
Chapter 16 The Citric Acid Cycle

Multiple Choice Questions

1. Production of acetyl-CoA (activated acetate)

Page: 603 Difficulty: 2 Ans: A

Which of the following is *not* true of the reaction catalyzed by the pyruvate dehydrogenase complex?

- A) Biotin participates in the decarboxylation.
- B) Both NAD^+ and a flavin nucleotide act as electron carriers.
- C) The reaction occurs in the mitochondrial matrix.
- D) The substrate is held by the lipoyl-lysine “swinging arm.”
- E) Two different cofactors containing —SH groups participate.

2. Production of acetyl-CoA (activated acetate)

Page: 603 Difficulty: 2 Ans: A

Which of the below is *not* required for the oxidative decarboxylation of pyruvate to form acetyl-CoA?

- A) ATP
- B) CoA-SH
- C) FAD
- D) Lipoic acid
- E) NAD^+

3. Production of acetyl-CoA (activated acetate)

Page: 603 Difficulty: 2 Ans: E

Which combination of cofactors is involved in the conversion of pyruvate to acetyl-CoA?

- A) Biotin, FAD, and TPP
- B) Biotin, NAD^+ , and FAD
- C) NAD^+ , biotin, and TPP
- D) Pyridoxal phosphate, FAD, and lipoic acid
- E) TPP, lipoic acid, and NAD^+

4. Production of acetyl-CoA (activated acetate)

Page: 603 Difficulty: 2 Ans: A

Which of the following statements about the oxidative decarboxylation of pyruvate in aerobic conditions in animal cells is correct?

- A) One of the products of the reactions of the pyruvate dehydrogenase complex is a thioester of acetate.
- B) The methyl ($-\text{CH}_3$) group is eliminated as CO_2 .
- C) The process occurs in the cytosolic compartment of the cell.
- D) The pyruvate dehydrogenase complex uses all of the following as cofactors: NAD^+ , lipoic acid, pyridoxal phosphate (PLP), and FAD.
- E) The reaction is so important to energy production that pyruvate dehydrogenase operates at full speed under all conditions.

5. Production of acetyl-CoA (activated acetate)**Page: 605 Difficulty: 3 Ans: D**

Glucose labeled with ^{14}C in C-3 and C-4 is completely converted to acetyl-CoA via glycolysis and the pyruvate dehydrogenase complex. What percentage of the acetyl-CoA molecules formed will be labeled with ^{14}C , and in which position of the acetyl moiety will the ^{14}C label be found?

- A) 100% of the acetyl-CoA will be labeled at C-1 (carboxyl).
- B) 100% of the acetyl-CoA will be labeled at C-2.
- C) 50% of the acetyl-CoA will be labeled, all at C-2 (methyl).
- D) No label will be found in the acetyl-CoA molecules.
- E) Not enough information is given to answer this question.

6. Reactions of the citric acid cycle**Page: 606 Difficulty: 3 Ans: A**

Which of the following is *not* true of the citric acid cycle?

- A) All enzymes of the cycle are located in the cytoplasm, except succinate dehydrogenase, which is bound to the inner mitochondrial membrane.
- B) In the presence of malonate, one would expect succinate to accumulate.
- C) Oxaloacetate is used as a substrate but is not consumed in the cycle.
- D) Succinate dehydrogenase channels electrons directly into the electron transfer chain.
- E) The condensing enzyme is subject to allosteric regulation by ATP and NADH.

7. Reactions of the citric acid cycle**Page: 607 Difficulty: 3 Ans: A**

Acetyl-CoA labeled with ^{14}C in both of its acetate carbon atoms is incubated with unlabeled oxaloacetate and a crude tissue preparation capable of carrying out the reactions of the citric acid cycle. After one turn of the cycle, oxaloacetate would have ^{14}C in:

- A) all four carbon atoms.
- B) no pattern that is predictable from the information provided.
- C) none of its carbon atoms.
- D) the keto carbon and one of the carboxyl carbons.
- E) the two carboxyl carbons.

8. Reactions of the citric acid cycle**Page: 607 Difficulty: 1 Ans: B**

Malonate is a competitive inhibitor of succinate dehydrogenase. If malonate is added to a mitochondrial preparation that is oxidizing pyruvate as a substrate, which of the following compounds would you expect to decrease in concentration?

- A) Citrate
- B) Fumarate
- C) Isocitrate
- D) Pyruvate
- E) Succinate

9. Reactions of the citric acid cycle**Page: 607 Difficulty: 1 Ans: A**Which of the following is *not* an intermediate of the citric acid cycle?

- A) Acetyl-coA
- B) Citrate
- C) Oxaloacetate
- D) Succinyl-coA
- E) α -Ketoglutarate

10. Reactions of the citric acid cycle**Page: 607 Difficulty: 2 Ans: D**

In mammals, each of the following occurs during the citric acid cycle except:

- A) formation of α -ketoglutarate.
- B) generation of NADH and FADH₂.
- C) metabolism of acetate to carbon dioxide and water.
- D) net synthesis of oxaloacetate from acetyl-CoA.
- E) oxidation of acetyl-CoA.

11. Reactions of the citric acid cycle**Page: 607 Difficulty: 3 Ans: B**Oxaloacetate uniformly labeled with ¹⁴C (i.e., with equal amounts of ¹⁴C in each of its carbon atoms) is condensed with unlabeled acetyl-CoA. After a single pass through the citric acid cycle back to oxaloacetate, what fraction of the original radioactivity will be found in the oxaloacetate?

- A) all
- B) 1/2
- C) 1/3
- D) 1/4
- E) 3/4

12. Reactions of the citric acid cycle**Page: 607 Difficulty: 1 Ans: B**Conversion of 1 mol of acetyl-CoA to 2 mol of CO₂ and CoA via the citric acid cycle results in the net production of:

- A) 1 mol of citrate.
- B) 1 mol of FADH₂.
- C) 1 mol of NADH.
- D) 1 mol of oxaloacetate.
- E) 7 mol of ATP.

13. Reactions of the citric acid cycle**Page: 607 Difficulty: 2 Ans: E**

Which one of the following is *not* associated with the oxidation of substrates by the citric acid cycle?

- A) All of the below are involved.
- B) CO₂ production
- C) Flavin reduction
- D) Lipoic acid present in some of the enzyme systems
- E) Pyridine nucleotide oxidation

14. Reactions of the citric acid cycle**Page: 607 Difficulty: 3 Ans: E**

The two moles of CO₂ produced in the first turn of the citric acid cycle have their origin in the:

- A) carboxyl and methylene carbons of oxaloacetate
- B) carboxyl group of acetate and a carboxyl group of oxaloacetate.
- C) carboxyl group of acetate and the keto group of oxaloacetate.
- D) two carbon atoms of acetate.
- E) two carboxyl groups derived from oxaloacetate.

15. Reactions of the citric acid cycle**Page: 610 Difficulty: 2 Ans: A**

The oxidative decarboxylation of α -ketoglutarate proceeds by means of multistep reactions in which all but one of the following cofactors are required. Which one is *not* required?

- A) ATP
- B) Coenzyme A
- C) Lipoic acid
- D) NAD⁺
- E) Thiamine pyrophosphate

16. Reactions of the citric acid cycle**Page: 610 Difficulty: 2 Ans: E**

The reaction of the citric acid cycle that is most similar to the pyruvate dehydrogenase complex-catalyzed conversion of pyruvate to acetyl-CoA is the conversion of:

- A) citrate to isocitrate.
- B) fumarate to malate.
- C) malate to oxaloacetate.
- D) succinyl-CoA to succinate.
- E) α -ketoglutarate to succinyl-CoA.

17. Reactions of the citric acid cycle**Page: 610 Difficulty: 2 Ans: E**

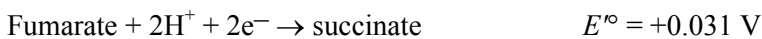
Which one of the following enzymatic activities would be decreased by thiamine deficiency?

- A) Fumarase
- B) Isocitrate dehydrogenase
- C) Malate dehydrogenase
- D) Succinate dehydrogenase
- E) α -Ketoglutarate dehydrogenase complex

18. Reactions of the citric acid cycle**Page: 611 Difficulty: 1 Ans: E**

The reaction of the citric acid cycle that produces an ATP equivalent (in the form of GTP) by substrate level phosphorylation is the conversion of:

- A) citrate to isocitrate.
- B) fumarate to malate.
- C) malate to oxaloacetate.
- D) succinate to fumarate.
- E) succinyl-CoA to succinate.

19. Reactions of the citric acid cycle**Page: 612 Difficulty: 3 Ans: B**The standard reduction potentials (E°) for the following half reactions are given.If succinate, fumarate, FAD, and FADH₂, all at 1 M concentrations, were mixed together in the presence of succinate dehydrogenase, which of the following would happen *initially*?

- A) Fumarate and succinate would become oxidized; FAD and FADH₂ would become reduced.
- B) Fumarate would become reduced; FADH₂ would become oxidized.
- C) No reaction would occur because all reactants and products are already at their standard concentrations.
- D) Succinate would become oxidized; FAD would become reduced.
- E) Succinate would become oxidized; FADH₂ would be unchanged because it is a cofactor, not a substrate.

20. Reactions of the citric acid cycle**Page: 612 Difficulty: 3 Ans: D**For the following reaction, $\Delta G^\circ = 29.7$ kJ/mol.

The reaction as written:

- A) can never occur in a cell.
- B) can only occur in a cell if it is coupled to another reaction for which ΔG° is positive.
- C) can only occur in a cell in which NADH is converted to NAD^+ by electron transport.
- D) may occur in cells at certain concentrations of substrate and product.
- E) would always proceed at a very slow rate

21. Reactions of the citric acid cycle**Page: 612 Difficulty: 1 Ans: D**All of the oxidative steps of the citric acid cycle are linked to the reduction of NAD^+ *except* the reaction catalyzed by:

- A) isocitrate dehydrogenase.
- B) malate dehydrogenase.
- C) pyruvate dehydrogenase
- D) succinate dehydrogenase.
- E) the α -ketoglutarate dehydrogenase complex.

22. Reactions of the citric acid cycle**Page: 612 Difficulty: 1 Ans: C**

Which of the following cofactors is required for the conversion of succinate to fumarate in the citric acid cycle?

- A) ATP
- B) Biotin
- C) FAD
- D) NAD^+
- E) NADP^+

23. Reactions of the citric acid cycle**Page: 612 Difficulty: 1 Ans: E**

In the citric acid cycle, a flavin coenzyme is required for:

- A) condensation of acetyl-CoA and oxaloacetate.
- B) oxidation of fumarate.
- C) oxidation of isocitrate.
- D) oxidation of malate.
- E) oxidation of succinate.

24. Reactions of the citric acid cycle**Page: 614 Difficulty: 3 Ans: A**

Which of the following intermediates of the citric acid cycle is prochiral?

- A) Citrate
- B) Isocitrate
- C) Malate
- D) Oxaloacetate
- E) Succinate

25. Reactions of the citric acid cycle**Page: 615 Difficulty: 2 Ans: D**The conversion of 1 mol of pyruvate to 3 mol of CO₂ via pyruvate dehydrogenase and the citric acid cycle also yields _____ mol of NADH, _____ mol of FADH₂, and _____ mol of ATP (or GTP).

- A) 2; 2; 2
- B) 3; 1; 1
- C) 3; 2; 0
- D) 4; 1; 1
- E) 4; 2; 1

26. Regulation of the citric acid cycle**Page: 621 Difficulty: 3 Ans: D**Entry of acetyl-CoA into the citric acid cycle is *decreased* when:

- A) [AMP] is high.
- B) NADH is rapidly oxidized through the respiratory chain.
- C) the ratio of [ATP]/[ADP] is low
- D) the ratio of [ATP]/[ADP] is high.
- E) the ratio of [NAD⁺]/[NADH] is high.

27. Regulation of the citric acid cycle**Page: 621 Difficulty: 3 Ans: E**Citrate synthase and the NAD⁺-specific isocitrate dehydrogenase are two key regulatory enzymes of the citric acid cycle. These enzymes are inhibited by:

- A) acetyl-CoA and fructose 6-phosphate.
- B) AMP and/or NAD⁺.
- C) AMP and/or NADH.
- D) ATP and/or NAD⁺.
- E) ATP and/or NADH.

28. The glyoxylate cycle**Page: 623 Difficulty: 2 Ans: A**

During seed germination, the glyoxylate pathway is important to plants because it enables them to:

- A) carry out the net synthesis of glucose from acetyl-CoA.
- B) form acetyl-CoA from malate.
- C) get rid of isocitrate formed from the aconitase reaction.
- D) obtain glyoxylate for cholesterol biosynthesis.
- E) obtain glyoxylate for pyrimidine synthesis.

29. The glyoxylate cycle**Page: 624 Difficulty: 2 Ans: E**

A function of the glyoxylate cycle, in conjunction with the citric acid cycle, is to accomplish the:

- A) complete oxidation of acetyl-CoA to CO₂ plus reduced coenzymes.
- B) net conversion of lipid to carbohydrate.
- C) net synthesis of four-carbon dicarboxylic acids from acetyl-CoA.
- D) net synthesis of long-chain fatty acids from citric acid cycle intermediates.
- E) both B and C are correct

30. The glyoxylate cycle**Page: 624 Difficulty: 2 Ans: A**

The glyoxylate cycle is:

- A) a means of using acetate for both energy and biosynthetic precursors.
- B) an alternative path of glucose metabolism in cells that do not have enough O₂.
- C) defective in people with phenylketonuria.
- D) is not active in a mammalian liver.
- E) the most direct way of providing the precursors for synthesis of nucleic acids (e.g., ribose).

Short Answer Questions**31. Production of acetyl-CoA (activated acetate)****Page: 602 Difficulty: 2**

The citric acid cycle begins with the condensation of acetyl-CoA with oxaloacetate. Describe three possible sources for the acetyl-CoA.

Ans: Acetyl-CoA is produced by (1) the pyruvate dehydrogenase complex, (2) β oxidation of fatty acids, or (3) degradation of certain amino acids.

32. Production of acetyl-CoA (activated acetate)**Page: 602 Difficulty: 1**

Briefly describe the relationship of the pyruvate dehydrogenase complex reaction to glycolysis and the citric acid cycle.

Ans: The pyruvate dehydrogenase complex converts pyruvate, the product of glycolysis, into acetyl-CoA, the starting material for the citric acid cycle.

33. Production of acetyl-CoA (activated acetate)**Pages: 602-605 Difficulty: 3**

Describe the enzymes, cofactors, intermediates, and products the pyruvate dehydrogenase complex.

Ans: The pyruvate dehydrogenase complex consists of multiple copies of each of three enzymes. The first enzyme to act is pyruvate dehydrogenase (E_1), which converts pyruvate to CO_2 and the hydroxyethyl derivative of thiamine pyrophosphate (TPP). The same enzyme then oxidizes the hydroxyethyl group to an acetyl group attached to enzyme-bound lipoate through a thioester linkage. The second enzyme, dihydrolipoyl transracetylase (E_2), transfers the acetyl group to coenzyme A, forming acetyl-CoA. The third enzyme, dihydrolipoyl dehydrogenase (E_3), oxidizes the dihydrolipoate to its disulfide form, passing the electrons through FAD to NAD^+ . (See Fig. 16-6, p. 605.)

34. Production of acetyl-CoA (activated acetate)**Page: 603 Difficulty: 3**

Suppose you found an overly high level of pyruvate in a patient's blood and urine. One possible cause is a genetic defect in the enzyme pyruvate dehydrogenase, but another plausible cause is a specific vitamin deficiency. Explain what vitamin might be deficient in the diet, and why that would account for high levels of pyruvate to be excreted in the urine. How would you determine which explanation is correct?

Ans: The most likely explanation is that the patient has a deficiency of thiamine, without which the cell cannot make thiamine pyrophosphate, the cofactor for pyruvate dehydrogenase. The inability to oxidize pyruvate produced by glycolysis to acetyl-CoA would lead to accumulation of pyruvate in blood and urine. The most direct test for this deficiency is to feed a diet supplemented with thiamine and determine whether urinary pyruvate levels fall.

35. Production of acetyl-CoA (activated acetate)**Page: 605 Difficulty: 2**

Match the cofactors below with their roles in the pyruvate dehydrogenase complex reaction.

Cofactors:

- A. Coenzyme A (CoA-SH)
- B. NAD^+
- C. Thiamine pyrophosphate (TPP)
- D. FAD
- E. Lipoic acid in oxidized form

Roles:

- _____ Attacks and attaches to the central carbon in pyruvate.
- _____ Oxidizes $FADH_2$.
- _____ Accepts the acetyl group from reduced lipoic acid.
- _____ Oxidizes the reduced form of lipoic acid.
- _____ Initial electron acceptor in oxidation of pyruvate.

Ans: C; B; A; D; E**36. Production of acetyl-CoA (activated acetate)****Page: 605 Difficulty: 3**

Two of the steps in the oxidative decarboxylation of pyruvate to acetyl-CoA do not involve the three carbons of pyruvate, yet are essential to the operation of the pyruvate dehydrogenase complex.

Explain.

Ans: The two steps catalyzed by dihydrolipoyl dehydrogenase (E_3) are required to regenerate the oxidized form of lipoate, bound to dihydrolipoyl transacetylase, from the dihydrolipoyl (reduced) form produced in the oxidation of pyruvate. First, FAD is reduced to $FADH_2$ to reoxidize the dihydrolipoate, then NAD^+ is reduced to NADH to reoxidize the $FADH_2$ to complete the reaction.

37. Production of acetyl-CoA (activated acetate)

Page: 605 Difficulty: 3

What is the function of FAD in the pyruvate dehydrogenase complex? How is it regenerated?

Ans: FAD serves as the electron acceptor in the re-oxidation of the cofactor dihydrolipoate. It is converted to $FADH_2$ by this reaction and is regenerated by the passage of electrons to NAD^+ .

38. Production of acetyl-CoA (activated acetate)

Page: 606 Difficulty: 2

The human disease beriberi is caused by a deficiency of thiamine in the diet. People with severe beriberi have higher than normal levels of pyruvate in their blood and urine. Explain this observation in terms of specific enzymatic reaction(s).

Ans: Thiamine is essential for the synthesis of the cofactor thiamine pyrophosphate (TPP). Without this cofactor the pyruvate dehydrogenase complex cannot convert pyruvate into acetyl-CoA, so the pyruvate produced by glycolysis accumulates.

39. Reactions of the citric acid cycle

Page: 606 Difficulty: 3

There are few, if any, humans with defects in the enzymes of the citric acid cycle. Explain this observation in terms of the role of the citric acid cycle.

Ans: The citric acid cycle is central to all aerobic energy-yielding metabolisms and also plays a critical role in biosynthetic reactions by providing precursors. Mutations in the enzymes of the citric acid cycle are likely to be lethal during fetal development.

40. Reactions of the citric acid cycle

Page: 607 Difficulty: 3

Preparation of an extract of muscle results in a dramatic decrease in the concentration of citric acid cycle intermediates compared to their concentrations in the tissue. However, in 1935, Szent-Gyorgi showed that the production of CO_2 by the extract increased when succinate was added. In fact, for every mole of succinate added, many extra moles of CO_2 were produced. Explain this effect in terms of the known catabolic pathways.

Ans: Succinate is an intermediate in the citric acid cycle that is not consumed but is regenerated by the operation of the cycle. Its addition to an extract depleted in citric acid cycle intermediates allows the cycle to resume operating, oxidizing acetyl-CoA to CO_2 .

41. Reactions of the citric acid cycle

Page: 607 Difficulty: 3

Draw the citric acid cycle *from isocitrate to fumarate only*, showing and naming each intermediate. Show where high-energy phosphate compounds or reduced electron carriers are produced or consumed, and name the enzyme that catalyzes each step.

Ans: This part of the citric acid cycle includes the reactions catalyzed by isocitrate dehydrogenase,

the α -ketoglutarate dehydrogenase complex, succinyl-CoA synthetase, and succinate dehydrogenase. (See Fig. 16-7, p. 607.)

42. Reactions of the citric acid cycle

Page: 607 Difficulty: 2

Show the three reactions in the citric acid cycle in which NADH is produced, including the structures. None of these reactions involves molecular oxygen (O_2), but all three reactions are strongly inhibited by anaerobic conditions; explain why.

Ans: NADH is produced in the reactions catalyzed by isocitrate dehydrogenase, the α -ketoglutarate dehydrogenase complex, and malate dehydrogenase. These reactions are indirectly dependent on the presence of O_2 because the NADH produced in the reactions is normally recycled to NAD^+ by passage of electrons from NADH through the respiratory chain to O_2 . See also Fig. 16-7, p. 607.

43. Reactions of the citric acid cycle

Page: 607 Difficulty: 3

At what point in the citric acid cycle do the methyl carbon from acetyl-CoA and the carbonyl carbon from oxaloacetate become chemically equivalent?

Ans: This happens with the formation of succinate.

44. Reactions of the citric acid cycle

Page: 607 Difficulty: 3

Show the reactions by which α -ketoglutarate is converted to malate in the citric acid cycle.

Ans: The reactions are those catalyzed by the α -ketoglutarate dehydrogenase complex, succinyl-CoA synthetase, succinate dehydrogenase, and fumarase. (See Fig. 16-7, p. 607.)

45. Reactions of the citric acid cycle

Page: 607 Difficulty: 2

Show the steps of the citric acid cycle in which a six-carbon compound is converted into the first four-carbon intermediate in the path. For each step, show structures of substrate and product, name the enzyme responsible, and show where cofactors participate.

Ans: The reactions are those catalyzed by isocitrate dehydrogenase, the α -ketoglutarate dehydrogenase complex, and succinyl-CoA synthetase. (See Fig. 16-7, p. 607.)

46. Reactions of the citric acid cycle

Page: 607 Difficulty: 3

Show the structures of the reactants and products for two of the four redox reactions in the citric acid cycle. Indicate where any cofactors participate, and label the reactants, products, and cofactors as oxidants or reductants in the reaction.

Ans: The four oxidation-reduction reactions are those catalyzed by isocitrate dehydrogenase, the α -ketoglutarate dehydrogenase complex, succinate dehydrogenase, and malate dehydrogenase. (See Fig. 16-7, p. 607.)

47. Reactions of the citric acid cycle

Page: 607 Difficulty: 3

Show the steps of the citric acid cycle *from succinyl-CoA to oxaloacetate only*. For each step, show

structures of substrate and product, name the enzyme responsible, and show where cofactors participate.

Ans: These are the steps catalyzed by succinyl-CoA synthetase, succinate dehydrogenase, fumarase, and malate dehydrogenase. (See Fig. 16-7, p. 607.)

48. Reactions of the citric acid cycle

Page: 607 Difficulty: 3

Explain why fluorocitrate, a potent inhibitor of the enzyme aconitase, is a deadly poison.

Ans: By inhibiting aconitase, fluorocitrate prevents the citric acid cycle from operating. This prevents the oxidation of acetyl-CoA and dramatically reduces the yield of ATP from carbohydrate and lipid catabolism. The resulting drop in ATP levels is lethal.

49. Reactions of the citric acid cycle

Page: 607 Difficulty: 3

The citric acid cycle is frequently described as the major pathway of aerobic catabolism, which means that it is an oxygen-dependent degradative process. However, none of the reactions of the cycle directly involves oxygen as a reactant. Why is the pathway oxygen-dependent?

Ans: The citric acid cycle produces NADH, which normally is recycled by passage of electrons from NADH to O₂ via the respiratory chain. With no O₂ to accept electrons from NADH, the accumulation of NADH effectively stops the citric acid cycle.

50. Reactions of the citric acid cycle

Page: 610 Difficulty: 2

In the citric acid cycle, a five-carbon compound is decarboxylated to yield an activated four-carbon compound. Show the substrate and product in this step, and indicate where any cofactor(s) participate(s).

Ans: The oxidation of α -ketoglutarate to succinyl-CoA involves five cofactors: lipoate, thiamine pyrophosphate (TPP), FAD, NAD⁺, and CoA-SH. (See p. 610.)

51. Reactions of the citric acid cycle

Page: 610 Difficulty: 3

CO₂ is produced in two reactions in the citric acid cycle. For each of these reactions, name and show the structures of reactant and product, name the enzyme, and show how any cofactors participate.

Ans: See the isocitrate dehydrogenase and α -ketoglutarate dehydrogenase reactions on p. 610.

52. Reactions of the citric acid cycle

Page: 611 Difficulty: 2

In which reaction of the citric acid cycle does substrate-level phosphorylation occur?

Ans: Substrate-level phosphorylation of GDP to GTP occurs in the succinyl-CoA synthetase reaction in which succinyl-CoA is converted to succinate during the citric acid cycle. (See p. 611.)

53. Reactions of the citric acid cycle

Page: 613 Difficulty: 3

Explain in quantitative terms the circumstances under which the following reaction can proceed.



Ans: A reaction for which ΔG° is positive can proceed under conditions in which the actual ΔG is negative. From the relationship

$$\Delta G = \Delta G^\circ + RT \ln \frac{[\text{product}]}{[\text{reactant}]}$$

it is clear that if the concentration of product is kept very low (e.g., by its removal in a subsequent metabolic step), the logarithmic term becomes negative and the actual ΔG can then have a negative value. (See also Chapter 13.)

54. Reactions of the citric acid cycle

Page: 616 Difficulty: 3

You are in charge of genetically engineering a new bacterium that will derive all of its ATP from sunlight by photosynthesis. Will you put the enzymes of the citric acid cycle in this organism? Briefly explain why or why not.

Ans: Yes; even though the citric acid cycle is not needed for catabolic reactions in this organism, the enzymes of the cycle are still essential. They produce precursors of amino acids (such as α -keto-glutarate and oxaloacetate), of heme (succinyl-CoA), and of a variety of other essential products.

55. The glyoxylate cycle

Pages: 623-624 Difficulty: 3

Germinating plant seeds can convert stored fatty acids into oxaloacetate and a variety of carbohydrates. Animals cannot synthesize significant quantities of oxaloacetate or glucose from fatty acids. What accounts for this difference?

Ans: Plants use the glyoxylate cycle to convert two molecules of acetyl-CoA into one four-carbon compound (such as oxaloacetate), then use this compound to make glucose (gluconeogenesis). In animals that lack the glyoxylate cycle, each acetyl group that enters the citric acid cycle yields two CO_2 , allowing no net conversion of acetyl groups into oxaloacetate.