LESSON 1

ATP and Cellular Respiration

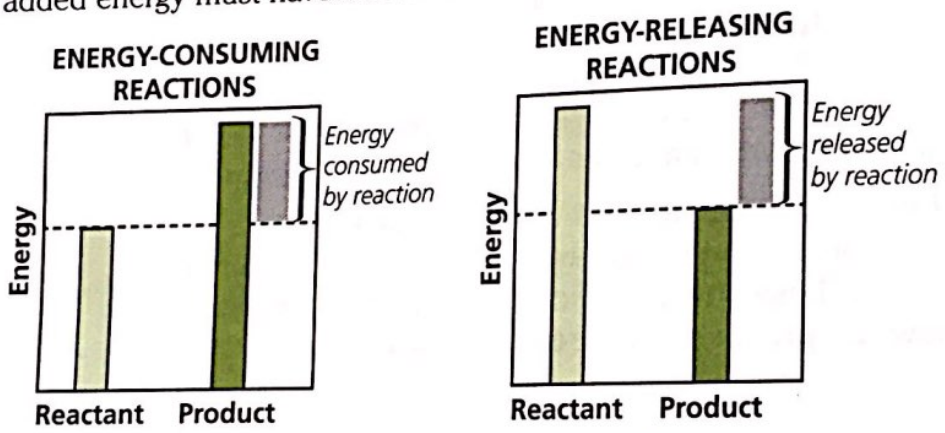
BIO.A.3.1.1, BIO.A.3.2.1, BIO.A.3.2.2

Millions of chemical reactions are carried out continuously in the body's cells. Some reactions release energy, but many reactions consume energy. How does a cell provide the energy to power its metabolic reactions?

Some chemical reactions release energy. Others absorb energy, storing it in the products in the form of chemical energy.

The Role of ATP

A reaction that consumes energy takes lower-energy reactants and changes them into higher-energy products. The atoms are the same, but the amount of energy in the products is higher. This added energy must have a source.



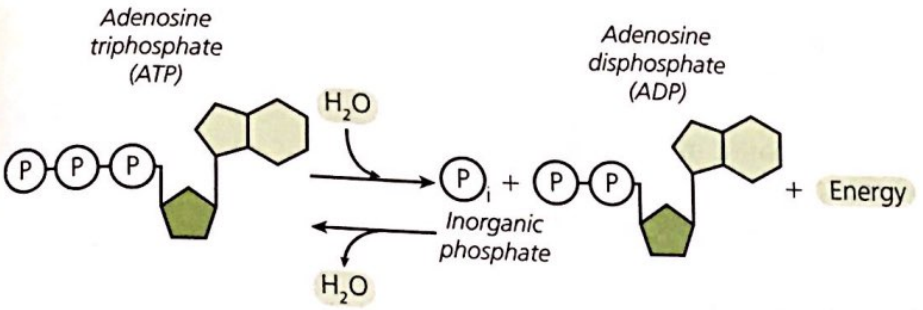
Some reactions require energy (left). Others release energy (right).

The energy changes shown in the graphs are distinct from the activation energy needed to drive a reaction, which is not shown. Enzymes help reactions to occur faster, but do not provide energy for them.

Some reactions do the opposite—they form lower-energy products, releasing some of the chemical energy stored in the reactants. Fortunately, these two types of reactions can be paired. The energy released by one reaction is used in the other.

An important energy-releasing reaction involves **adenosine triphosphate,** or **ATP.** A molecule of ATP includes three phosphate groups. When the end phosphate group is removed, energy is released. This energy helps to power many of the reactions that are essential to life.

ATP, adenosine triphosphate, is a small, soluble molecule that provides energy to reactions throughout the cell. For this reason, ATP is known as the "energy currency" of cells.



ATP is hydrolyzed to form ADP and a phosphate group. ADP and phosphate can be combined to form ATP.

ATP is broken down by hydrolysis to form ADP (adenosine diphosphate) plus a phosphate group. These products can be joined together again, by dehydration synthesis, into ATP. ATP is continuously broken down and re-formed in living cells.

The bond that attaches the last phosphate group to the ATP molecule releases energy when broken. Some of this energy is released as heat.

ATP is broken down into ADP and a phosphate group. These products can then be reassembled to form more ATP.

ATP is changed to ADP by hydrolysis; ADP is changed back to ATP by dehydration synthesis reactions.

Which comparison between ATP and ADP is correct?

A ATP stores less chemical energy than ADP and phosphate.

B ATP stores more chemical energy than ADP and phosphate.

C Less energy is used to form ATP than is released from ATP hydrolysis.

D More energy is used to form ATP than is released from ATP hydrolysis.

Choices C and D are incorrect because the energy used to form ATP must be equal to the energy released upon ATP hydrolysis. (Note that some of the released energy is lost as heat.) ATP is a carrier of stored chemical energy. It releases this energy upon hydrolysis to ADP and phosphate. ATP stores more chemical energy than the products it forms. Therefore, choice B is correct and choice A is incorrect.

The First Stage of Cellular Respiration

ATP is continuously produced and consumed in the cell. Without a constant supply of ATP, the cell would not be able to perform all of the functions it needs to survive. The energy required to reassemble ATP is supplied by **cellular respiration.** This process breaks down organic molecules, such as glucose, that originate in food. The net equation for aerobic respiration is shown below. Notice that it requires oxygen and produces carbon dioxide.

$$\underset{\text{(glucose)}}{C_6H_{12}O_6} + \underset{\text{(oxygen)}}{6O_2} \longrightarrow \underset{\text{(carbon dioxide)}}{6CO_2} + \underset{\text{(water)}}{6H_2O}$$

The word *respiration* also refers to breathing, which takes oxygen into the body and expels carbon dioxide.

Food provides organisms with a source of chemical energy.

Respiration takes place in three distinct stages. Each stage releases a bit more of the chemical energy stored in a glucose molecule. The first stage takes place in the cytoplasm of the cell. Glucose molecules are broken down into smaller molecules during *glycolysis*. Oxygen is not involved in this process, and only two molecules of ATP are assembled from the energy released from a glucose molecule.

The equation on page 57 shows *aerobic respiration*, or respiration that involves oxygen. Other forms of cellular respiration occur without use of oxygen. They are called *anaerobic respiration*. One type of anaerobic respiration is fermentation. During fermentation, organisms carry out glycolysis, but not the later stages that occur in aerobic respiration. Fermentation converts glucose into ethanol and carbon dioxide, or into lactic acid. Anaerobic respiration releases less of the energy (ATP) stored in glucose than aerobic respiration does.

Which types of respiration are useful in increasing the amount of gas in a food product?

A fermentation producing lactic acid only

B fermentation producing carbon dioxide and ethanol only

C aerobic respiration and fermentation producing lactic acid

D aerobic respiration and fermentation producing carbon dioxide and ethanol

Choices A and C are incorrect because lactic acid fermentation does not produce a gas. Choice D is incorrect because aerobic respiration uses as many oxygen gas molecules as the carbon dioxide molecules it produces. Only fermentation producing ethanol and carbon dioxide, which does not consume oxygen, can increase the amount of gas. Choice B is correct.

Respiration in the Mitochondria

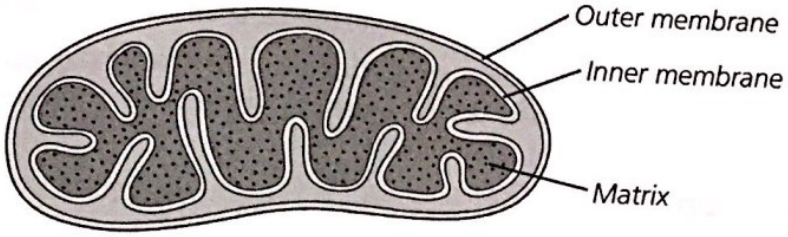
The later stages of respiration take place in the **mitochondria** of eukaryotic cells. This organelle has two membranes. The outer membrane surrounds the organelle and separates it from the rest of the cell. The inner membrane is folded over many times, creating a larger surface area inside the mitochondrion. Because reactions occur on the inner membrane, a high surface area allows more reactions to take place at once.

Aerobic **cellular respiration** breaks down glucose and oxygen to form carbon dioxide and water. The reaction is a net reaction, or the sum of many separate reactions occurring in the cell. The production of water and carbon dioxide, and the use of oxygen, all take place at different stages.

Glycosis means "the splitting of sugar." It is the first stage of respiration. It takes place in the cell's cytoplasm.

Aerobic means "requiring air or oxygen." The prefix *an-* means "not." *Anaerobic respiration* takes places without oxygen. A type of anaerobic respiration is *fermentation*. Fermentation by yeast and bacteria is used in food making.

Mitochondria are organelles in animal and plant cells that produce energy (ATP) for the cell.



The second and third stages of aerobic respiration take place in the matrix of the mitochondria.

The mitochondrial matrix is where the second stage of aerobic respiration, the *citric acid cycle*, takes place. Enzymes in the matrix help to break down the products of glucose in a series of chemical reactions. The carbon compounds from glucose are converted to carbon dioxide. This releases even more energy from these compounds. However, most of the ATP is still to be produced.

The first two stages have been building up hydrogen (H^+) ions in the matrix. In the third stage of respiration, these ions flow across the inner membrane. As they do so, they power an enzyme called ATP synthase, which is attached to the inner membrane. This enzyme synthesizes ATP from ADP and phosphate. As ions exit the matrix, ATP is produced.

The table shows the number of ATP molecules produced at each stage of aerobic cellular respiration.

STAGES OF AEROBIC CELLULAR RESPIRATION

Stage	Description	Number of ATP per Glucose
I	Glucose is broken down.	2
II	Carbon compounds are converted to CO_2.	2
III	ATP synthase produces ATP.	32–34
Total		36–38

Explain how the structure of the inner mitochondrial membrane aids in the function of the mitochondrion.

In cellular respiration, most of the ATP is produced when ions flow across the inner mitochondrial membrane, powering ATP synthase. This enzyme synthesizes ATP from ADP and phosphate. Having a larger surface area for these processes to occur increases the rate of ATP production. The highly folded structure of the membrane increases its surface area.

All eukaryotes, including plants, fungi, animals, and protists, contain mitochondria. These organelles may have originated as free-living prokaryotes that found a home in a eukaryotic cell.

The *citric acid cycle* is also called the *Krebs cycle*. It breaks down the carbon compounds from glucose to form carbon dioxide.

The matrix and inner membrane of the mitochondria are important sites of ATP production.

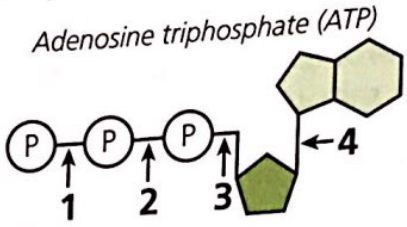
Think of the glucose molecule as a wet sponge. Each stage of respiration squeezes a bit more water (energy) out of the sponge.

Most of the ATP is produced in the third stage of respiration.

IT'S YOUR TURN

Please read each question carefully. For a multiple-choice question, circle the letter of the correct response. For a constructed-response question, write your answers on the lines.

Use the diagram below to answer question 1.



1 The breaking of which bond powers reactions in the cell?

- **A** bond 1
- **B** bond 2
- **C** bond 3
- **D** bond 4

2 Which pair of molecules are broken down by the cell to release energy?

- **A** ADP and glucose
- **B** ATP and glucose
- **C** ATP and carbon dioxide
- **D** ADP and carbon dioxide

3 Which pair of compounds are raw materials for cellular respiration?

- **A** glucose and ATP
- **B** oxygen and glucose
- **C** carbon dioxide and ATP
- **D** carbon dioxide and oxygen

4 Which does **not** take place in the mitochondria of the cell?

- **A** Carbon dioxide is produced.
- **B** Hydrogen ions cross a membrane.
- **C** Glucose is broken down into organic compounds.
- **D** The ATP synthase enzyme combines ADP and phosphate.

5 In which organism does respiration **not** take place in the mitochondria?

A bacteria

B maple tree

C seaweed

D yeast

6 You are preparing for a marathon. The night before the race, you eat a large bowl of pasta and a baked potato. Both are high in carbohydrates. During the race, you begin to feel hot and thirsty. You drink an energy drink to help you cool down.

A Explain how your meal helps you to prepare to supply energy to your muscle cells during the marathon.

B Explain why you begin to feel hot during the race, in terms of energy and cellular respiration.

C During intense effort, muscle cells may switch to anaerobic respiration. Describe what you should do to avoid this during the race.