Interactive Biology Multimedia Courseware

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Cellular Respiration
Program Supplement

Cellular Respiration
TEACHING OBJECTIVES

The following subject areas are illustrated throughout the Interactive Biology Multimedia program, *Cellular Respiration*. Ideally, these areas would be augmented with additional course work outside of this program. *(Click on a subject to jump ahead.)*

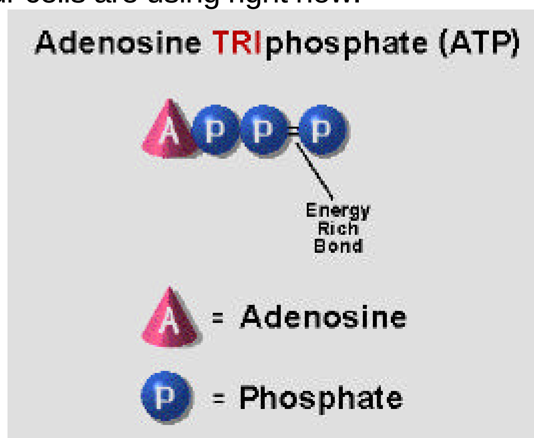
- **Introduction to cellular respiration, and adenosine triphosphate (ATP) as an energy providing molecule.**
- **Movement of electrons in oxidation-reduction reactions.**
- **Glycolysis**: Including an overview of the glycolytic chemical pathway and net energy yield.
- **Anaerobic respiration**: Including lactate and alcoholic fermentation.
- **Aerobic respiration**: Including the Krebs cycle and the electron transport chain.

Study Guide #1
INTRODUCTION TO CELLULAR RESPIRATION

What do organisms such as birds, humans, fish and bacteria have in common? All organisms, whether they are composed of trillions of cells like humans or composed of a single cell such as yeast, need to produce energy to survive.

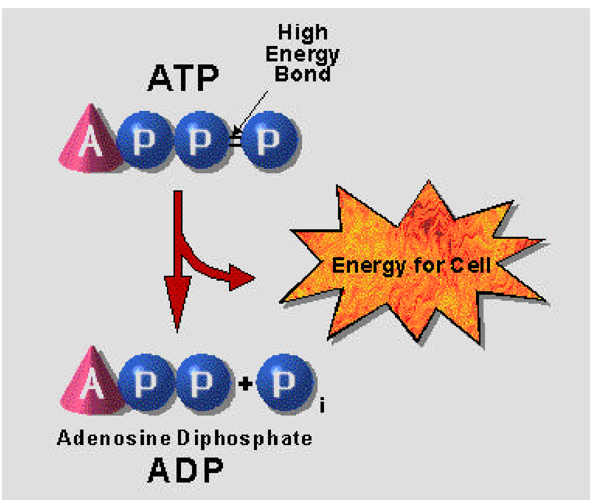
You are no doubt aware that humans and other animals must consume food to live. This food is used by your cells to make the energy required to fuel the body. The process of converting the food you eat into a source of energy that can be used by your body is called cell respiration.

Your body is constantly carrying out functions that require energy. Even while you sleep, many complex chemical reactions are taking place. These reactions all require specific types of energy molecules. The food you ate this morning has been converted into the energy molecules that your cells are using right now.



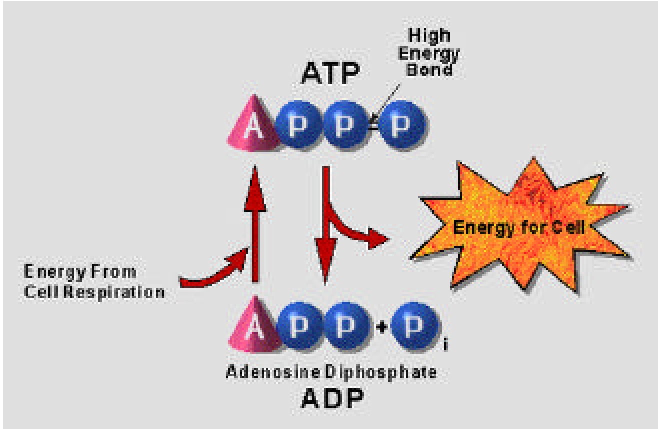
These molecules were formed by the energy released during cell respiration. The energy released during cell respiration was packaged by your cells into a form of chemical energy. The type of energy molecule used to fuel chemical reactions inside your body is adenosine triphosphate or ATP for short.

ATP is composed of an adenosine molecule with three-phosphate molecules attached end to end. In the ATP molecule, energy is stored in the bond holding the third phosphate molecule to the second phosphate molecule. This bond is often called a high-energy bond.



When a cell in your body requires energy, the terminal (or third) phosphate is broken off of an ATP molecule. This releases energy that was stored in the bond holding this phosphate on. Energy in this form is usable by cells.

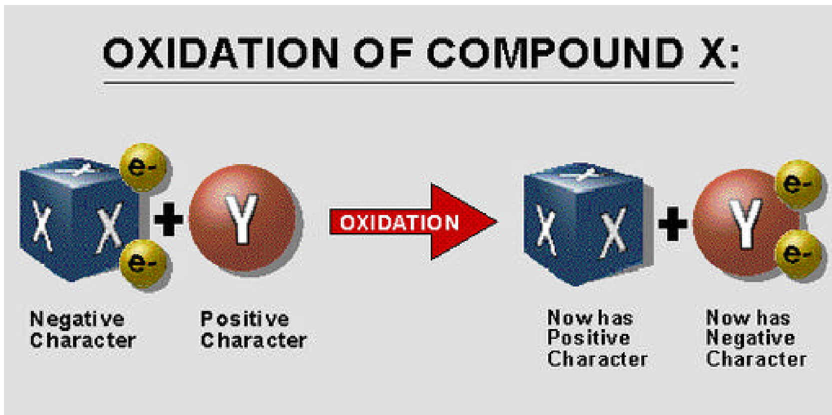
When the terminal phosphate is broken off, ATP is changed into adenosine diphosphate, or ADP. When energy is given off during cell respiration, an inorganic phosphate molecule is added back to ADP, and ATP is formed once more. This ATP molecule can then fuel another chemical reaction, be turned into ADP, and once again be converted into ATP where energy is stored for future use by the cell.



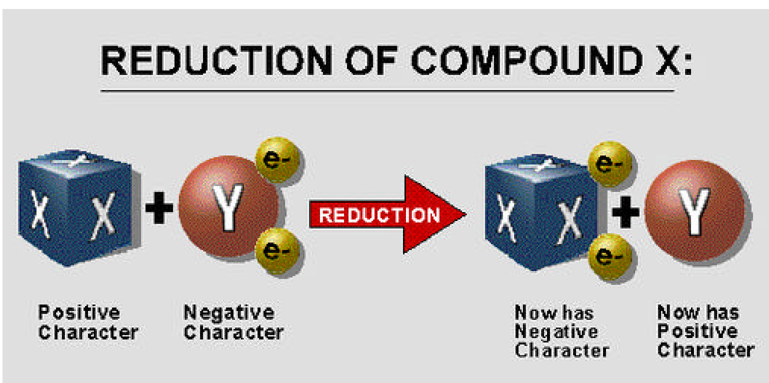
Study Guide #2
OXIDATION-REDUCTION REACTIONS

An Introduction to Aerobic and Anaerobic Respiration

As you learned in Study Guide #1, the basis of cell respiration is the conversion of food energy into a source of energy that can be used by the cell. This energy is in the form of ATP. The reactions taking place during cell respiration that make a transfer of energy possible are called oxidation-reduction reactions.



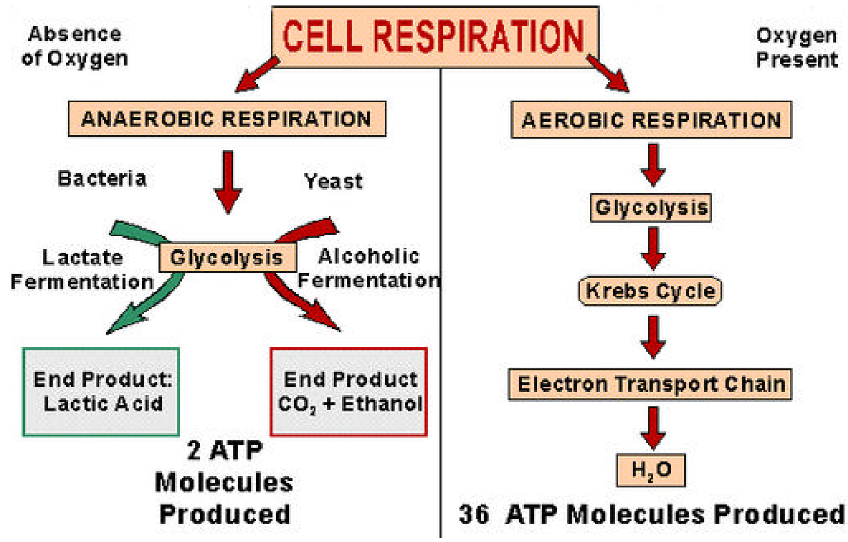
Electrons are very small, negatively charged particles associated with atoms. The term 'oxidation' refers to any reaction in which an atom or a compound loses electrons. This results in an atom or a compound with a slightly more positive charge.



The term 'reduction' refers to any reaction in which an atom or a compound gains electrons. This results in an atom or a compound with a slightly more negative charge.

Oxidation-reduction reactions are employed in two separate types of cellular respiration: anaerobic respiration and aerobic respiration.

Anaerobic respiration is carried out by such organisms as yeast and some bacteria. This is a type of respiration in which oxygen is not involved, and it ends in the production of two (2) ATP molecules. Under strenuous activity, our muscle cells will also employ this type of respiration. Aerobic respiration is carried out by all animals as well as plants. This is a type of respiration in which oxygen is involved, and it ends in the production thirty-six (36) ATP molecules.

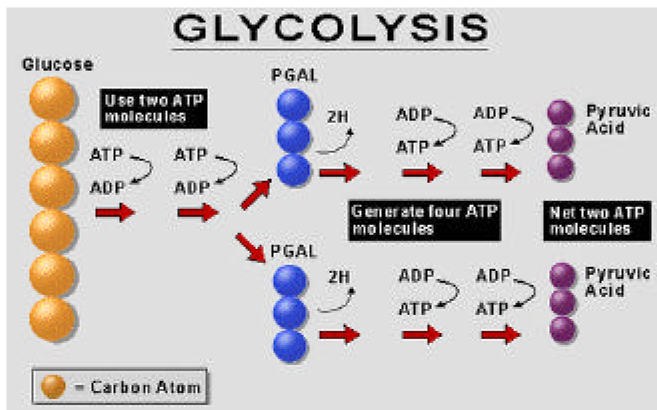

CELL RESPIRATION
Absence of Oxygen
Oxygen Present
ANAEROBIC RESPIRATION
AEROBIC RESPIRATION
Bacteria
Yeast
Lactate Fermentation
Glycolysis
Alcoholic Fermentation
End Product: Lactic Acid
End Product CO_2 + Ethanol
2 ATP Molecules Produced
Glycolysis
Krebs Cycle
Electron Transport Chain
H_2O
36 ATP Molecules Produced

Study Guide #3
GLYCOLYSIS

Whether it is aerobic or anaerobic respiration, the first stage of cellular respiration is a chemical pathway known as glycolysis.

Glycolysis is the first stage of energy production in cells. The meaning of the word is sugar (from "glyco") splitting (from "lysis"). In this chemical pathway, the sugar, glucose, is split apart.

Glucose is obtained from eating carbohydrates. Our bodies can also obtain glucose by breaking down other food types such as proteins and fats, and then converting them into sugar molecules. Many of the foods we eat will eventually be converted into glucose and used as an energy source or stored as fat for later use.



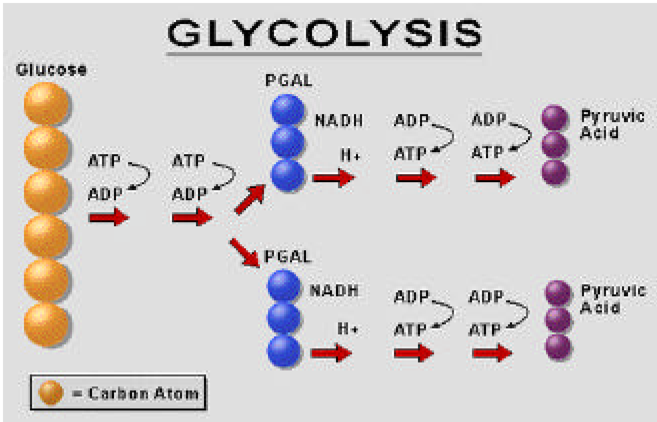
Many stages are involved in the production of ATP through glycolysis. At all of these stages, protein molecules known as enzymes speed up the reaction. In the first step of glycolysis, glucose is split into two molecules of phosphoglyceraldehyde, or PGAL. This step actually costs the cell two ATP molecules. In other words, it takes two molecules of ATP to split glucose into two PGAL molecules.

The cell expends energy to convert glucose into PGAL for one reason: PGAL can be converted into pyruvic acid, which provides four molecules of ATP. The cell "spends" two ATP, but receives four ATP in return. The cell winds up with an extra two ATP molecules through glycolysis.

Also produced in glycolysis are two (2) NADH molecules. NADH is like an energy well. Energy is stored in NADH molecules and can be converted into ATP.

During one step in glycolysis, two pairs of hydrogen atoms are released. Two pairs four hydrogen atoms total.

From each pair, one hydrogen atom, its electron, and the electron from the second hydrogen atom combine with one (1) NAD+ molecule to form one (1) NADH. The second hydrogen atom from the pair, in giving up its electron to NAD+, becomes a hydrogen ion, otherwise known as a proton. Protons, as you'll see later, play a very important role in the manufacturing of ATP.



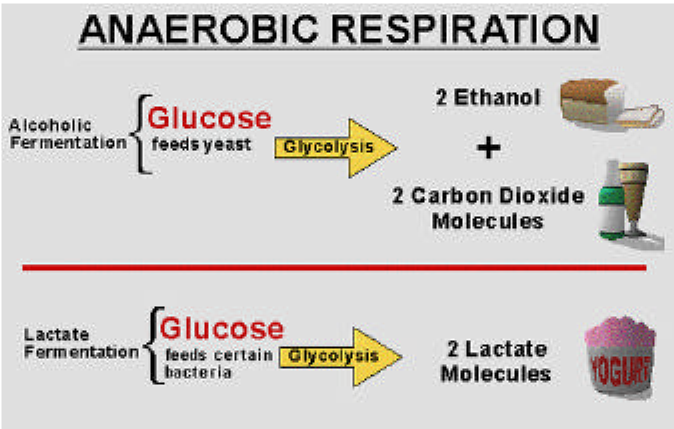
Time for a quick review. Hydrogen gave up its electron to NAD+, so which was oxidized and which was reduced?

Reduction is a gain of electrons, so NAD+ was reduced. For one element to be reduced, another must be oxidized. The element oxidized in this reaction was hydrogen.

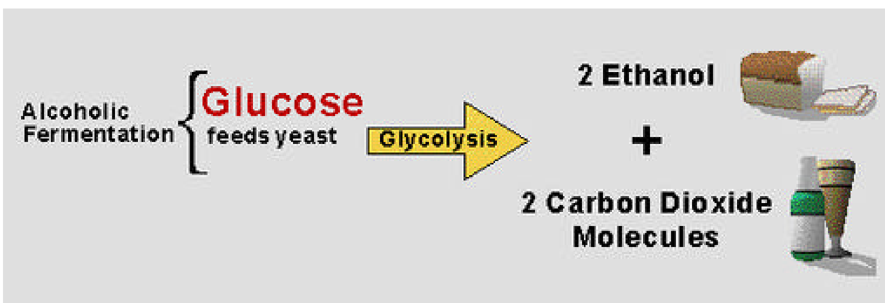
Study Guide #4
ANAEROBIC RESPIRATION

Recall that some organisms, as well our muscle cells at certain times, undergo respiration that does not require oxygen. This is anaerobic respiration.

Two important types of anaerobic respiration are alcoholic fermentation and lactate fermentation. Both of these types of respiration employ glycolysis (that is, glucose is broken down in both), but both end up with different products.



In lactate fermentation, bacteria, such as the kind found in yogurt, break down glucose into lactic acid. Your muscle cells can also produce lactic acid. During periods of strenuous exercise, your muscle cells do not have enough oxygen to carry out aerobic respiration. In this circumstance, muscle cells undergo lactate fermentation and lactic acid can build up in the muscle cells. This lactic acid is slowly transported to the liver by the blood, but while it remains in your muscles it can cause fatigue and pain. This is why your legs sometimes hurt for several minutes after you run.



Yeast carries out alcoholic fermentation. This type of respiration undergoes the same steps in glycolysis, but ends in the production of ethanol and carbon dioxide (CO_2). Ethanol is the alcohol found in such beverages as beer and wine. Yeast is used to not only make alcoholic beverages, but is also used to make bread. The CO_2 given off causes the bread to rise and the alcohol that is produced evaporates while baking.

In summary, the difference between lactate fermentation and alcoholic fermentation is their end products, lactic acid in lactate fermentation, and ethanol and carbon dioxide in alcoholic fermentation.

Study Guide #5
AEROBIC RESPIRATION

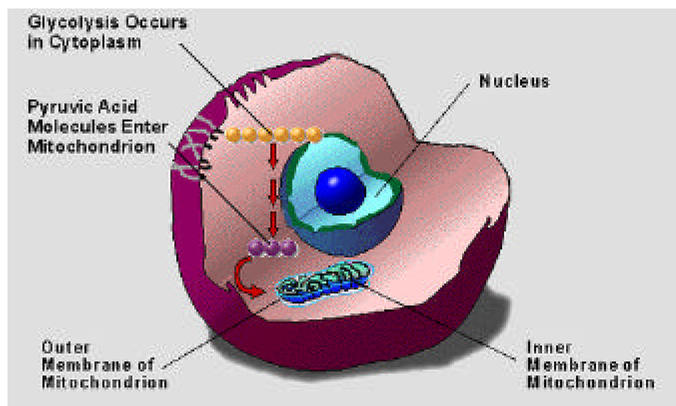
Mitochondria

While fermentation does produce energy for the cell, a much more efficient way of manufacturing ATP is through the mechanism of aerobic respiration.

Aerobic respiration picks up where glycolysis leaves off. Aerobic respiration takes the two molecules of pyruvic acid made during glycolysis and, through several reactions, produces many more ATP molecules than glycolysis alone yields.

Whereas glycolysis occurs in the cell's cytoplasm, aerobic respiration occurs in specialized cellular organelles called mitochondria. Mitochondria are called "powerhouses" of the cell because it is within them that most of the cell's ATP is made.

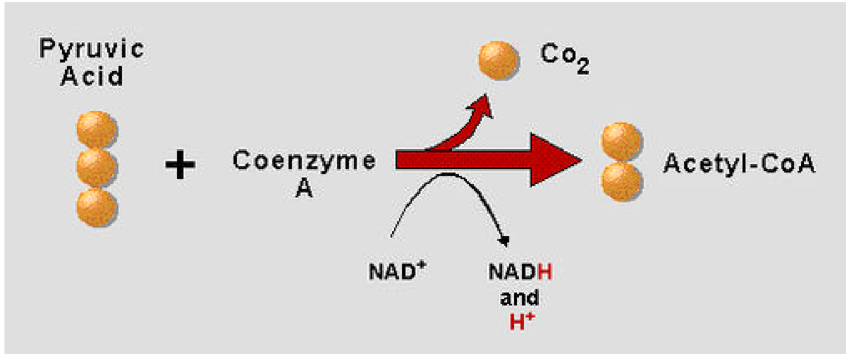
Mitochondria have both an outer as well as an inner membrane. The inner membrane is highly folded, and these folds are known as cristae. Within the cristae are enzymes, which play an essential role in aerobic respiration. A gel-like substance known as the matrix fills the interior of mitochondria.



The two membranes of a mitochondrion have different qualities. Remember that pyruvic acid was the end product of glycolysis. Pyruvic acid can diffuse (or move freely) across the outer membrane, which means pyruvic acid can move into the mitochondria. Pyruvic acid cannot diffuse across the inner membrane, or the cristae. Instead, it must be transported across the inner membrane. This means that once pyruvic acid crosses the cristae, it cannot then cross back out of the mitochondria. It remains inside where aerobic respiration can take place rather than outside where it cannot.

Upon entering the matrix, pyruvic acid combines with another molecule known as coenzyme A to form a new molecule known as ACETYL-CoA. Also formed are one molecule of NADH and CO_2.

Time for a quick review. One mitochondria has two membranes, an outer membrane and an inner membrane (or cristae).



Pyruvic acid diffuses across the outer membrane and is transported across the inner membrane.

One molecule of pyruvic acid combines with one molecule of Coenzyme A to form one molecule of Acetyl-CoA. One molecule of NADH is also produced.

The next step in aerobic respiration is sending the Acetyl-CoA just produced through the Krebs cycle.

Study Guide #6
AEROBIC RESPIRATION

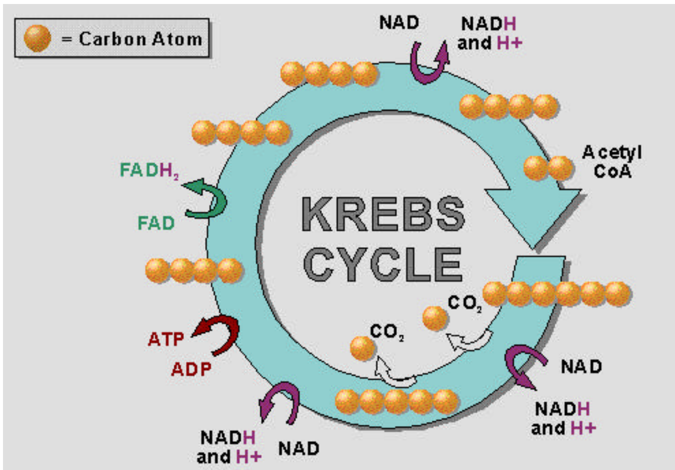
Krebs Cycle

First, a review of the steps that have taken place so far. In glycolysis, one molecule of glucose was broken down into two molecules of pyruvic acid. This resulted in two ATP and two NADH molecules being formed.

These two molecules of pyruvic acid then moved into the mitochondria. Here, they combine with two molecules of Coenzyme A and form two molecules of Acetyl-CoA. Two NADH are also formed.

Total reaction so far: one glucose molecule has become two molecules of Acetyl-CoA. Two ATP and four NADH have been formed.

The two molecules of Acetyl-CoA now enter into the Krebs Cycle. This is the next major step in aerobic respiration.



The Krebs Cycle is a complete cycle. In other words, it ends exactly where it begins. It starts with one of the Acetyl-CoA molecules combining with a four-carbon compound. It ends up with the reformation of the same four-carbon compound. This is able to again combine with Acetyl-CoA and repeat the cycle once more.

Many reactions take place during the Krebs Cycle. Most of these reactions are energy yielding, that is, many of them produce NADH or a molecule similar to NADH known as FADH2. FADH2, like NADH, is an electron acceptor that plays a vital role in the upcoming electron transport chain. Also produced in the Krebs cycle is one molecule of ATP and 4 molecules of CO_2 are released.

The TWO Acetyl-CoA molecules formed from the single glucose molecule during glycolysis go through the Krebs Cycle independently. At the end of the cycle, the two molecules of Acetyl-CoA have yielded a total of:

6 NADH
2 FADH2
2 ATP

The total energy produced so far from glycolysis, the formation of Acetyl-CoA, and the Krebs Cycle is:

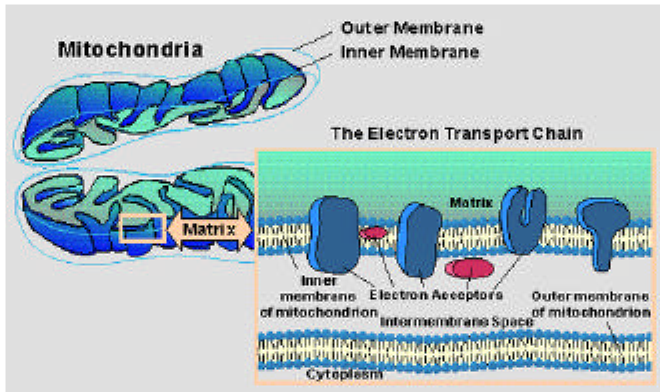
4 ATP
10 NADH
2 FADH2

Usable, chemical bond energy is stored directly in ATP molecules. In the critical next step in aerobic respiration, potential energy stored in electrons in NADH and FADH2 is converted into usable chemical bond energy as ATP.

Study Guide #7
AEROBIC RESPIRATION

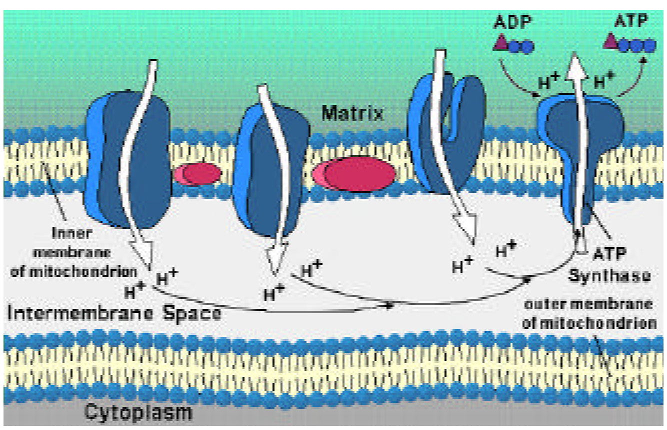
Electron Transport Chain

The electron transport chain is a very powerful tool in generating ATP. Aerobic respiration yields a total of 36 ATP molecules. So far (in glycolysis and the Krebs Cycle) the breakdown of glucose has given 4 ATP, therefore the electron transport chain generates the vast majority of ATP in aerobic respiration.



Recall that mitochondria have an inner and outer membrane. The electron transport chain is found on the inner mitochondrial membrane. This chain is composed of a series of enzymes and coenzymes that function as electron acceptors.

Two electrons are carried to the electron transport chain by each NADH and $FADH_2$ molecule. The electrons from these molecules are passed along the chain from acceptor to acceptor until they finally reach molecular oxygen, which is the final electron acceptor in aerobic respiration. After the molecular oxygen receives electrons, it combines with free hydrogen ions to form water.



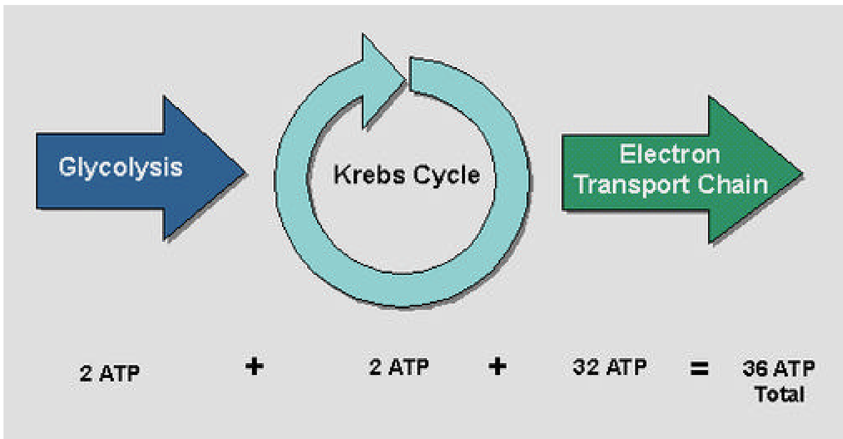
As these electrons travel along the chain, their energy is given off in small amounts. This energy is used to move hydrogen ions or protons from the matrix into the space between the two mitochondria membranes known as the intermembrane space.

These protons want to move back into the matrix, but in order to do so they must pass through the tunnel shaped enzyme ATP synthase. As these protons pass through, energy is given off and ADP on the matrix side of the enzyme is made into ATP.

The two electrons donated from each NADH result in the formation of 3 ATP. The two electrons donated from each $FADH_2$ result in the formation of 2 ATP.

The two NADH formed in glycolysis cannot pass through the mitochondrial membranes, and instead transfer their electrons to two $FADH_2$ molecules inside mitochondria. So although 10 NADH are formed through glycolysis and the Krebs Cycle, only 8 donate electrons directly to the electron transport chain. The sum total of electron donors is:

8 NADH (x3 ATP per NADH= 24 ATP)
4 $FADH_2$ (x2 ATP per FADH2= 8 ATP)



When we add the 32 ATP formed from the electron transport chain to the 4 ATP formed in glycolysis and the Krebs Cycle, we wind up with a sum total of 36 ATP produced through aerobic respiration.

Cellular Respiration
QUIZ PACK

The following quizzes are meant to test student understanding of specific topic areas covered in the Interactive Biology Multimedia Courseware program, *Cellular Respiration*. Many, but not all, of these questions have been addressed directly in the study guides designed to strengthen student understanding of these topics.

QUIZ #1 Introduction to Cell Respiration and The Energy Molecule
QUIZ #2 Oxidation-Reduction Reactions
QUIZ #3 Glycolysis
QUIZ #4 Anaerobic Respiration
QUIZ #5 Aerobic Respiration: Mitochondria
QUIZ #6 Aerobic Respiration: Krebs Cycle and The Electron Transport Chain
EXAM Comprehensive Exam

Quiz #1
Introduction To Cell Respiration
And The Energy Molecule

1. The process of converting food into a usable source of energy is called cellular respiration.

   A. True
   B. False

2. Many organisms are able to survive without producing energy.

   A. True
   B. False

3. The energy used to fuel the chemical reactions inside of your body is in the form of ________.

   A. food
   B. ADP
   C. ATP
   D. protein

4. This energy molecule used in fueling the chemical reactions inside of your body is composed of ________.

   A. meats, fruits, and vegetables
   B. an adenosine molecule connected to 2 phosphate groups
   C. an adenosine molecule connected to 3 phosphate groups
   D. amino acids linked together in polypeptides

5. Energy used in fueling these reactions is stored ________.

   A. in refrigerators
   B. in the bond between the first and second phosphate group
   C. in the bond between the second and third phosphate group
   D. in the bonds connecting each amino acid

6. Once these molecules have been used to provide energy, they can be converted back to energy providing molecules by what?

   A. No process that we currently know of.
   B. Reconnecting a second phosphate group.
   C. Reconnecting a third phosphate group.
   D. Reconnecting each amino acid in the polypeptide chain.

Quiz #2
Oxidation-Reduction Reactions
Aerobic vs. Anaerobic Respiration

1. Although important in many processes, oxidation-reduction reactions play only a minor role in cell respiration.

   A. True
   B. False

2. Electrons carry a positive charge.

   A. True
   B. False

3. The term oxidation refers to any reaction in which ________.

   A. oxygen is involved
   B. an atom or compound gains electrons
   C. an atom or compound loses electrons
   D. oxygen's electron orbitals become slightly larger

4. The term reduction refers to any reaction in which ________.

   A. oxygen is not involved
   B. an atom or compound gains electrons
   C. an atom or compound loses electrons
   D. oxygen's electron orbitals become slightly smaller

5. Aerobic respiration is carried out in the ________, and leads to the production of ________.

   A. absence of oxygen, 2 ATP molecules
   B. presence of oxygen, 2 ATP molecules
   C. absence of oxygen, 36 ATP molecules
   D. presence of oxygen, 36 ATP molecules

6. Anaerobic respiration is carried out in the _______, and leads to the production of ________.

   A. absence of oxygen, 2 ATP molecules
   B. presence of oxygen, 2 ATP molecules
   C. absence of oxygen, 36 ATP molecules
   D. presence of oxygen, 36 ATP molecules

Quiz #3
Glycolysis

1. Whether it is aerobic or anaerobic respiration, the first stage in cellular respiration is glycolysis.

   A. True
   B. False

2. Glycolysis stands for "sugar splitting".

   A. True
   B. False

3. In many of the reactions in glycolysis, ________ molecules known as ________ speed up the reaction rate.

   A. protein, enzymes
   B. carbohydrate, enzymes
   C. protein, glucose
   D. carbohydrate, glucose

4. In the first stage of glycolysis, ________ is split into ________ molecules of PGAL (phosphoglyceraldehyde).

   A. glyceraldehyde, four
   B. glyceraldehyde, two
   C. glucose, four
   D. glucose, two

5. In a later stage of glycolysis, the ________ PGAL molecules are converted into molecules of pyruvic acid.

   A. two, two
   B. two, four
   C. four, two
   D. four, four

6. In glycolysis, the cell spends ________ molecules of ATP and produces ________ molecules of ATP for a net gain of _______.

   A. 0, 2, 2
   B. 2, 2, 0
   C. 2, 4, 2
   D. 4, 4, 0

7. Hydrogen without its electron is also known as ________.

   A. a hydrogen ion
   B. a proton
   C. Both A and B
   D. Neither A nor B

8. During glycolysis, a hydrogen atom, its electron, and an electron from a second hydrogen atom combine with ________ to form ________.

   A. ADP, ATP
   B. ATP, ADP
   C. NAD+, NADH
   D. NADH, NAD+

9. By receiving electrons, the molecule in question #8 ________.

   A. was ionized
   B. was oxidized
   C. was reduced
   D. Both A and C

Quiz #4
Anaerobic Respiration

1. Cells in our body never undergo anaerobic respiration.

   A. True
   B. False

2. Two important types of anaerobic respiration are lactate fermentation and alcoholic fermentation.

   A. True
   B. False

3. In lactate fermentation, bacteria, such as the ones found in yogurt, break down ________ and end up with ________.

   A. lactic acid, glucose
   B. glucose, lactic acid
   C. ethanol and carbon dioxide, glucose
   D. glucose, ethanol and carbon dioxide

4. In alcoholic fermentation, yeast cells break down ________ and end up with ________.

   A. lactic acid, glucose
   B. glucose, lactic acid
   C. ethanol and carbon dioxide, glucose
   D. glucose, ethanol and carbon dioxide

5. When your muscles still ache soon after exercising, it is most likely due to a buildup of ________ in your cells.

   A. carbon dioxide
   B. lactic acid
   C. glucose
   D. ethanol

Quiz #5
Aerobic Respiration: Mitochondria

1. Anaerobic respiration produces far more ATP than does aerobic respiration.

   A. True
   B. False

2. Mitochondria are known as "powerhouses" of the cell.

   A. True
   B. False

3. Aerobic respiration uses the two molecules of pyruvic acid that are produced in glycolysis.

   A. True
   B. False

4. Mitochondria have two distinct membranes, with the inner one known as ________.

   A. the nuclear membrane
   B. the cristae
   C. the cell membrane
   D. the golgi apparatus

5. A gel-like substance known as ________ fills the interior of mitochondria.

   A. the cytosol
   B. glycogen
   C. plasmolysis
   D. the matrix

6. Glycolysis takes place ________.

   A. in the cytoplasm of the cell
   B. inside of mitochondria
   C. outside of the cell
   D. All of the above

7. Pyruvic acid ________ across the outer mitochondrial membrane and ________ across the inner mitochondrial membrane.

   A. is transported, cannot get
   B. is transported, diffuses
   C. diffuses, cannot get
   D. diffuses, is transported

8. Pyruvic acid combines with coenzyme A to form one molecule of ________.

   A. Pyruvic coenzyme A
   B. enzymatic pyruvic acid
   C. acetyl-CoA
   D. None of the above.

Quiz #6
Aerobic Respiration:
Krebs Cycle And The Electron Transport Chain

1. The Krebs Cycle begins and ends with the same compounds.

   A. True
   B. False

2. The electron transport chain produces less ATP molecules than glycolysis does.

   A. True
   B. False

3. In the Krebs Cycle, hydrogen atoms and electrons are transferred to ________.

   A. NAD+ making NADH
   B. FAD making $FADH_2$
   C. Both A and B.
   D. Neither A nor B.

4. The electron transport chain is found ________.

   A. in the cell's cytoplasm
   B. on the outer mitochondrial membrane
   C. on the inner mitochondrial membrane
   D. in the nucleus

5. Electrons delivered to the electron transport chain travel along the chain until they are finally passed to ________.

   A. oxygen molecules
   B. the outside of the cell
   C. NADH
   D. glucose

6. Energy released by the electrons as they travel along the ETC is used to pump ________ from the matrix into the ________.

A. protons, cytoplasm of the cell
B. protons, intermembrane space
C. glucose, cytoplasm of the cell
D. glucose, intermembrane space

7. Hydrogen ions passing through the enzyme ________ provide the energy to convert ADP to ATP.

   A. reverse transcriptase
   B. ATP synthase
   C. ATP reductase
   D. ATPase

8. The two electrons donated from each NADH result in the formation of ________ ATP molecules.

   A. 1
   B. 2
   C. 3
   D. 4

9. At the end of aerobic respiration, ________ ATP molecules have been produced.

   A. 6
   B. 16
   C. 26
   D. 36

Cellular Respiration
Comprehensive Exam

The following exam is based on the Interactive Biology Multimedia Courseware program, *Cellular Respiration*. Most, but not all, of these questions have been addressed directly in the study guides. All of the questions on this exam, however, are based on information put forth in the program.

Please determine if the following statements are true of false.

1. Cellular respiration is the process of converting food into a usable source of energy.

   A. True
   B. False

2. Many organisms are able to survive without producing energy.

   A. True
   B. False

3. Oxidation-reduction reactions play an important role in cell respiration.

   A. True
   B. False

4. Electrons carry a negative charge.

   A. True
   B. False

5. The first step in both aerobic and anaerobic respiration is glycolysis.

   A. True
   B. False

6. Glycolysis stands for "protein splitting".

   A. True
   B. False

7. Being aerobic organisms, cell in our body will never undergo anaerobic respiration.

   A. True
   B. False

8. Anaerobic respiration produces far more ATP than does aerobic respiration.

   A. True
   B. False

9. Mitochondria are known as the "powerhouses" of the cell.

   A. True
   B. False

10. The Krebs Cycle begins and ends with the same compounds.

    A. True
    B. False

11. The electron transport chain produces more ATP molecules than does glycolysis.

    A. True
    B. False

In the following portion of the exam, please choose the letter beside the word, words, or phrase that best completes each sentence.

12. ATP, the molecules providing the energy to fuel the chemical reactions inside of your body, is composed of ________.

A. meats, fruits, and vegetables
B. an adenosine molecule connected to 2 phosphate groups
C. an adenosine molecule connected to 3 phosphate groups
D. amino acids linked to an adenosine molecule

13. Energy used in fueling these reactions is stored ________.

A. in refrigerators
B. in the bond between the first and second phosphate groups
C. in the bond between the second and third phosphate groups
D. in the bonds connecting each amino acid

14. Aerobic respiration is carried out in the _______, and leads to the production of ________.

A. absence of oxygen, 2 ATP molecules
B. presence of oxygen, 2 ATP molecules
C. absence of oxygen, 36 ATP molecules
D. presence of oxygen, 36 ATP molecules

15. Anaerobic respiration is carried out in the _____ and leads to the production of ________.

A. absence of oxygen, 2 ATP molecules
B. presence of oxygen, 2 ATP molecules
C. absence of oxygen, 36 ATP molecules
D. presence of oxygen, 36 ATP molecules

16. In the first stage of glycolysis, ________ is split into _______ molecules of PGAL (phosphoglyceraldehyde).

A. glyceraldehyde, 2
B. glyceraldehyde, 4
C. glucose, 2
D. glucose, 4

17. Glycolysis ends with the production of ________ molecules of pyruvic acid.

A. 2
B. 4
C. 6
D. 8

18. In glycolysis, the cell expends ________ molecules of ATP and produces ________ molecules of ATP for a net gain of _______.

A. 0, 2, 2
B. 2, 2, 0
C. 2, 4, 2
D. 4, 4, 0

19. Hydrogen without its electron is also known as ________.

A. a hydrogen ion
B. a proton
C. Both A and B
D. Neither A nor B

20. What is produced at the end of lactate fermentation?

A. Lactic acid
B. Lactose
C. Glucose
D. All of the above.

21. What is produced at the end of alcoholic fermentation?

A. Ethanol
B. Carbon dioxide
C. Both A and B
D. Always A and sometimes B

22. The gel-like substance filling the interior of mitochondria is known as ________.

A. the cytosol
B. glycogen
C. the matrix
D. plasmolysis

23. Glycolysis takes place ________.

A. in the cytoplasm of the cell
B. inside of mitochondria
C. outside of the cell
D. All of the above

24. Pyruvic acid ________ across the outer mitochondrial membrane and ________ across the inner mitochondrial membrane.

A. is transported, cannot get
B. is transported, diffuses
C. diffuses, cannot get
D. diffuses, is transported

25. Pyruvic acid is converted into acetyl-CoA which is ________.

A. used as cellular energy
B. used to synthesize glucose
C. used in the Krebs Cycle
D. Both B and C

26. In the Krebs Cycle, hydrogen atoms and electrons are transferred to ________.

A. NAD+ making NADH
B. FAD making FADH2
C. Both A and B
D. Neither A nor B

27. The electron transport chain is found ________.

A. in the cell's cytoplasm
B. on the outer mitochondrial membrane
C. on the inner mitochondrial membrane
D. in the nucleus

28. Energy released by the electrons as they travel along the ETC is used to pump ________ into the ________.

A. protons, cytoplasm of the cell
B. protons, intermembrane space
C. glucose, cytoplasm of the cell
D. glucose, intermembrane space

29. Hydrogen ions passing through the enzyme ATP synthase provide the energy to ________.

A. convert ATP back into ADP
B. convert ADP back into ATP
C. link together many ATP molecules
D. break the links between ATP molecules

In the following portion of the exam, please fill in the word or words that best completes each sentence.

30. The term oxidation refers to any reaction in which an atom or compound ________________________ electrons.

31. The term reduction refers to any reaction in which an atom or compound _________________ electrons.

32. In many of the reactions in glycolysis, protein molecules known as ____________ speed up reaction rates.

33. Mitochondria have two membranes, with the inner one known as ____________.

34. ___________________________ is the final electron acceptor in aerobic respiration.

Cellular Respiration
Answer Guide

QUIZ PACK

QUIZ #1	QUIZ #2	QUIZ #3	QUIZ #4	QUIZ #5	QUIZ #6
1. A	1. B	1. A	1. B	1. B	1. A
2. B	2. B	2. A	2. A	2. A	2. B
3. C	3. C	3. A	3. B	3. A	3. C
4. C	4. B	4. D	4. D	4. B	4. C
5. C	5. D	5. A	5. B	5. D	5. A
6. C	6. A	6. C		6. A	6. B
		7. C		7. D	7. A
		8. C		8. C	8. C
		9. C			9. D

COMPREHENSIVE EXAM

1. A	11. A	21. C	31. gains
2. B	12. C	22. C	32. enzymes
3. A	13. C	23. A	33. the cristae
4. A	14. D	24. D	34. oxygen
5. A	15. A	25. C	
6. B	16. C	26. C	
7. B	17. A	27. C	
8. B	18. C	28. B	
9. A	19. C	29. B	
10. A	20. A	30. loses	

Cellular Respiration
GLOSSARY

acetyl CoA: a compound resulting from the combination of an acetyl group, which comes from the breakdown of pyruvic acid, and coenzyme A; the molecule that enters the Krebs Cycle following glycolysis.

aerobic respiration: a type of respiration in which free oxygen is used to oxidize organic compounds to carbon dioxide and water.

adenosine diphosphate (ADP): the lower-energy compound that is formed when a phosphate group is removed from ATP; consists of an adenosine molecule with two phosphate groups attached.

alcoholic fermentation: a form of anaerobic respiration following glycolysis that is carried out by yeast and some bacteria; respiration with carbon dioxide and ethanol as final products.

anaerobic respiration: respiration that is carried out in the absence of oxygen; does not utilize oxygen as the final electron acceptor.

atom: the smallest unit of matter that displays the characteristic properties of an individual element.

adenosine triphosphate (ATP): the energy-carrying molecule found in cells; consists of an adenosine molecule with three phosphate groups attached.

carbon dioxide: a molecule consisting of an atom of carbon bonded to two oxygen atoms.

cellular respiration: the process of generating energy from the breakdown of food; results in the production of ATP molecules.

chemiosmotic coupling hypothesis: description of energy flow in the electron transport chain. Electrons move from acceptor to acceptor, providing energy to transport protons from the matrix into the intermembrane space. Protons then follow concentration gradient out of cell through ATP synthase enzymes, fueling production of ATP on matrix side of membrane.

cristae: folds in the inner mitochondrial membrane; electron transport chain located here.

cytochrome: electron acceptor in the electron transport chain.

electron: subatomic particle that carries a negative charge.

electron transport chain (ETC): a series of electron acceptors found in cristae; used to convert electron potential energy into chemical bond energy held in ATP.

enzyme: protein molecule that catalyzes, or speeds up, biochemical reactions but is not itself altered in the reaction.

ethanol: alcohol that is produced as a result of fermentation.

flavin adenine dinucleotide (FAD): coenzyme, carrier of protons and electrons in Krebs Cycle as well as electron transport chain.

fat: food storage molecule.

glucose: sugar used in the beginning of glycolysis; made available by the breakdown of many food sources, especially carbohydrates.

glycolysis: chemical pathway where glucose is converted into pyruvate.

Krebs Cycle: second stage of aerobic respiration that begins with acetyl-CoA (formed from pyruvic acid provided by glycolysis) combining with oxaloacetate and ends in the reformation of oxaloacetate; oxygen is required in this cycle and CO_2 is given off.

matrix: gel-like substance surrounding the cristae mitochondria.

mitochondria: cellular organelles in which pyruvic acid converted to acetyl-CoA; location of Krebs Cycle and electron transport chain. Powerhouses of the cell.

molecule: two or more atoms that are chemically bonded to one another.

nicotinamide adenine dinucleotide (NAD^+): coenzyme that serves as an electron and hydrogen carrier; involved in Krebs Cycle and electron transport chain.

oxidation: removal of electrons from a molecule or atom.

oxidation-reduction reaction: reaction involving the transfer of electrons from one atom or compound to another.

phosphorylation: transfer of a phosphate group from one compound to another, accompanied by a transferal of energy.

protein: large molecule (macromolecule) consisting of amino acids linked together.

proton: subatomic particle with a positive electrical charge.

pyruvic acid: three-carbon compound formed as an end product of glycolysis.

reduction: the addition of electrons to a molecule or atom.