AP® BIOLOGY
2015 SCORING GUIDELINES

Question 2

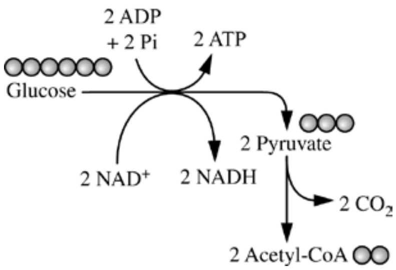

Figure 1. Glycolysis and pyruvate oxidation

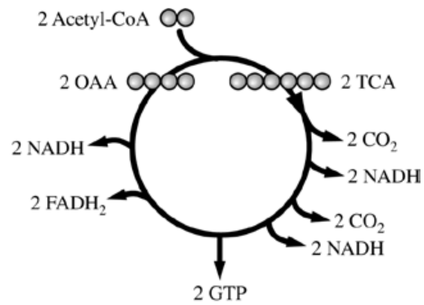

Figure 2. Krebs cycle

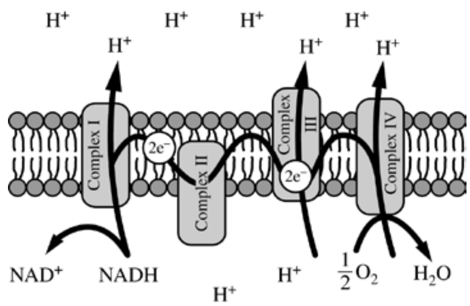

Figure 3. Electron transport chain

Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.

(a) Using the information above, **describe** ONE contribution of each of the following in ATP synthesis.
- Catabolism of glucose in glycolysis and pyruvate oxidation
- Oxidation of intermediates in the Krebs cycle
- Formation of a proton gradient by the electron transport chain

Process	**Description (1 point each box; 3 points maximum)**
Catabolism of glucose in glycolysis and pyruvate oxidation	• Produces NADH for use in ETC • Produces acetyl-CoA for entry into Krebs cycle • Provides energy for (substrate level) phosphorylation of ADP
Oxidation of intermediates in the Krebs cycle	• Produces NADH or FADH2 for use in ETC • Releases high energy electrons for use in ETC • Provides energy to pump protons against their concentration gradient • Produces GTP for (substrate level) phosphorylation of ADP
Formation of a proton gradient by the electron transport chain	• The flow of protons through membrane-bound ATP synthase generates ATP • Provides energy for (oxidative) phosphorylation of ADP

Question 2 (continued)

(b) Use each of the following observations to **justify** the claim that glycolysis first occurred in a common ancestor of all living organisms.

- Nearly all existing organisms perform glycolysis.
- Glycolysis occurs under anaerobic conditions.
- Glycolysis occurs only in the cytosol.

Observation	**Justification (1 point each box; 3 points maximum**)
Nearly all existing organisms perform glycolysis	• Trait/gene/process originated early and was inherited/passed down/highly conserved • Glycolysis provided a selective advantage that was passed on to descendants
Glycolysis occurs under anaerobic conditions	Origin of glycolysis pre-dates free atmospheric oxygen/photosynthesis
Glycolysis occurs only in the cytosol	Origin of glycolysis pre-dates cell types with membrane-bound organelles/eukaryotes/endosymbiosis

(c) A researcher estimates that, in a certain organism, the complete metabolism of glucose produces 30 molecules of ATP for each molecule of glucose. The energy released from the total oxidation of glucose under standard conditions is 686 kcal/mol. The energy released from the hydrolysis of ATP to ADP and inorganic phosphate under standard conditions is 7.3 kcal/mol. **Calculate** the amount of energy available from the hydrolysis of 30 moles of ATP. **Calculate** the efficiency of total ATP production from 1 mole of glucose in the organism. **Describe** what happens to the excess energy that is released from the metabolism of glucose.

	Calculation/description (**1 point each box; 3 points maximum**)
Calculate available energy in ATP	219 kcal
Calculate efficiency	0.31 - 0.32 or 31 - 32%
Describe fate of excess energy	Released as heat/increases entropy

(d) The enzymes of the Krebs cycle function in the cytosol of bacteria, but among eukaryotes the enzymes function mostly in the mitochondria. **Pose** a scientific question that connects the subcellular location of the enzymes in the Krebs cycle to the evolution of eukaryotes.

Question (1 point)

- A valid scientific question related to evolution of eukaryotes (e.g., Since the Krebs cycle occurs in the “cytoplasm” of the mitochondria (matrix), does it suggest that mitochondria were once prokaryotes?)

PAGE FOR ANSWERING QUESTION 2

2A[1]

a) The catabolism of glucose provides the raw materials for the further stages of cellular respiration. First, NADH is produced for use as a proton donor in the electron transport chain. Second, oxidized pyruvate is provided for the Kreb's Cycle. The Kreb's Cycle produces NADH and $FADH_2$ which are necessary proton donors in the electron transport chain. The formation of a proton gradient in the electron transport chain uses energy from the previous processes to pump protons across the inner membrane. This is neccessary because the cell then harnesses the energy of this concentration gradient by using the H^+ ions to pass through the ATP Synthase molecules which creates ATP by pressing ADP and P_i together.

b) The fact that all organisms perform glycolysis is an example of a homologous cellular process and suggests all life are descended from one common ancestor capable of performing the reaction. Glycolysis occuring in anaerobic conditions is further evidence since the early Earth atmosphere had low concentrations of O_2 so the process had to be anaerobic. Finally, occuring in the cytoplasm is neccessary because the process had to be performed by a very simple organism lacking internal membrane structures.

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2A₂

c) Energy from hydrolysis of 30 mol ATP = 30 mol · 7.3 $\frac{kcal}{mol}$ = **219 kcal**

1 mol glucose · 30 mol ATP/mol glucose = 30 mol ATP ⟹ 219 kcal

% Efficiency = 219 kcal / 686 kcal · 100% = **31.9%**

Excess energy is lost to the environment as heat.

d) Do mitochondria in modern eukaryotes descend from endocytosed prokaryotes that could perform the Kreb's Cycle?

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a. The catabolism of glucose allows for two molecule of ATP to be produced, as well as for two molecules of NAD+ to become NADH, which is later used in the electron transport chain. The glucose is now pyruvate, which forms two more molecules of NADH, and becomes Acetyl-CoA, which moves on to the krebs cycle. In the Krebs cycle, the Acetyl CoA is oxidized several times, forming more NADH and $FADH_2$, which are used as ~~electron~~ donators in the ETC. The formation of a proton gradient by the ETC pumps protons across the membrane, which diffuses back into the mitochondria via ATP synthase, a which uses the energy made by the protons flowing to create ATP ~~a~~ out of ADP and inorganic phosphate.

B. Glycolysis likely first occured in the universal common ancestor, as almost all organisms in existance perform it, meaning that glycolysis was developed in organisms a very long ~~time~~ time ago. ~~Even~~ Even organisms that live in oxygen free areas

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 2B2

can perform glycolysis, as it does not require require any oxygen, showing that glycolysis was developed before Earth's atmosphere had high enough concentrations of oxygen. It also only occurs in the cytosol, a cellular organ which all cells, prokaryotic and eukaryotic contain is some shape.

c In this particular organism, 219 kcal of energy is released by the hydrolysis of 30 moles of ATP. The efficiency of total ATP production from 1 mole of glucose in the organism is .32 efficiency. The excess energy released from the metabolism of glucose ends up being lost as heat in the organism.

d Is it likely that a cell, which could not do the Krebs Cycle by itself, engulfed, but did not destroy a prokaryotic cell, which then evolved with the ~~cell~~ other cell to become mitochondria, while the larger cell became eukaryotic?

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2C1

- a) Many parts of cellular respiration play a huge role of ATP sythesis. For example, the catobolism of glucose in glycolosis and pyruvate oxidation produces the electron carrier NADH, which later donates its' electrons to the ETC which creates a proton gradient which activates ATP sythase which synthesizes ATP. Also, the oxidation of intermediates in the Krebs cycle produces the two electron carriers NADH and $FADH_2$ which donate electrons to the ETC and creates a proton gradient making the synthesis of ATP possible. Finally, the formation of ~~[illegible]~~ a proton gradient by the ETC changes the pH on the other side of the membrane which when the protons fall through ATP synthase, allows ATP to be formed.
- b) It is believed that glyeolosis first occurred in a common ancestor of all living organisms. This is supported by the fact that nearly all organisms perform glycolosis and if all organisms perform glycolosis, there has to be a common ancestor for ~~this~~ glycolosis to originate from. It is also supported by the fact that glycolosis occurs under anaerobic conditions which means that

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2C2

oxygen is not necessary so early organisms could have performed glycolosis without the use of oxygen. Finally, it is supported by the fact that glycolysis occurs only in the cytosol. This is important because this means that ~~the~~ membrane-bound organelles like mitochondria are not necessary for glycolosis so early bacteria and other single-celled organisms could have done it.

- c) a. 30 moles ATP · 7.3 kcal/mol = 219 kcal

b.

c. The excess energy is used up by the cell for many different purposes such as moving a vesicle from the Golgi to another part of the cell.

- d) How does the endosymbiotic theory relate to the location of the enzymes used in the Krebs cycle during cellular respiration?

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Question 2

Question 2 was written to the following Learning Objectives in the AP® Biology Curriculum Framework: 1.14, 1.15, 1.16, and 2.9.

Overview

This question was based on the biochemistry and evolution of aerobic cellular respiration. Students were presented with three key figures illustrating the distinct metabolic pathways contributing to the synthesis of ATP. Students were asked to describe one contribution from each of the metabolic pathways to ATP synthesis. Students were then asked to use three observations to justify the claim that glycolysis first occurred in the common ancestor of all living organisms. Students were then asked to calculate the amount of energy released from 30 moles of ATP and to calculate the efficiency of ATP synthesis from 1 mole of glucose. Students were then asked to describe the fate of excess energy that is released from the metabolism of glucose. Finally, students were asked to pose a scientific question connecting the cellular location of the Krebs cycle in prokaryotes and eukaryotes to the evolution of eukaryotes.

Sample: 2A
Score: 10

The response earned 1 point in part (a) for describing that NADH produced in glycolysis is used in the electron transport chain. The response earned 1 point for describing that NADH produced in the Krebs cycle is necessary in the electron transport chain. The response also earned 1 point for describing that cells harness the energy of the concentration gradient and H^+ ions pass through the ATP synthase, which creates ATP.

The response earned 1 point in part (b) for citing glycolysis as an example of a homologous cellular process that justifies the observation that nearly all existing organisms perform glycolysis. The response earned 1 point for citing that the early Earth had an atmosphere with low concentrations of O_2 to justify the observation that glycolysis occurs under anaerobic conditions. The response earned 1 point for citing that the process had to be performed by a very simple organism lacking internal membrane structures to justify the observation that glycolysis occurs only in the cytosol.

The response earned 1 point in part (c) for calculating 219 kcal. The response earned 1 point for calculating 31.9 percent efficiency. The response also earned 1 point for describing that the excess energy was lost as heat.

The response earned 1 point in part (d) for posing a valid scientific question related to evolution of eukaryotes.

Sample: 2B
Score: 8

The response earned 1 point in part (a) for describing that NADH produced in glycolysis is later used in the electron transport chain. The response earned 1 point for describing that NADH produced in the Krebs cycle is used in the ETC. The response also earned 1 point for describing that the energy provided by the protons flowing through ATP synthesis is used to create ATP.

The response earned 1 point in part (b) for citing that the early Earth had an atmosphere with low concentrations of O_2 as a way to justify the observation that glycolysis occurs under anaerobic conditions.

Question 2 (continued)

The response earned 1 point in part (c) for calculating 219 kcal and 1 point for calculating an efficiency of 0.32. The response earned 1 point for describing that the excess energy was lost as heat.

The response earned 1 point in part (d) for posing a valid scientific question related to evolution of eukaryotes.

Sample: 2C
Score: 6

The response earned 1 point in part (a) for describing that NADH produced in glycolysis donates electrons to the ETC, and 1 point for describing that NADH produced in the Krebs cycle donates electrons to the ETC. The response earned 1 point for describing that as protons fall through ATP synthase, ATP is formed.

The response earned 1 point in part (b) for citing that membrane-bound organelles are not needed for glycolysis, so early bacteria could have performed glycolysis as a way to justify the observation that glycolysis occurs only in the cytosol.

The response earned 1 point in part (c) for calculating 219 kcal.

The response earned 1 point in part (d) for posing a valid scientific question related to the evolution of eukaryotes.