

Study question answers 2013 – Topic 3 Cellular energetics

Multiple choice questions (1 mark per answer)

1. Cellular respiration...
 - a. Refers to the capture of light energy and its storage as chemical energy in carbohydrates.
 - b. Cannot occur in the absence of O₂.
 - c. Does not occur in plant cells.
 - d. Refers to the metabolic reactions through which chemical energy from carbohydrates, fats and/or proteins is converted to ATP.
 - e. All of the above are true of cellular respiration.

2. ATP...
 - a. Consists of the nucleoside adenosine with three phosphate groups linked to the 5' carbon of the ribose sugar.
 - b. Is synthesized by the enzyme adenylyl cyclase and broken down by the enzyme phosphodiesterase.
 - c. Is a pyrimidine nucleotide capable of transferring energy through the loss of a phosphate group to power cellular reactions.
 - d. Is found in DNA.
 - e. All of the above are true of ATP.

3. Glycolysis...
 - a. Occurs in the mitochondrial matrix.
 - b. Refers to the partial oxidation of glucose resulting in the transfer of energy to ATP and NADH and the loss of a C atom as CO₂.
 - c. Refers to the coupling of ATP synthesis to the creation of a proton-motive force by electron transport.
 - d. Takes place in virtually all organisms.
 - e. All of the above are true of glycolysis.

4. Which one of the following statements is correct?
 - a. In the process of lactate fermentation, a 3-C molecule of pyruvate is converted to a 2-C lactate molecule by the addition of two electrons from NADH and the loss of CO₂.
 - b. In the process of alcoholic fermentation, a 3-C molecule of pyruvate is converted to a 3-C ethanol molecule by the addition of two electrons from NADH.
 - c. In the process of pyruvate oxidation, a 3-C molecule of pyruvate is converted to a 2-C acetyl-CoA molecule with the generation of NADH and the loss of CO₂.
 - d. All of the statements above are correct.
 - e. None of the statements above is correct.

5. ATP is generated by substrate-level phosphorylation...

- a. In glycolysis and pyruvate oxidation but not the citric acid cycle.
 - b. When the proton gradient across the inner mitochondrial membrane drives ATP synthase.
 - c. When a phosphate group is transferred from a phosphorylated substrate to ADP.
 - d. In lactate and alcoholic fermentation as well as glycolysis.
 - e. Only when O₂ is available.
6. Which one of the following statements about the mitochondrion is correct?
- a. The mitochondrial matrix contains mDNA, ribosomes and the enzymes involved in glycolysis, pyruvate oxidation and the citric acid cycle.
 - b. Protons that accumulate in the intermembrane spaces of the cristae drive ATP synthases located in the outer mitochondrial membrane.
 - c. The inner mitochondrial membrane is greater in surface area and enriched in protein compared to the outer mitochondrial membrane.
 - d. The mitochondrion is thought to have originated as an anaerobic bacterium that was engulfed by a larger prokaryotic cell and not digested, giving rise to an endosymbiotic relationship.
 - e. All of the statements above are true of the mitochondrion.
7. Which one of the following equations describes the citric acid cycle?
- a. $10 \text{ NADH} + 10 \text{ H}^+ + 5 \text{ O}_2 + 30 \text{ ADP} + 30 \text{ Pi} \rightarrow 10 \text{ NAD}^+ + 10 \text{ H}_2\text{O} + 30 \text{ ATP}$
 - b. $\text{glucose} + 2 \text{ NAD}^+ + 2 \text{ ADP} + 2 \text{ Pi} \rightarrow 2 \text{ pyruvate} + 2 \text{ NADH} + 2 \text{ ATP}$
 - c. $\text{acetyl-CoA} + 3 \text{ NAD}^+ + \text{FAD} + \text{ADP} + \text{Pi} \rightarrow 2 \text{ CO}_2 + 3 \text{ NADH} + \text{FADH}_2 + \text{ATP} + \text{CoA}$
 - d. $\text{pyruvate} + \text{NAD}^+ + \text{CoA} \rightarrow \text{acetyl-CoA} + \text{NADH} + \text{CO}_2$
 - e. None of the above equations describes the citric acid cycle.
8. Which one of the following statements about the electron transport chain is **not** correct?
- a. The electron transport chain consists primarily of integral membrane proteins organized into large complexes that are freely mobile along the inner mitochondrial membrane.
 - b. In addition to transferring electrons, complexes I, III and IV also pump protons from the intermembrane space to the mitochondrial matrix, creating a proton gradient across the inner mitochondrial membrane.
 - c. Ubiquinone, a hydrophobic coenzyme localized to the nonpolar interior of the membrane, and cytochrome c, a peripheral membrane protein located on the intermembrane space side of the membrane, play key roles in the electron transport chain by carrying electrons between the protein complexes.
 - d. The direction of transfer of electrons along the electron transport chain is determined by the affinity of the various carriers for electrons, with O₂ being the ultimate electron acceptor.
9. In oxidative phosphorylation...
- a. The proton gradient established by O₂-dependent electron transport is used to drive ATPases.
 - b. A phosphate group is transferred from a phosphorylated substrate to ADP with the consumption of O₂.

- c. The rate of ATP synthesis is regulated by allosteric activation and/or inhibition of ATP synthase, thereby linking ATP generation to the ATP needs of the cell.
- d. The energy stored in NADH and FADH₂ is converted to ATP, accounting for most of the ATP generated by the complete oxidation of glucose.
- e. All of the above are true of oxidative phosphorylation.

10. ATP synthase...

- a. Is a protein complex located in the inner mitochondrial membrane; it consists of two major components, one of which is embedded in the membrane and linked to the second component by means of a stator stalk.
- b. Functions as a molecular rotary motor in which proton flow through the complex turns a molecular gear that drives ATP synthesis.
- c. Can be uncoupled from the proton motive force by proteins such as UCP1 that dissipate the proton gradient across the inner mitochondrial membrane by serving as proton carriers.
- d. All of the above statements are true of ATP synthase.
- e. None of the above statements is true of ATP synthase.

11. An allosteric inhibitor...

- a. Decreases the activity of an enzyme by binding to a regulatory site that is distinct from the active site of the enzyme.
- b. Decreases the activity of an enzyme by catalyzing the (covalent) addition to the enzyme of an inorganic phosphate group.
- c. Decreases the activity of an enzyme by competing with the substrate for the active site on the enzyme.
- d. Alters the activity of one or more enzymes in a pathway so as inhibit the pathway.
- e. None of the above adequately describes an allosteric inhibitor.

12. Based on the idea of feedback regulation, which of the following sets of molecules should act as allosteric inhibitors of the activity of the pyruvate dehydrogenase complex (PDH)?

- a. PDH kinase and ATP
- b. NAD⁺, AMP and CoA
- c. NADH, ATP and acetyl-CoA
- d. AMP, NADH and FADH₂
- e. None of the above would act as allosteric inhibitors of PDH

Written answer questions (use the marks specified to gauge the content needed for your answer; in all cases, the answer must not exceed the space indicated)

- Complete the following statements by filling in the blank (1 mark per answer).
 - Porins** in the outer mitochondrial membrane allow the free passage of small molecules such as water, ions and pyruvate.
 - In the **chemiosmotic model** of ATP synthesis, ATP synthase is driven by a proton (H^+) gradient established through electron transfer along the electron transport chain.
 - In biological systems, **oxidation** typically involves the loss of two electrons (e^-) and two protons (H^+) with the release of energy.
 - Ubiquinone** and **cytochrome c** function as electron carriers in the electron transport chain, shuttling electrons from complexes I and II to complex III, and from complex III to complex IV, respectively.
 - Citrate and ATP serve as allosteric **inhibitors** of glycolysis.

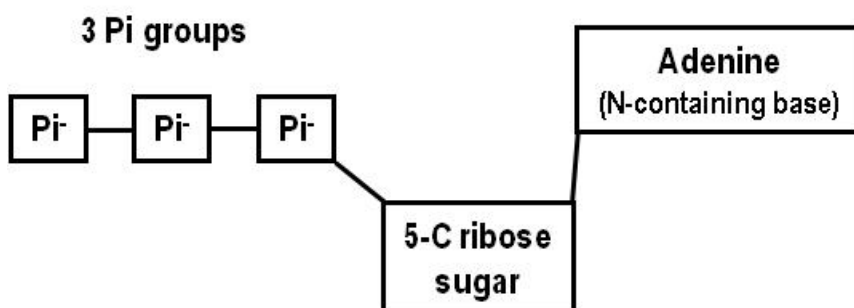
- Distinguish between substrate-level phosphorylation and oxidative phosphorylation. (2 marks)

These two forms of ATP synthesis can be distinguished on the basis of the source of the energy used to drive the reaction and the source of the phosphate group that is added to ADP. In oxidative phosphorylation, the energy of a proton gradient is used to drive ATP synthesis from ADP and inorganic Pi whereas in substrate-level phosphorylation, Pi is transferred from a phosphorylated intermediate directly to ADP. (2 marks)

- What is allosteric regulation? Explain its significance to cellular respiration. (2 marks)

Allosteric regulation refers to the interconversion of an enzyme between two forms, one of which is more catalytically active than the other, by the binding of an effector molecule to an allosteric site on the enzyme. (1 mark) Allosteric regulation is significant with respect to the regulation of cellular respiration, because enzymes of glycolysis, pyruvate oxidation and the citric acid cycle are allosterically regulated by the substrates and products of cellular respiration so as to match ATP supply to ATP demand. (1 mark)

- Sketch and label a molecule of ATP. Use your sketch to explain why the hydrolysis of ATP releases energy. (3 marks)



In the hydrolysis of ATP, the third Pi group is removed. Because Pi carries a negative charge, ATP and ADP also carry a negative charge. Loss of the Pi releases

energy as the negatively charged molecules repel each other. (1 mark) In addition, the transition from one molecule to two independent molecules increases entropy (disorder), thereby releasing energy.

(0.5 marks)

(0.5 marks each for adenine, ribose, and 3 Pi groups)

5. The complete oxidation of 1 molecule of glucose can give rise to 36 (in eukaryotes) to 38 (in prokaryotes) molecules of ATP. Briefly explain how these ATP are produced, i.e. link ATP output to the various steps in cellular respiration. (5 marks)

Glycolysis of one molecule of glucose yields 2 ATP by substrate-level phosphorylation and 2 NADH. (1 mark) Pyruvate oxidation yields 1 NADH; since glycolysis produces two molecules of pyruvate, pyruvate oxidation yields 2 NADH per molecule of glucose. (1 mark) Each turn of the citric acid cycle produces 1 ATP by substrate-level phosphorylation, 3 NADH and 1 FADH₂. Since glycolysis produces two molecules of pyruvate, the citric acid cycle yields 2 ATP, 6 NADH and 2 FADH₂ per molecule of glucose. (1 mark) In oxidative phosphorylation, transfer of the two electrons from NADH causes sufficient proton pumping to generate ~3 molecules of ATP, while transfer of the two electrons from FADH₂ generates ~2 molecules of ATP. Thus, the 10 NADH generated via glycolysis, pyruvate oxidation and the citric acid cycle yield 30 ATP, while the 2 FADH₂ of the citric acid cycle generate 4 ATP. (1 mark) In total then, 34 ATP are generated by oxidative phosphorylation and 4 by substrate-level phosphorylation, giving 38 in total. In eukaryotes, NADH produced by glycolysis in the cytoplasm of the cell must be transferred into the mitochondrion for oxidative phosphorylation. The energy cost of this process lowers the theoretical yield to 36 ATP. (1 mark)

6. Discuss structure-function relationships of the mitochondrion. That is, discuss structural features of the mitochondrion that contribute to its function as the energy powerhouse of the cell. (4 marks)

To answer this question, identify structural features of the mitochondrion and relate these features to the function of the mitochondrion. For example, a prominent structural feature is the highly folded inner membrane. The folds serve to increase membrane surface area, providing space for high levels of the membrane proteins involved in the electron transport chain as well as high levels of ATP synthase, the protein complex responsible for ATP synthesis. (1 mark) The relatively impermeable inner mitochondrial membrane also serves to divide the interior of the mitochondrion into two compartments, the matrix and the intermembrane space. This feature is important in allowing a proton gradient to be established across the inner membrane to drive ATP synthase. (1 mark) And so on...

7. Hibernating animals such as the ground squirrel actively suppress mitochondrial respiration as a mechanism of lowering metabolic rate to conserve energy. Based on your knowledge of energy-consuming activities in the cell, suggest other mechanisms that could be used to lower ATP demand during hibernation. (3 marks)

To answer this question, think about processes in the cell that require energy... For example, energy is required for the synthesis of molecules and macromolecules. A reduction in ATP demand could be achieved by suppressing biosynthesis. (1 mark) Energy is required for movement within the cell and/or cell movement. In animals, muscle cells are cells that exhibit high levels of movement. A reduction in ATP demand could be achieved by reducing muscle activity. (1 mark) Energy is required for electrical work to create the electrochemical gradients that allow nervous signals to be transmitted. A reduction in activity within the nervous system would reduce ATP demand. (1 mark) And so on...

8. The compound 2,4-dinitrophenol (DNP) acts as a H^+ ionophore, i.e. it makes membranes permeable to protons (H^+ ions). Describe an experimental approach based on DNP that could be used to test the chemiosmotic model of ATP synthesis. Explain the rationale for the experimental approach, and discuss the expected results. (5 marks)

To answer this question, note the key elements of the chemiosmotic model (i.e. generation of a proton gradient by means of the electron transport chain, and use of the proton gradient to drive ATP synthase). Point out that treatments that eliminate the proton gradient should also eliminate ATP synthesis if the chemiosmotic model is correct – this is the rationale for the experimental approach. Experiments would need to be carried out on isolated mitochondria, so mention the use of differential centrifugation to isolate the mitochondria. Isolated mitochondria could be incubated with DNP and compared with those incubated without DNP. ATP production between these two scenarios would be compared, and the expected results would be a reduction of ATP synthesis in the presence of DNP if the chemiosmotic model is correct.