4.1 Introduction to Cellular Respiration and Fermentation

Textbook pp. 168–171

Vocabulary

aerobic cellular respiration
obligate aerobe
substrate-level phosphorylation
oxidative phosphorylation
glycolysis
pyruvate oxidation
citric acid cycle
anaerobic respiration
fermentation
obligate anaerobe
facultative anaerobe

STUDY TIP

Use a Graphic Organizer
Make a comparison chart for the three main types of respiratory pathways. This will help you to understand how they are related.

MAIN IDEA: There are three main types of respiratory pathways: aerobic respiration, anaerobic respiration, and fermentation. They all produce ATP. Mitochondria generate most of the ATP that is used in eukaryotic cells.

1. The energy that plants store in sugars, such as glucose, originally came from _____. KEY
2. The main purpose of cellular respiration is _____. KEY
3. Aerobic cellular respiration can only take place in the presence of the gas _____, which explains its relationship to breathing. The end products of aerobic cellular respiration are _____, _____, and _____. KEY
4. Anaerobic cellular respiration and fermentation take place in the absence of _____. The end products of fermentation can be _____ and _____. KEY
5. Label the parts of the mitochondrion in **Figure 1** below. KEY

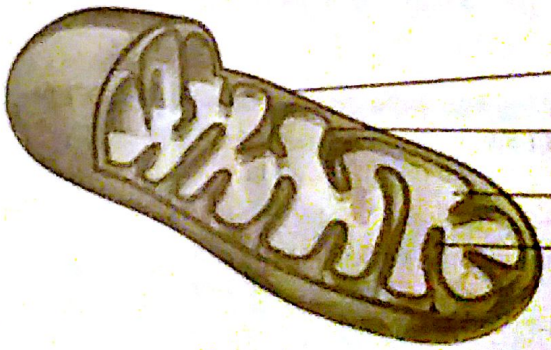


Figure 1

MAIN IDEA: The four stages of aerobic cellular respiration are glycolysis, pyruvate oxidation, the citric acid cycle, and the electron transport chain.

6. Glycolysis starts with the molecules _____ and _____ and ends with the molecules _____ and _____. It takes place in _____. KEY
7. The citric acid cycle starts with the molecules _____ and _____ and ends with the molecules _____, _____, and _____. It takes place in _____. KEY

8. The electron transport chain transfers high energy electrons from _____ and _____ to _____. The electron transfer results in the formation of _____, _____, _____, and _____. It takes place _____. K/U

9. ATP that is formed directly by the transfer of a phosphate group to ADP using an enzyme is referred to as _____. K/U

10. ATP that is formed indirectly by the transfer of a phosphate group through a series of redox reactions is called _____. K/U

MAIN IDEA: Aerobic respiration pathways use electron transport systems to generate ATP by oxidative phosphorylation, using oxygen as the final oxidizing agent. Fermentation pathways lack such transport systems and rely on an organic compound. Anaerobic respiration uses an inorganic substance other than oxygen as the final oxidizing agent.

11. Use **Table 1** to compare the three respiration pathways. K/U TI

Table 1 Comparison of Respiration Pathways

	Aerobic cellular respiration	Anaerobic cellular respiration	Fermentation
Molecules used			
Location in cells			
Amount of energy produced			
Waste products			

12. Complete these paragraphs to describe the key differences between obligate aerobes, obligate anaerobes, and facultative anaerobes. K/U

(a) Most eukaryotes are _____ aerobes. This means they cannot live without _____ and they use _____ cellular respiration most of the time.

(b) Organisms that can extract _____ from food molecules with or without using _____ are known as _____ anaerobes. _____ is an example of this type of organism.

(c) Many organisms always extract _____ from their food without using oxygen. These are called _____ anaerobes, and include bacteria and protests that live in _____ environments. These organisms use two processes to extract energy: _____, which does not use an _____ system, and _____ respiration, which uses an _____ compound as the final oxidizing agent.

4.2 Aerobic Respiration: The Details

Textbook pp. 172–182

Vocabulary

decarboxylation reaction
dehydrogenation
proton gradient
proton-motive source
chemiosmosis

MAIN IDEA: Glycolysis extracts energy from sugar molecules and produces ATP.

1. Why is the first phase of glycolysis known as the energy investment phase? K/U T/I

2. What is the source of the original two ATP molecules used in glycolysis? K/U

3. How many molecules of ATP are generated during glycolysis and how are they formed? K/U T/I

4. The fructose-1,6-biphosphate molecule appears to be symmetrical and yet it is split to form two different molecules. Identify the two molecules formed and explain how this is possible. K/U T/I

LEARNING TIP

P_i
The "P_i" used in the drawings refers to a free inorganic phosphate molecule and not to a phosphorous atom.

5. Use **Table 1** to summarize the types of chemical reactions involved during cellular respiration. K/U C

Table 1 Types of Reactions Involved in Cellular Respiration

Type of reaction	Description of reaction
phosphorylation	
isomerization	
lysis	
redox	
decarboxylation	
dehydrogenation	

6. Only 2.2 % of the energy in one glucose molecule is converted into ATP during glycolysis. The remaining 97.8 % has been lost as _____ or is still stored in _____ and _____. K/U

MAIN IDEA: Pyruvate oxidation converts two pyruvate molecules into two acetyl-CoA molecules, NADH, H^+, and CO_2 waste.

7. Fill in **Figure 1** below to show the reactants and products of pyruvate oxidation. K/U C

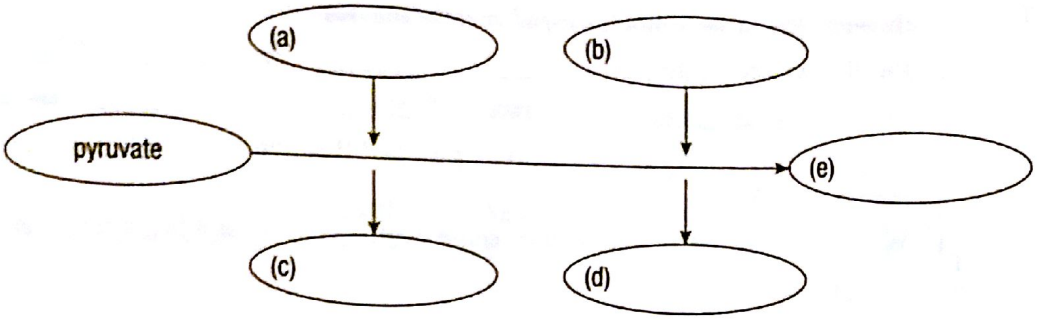


Figure 1

8. Explain why a transport protein is needed in the diffusion of pyruvate into the mitochondrion. K/U T/I

MAIN IDEA: The citric acid cycle consists of eight enzyme-catalyzed reactions. It uses acetyl-CoA to produce reducing power and energy, in the form of NADH, $FADH_2$, and ATP, and releases CO_2.

9. Write the names of the carbohydrate molecules involved in the citric acid cycle shown in **Figure 2.** K/U

(a) _____ (e) _____

(b) _____ (f) _____

(c) _____ (g) _____

(d) _____

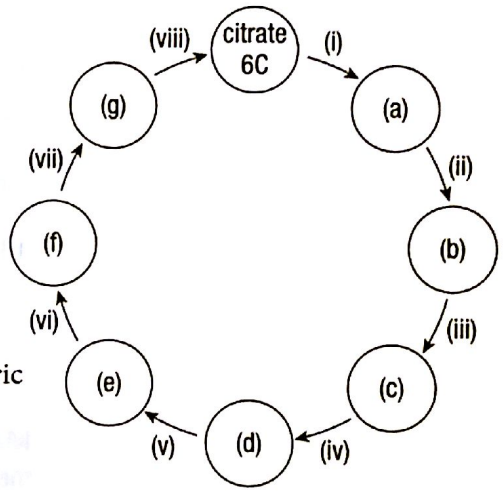


Figure 2

10. Write the names of the enzymes involved in creating each product in the citric acid cycle, shown in Figure 2. K/U

(i) _____ (v) _____

(ii) _____ (vi) _____

(iii) _____ (vii) _____

(iv) _____ (viii) _____

11. Mark the locations where carbon dioxide, NADH, and $FADH_2$ are released and where ATP is produced during the citric acid cycle on Figure 2. K/U

MAIN IDEA: The electron transport chain converts the potential energy from NADH and $FADH_2$ into chemical potential energy in ATP.

12. NADH delivers _____ and _____ to _____. This causes _____ to be pumped through the inner mitochondrial membrane. K/U

13. $FADH_2$ is used to deliver _____ and _____ to _____ and _____. This causes _____ to be pumped through the inner mitochondrial membrane. K/U

14. Where does the electron transport chain begin? Why must it begin there? K/U T/I

15. What happens to oxygen after it draws electrons from complex IV? K/U T/I

MAIN IDEA: Chemiosmosis is the process of pumping protons across the inner mitochondrial membrane, and establishing a proton gradient. This in turn creates a proton-motive force that provides the energy used to produce ATP.

16. Describe the processes needed to move protons from the matrix into the intermembrane space. K/U

17. Describe the processes needed to move protons from the intermembrane space back into the matrix. K/U

18. Describe how the proton motive force is used to drive the production of ATP. What is the name of this type of ATP production? K/U

MAIN IDEA: Harnessing the potential energy that is present in a proton gradient to synthesize ATP is fundamental to almost all forms of life and developed early in the evolution of life. Uncoupling electron transport and the synthesis of ATP can be caused by making the inner mitochondrial membrane permeable to protons. The energy that is released during electron transport is then converted to thermal energy.

19. Describe the purpose of brown adipose fat. K/U A

20. Suggest potential differences in brown adipose fat production for the following mammals. K/U T/I A

    (a) large tropical mammals

    (b) small temperate rodents

    (c) temperate mammals that hibernate

The Efficiency and Regulation of Cellular Respiration

Textbook pp. 183–189

Vocabulary

metabolic rate | basal metabolic rate | beta-oxidation

MAIN IDEA: Aerobic cellular respiration produces a maximum of 38 ATPs per glucose molecule and has a maximum efficiency of about 41 %. Cellular respiration is regulated by negative feedback mechanisms and is able to remain flexible and responsive to changing demands for ATP. Creatine phosphate can act as a quick but short-term source of additional energy in cells.

1. Use **Table 1** to summarize the net ATP production per molecule of glucose at each stage of cellular respiration. K/U

Table 1 ATP Production During Aerobic Cellular Respiration

Stage	Number of ATP produced	Number of ATP added	Net number of ATP produced
glycolysis			
pyruvate oxidation			
citric acid cycle			
electron transport chain			

2. Explain the role of phosphofructokinase in the control of glucose metabolism. Include a description of the conditions that inhibit and stimulate phosphofructokinase action. K/U T/I A

3. Compare the cell's use of creatine phosphate and brown adipose fat for the storage of energy. K/U T/I

MAIN IDEA: Metabolic rate and basal metabolic rate vary, based on changes in growth, development, age, health and gender. The overall rate of aerobic cellular respiration is often measured by the rate of oxygen consumption.

4. Many teenagers increase their intake of food without weight gain. Suggest examples of other uses for these excess nutrients that are not stored as fat. K/U T/I

5. The metabolic rate of an individual is difficult to measure directly. However, the rate and volume of air that an individual breathes can be directly measured. Discuss how breathing can indicate metabolic rate. KU AI

MAIN IDEA: Reactions leading from glycolysis through pyruvate oxidation are used to oxidize the glucose, other carbohydrates, lipids, and proteins that enter the cellular respiratory pathway. Many important molecules are synthesized from the intermediate chemicals produced during glycolysis and the citric acid cycle.

6. Draw a table to summarize the biochemical advantages and disadvantages of using lipids and proteins as sources of chemical potential energy during cellular respiration instead of carbohydrates. KU TI C

7. If a biochemist wishes to produce a weight-loss drug, how could the drug be designed to alter phosphofructokinase? KU TI AI

MAIN IDEA: Due to the significant mass of water bonded to them, carbohydrates are heavier than lipids to carry around as fuel.

8. Suggest reasons that organisms may be adapted to use lipids and glycerol for the storage of chemical potential energy. KU TI

9. Suggest reasons that organisms do not use excess ATP for the storage of chemical potential energy. KU TI

Anaerobic Pathways: Life Without Oxygen

Textbook pp. 190–194

Vocabulary

alcohol fermentation

lactate fermentation

MAIN IDEA: Fermentation pathways enable organisms to use glycolysis as a source of ATP, without an electron transport chain.

1. In what type of environment do organisms perform fermentation? K/U

2. How does fermentation affect the levels of NAD^+ and NADH? K/U

3. Name three organisms that perform fermentation. K/U

STUDY TIP

Working Together

Working with a partner or in small groups will help you to learn and test each other on how well you understand the concepts.

MAIN IDEA: Alcohol fermentation is performed by yeast and has significant commercial value.

4. Use a flow chart to outline the chemical stages of alcoholic fermentation by yeast. K/U C

5. Yeast is an important commercial organism because engineers are able to use its capablilities of fermentation to create usful products. Describe two industrial uses of yeast. K/U A

MAIN IDEA: Lactate fermentation in muscles provides a supplementary source of ATP when energy demands are very high and oxygen supply is low.

6. Add labels to **Figure 1** to show the basic process of lactate fermentation. K/U C

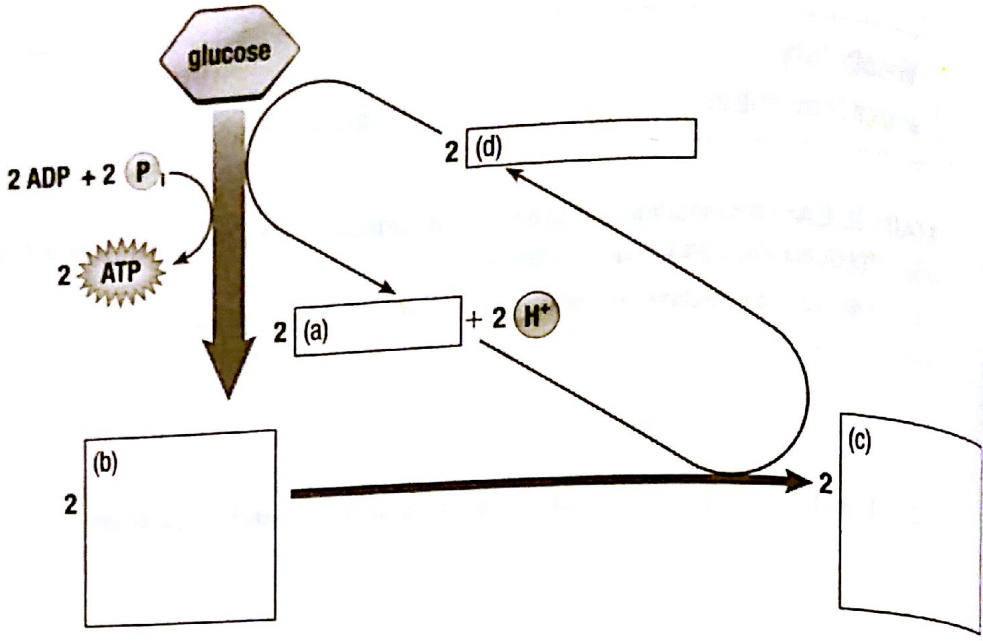


Figure 1

7. It was once thought that oxygen deficit results in the accumulation of lactic acid due to the activation of the lactic acid respiratory pathway. During strenuous exercise, lactate would accumulate in muscle tissue resulting in muscle cramps. Why is this untrue? K/U T/I

MAIN IDEA: Anaerobic respiration uses inorganic substances other than O_2 as terminal acceptors in an electron transport chain.

8. List three inorganic compounds that can be used by anaerobic organisms in place of oxygen as electron acceptors. K/U T/I

9. Use **Table 1** to compare the three types of cellular respiration. K/U C

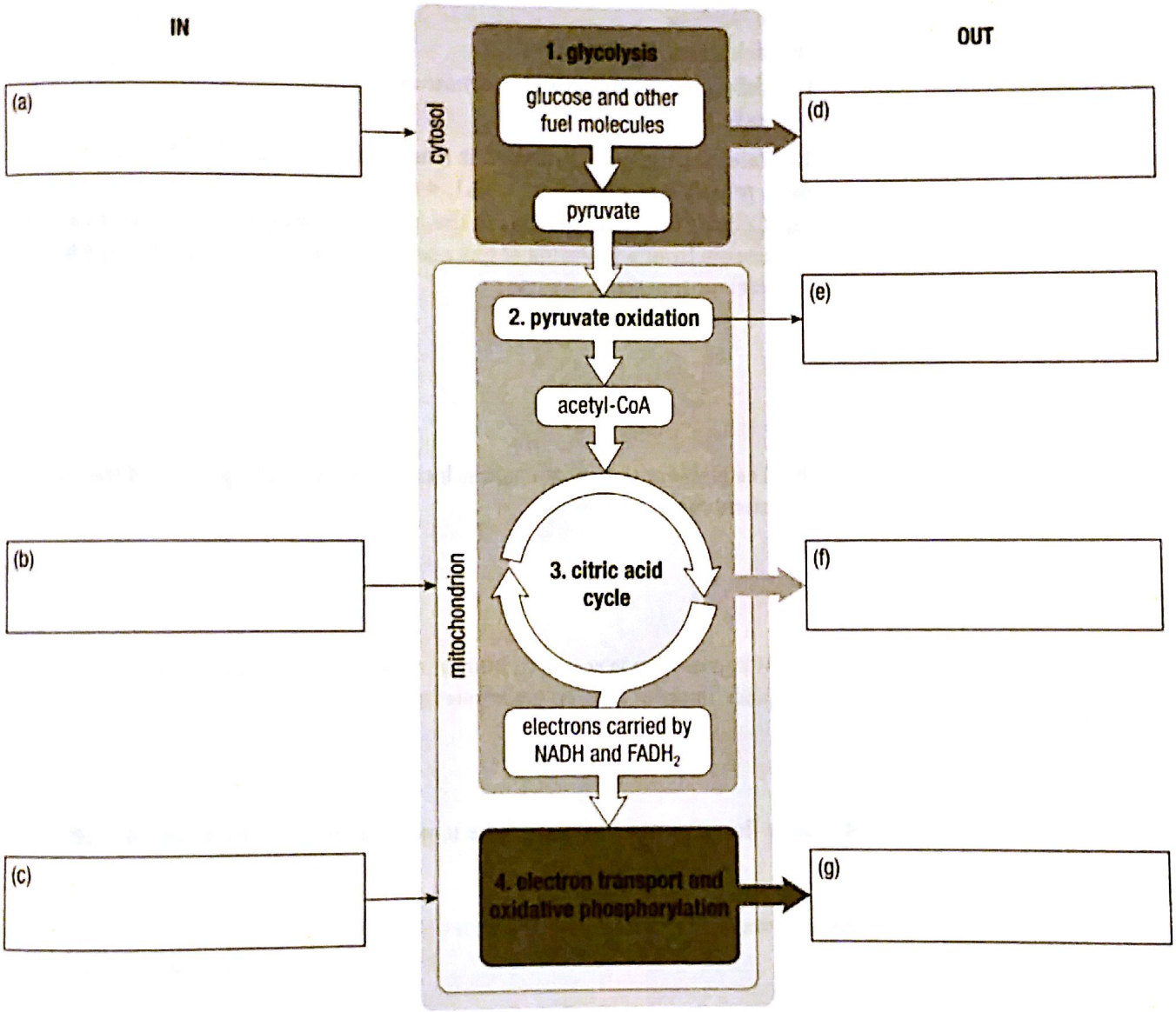
Table 1 Cellular Respiration

	Aerobic cellular respiration	Alcoholic fermentation	Lactate fermentation
Chemicals needed			
Amount of energy produced			
Products			
Parts of cell involved			
Examples of organisms			

Cellular Respiration

On the flow chart below, mark the locations of the formation and release of each compound listed below during cellular respiration. Be sure to include the number of each molecule used/produced at each step.

ATP
NADH
$FADH_2$
CO_2
H_2O



CHAPTER 4 QUESTIONS

K/U Knowledge/Understanding
T/I Thinking/Investigation
C Communication
A Application

1. Which process converts the energy in glucose into energy in the form of ATP most efficiently? (4.4) K/U
   (a) alcohol fermentation
   (b) aerobic respiration
   (c) anaerobic respiration
   (d) lactate fermentation
2. During the process of glycolysis, some hydrogen atoms are removed from glucose in the formation of pyruvate. This is an example of which process? (4.1) K/U
   (a) hydrolysis
   (b) dehydration
   (c) dehydration synthesis (condensation)
   (d) reduction
3. Indicate whether each statement is true or false. If you think the statement is false, rewrite it to make it true. (4.1, 4.4) K/U
   (a) Cellular respiration results in the relatively rapid, uncontrolled release of energy from a molecule of glucose to produce ATP for use by cells for various functions.

   (b) The electron transport chain is located on the inner portion of the cell membrane.

   (c) When oxygen is scarce in human muscle tissue, lactate fermentation takes place in order to keep glycolysis running.

4. Use a flow chart to summarize the major reactions of glycolysis. (4.2) K/U C