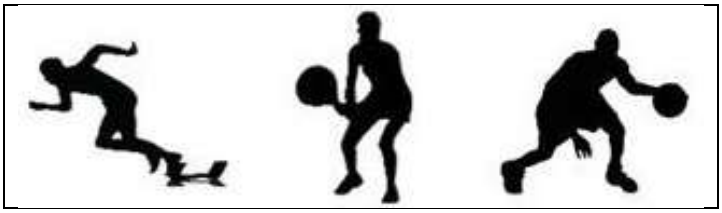
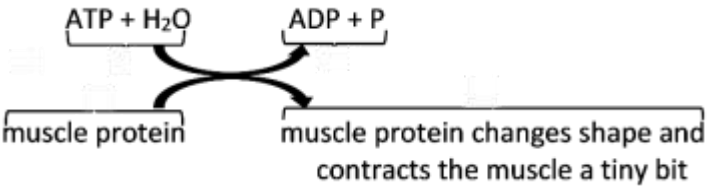
How do muscles get the energy they need for athletic activities?[1]

To play a sport, run a race, or any other type of athletic activity, your muscles must contract. Muscle cells need energy to contract.



1. What do you already know about the processes that provide the energy for muscle contraction?

The **hydrolysis of ATP** is the immediate source of energy for muscle contraction. A single muscle contraction requires many many repeats of the coupled reactions shown in this figure.

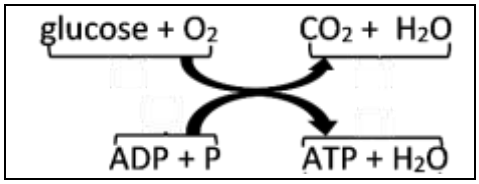


The pair of curved arrows represents coupled reactions; the top reaction provides the energy needed for the bottom reaction.

2a. Circle the chemical reaction that provides the energy for muscles to contract.

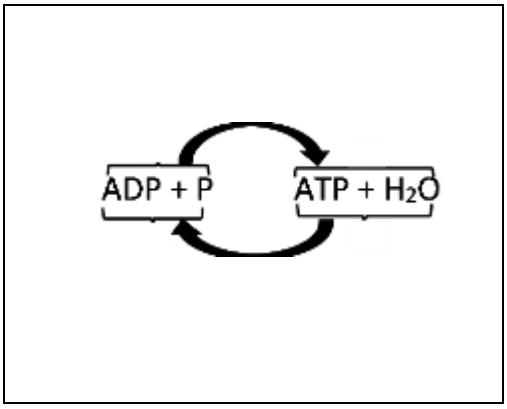
2b. Why is this reaction called the hydrolysis of ATP?

A typical muscle cell at rest has only enough ATP to power 1 or 2 seconds of contraction. For physical activity that lasts longer than 1 or 2 seconds, muscle cells need to make more ATP. One way that a muscle cell can make more ATP is aerobic cellular respiration. This figure shows that, in **aerobic cellular respiration**, glucose and oxygen are inputs for reactions that provide the energy to make ATP.



3a. Inside each muscle cell, there is a constant cycle of synthesis and breakdown of ATP. Add to the top of this diagram to show how aerobic cellular respiration makes ATP.

3b. Add to the bottom of this diagram to show how ATP is used to provide the energy for muscle contraction. (Hint: Notice that ATP is on the right in this figure.)

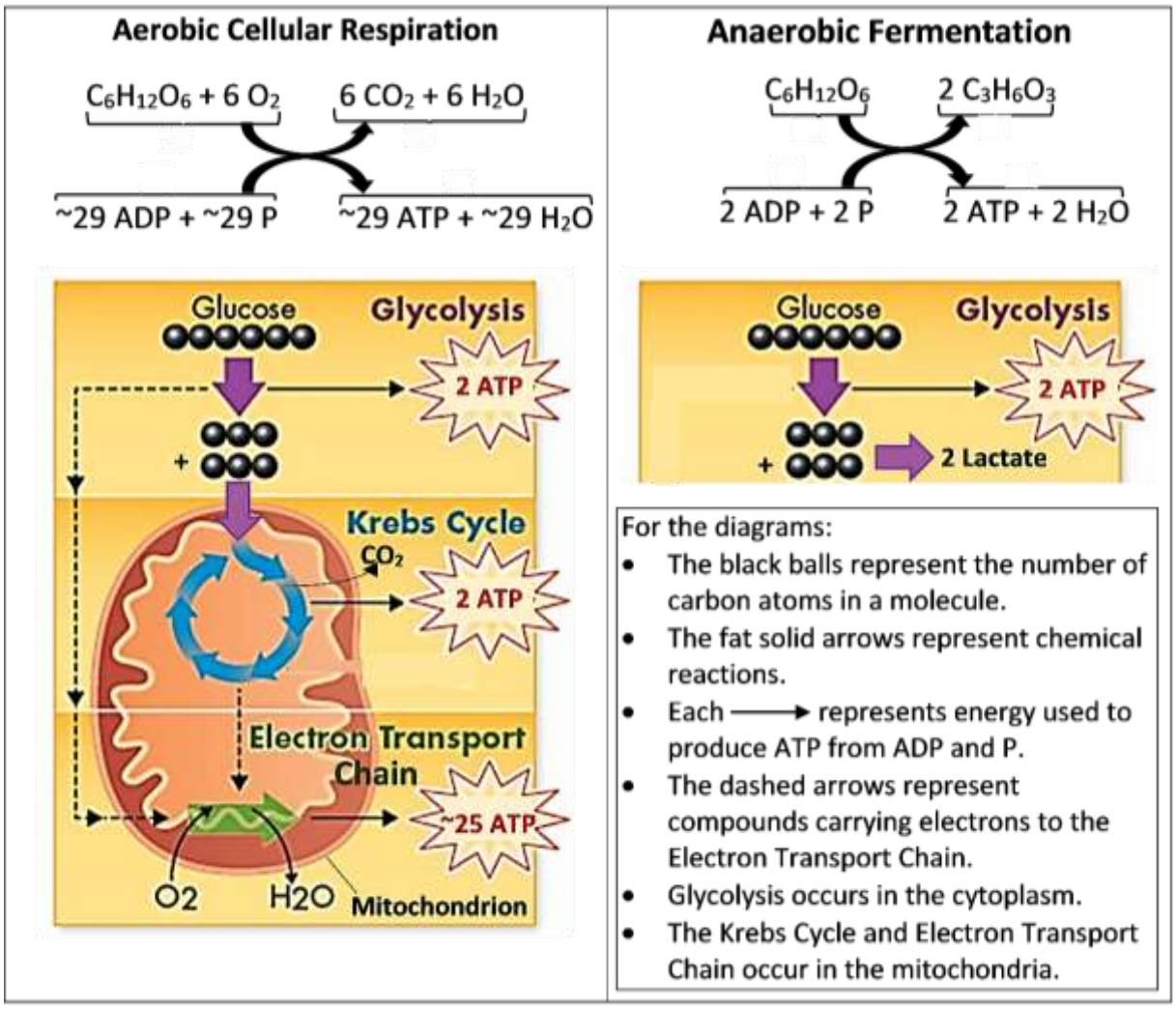


3c. When a muscle cell contracts, the cycle of breakdown and synthesis of ATP speeds up. Explain why.

---

[1] By Dr. Ingrid Waldron, Biology Dept, Univ Pennsylvania, ©2024, but freely available for classroom use. This Student Handout (including a Google Doc version) and Teacher Notes (with instructional suggestions and background information) are available at https://serendipstudio.org/exchange/bioactivities/energyathlete.

In addition to **aerobic cellular respiration**, the other main process that makes ATP in muscle cells is **anaerobic fermentation**. Examine the figure below to learn more about these processes.



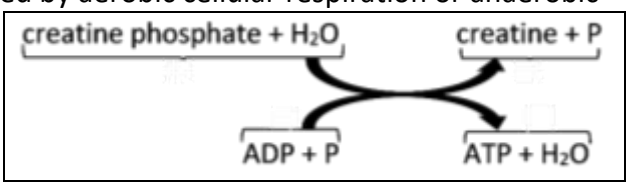
4a. Which molecule is an input for aerobic cellular respiration, but not for anaerobic fermentation?

4b. What does anaerobic mean?

5a. Per molecule of glucose, aerobic cellular respiration produces about _____ molecules of ATP, but anaerobic fermentation produces only _____ molecules of ATP.

5b. What processes and organelles are responsible for the additional ATP produced during aerobic cellular respiration?

Most of the ATP for muscle contraction is produced by aerobic cellular respiration or anaerobic fermentation. However, muscle cells can produce a brief burst of ATP by using energy from the **hydrolysis of creatine phosphate** (= phosphocreatine).



The primary process that produces ATP for muscle contraction varies, depending on the intensity and duration of physical activity. To learn more, read the following information and answer questions 6-8.

- Hydrolysis of creatine phosphate can produce ATP more rapidly than anaerobic fermentation or aerobic cellular respiration. Muscle cells typically have enough creatine phosphate to supply ATP for about 10 seconds of intense activity.
- Anaerobic fermentation is simpler and faster than aerobic cellular respiration, so anaerobic fermentation can provide ATP for fairly brief, intense athletic events. However, anaerobic fermentation uses up glucose supplies quickly and increases muscle fatigue, so anaerobic fermentation can be a major source of ATP for only about a minute.
- Aerobic cellular respiration is the slowest of these ways of producing ATP. But, aerobic cellular respiration produces much more ATP per glucose molecule than anaerobic fermentation, and aerobic cellular respiration can make ATP in muscle cells for hours.

The relative importance of these three processes varies for different sports. For example, consider these different types of races.

Running Distance	Running Time (world record; US high school record)	Speed
100 m	9.6 seconds; 10.0 seconds	10.4; 10.0 m/sec.
400 m	43.2 seconds; 44.7 seconds	9.3; 8.9 m/sec.
Marathon (42.2 km)	2 hours 3 min. 23 sec.; 2 hours 23 min. 47 sec.	5.7; 4.9 m/sec.

6a. During a marathon, which process in muscle cells do you think produces most of the ATP?

hydrolysis of creatine phosphate ___ anaerobic fermentation ___

aerobic cellular respiration ___

6b. Explain your reasoning.

7. During a 100 m sprint, hydrolysis of creatine phosphate is the most important process that produces ATP in muscle cells. Hydrolysis of creatine phosphate is less important for longer races. Explain why hydrolysis of creatine phosphate is a major contributor to ATP production for a 100 m sprint, but not for longer races.

8a. Anaerobic fermentation supplies much of the ATP that muscle cells need for a 400 m race. For this race, what is an advantage of anaerobic fermentation over aerobic cellular respiration?

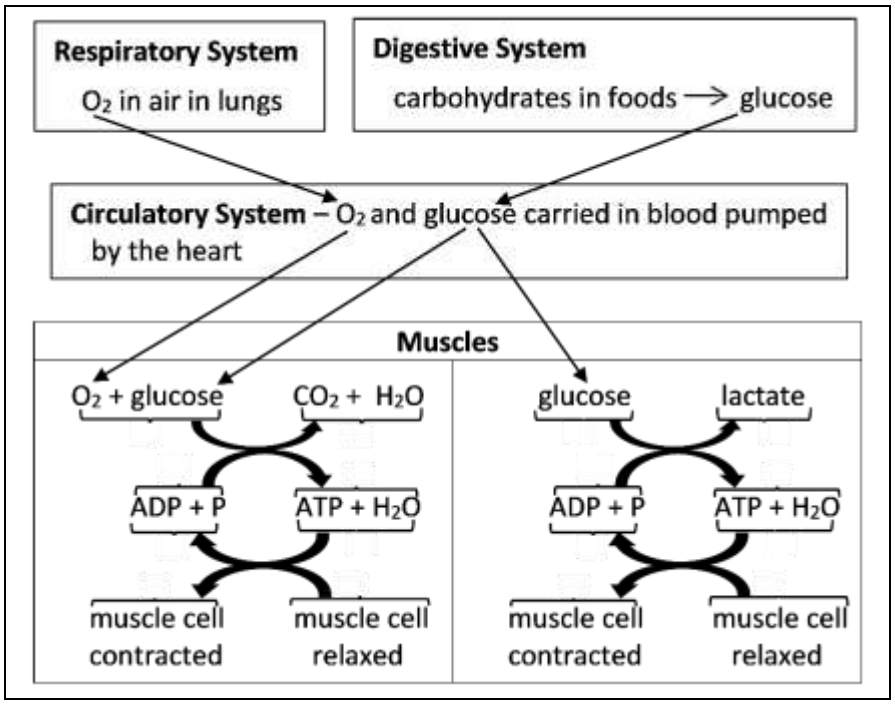
8b. What is a disadvantage of anaerobic fermentation for longer races?

How Oxygen and Glucose Get to Your Muscles

This flowchart shows how your respiratory, digestive, and circulatory systems cooperate to supply your muscles with oxygen and glucose.

9. Draw a solid line around aerobic cellular respiration in this figure. Draw a dashed line around anaerobic fermentation.

10. How does the circulatory system contribute to the energy supply for physical activity?



How Regular Aerobic Exercise Can Improve Athletic Performance

Aerobic exercise includes running, swimming, and sports that involve a lot of running (e.g. basketball and soccer). Regular aerobic exercise results in multiple changes in a person's body, including the effects listed in the table below.

11. Complete the table to explain how each listed effect of regular aerobic exercise increases the rate of cellular respiration in muscle cells.

Effect of Regular Aerobic Exercise	How This Increases the Rate of Aerobic Cellular Respiration
A. Heart can pump more blood per second.	
B. Muscles have more capillaries. (Capillaries are the smallest blood vessels where glucose and oxygen diffuse from the blood into the muscle cells.)	
C. Muscle cells have more mitochondria.	

Thus, regular aerobic exercise results in higher rates of cellular respiration in muscle cells. This improves athletic performance in longer races and in sports that involve a lot of running.