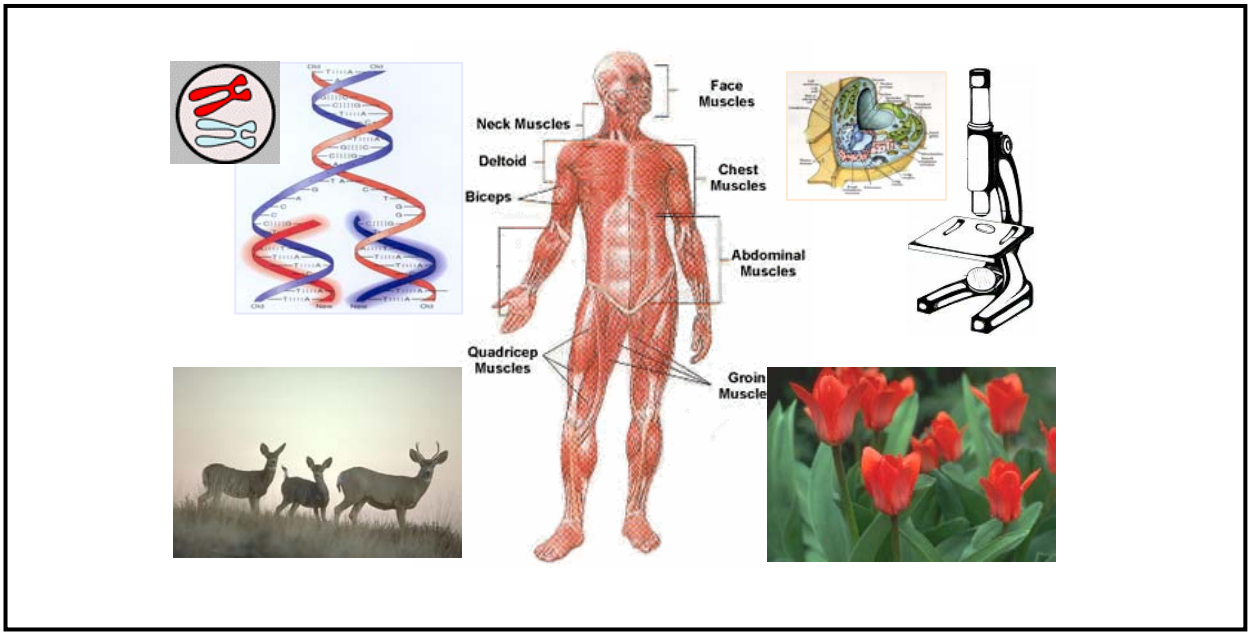
Project EASE

(Effective Alternative Secondary Education)

BIOLOGY



MODULE 5

Cellular Respiration

BUREAU OF SECONDARY EDUCATION
Department of Education
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Module 5
Cellular Respiration

What this module is about

In Module 4, we learned that the energy trapped from the sun is stored in the food as chemical energy. Photosynthesis is an energy conversion process performed by plants. The present module discusses another energy conversion process carried out by living organisms wherein the stored energy in foods is being harvested.

This module contains five (5) lessons:

- **Lesson 1 – Kinds of Food**
- **Lesson 2 – Mitochondrion**
- **Lesson 3 – Cellular Respiration**
- **Lesson 4 – Electron Transport System**
- **Lesson 5 – Energy From a Glucose Molecule**

What you are expected to learn

After going through this module, you are expected to:

1. classify the foods you eat into different food groups;
2. describe the structure of the cell where cellular respiration occurs;
3. discuss the different stages of cellular respiration;
4. count the number of adenosine triphosphate produced from one molecule of glucose;
5. describe how to tap the energy from lipids and proteins;
6. relate dieting to cellular respiration; and
7. list factors that destroy cellular respiration.

How to learn from this module

Here's a simple guide for you in going about the module.

1. Read the instructions carefully.
2. Take the pretest before reading the rest of the module.
3. Do all the activities and exercises.
4. Use the concepts discussed in each lesson to explain the results of the activities or exercises.
5. Take the posttest after you have finished the lessons and performed all activities or exercises.

What to do before (Pretest)

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Which of the following is processed food?
   a. adobong manok
   b. cooked rice
   c. fried saba banana
   d. hotdog

2. Which of the following is a "go food"?
   a. boiled egg
   b. boiled young corn
   c. chinese ham
   d. ripe pineapple slice

3. Which of the following organelles present in the cell is associated with cellular respiration?
   a. chloroplast
   b. endoplasmic reticulum
   c. mitochondrion
   d. nucleus

4. How do you call the infoldings of the inner membrane of the mitochondrion?
   a. cristae
   b. matrix
   c. ribosome
   d. vesicles

5. During glycolysis, 6-carbon sugar is broken down into 3-carbon sugar. Which of the following 3-carbon sugars is readily used by the cells?
   a. PGA
   b. PGAL
   c. DHAP
   d. phosphoenal pyruvate

6. What is the net gain of ATP during glycolysis?
    a. 1
    b. 2
    c. 3
    d. 4

7. How many NADH molecules are produced during glycolysis?
    a. 1
    b. 2
    c. 3
    d. 4

8. Where does glycolysis occur?
    a. cytoplasm
    b. matrix of the mitochondrion
    c. inner membrane of the mitochondrion
    d. outer membrane of the mitochondrion

9. Pyruvate is the product of glycolysis. If there is no oxygen available to cells of the human body, what becomes of pyruvate?
    a. alcohol
    b. CO_2
    c. lactic acid
    d. a and c

10. If glucose is completely degraded by cells, what are the products of degradation?
    a. water and oxygen
    b. lactic acid and oxygen
    c. ethanol and carbon dioxide
    d. carbon dioxide and water

11. How many molecules of ATP are produced from one glucose molecule?
    a. 4
    b. 12
    c. 30
    d. 38

12. If you did not eat for three days, where did your cell get the glucose for ATP production?
    a. blood sugar
    b. glycogen in the liver
    c. glycogen present in the muscle
    d. protein in the blood

13. 13. What is the entry point of lipid into cellular respiration so that the cell can get energy?
    a. DHAP and pyruvate
    b. Pyruvate and oxaloacetate
    c. DHAP and acetyl CoA
    d. Coenzyme A and acetyl CoA

14. Which of the following is the possible entry point of proteins into cellular respiration?
    a. acetyl CoA
    b. alpha ketoglutarate
    c. pyruvate
    d. all of three

15. . Which of the following is removed or minimized when you go on diet?
    a. rice
    b. chicken meat
    c. vegetable
    d. fruit

16. Which of the following can destroy cellular respiration?
    a. snake venom
    b. cholera toxin
    c. 2,4-dinitrophenol
    d. all of them

Key to answers on page 26.

Before you start with the lessons, familiarize yourself with the following terms:

Terms	Definitions
Adenosine triphosphate	High energy molecule utilized by working cells as source of energy
Cellular respiration	Catabolic process to harvest energy from foods
Glycolysis	First step of cellular respiration wherein the six-carbon glucose is broken down to 2 molecules of 3-carbon compounds
Oxidation	Process wherein a substance loses electrons or combines with oxygen
Reduction	Process wherein a substance gains electrons or loses oxygen
Electron transport system	A series of substances that accept or carry electrons
Kreb's cycle	3rd phase of cellular respiration
Metabolic poison	Substance that destroys the electron transport system

Lesson 1. Kinds of Foods

Below is a collage of the different kinds of foods you normally eat everyday. It may come from the plants directly or indirectly.

Figure 1. Kinds of Food

The foods in the picture are either processed or unprocessed. Processed foods include cakes, pasta, pansit and pan de sal. Examples of unprocessed foods are cooked rice, fresh banana, boiled corn and suman. Processed and unprocessed foods are grouped further into carbohydrates, lipids and proteins.

Why do we need food? Food is the source of energy. In order to function properly, living organisms need energy. The energy in the food is a potential energy. Table 1 lists the food and its corresponding amount of energy per serving.

Table 1. Nutrition Guide

Food	Portion size*	Per 100 grams (3.5 oz)	Energy content
Egg (1 average size)	90 calories	150 calories	Medium
Egg (fried)	120 calories	180 calories	Medium to High
Rice (white boiled)	420 calories (300 g)	140 calories	Low calorie
Rice (egg-fried)	500 calories	200 calories	High in portion
Milk	175 calories (250ml/half pint)	70 calories	Medium to High
Banana	107 calories	65 calories	Low calorie
Biscuit	86 calories per biscuit	480 calories	High
Bread (white)	96 calories (1 slice, 40 grams)	240 calories	Medium
Cheese	200 calories	428 calories	High
Butter	112 calories	750 calories	High
Sugar (white table sugar)	20 calories (1 teaspoon)	400 calories	Medium
Corn flakes	130 calories (35 grams)	370 calories	Medium to High
Cheese average	110 cals (25g)	440 cals	high
Cottage cheese	49 cals	98 cals	Low calorie
Cream cheese	200 cals	428 cals	high

Fruit	Calories per piece	Carbs (grams)
Apple	44 calories	10.5
Apple cooking	35 calories	9
Apricot	30 calories	6.7
Avocado	150 calories	2
Banana	107 calories	26
Guava	24 calories	4.4
Mango	40 calories	9.5
Melon	110 calories	26

Meat Type	Calories	Fat
Bacon Calories (average rashers)	500	45g
Beef Calories (average lean)	275	20g
Lamb breast (roast)	398	30g
Lamb Chops (grilled)	368	28g
Lamb Cutlets (grilled)	375	31g
Lamb Leg (roast)	270	17g
Lamb Shoulder (roast)	320	24g
Pork Belly rashers (grilled)	400	35g
Pork Chops (grilled)	340	24g
Chicken	140 calories	12 g
Lamb breast (roast)	398 calories	30g

Figure 2 is a food pyramid. The food pyramid shows you and your family the kinds of food to eat everyday. The foods to be eaten less are found at the top of the pyramid. The foods to be eaten more are found at the base of the pyramid. Thus, the foods to eat more often are breads, cereals, fruits and vegetables and the foods to be eaten sparingly are sweets and fats.

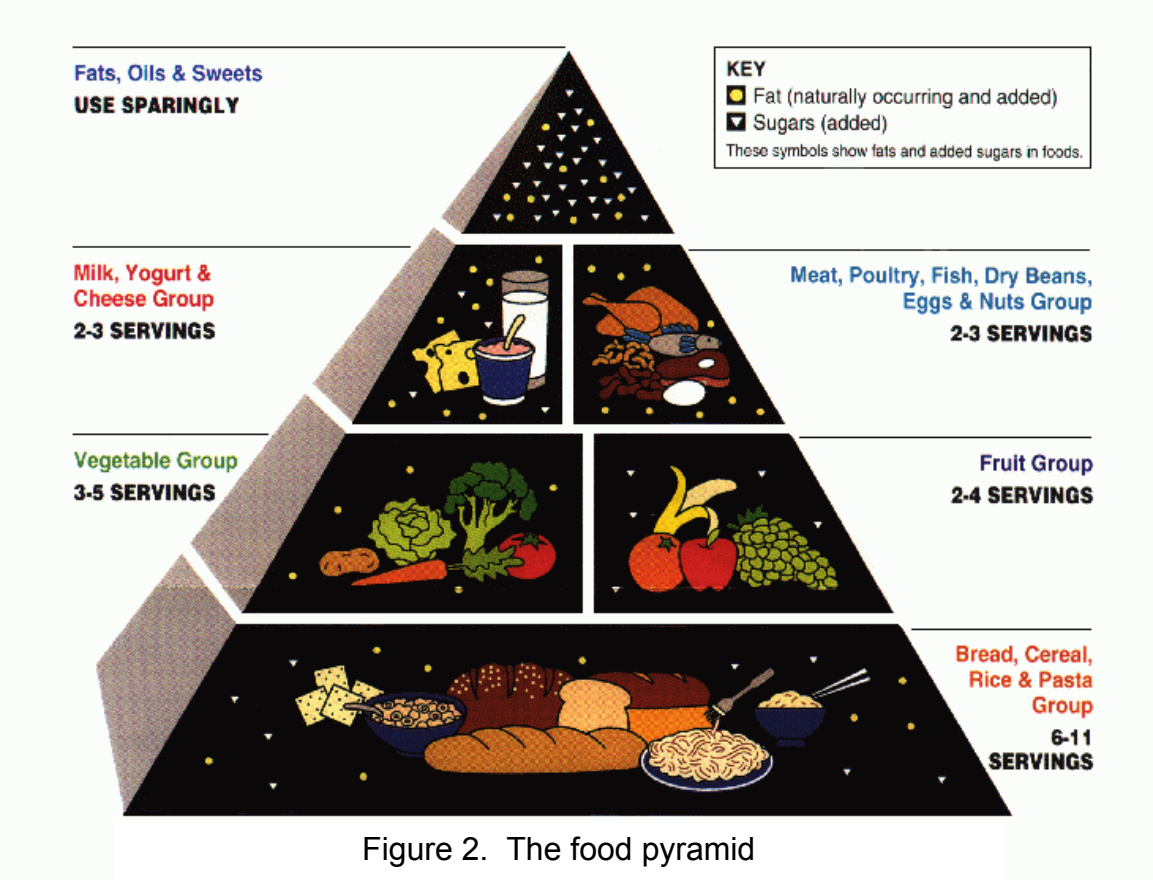


Figure 2. The food pyramid

What you will do

Activity 1.1 How much energy do I get from the food I eat?

What you need: nutrition guide and food pyramid
paper and pencil

What to do:

1. Suppose you ate the following foods at breakfast:
    a. one boiled egg
    b. 250 ml milk
    c. 2 slices of white bread
    d. average sized cheese
    e. banana
2. Using the nutrition guide, how many calories of food did you consume?
3. Using the food pyramid, do the foods you have eaten belong to the food to be eaten sparingly? or "food to be eaten more"?

Key to answers on page 26.

What you will do

Self-Test 1.1

Direction: Write the word **TRUE** if the statement is correct and **FALSE** if the statement is wrong.

1. There are bacteria in your mouth that produce acid.
2. Fiber helps reduce the amount of cholesterol in the blood.
3. Thin French fries are better for you than thick chips.
4. An apple a day, keeps the doctor away.
5. You can have too much of some vitamins.
6. Only bacteria cause food poisoning.
7. Eating too much salt can cause high blood pressure.
8. Milk and cheese are good sources of calcium.
9. Starchy foods make you gain weight.

Key to answers on page 26.

The foods must be digested to simple forms such as glucose, amino acids and triglycerides. These are then transported to cells. The immediate energy source of the cells is glucose. Glucose inside the cell is broken down to release the stored energy. This stored

energy is harvested in the form of adenosine triphosphate (ATP). ATP is a high-energy molecule needed by working cells. We shall first discuss the part of the cell where ATP is being produced.

Lesson 2. Mitochondria

Mitochondria are membrane-enclosed **organelles** distributed through the cytoplasm of most eukaryotic cells. Their main function is the conversion of the potential energy of food molecules into ATP. This organelle has important parts. What are they?

1. **An outer membrane that encloses the entire structure**. It contains many complexes of integral membrane proteins that form openings. A variety of molecules and ions move in and out of the mitochondrion through the openings.

2. **An inner membrane that encloses a fluid-filled matrix**. This membrane contains five complexes of integral proteins such as:

    - NADH dehydrogenase
    - succinate dehydrogenase
    - cytochrome c reductase (the cytochrome b-c_1 complex)
    - cytochrome c oxidase
    - ATP synthase

As shown in the diagram, the inner membrane is thrown into folds with shelf like cristae projecting into the matrix.

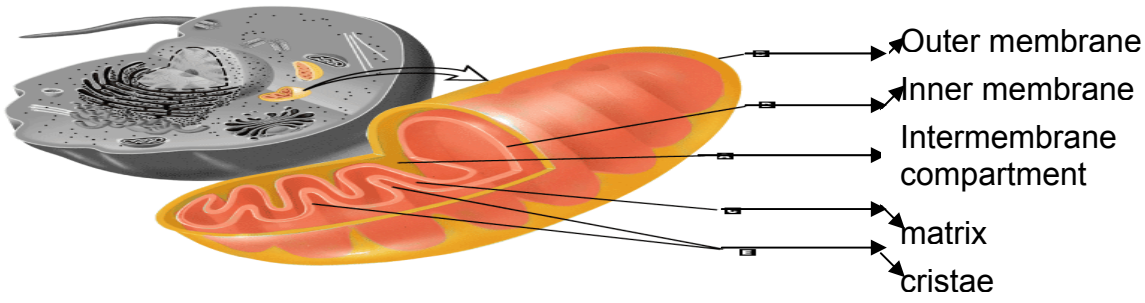


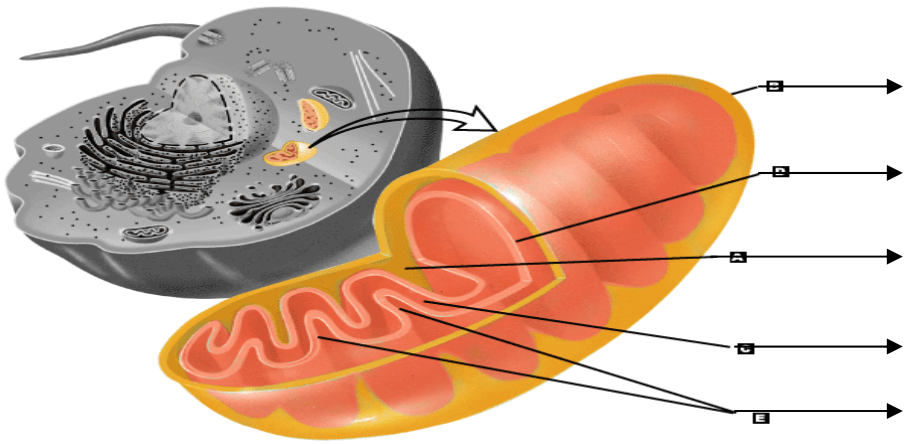
Figure 3. The Mitochondria

3. An intermembrane compartment between the outer and inner membrane
4. The matrix contains a complex mixture of soluble enzymes that catalyze the respiration of pyruvic acid and other small organic molecules.
5. A small number (some 5–10) of circular molecules of **DNA**

What you will do

Activity 2.1

1. Below is an illustration of a mitochondrion.
2. Label the parts of the mitochondrion being indicated.



Key to answers on page 26.

What you will do

Self-Test 2.1

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Which cell process occurs within the mitochondria?
   a. exocytosis
   b. cyclosis
   c. cellular respiration
   d. photosynthesis

2. The inner membrane of the mitochondria has infoldings. How do you call these structures?
   a. chromatin
   b. the middle lamella
   c. cristae
   d. cytoplasm

3. Scientists think that mitochondria may have once been separate living organisms for all of the following reasons *except* that they
   a. have cilia and flagella
   b. have their own DNA
   c. can reproduce
   d. can produce their own protein

Key to answers on page 26.

Lesson 3. Cellular Respiration

The process by which energy is harvested from food is called ***cellular respiration.*** Before we discuss the process, we shall first perform an activity wherein an organism would utilize the substance produced during photosynthesis. The organism you will use in the activity is yeast and the photosynthetic product is sucrose, the table sugar. Table sugar is a double sugar.

What you will do

Activity 3.1 Cellular Respiration in Yeast

What do you need:

distilled water	pH paper
2.5 grams table sugar	test tube
baker's yeast	test tube rack
balloon	rubber band

What to do?

1. Warm water to 37 ^{o}C.
2. Place lukewarm water in a test tube.
3. Add sugar to produce 5% sugar solution. Dip a pH paper into the mixture. Match the color of the wet pH paper with the accompanying color chart.
4. Drop 5-10 granules of yeast.
5. Mix with swirling motion.
6. Place test tube in a test tube rack.
7. Attach a balloon to the mouth of the test tube.
8. Secure the balloon with a rubber band.
9. Wait for a few minutes.
10. Once the balloon is fully inflated, remove the balloon and tie it with a rubber band.
11. Dip another pH paper. Note the color change of the pH paper.

Questions:

1. What does the yeast represent?
2. What is the purpose of sugar?
3. Why did we use lukewarm water?
4. What was the pH of the sugar solution?
5. What did you notice at the surface of the sugar solution when you dropped the yeast?
6. What happened to the balloon after attaching it to the mouth of the test tube?
7. What filled up the balloon? Explain your observation.

8. What was the pH of the mixture after removing the balloon?

Key to answers on page 27.

In the activity, you saw bubbles coming out from the mixture. This means that the yeast fed on the sugar. One evidence is the formation of bubbles. The gas in the bubble is carbon dioxide. The mixture became acidic as shown by the color change of the pH paper.

We shall now discuss how yeast converted sugar to carbon dioxide and acidic substance. The first step of cellular respiration is ***glycolysis***.

Glycolysis

Glycolysis occurs in the cytoplasm of the cell. During this stage, the six-carbon glucose ($C_6H_{12}O_6$) is broken down into two (2) molecules of three-carbon sugars – glyceraldehydes phosphate (GAP) and dihydroxyacetone phosphate (DHAP). GAP is also known as phosphoglyceraldehyde (PGAL). The breakdown requires two molecules of ATP.

Cells most readily use PGAL. Thus, DHAP is converted into PGAL by enzyme *isomerase.* There are now two (2) molecules of PGAL. The two molecules of PGAL will be converted to two molecules of pyruvic acid.

At the end of glycolysis, four (4) molecules of ATP are produced and two (2) molecules of nicotinamide adenine dinucleotide phosphate hydrogen (NADH), also a high-energy molecule. Since 2 ATP were used up at the beginning, the net gain of ATP is two (2). Glycolysis is summarized in Figure 4.

Glycolysis can occur with or without oxygen in the cytoplasm. In the presence of oxygen, it is the first stage of cellular respiration. Without oxygen, glycolysis allows cells to make small amount of ATP.

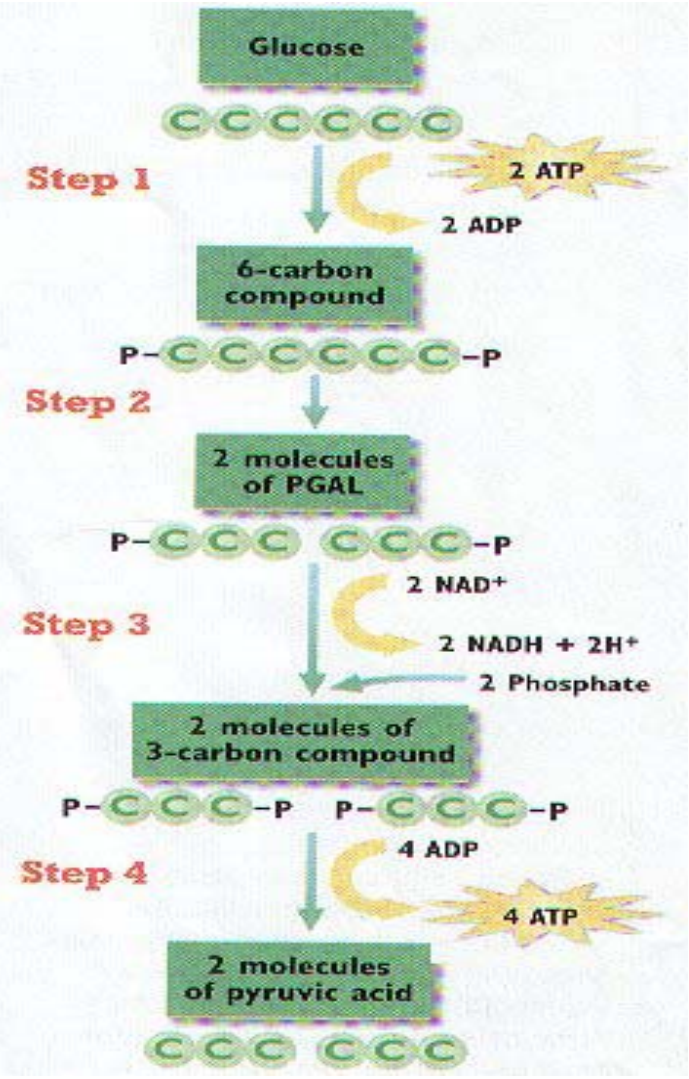


Figure 4. Glycolysis

This process is called **fermentation**. Here, pyruvate would go through one of the following routes:

1. **Alcohol fermentation**, which is performed by certain microorganisms such as yeast. Pyruvic acid is converted into alcohol such as ethanol, a two-carbon compound. Winemaking industries take advantage of this process to produce wine and liquor.

2. **Acid fermentation**, which is carried out also by some microorganisms such as the bacteria *Lactobacillus acidophilus* in yogurt. These microorganisms change pyruvic acid into acids such as lactic acid. This is the process we observed in Activity 2.1.

3. In humans, pyruvic acid is converted into lactic acids in muscles when oxygen is depleted. The lactic acid in muscles causes the stiffness couch-potatoes or those who just had very strenuous activities such as hiking or mountain climbing feel. This stiffness goes away after a few days since the cessation of strenuous activity allows aerobic conditions to return to the muscle and lactic acid can be converted into ATP via the normal aerobic respiration pathway.

Oxidation of Pyruvic Acid: transition process

When oxygen is present, we call this condition as aerobic. Many organisms can produce more energy in the form of ATP from pyruvic acid. Among eukaryotic cells like the human cells, the two molecules of pyruvic acid produced during glycolysis move to the mitochondrion. Among prokaryotes, it is done in the cell membrane.

Upon arrival of the pyruvic acid in the mitochondrion, it will undergo oxidation. This is done through removal of a carbon atom from pyruvic acid. The carbon atom combined with oxygen atoms and is released in the form of carbon dioxide. Also, two electrons and two hydrogen ions are freed into the matrix of the mitochondrion. The two electrons and one hydrogen ion are picked by electron carrier NAD^+ (oxidized nicotinamide adenine nucleotide) to form the higher energy form NADH. Coenzyme A, a cofactor, attaches to the remaining two-carbon unit called acetyl unit forming acetyl Coenzyme A (Acetyl Co-A). The process is summarized in Figure 5.

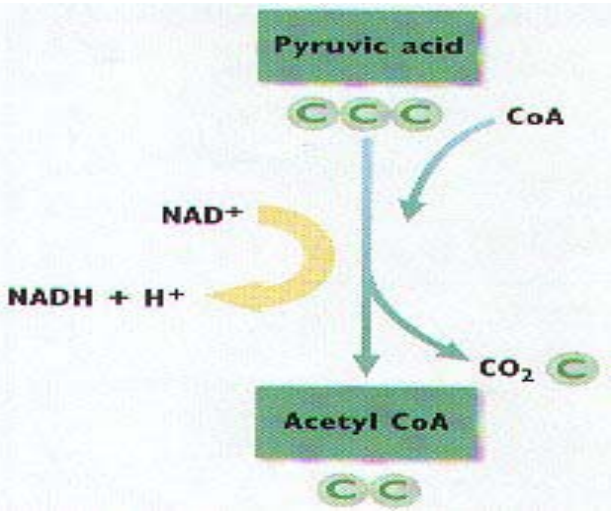


Figure 5. Oxidation of Pyruvic acid

Since there are two molecules of pyruvic acid from glucose that undergo oxidation, two molecules of acetyl Co-A, two molecules of carbon dioxide and two molecules of NADH are generated during this transition step.

Kreb's Cycle

Acetyl co- A, the product of pyruvic acid oxidation, would go through a cyclic process called Kreb's Cycle. Kreb's Cycle happens in the matrix of mitochondrion. As shown in Figure 6, acetyl co-A interacts with a 4-carbon compound (oxaloacetic acid) to form citric acid, a six-carbon compound. In step 2 of the cycle, citric acid loses two electrons and two hydrogen atoms and is converted to 5-carbon compound (alpha ketoglutaric acid). One molecule of carbon dioxide is also released. Two electrons and one hydrogen ion are picked up by NAD^+ to become NADH.

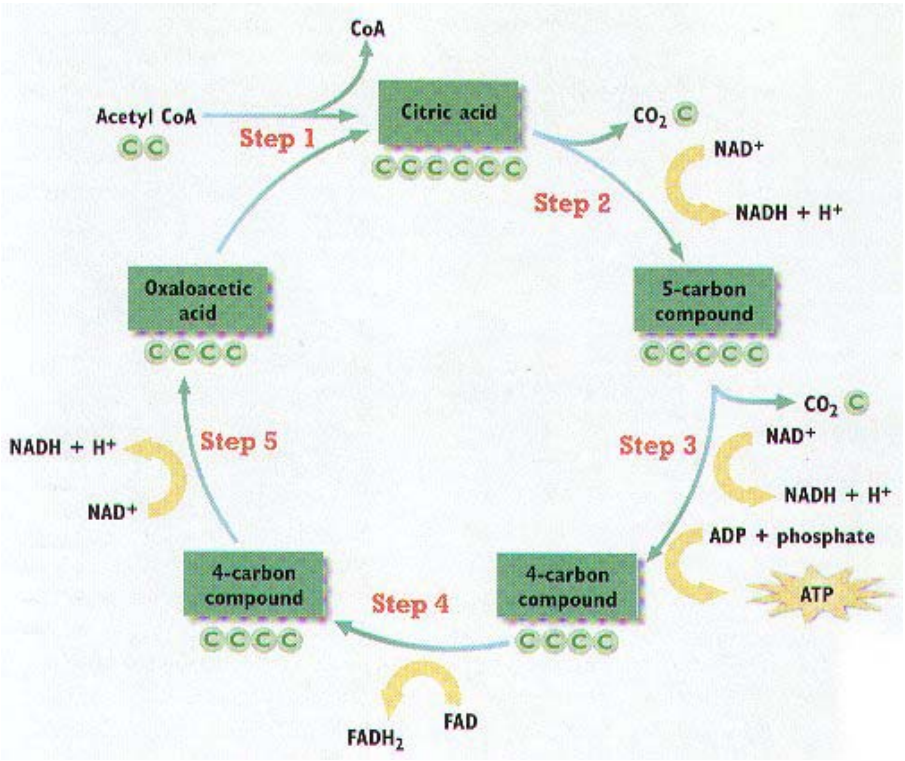


Figure 6. Kreb's Cycle

Alpha ketoglutaric acid releases carbon dioxide, loses two electrons and two hydrogen ions and becomes 4- carbon succinic acid. NAD+ picks up the two electrons and one hydrogen ion and is reduced to NADH. At this point of the Kreb's Cycle, one molecule of ATP is formed.

Changing the position of atoms converts succinic acid to fumaric acid. The process releases two electrons and 2 hydrogen ions. The electron carrier flavin adenine dinucleotide picks up the two electrons and two hydrogen ions and is converted to FADH2. Fumaric acid is converted to malic acid. The last step of Kreb's Cycle involves atomic rearrangement of malic acid to yield oxaloacetic acid. Two electrons and two hydrogen ions are released. NAD+ picks up two electrons and one hydrogen ion.

The points in the Kreb's Cycle where electrons are released and picked up by electron carriers are energy carrier-generating steps.

Since there are two molecules of acetyl co-A from one glucose molecules, there are two rounds of Kreb's Cycle. The first substance produced in the Kreb's Cycle is citric acid. So Kreb's Cycle is also called Citric Acid Cycle.

What you will do

Self-Test 3.1

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Which of the following is the cell's immediate source of energy?
   a. carbon dioxide
   b. glucose
   c. fats
   d. amino acid

2. Where does glycolysis occur in the cell?
   a. nucleus
   b. lysosome
   c. mitochondrion
   d. cytoplasm

3. What is the product of glycolysis?
   a. carbon dioxide
   b. dihydroxyacetone phosphat
   c. phosphoglyceraldehyde
   d. pruvate

4. How many ATP molecules are used up during glycolysis?
   a. 1
   b. 2
   c. 3
   d. 4

5. How many ATPs are produced during glycolysis?
   a. 1
   b. 2
   c. 3
   d. 4

6. What is the net gain of ATP during glycolysis?
   a. 1
   b. 2
   c. 3
   d. 4

7. Fermentation process is the conversion of
   a. glucose to pyruvate
   b. pyruvic acid to lactic acid
   c. pyruvic acid to ethanol
   d. b and c

8. Where does the oxidation of pyruvic acid occur in human cells?
   a. cytoplasm
   b. mitochondrion
   c. nucleus
   d. plasma membrane

9. What is the product of pyruvic acid oxidation?
   a. electron
   b. coenzyme A
   c. acetyl co-A

10. How many molecule/s of carbon dioxide is/are released from one pyruvic acid molecule being oxidized?
    a. 1
    b. 2
    c. 3
    d. 4

11. When acetyl co-A enters the Kreb's Cycle, what substance must it interact with?
    a. succinic acid
    b. oxaloactic acid
    c. malic acid
    d. citric acid

12. In one round of Kreb's Cycle, how many carbon dioxide molecules are released?
    a. 1
    b. 2
    c. 3
    d. 4

13. In one round of Kreb's Cycle, how many NADH molecules are produced?
    a. 0
    b. 1
    c. 2
    d. 3

14. In one round of Kreb's Cycle, how many FADH2 molecules are produced?
    a. 0
    b. 1
    c. 2
    d. 3

15. A glucose molecule is completely broken down to carbon dioxide and water molecules. How many rounds of Kreb's Cycle are possible?
    a. 0
    b. 1
    c. 2
    d. 3

Key to answers on page 27.

Lesson 4. Electron Transport System

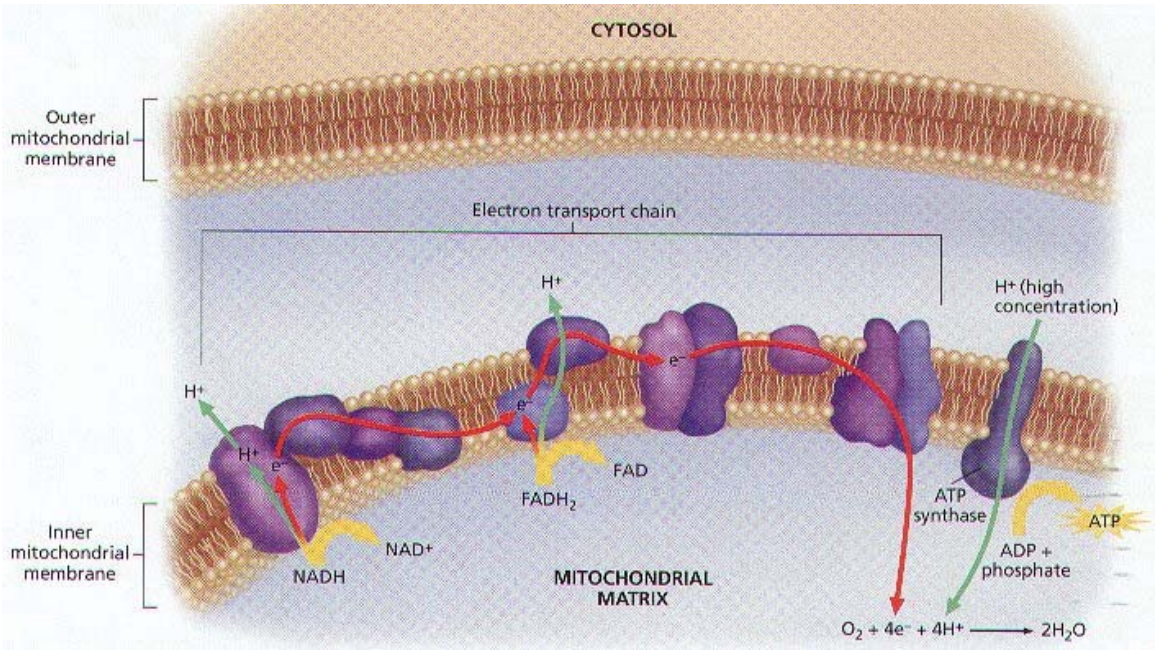


Figure 7. Electron Transport System

This system is located in the cristae of the inner membrane of the mitochondrion. It is composed of a series of electron carriers and proteins associated with ATP synthesis. The components of the system are arranged as shown in Figure 7. The high-energy molecules, NADH and FADH2, move to the electron transport system.

Here, electrons and the hydrogen ions they carry are released. The released hydrogen ions help build up the hydrogen ion gradient in the intermembrane compartment.

The freed electrons are passed from one carrier to another down the chain. As electrons are passed from one carrier to another, energy is released. The electron transport chain uses this released energy as it pumps hydrogen ions from intermembrane compartment into the matrix. As the hydrogen ions move from high concentration to low concentration through the ***ATP synthase complex*** in the cristae, the enzyme ATP synthase adds phosphate to adenosine dinucleotide phosphate (ADP+) to yield ATP. The moving hydrogen ions provide the energy for this reaction.

$$ADP^{+} + Pi \longrightarrow ATP$$

How many ATP molecules are produced from a pair of electrons carried by NADH? This yields three (3) ATP molecules. This is not true with the electrons carried by $FADH_2$. The electron pair produce only two (2) molecules because $FADH_2$ bypasses the first complex of the electron transport chain as shown in Figure 7.

Since the production of ATP is tied with the electrochemical gradient of hydrogen ions, the mechanism is called ***Chemiosmosis***.

Towards the end of the chain, the electrons have lost most of its energy. These low energy electrons are accepted by oxygen gas. Together with hydrogen ions, water is formed.

$$\mathbf{O_2 + 4\,e^{-} + 4H+ \longrightarrow 2H_2O}$$

The synthesized ATP diffuses out of the mitochondrion through channel proteins into the cytoplasm.

Metabolic poisons can destroy the electron transport system. What are some examples of metabolic poisons? It includes the snake venom and toxins secreted by bacteria that cause pertussis and cholera.

What you will do

Self-Test 4.1

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Where do we find the electron transport chain?
   a. outer membrane of the mitochondrion
   b. intermembrane compartment
   c. cristae
   d. cytoplasm

2. What makes up the electron transport system?
   a. electron carriers only
   b. proteins and electron carriers
   c. proteins only
   d. can not be determined

3. Which of the following is responsible for the build up of the hydrogen gradient?
   a. hydrogen ions carried by NADH
   b. hydrogen ions carried by $FADH_2$
   c. hydrogen ions left in the matrix
   d. all of them

4. During the synthesis of ATP, what is the direction of hydrogen flow?
   a. from matrix to intermembrane space
   b. from intermembrane space to matrix
   c. from matrix of mitochondrion to cytoplasm
   d. from cytoplasm to matrix of mitochondrion

5. How many ATP molecules are produced from a pair of electrons delivered by NADH to the electron transport system?
   a. 0
   b. 1
   c. 2
   d. 3

6. How many ATP molecules are produced from a pair of electrons delivered by $FADH_2$ to the electron transport system?
   a. 0
   b. 1
   c. 2
   d. 3

Key to answers on page 27.

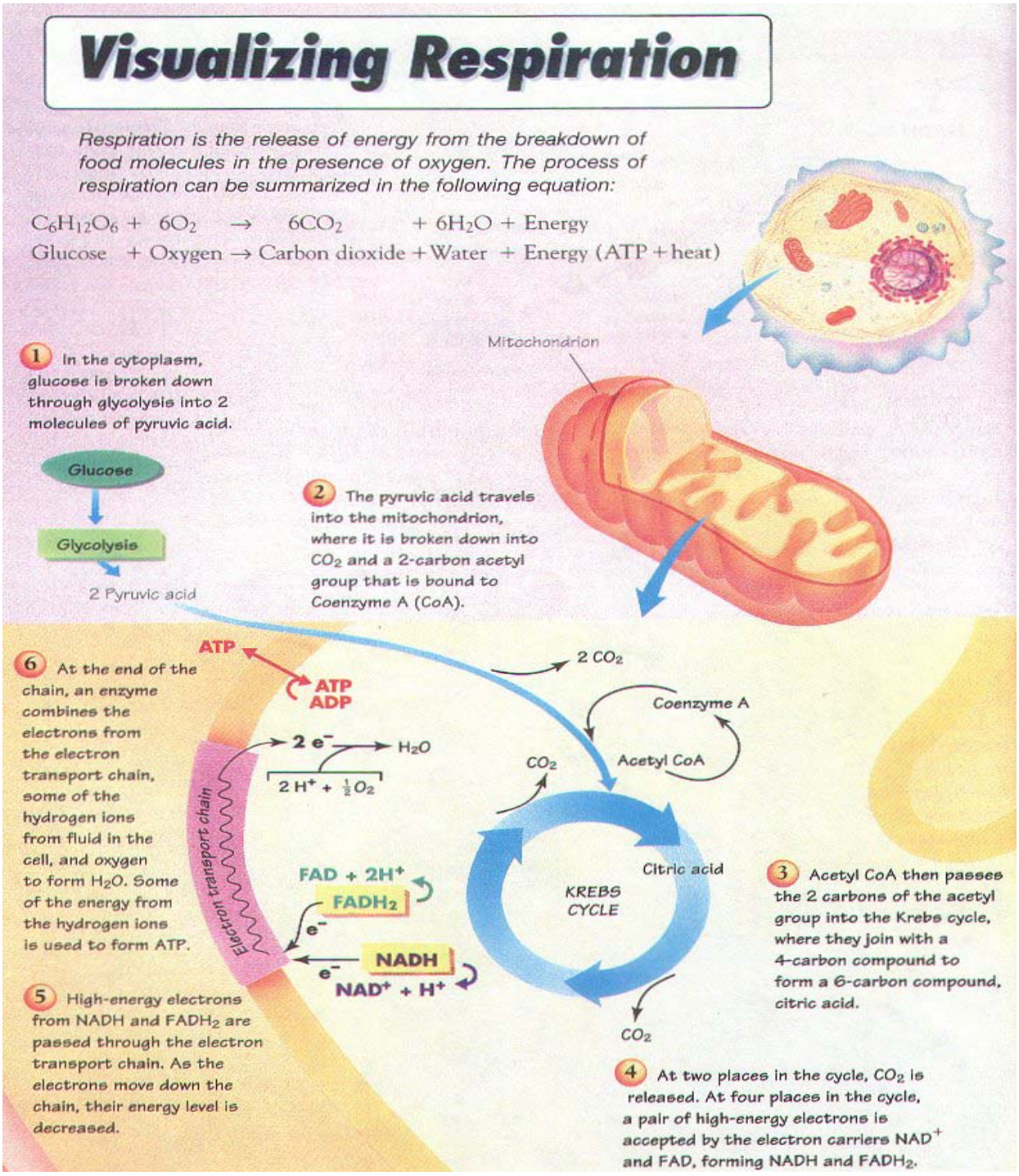


Figure 8. Summary of Cellular Respiration
http://www.sirinet.net/~jgjohnso/visrespiration.html

From Lessons 3 and 4, you learned that the first step, glycolysis is anaerobic phase while oxidation of pyruvic acid, Kreb's Cycle and Electron Transport System make up the aerobic phase. Figure 8 visualizes the entire process.

Lesson 5. Energy From A Glucose Molecule

We have discussed the process by which energy, ATP, can be harvested from food. Let us now count the number of ATP obtained from a molecule of glucose when it is broken down completely to carbon dioxide and water. During glycolysis, 2 ATP were used up but this produced directly 4 ATP (adenosine triphosphate). The net is 2 ATP. From the two rounds of Kreb's cycle, 2 ATP are also produced directly. There are 10 molecules of NADH produced from one glucose molecule. As each NADH enters the electron transport system, it yields 3 ATP. From 10 NADH, 30 ATP molecules are produced. Two $FADH_2$ molecules are produced from the two rounds of Kreb's Cycle. The two $FADH_2$ molecules generate 4 ATP. Figure 9 outlines the number of ATP molecules synthesized when high-energy molecules deliver electrons and hydrogen ions to the electron transport chain in the mitochondrion.

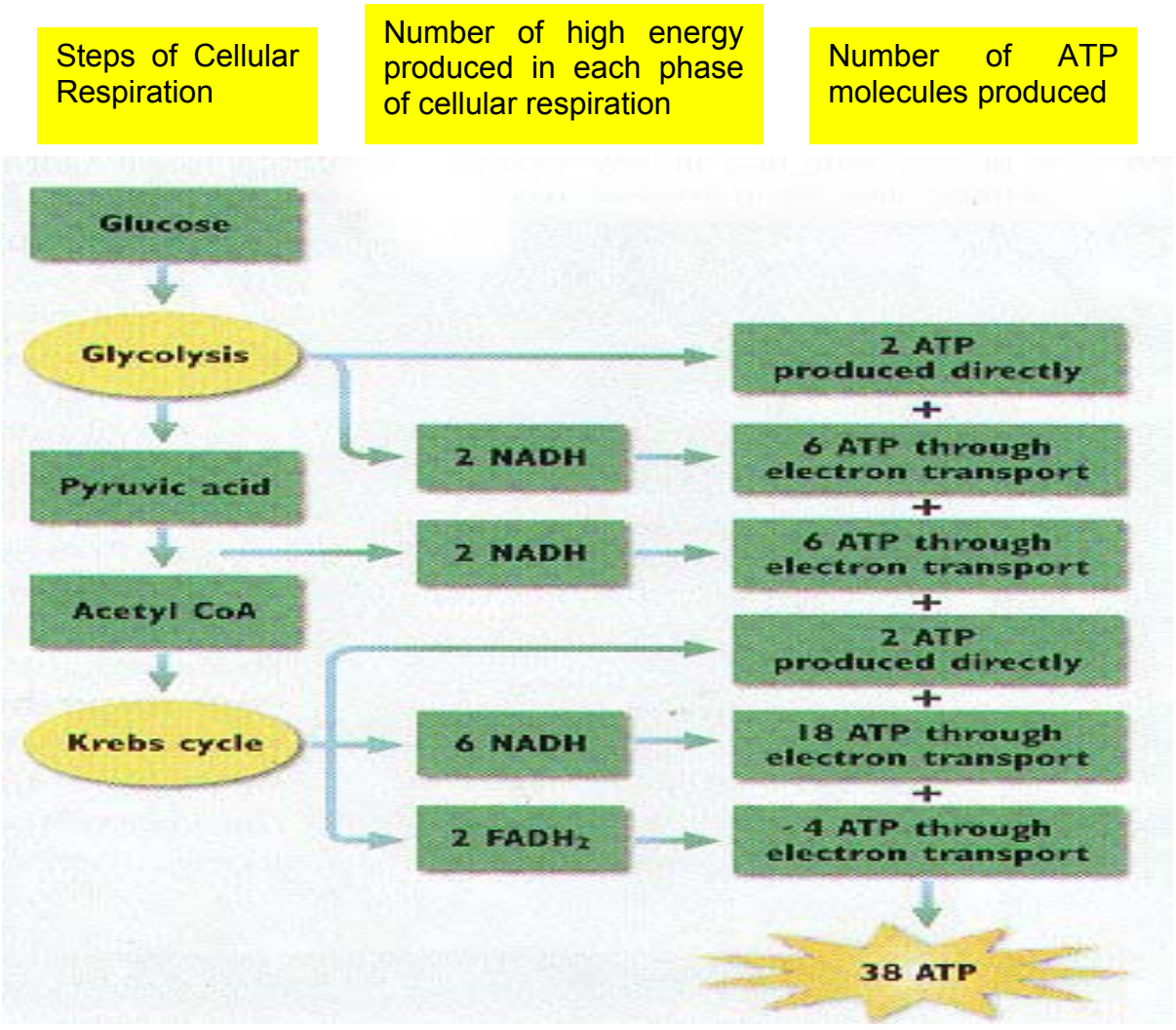


Figure 9. ATP Molecules Synthesis

Most eukaryotic cells produce only about 36 ATP Molecules per Glucose Molecule.

Why? About two molecules of ATP are used to transport 2 NADHs that are formed in the cytoplasm. If a cell produces 38 ATP Molecules, the efficiency would be 66%.

This amount of energy is derived from glucose only which can be obtained from starch, glycogen and other carbohydrates.

What you will do

Activity 5.1

1. There are 4 molecules of glucose that enter the cellular respiration process. The substances were completely changed to carbon dioxide and water.

2. Compute the following:
    a. Number of carbon dioxide released
    b. Total number NADH molecules that carried electrons to the electron transport system
    c. Total number of $FADH_2$ that brought electrons to the electron transport system.
    d. Number of ATP produced
        1. directly
        2. through the electron transport system

Key to answers on page 27.

What you will do

Self-Test 5.1

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. How many ATP molecules are used up during cellular respiration?
    a. 1 b. 2 c. 3 d. 4

2. How many ATP molecules can be produced from one NADH molecule
    a. 1 b. 2 c. 3 d. 4

3. How many ATP molecules can be produced from one $FADH_2$ molecule?
    a. 1 b. 2 c. 3 d. 4

4. How many NADH molecules are produced from one glucose molecule?
   a. 4 b. 6 c. 8 d. 10

5. How many $FADH_2$ molecules are generated from one glucose molecule that enters cellular respiration?
   a. 0 b. 1 c. 2 d. 3

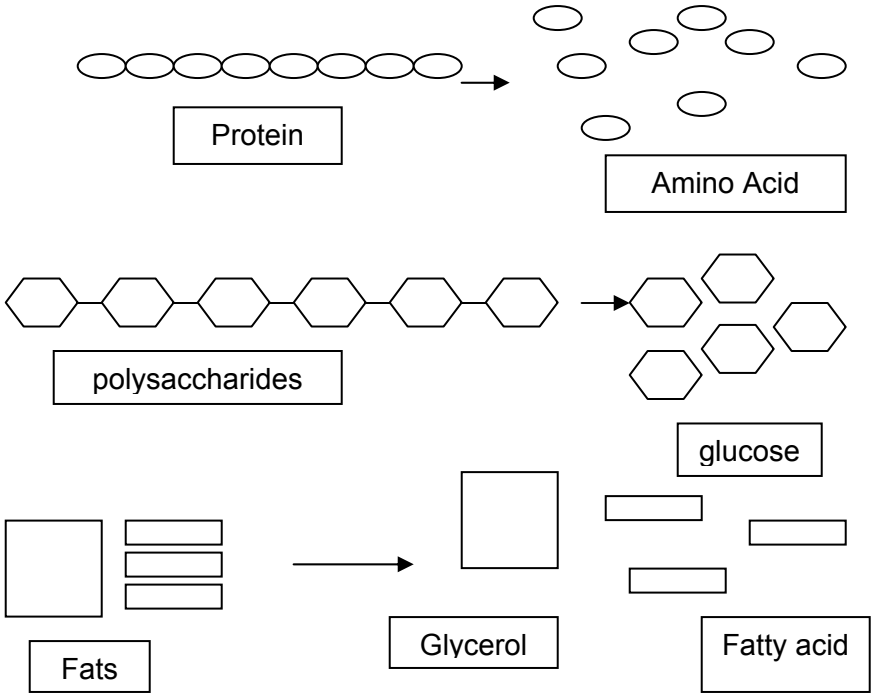
6. If glucose is completely degraded to carbon dioxide and water, how many molecules of ATP can be produced?
   a. 4 b. 22 c. 30 d. 38

Key to answers on page 28.

It is not only sugars that we eat everyday. Our foods also include complex carbohydrates, lipids and proteins. How do these foods enter into cellular respiration such that we can get energy from them?

Proteins are digested into amino acids. Amino acids may be converted into pyruvic acid, acetyl CoA, oxaloacetic acid, alpha ketoglutaric acid, or succinic acid such that they could enter cellular respiration and release energy as ATP

Complex carbohydrates, polysaccharides, like starch are broken down into glucose. Glucose is transported to cells.



Lipid is digested and changed to fats. Fats are broken into glycerol and fatty acid. Glycerol is changed into dihydrogen acetone phosphate, then to PGAL, which is a part of glycolysis. Fatty acid is broken into 2-carbon compound with coenzyme A called acetyl CoA that enters the Kreb's Cycle.

What you will do

Activity 5.2

1. A fatty acid is derived from fat. Suppose the fatty acid that contains 30 carbon atoms is cut into 2-carbon compound acetyl CoA.

    a. How many acetyl CoA molecules are produced from the fatty acid?
    b. How many rounds of Kreb's Cycle are if all the acetyl CoA molecules are converted to carbon dioxide and water?
    c. How many NADH molecules were generated?
    d. How many $FADH_2$ were produced?

Key to answers on page 28.

What you will do

Self-Test 5.2

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Before lipid can be used by cells as source of energy, what must be done to lipid?
    a. It must be converted to fats.
    b. Fats must be broken to glycerol and fatty acid
    c. both a and b

2. Which of the following is the point of entry of glycerol into cellular respiration?
    a. PGAL
    b. fatty acid
    c. dihydroxyacetone phosphate

3. What is the point of entry of proteins into cellular respiration?
    a. PGAL
    b. pyruvic acid
    c. oxaloacetic acid
    d. b and c

Key to answers on page 28.

Let's Summarize

1. Energy is derived from food.
2. Cellular respiration is a catabolic process which allows the organism to harvest the stored energy in food.
3. Glycolysis may occur with or without oxygen. It breaks down glucose into pyruvic acid.
4. Pyruvic acid is oxidized into acetyl CoA.
5. Acetyl CoA enters Kreb's Cycle.
6. NADH and $FADH_2$ are high-energy molecules. They bring the electrons and hydrogen to the electron transport system where more ATP molecules are synthesized.
7. A molecule of glucose completely converted to carbon dioxide and water through cellular respiration generates 38 molecules of ATP.
8. Lipids and proteins can also be a source of energy.
9. Lipid is changed to glycerol and fatty acid.
10. Glycerol is changed to DHAP, then to PGAL.
11. Fatty acid is oxidized into Acetyl CoA.
12. Proteins are converted to amino acid. Amino acid may be converted into pyruvic acid, acetyl CoA or different intermediates of the Kreb's cycle such that working cells can get energy from proteins.

Posttest

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Which of the following foods should be eaten less?
   a. chicharon
   b. rice
   c. chicken meat
   d. fresh fruits

2. Which of the following substances is the immediate energy source of a working cell?
   a. glucose
   b. lactose
   c. butter
   d. beef

3. Where does glycolysis occur in the cell?
   a. plasma membrane
   b. mitochondrion
   c. cytoplasm
   d. nucleus

4. Where does Kreb's Cycle occur in the cell?
    a. matrix
    b. cytoplasm
    c. outer membrane of the mitochondrion
    d. inner membrane of the mitochondrion

5. Which of the following substances is produced by muscle cells when there is no oxygen available?
    a. sugar
    b. alcohol
    c. acetic acid
    d. lactic acid

6. How many ATP molecules are used during the initial steps of glycolysis?
    a. 0
    b. 1
    c. 2
    d. 3.0

7. How many ATP molecules were directly produced during glycolysis?
    a. 1
    b. 2
    c. 3
    d. 4.0

8. Fermentation is a process that involves
    a. glycolysis only
    b. glycolysis and Kreb's Cycle
    c. glycolysis and oxidation of pyruvic acid
    d. conversion of pyruvic acid to either acid or alcohol

9. Which of the following is produced if glucose is burned in the cells?
    a. Adenosine Triphosphate
    b. Carbon dioxide
    c. Oxygen
    d. a and b

10. Which of the following is **NOT** a correct association?
    a. matrix-Kreb's Cycle
    b. cytoplasm-glycolysis
    c. cristae-electron transport system
    d. plasma membrane- oxidation of pyruvic acid

11. Which of the following processes produces the greatest yield of adenosine triphosphate?
    a. glycolysis
    b. Kreb's Cycle
    c. fermentation
    d. electron transport chain

12. Which of the following substances is the final acceptor of electrons in aerobic respiration?
    a. FAD
    b. NAD+
    c. water
    d. oxygen

13. The carbon dioxide released during cellular respiration is produced during
    a. Glycolysis
    b. Kreb's Cycle
    c. Pyruvic acid oxidation
    d. b and c

14. How many ATP molecules are produced through the electron transport system?
    a. 4
    b. 12
    c. 24
    d. 34

15. Which of the following processes occurs in the inner membrane of the mitochondrion?
    a. Kreb's cycle
    b. Fermentation
    c. Glycolysis
    d. Oxidation of pyruvic acid

16. Which of the following is **NOT** true about fats?
    a. fatty acids are converted to acetyl CoA
    b. fats are converted to proteins
    c. glycerol is converted to PGAL
    d. none of the above

17. Which of the following is **NOT** true about fermentation?
    a. it is an anaerobic process
    b. the end product is toxic to cells
    c. muscle cells produces ethanol in the absence of oxygen
    d. It results to two molecules of ATP per glucose molecules?

18. How many molecules of carbon dioxide are produced from one glucose molecule completely degraded to water and carbon dioxide?
    a. 2
    b. 3
    c. 4
    d. 6

19. Which of the following ions are used to drive the synthesis of ATP during cellular respiration?
    a. sodium ions
    b. phosphate ions
    c. hydrogen ions
    d. potassium ions

20. Which of the following is the entry point of proteins into cellular respiration?
    a. acetyl CoA
    b. oxaloacetic acid
    c. pyruvic acid
    d. all of them

Key to answers on page 28.

Key to Answers

Pretest

1. d	5. b	9. d	13. c
2. b	6. b	10. d	14. d
3. c	7. b	11. d	15. a
4. a	8. a	12. b	16. d

Lesson 1

Activity 1.1

	Number of calories
Egg	90 calories
Milk	70 calories
White bread	96 x 2= 192 calories
Cheese	200 calories
Banana	107 calories
Total	579 calories

Self-Test 1.1

1. TRUE	6. FALSE
2. TRUE	7. TRUE
3. TRUE	8. TRUE
4. TRUE	9. TRUE
5. FALSE	10.TRUE

Lesson 2

Activity 2.1

a. outer membrane
b. inner membrane
c. intermembrane compartment
d. matrix
e. cristae

Self- Test 2.1

1. c
2. c
3. b

Lesson 3

Activity 3.1

1. the cell doing cellular respiration
2. the source of carbohydrate, glucose to be broken down by the cell
3. Metabolic process occurs at room temperature to around 37^{o}C.
4. near neutral
5. bubbles
6. It was inflated.
7. carbon dioxide
8. bellow neutral (acidic)

Self-Test 3.1

1, b	6. b	11. b
2. d	7. d	12. b
3. d	8. b	13. d
4. b	9. c	14. b
5. d	10. c	15. c

Lesson 4

Self-Test 4.1

1. c
2. b
3. d
4. b
5. d
6. c

Lesson 5

Activity 5.1

2.a Number of CO_2 = 6 CO_2/glucose x 4 glucose = 24 CO_2 molecules
2.b NADH = 10 NADH /glucose x 4 glucose = 40 NADH molecules
2.c $FADH_2$ = 2 $FADH_2$/glucose x 4 glucose = 8 $FADH_2$ molecules
2.d.1 $ATP_{directly}$ = 4 ATP/ glucose x 4 glucose = 16 ATP molecules
2.d.2 ATP_{ETS} = 38 ATP/glucose x glucose = 152 ATP molecules

Self-Test 5.1

1. b
2. c
3. b
4. d
5. c
6. d

Activity 5.2

1.a. 15
1.b. 15
1.c. NADH = 3 NADH/Kreb's Cycle x 15 Kreb's Cycles
= 45 NADH
1.d FADH2 = 1 FADH/ Kreb's Cycle x 15 Kreb's Cycles
= 15 FADH2

Self-Test 5.2

1. c
2. c
3. d

Posttest

1. b	6. c	11. d	16. b
2. a	7. d	12. d	17. c
3. c	8. d	13. d	18. d
4. a	9. d	14. d	19. c
5. c	10.d	15. d	20. d

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