellular respiration?
   a. It functions as an electron carrier.
   b. It functions as an enzyme.
   c. It is the final electron acceptor for anaerobic respiration.
   d. It is a nucleotide source for the synthesis of ATP.

The correct answer is a—It functions as an electron carrier.
   A. Answer a is correct. NAD$^+$ becomes reduced during several different stages of glycolysis and cellular respiration. The reduced NADH carries both electrons and a proton.

The correct answer is a—
   B. Answer b is incorrect. NAD$^+$ is not an enzyme. It does function as a coenzyme in some cases, but this is part of its role as an electron carrier.

The correct answer is a—
   C. Answer c is incorrect. Although NAD$^+$ is capable of binding electrons, it functions as a carrier, not a final acceptor. Anaerobic respiration uses CO$_2$ or SO$_4$ as final electron acceptors.

The correct answer is a—
   D. Answer d is incorrect. NAD$^+$ is composed, in part, of an AMP nucleotide; however, that nucleotide does not directly contribute to the production of ATP in a cell.

8. Which of the following is NOT a product of glycolysis?
   a. ATP
   b. Pyruvate
   c. CO$_2$
   d. NADH

The correct answer is c—
   A. Answer a is incorrect. ATP is produced during the oxidation of glyceraldehyde-3-phosphate to pyruvate.

The correct answer is c—
   B. Answer b is incorrect. Pyruvate is the final product of glycolysis.

The correct answer is c—
   C. Answer c incorrect. The production of CO$_2$ as a consequence of the breakdown of pyruvate does not occur until the beginning of aerobic respiration.

The correct answer is c—
   D. Answer d is incorrect. NADH is produced during the oxidation of glyceraldehyde-3-phosphate.
9. Why is fermentation an important metabolic function in cells?
   a. It generates glucose for the cell in the absence of O₂.
   b. It oxidizes NADH to NAD⁺.
   c. It oxidizes pyruvate.
   d. It produces ATP.

   The correct answer is b—
   A. Answer a is incorrect. Glucose is synthesized as a result of photosynthesis, not fermentation.
   B. Answer b is correct. Glycolysis provides a source of ATP for a cell even in the absence of O₂. In order for glycolysis to continue, the cell must provide a constant source of NAD⁺. Fermentation provides that supply.
   C. Answer c is incorrect. The reactions associated with fermentation reduce pyruvate to ethanol or lactic acid.
   D. Answer d is incorrect. Fermentation allows ATP production by glycolysis to continue. The reactions associated with fermentation do not directly produce ATP.

10. Which of the following statements is NOT true about the oxidation of pyruvate?
    a. Pyruvate oxidation occurs in the cytoplasm.
    b. Pyruvate oxidation only occurs if oxygen is present.
    c. Pyruvate is converted into acetyl-CoA.
    d. Pyruvate oxidation results in the production of NADH.

    The correct answer is a—Pyruvate oxidation occurs in the cytoplasm.
    A. Answer a is correct. Pyruvate oxidation occurs within the matrix of the mitochondria.
    B. Answer b is incorrect. Pyruvate oxidation is regulated by the presence of O₂.
    C. Answer c is incorrect. Pyruvate is converted to acetyl-CoA during the initial step of pyruvate oxidation.
    D. Answer d is incorrect. The by-products of pyruvate oxidation are CO₂ and NADH.

11. The Krebs cycle occurs in which region of a mitochondrion?
    a. The inner membrane
    b. The intermembrane space
    c. The outer membrane
    d. The matrix

    The correct answer is d—
A. Answer a is incorrect. The inner mitochondrial membrane is the location of the electron transport chain and the enzyme ATP synthase.

The correct answer is d—

B. Answer b is incorrect. The intermembrane space is the region between the inner and outer membranes of the mitochondrion. This is the region in which protons accumulate.

The correct answer is d—

C. Answer c is incorrect. The outer mitochondrial membrane is important for the transport of materials.

The correct answer is d—The matrix

D. Answer d is correct. The matrix of the mitochondrion is a very protein-dense region that contains the enzymes required for the individual reactions of the Krebs cycle.

12. What happens to the electrons carried by NADH and FADH$_2$?
   a. They are pumped into the intermembrane space.
   b. They are transferred to the ATP synthase.
   c. They are moved between proteins in the inner membrane of the mitochondrion.
   d. They are transported into the matrix of the mitochondrion.

   The correct answer is c—
   
   A. Answer a is incorrect. Hydrogen ions (protons) are pumped into the intermembrane space.

   The correct answer is c—
   
   B. Answer b is incorrect. The ATP synthase does not interact with electrons. It is the movement of protons through the enzyme that triggers the addition of a phosphate group to a molecule of ADP.

   The correct answer is c—They are moved between proteins in the inner membrane of the mitochondrion.

   C. Answer c is correct. The electron carriers transfer their electrons to the proteins of the electron transport chain located in the inner mitochondrial membrane. Protons are pumped using the energy from the process of electron transport.

   The correct answer is c—

   D. Answer d is incorrect. The electrons move along the inner membrane of the mitochondrion. The final electron acceptor is found within the matrix; however, the electrons are not directly transported into the matrix.

13. Can cellular respiration occur in the absence of O$_2$?
   a. No, O$_2$ is required as the final electron acceptor.
   b. No, anaerobic organisms only need glycolysis and fermentation.
   c. Yes, because oxygen can be generated by splitting H$_2$O.
   d. Yes, but only when another final electron acceptor is available.

   The correct answer is d—
A. Answer a is incorrect. O₂ is the final electron acceptor for aerobic respiration; however, anaerobic respiration uses other molecules in place of O₂.

The correct answer is d—

B. Answer b is incorrect. All cells, aerobic or anaerobic, use glycolysis and fermentation. Anaerobic cells are not limited to these reactions and can undergo an anaerobic version of cellular respiration to increase the amount of ATP produced.

The correct answer is d—

C. Answer c is incorrect. The splitting of H₂O is associated with the process of photosynthesis and is not part of either glycolysis or respiration.

The correct answer is d—Yes, but only when another final electron acceptor is available.

D. Answer d is correct. Cellular respiration only requires that the electrons removed during the Krebs cycle have a final destination. Anaerobic organisms reduce CO₂ or SO₄ during cellular respiration.

14. Catabolism of fatty acids results in the production of—
   a. pyruvate
   b. glucose
   c. acetyl-CoA
   d. citrate

The correct answer is c—

A. Answer a is incorrect. Pyruvate is produced from glucose, or through the oxidation of certain amino acids.

The correct answer is c—

B. Answer b is incorrect. Glucose is produced by the breakdown of polysaccharides, or it is manufactured during photosynthesis.

The correct answer is c—acetyl-CoA

C. Answer c is correct. The long carbon chain of a fatty acid is broken into acetyl groups that can react with coenzyme A to form acetyl-CoA.

The correct answer is c—

D. Answer d is incorrect. Citrate is the product of the combination of acetyl-CoA and oxaloacetate at the start of the Krebs cycle.

15. What evidence supports the idea that glycolysis evolved early in the history of life?
   a. Glucose is a simple molecule.
   b. The reaction of glycolysis is common to all living things.
   c. Glycolysis requires few steps compared with other reactions.
   d. All of the above.

The correct answer is b—

A. Answer a is incorrect. Many other molecules have a similar structure to glucose; however, they are not central to cellular metabolism.
The correct answer is b—The reaction of glycolysis is common to all living things.

B. Answer b is correct. The fact that glycolysis occurs in all living organisms and does not significantly differ from a bacterial cell to you supports the idea that this series of reactions originated early in the evolution of life.

The correct answer is b—

C. Answer c is incorrect. The number of steps involved in glycolysis is not a significant factor.

The correct answer is b—

D. Answer d is incorrect. Of the three possible answers listed, only one directly addresses the evolutionary significance of glycolysis.

Challenge Questions

1. Use the following table to outline the relationship between the molecules and the metabolic reactions

<table>
<thead>
<tr>
<th>Molecules</th>
<th>Glycolysis</th>
<th>Cellular Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyruvate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Answer—

<table>
<thead>
<tr>
<th>Molecules</th>
<th>Glycolysis</th>
<th>Cellular Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose</td>
<td>Is the starting material for the reaction</td>
<td>Does not directly use glucose; however, does use pyruvate derived from glucose</td>
</tr>
<tr>
<td>Pyruvate</td>
<td>The end product of glycolysis</td>
<td>The starting material for cellular respiration</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Not required</td>
<td>Required for aerobic respiration, but not for</td>
</tr>
<tr>
<td></td>
<td>anaerobic respiration</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>ATP</strong></td>
<td><em>Produced through substrate-level phosphorylation</em></td>
<td><em>Produced through oxidative phosphorylation. More produced than in glycolysis</em></td>
</tr>
<tr>
<td><strong>CO₂</strong></td>
<td><em>Not produced</em></td>
<td><em>Produced during pyruvate oxidation and Krebs cycle</em></td>
</tr>
</tbody>
</table>

2. Human babies and hibernating or cold-adapted animals are able to maintain body temperature (a process called *thermogenesis*) due the presence of brown fat. Brown fat is characterized by a high concentration of mitochondria. These brown fat mitochondria have a special protein located within their inner membranes. *Thermogenin* is a protein that functions as a passive proton transporter. Propose a likely explanation for the role of brown fat in thermogenesis based on your knowledge of metabolism, transport, and the structure and function of mitochondria.

**Answer**—The electron transport chain of the inner membrane of the mitochondria functions to create a hydrogen ion concentration gradient by pumping protons into the intermembrane space. In a typical mitochondrion, the protons can only diffuse back down their concentration gradient by moving through the ATP synthase and generating ATP. If protons can move through another transport protein then the potential energy of the hydrogen ion concentration gradient would be “lost” as heat.