**How do muscles get the energy they need for athletic activity?**[[1]](#footnote-1)

All athletic activity depends on muscle contractions that require energy. Inside muscle cells, the breakdown of ATP provides the energy for the molecular reactions that result in muscle contraction.

A typical muscle cell at rest has only enough ATP for ~2 seconds of contraction. To continue contraction for more than 2 seconds, a muscle cell needs to use energy from other molecules like the simple sugar glucose to restore the ATP molecules.

|  |  |  |
| --- | --- | --- |
| Energy from Glucose | http://classconnection.s3.amazonaws.com/131/flashcards/1110131/jpg/the_atp_cycle1330914233110.jpg | Energy for Muscle Contraction ATP = adenosine triphosphate ADP = adenosine diphosphate; P = phosphate  |

Two processes use the energy from glucose to produce ATP:

* aerobic respiration (Aerobic means that a process requires air or, specifically, oxygen = O2.)
* anaerobic fermentation (Anaerobic means that the process does not require O2.)

**1.** The coupled chemical reactions shown in the boxes below summarize the processes of anaerobic fermentation and aerobic respiration. In both cases, the breakdown of a glucose molecule to smaller molecules releases energy which is used in the production of ATP. Write in the names of any molecules you recognize in the first chemical equation in each box. Fill in the blanks in the last chemical equation shown.

**Aerobic Respiration**

 C6H12O6 + 6 O2  6 CO2 +6 H2O

 \/

 \/

~29 \_\_\_\_ + ~29 P ~29 \_\_\_\_

**Anaerobic Fermentation**

 C6H12O6 2 C3H6O3

 \/

 \/

2 ADP + 2 P 2 ATP

 \/

 represents chemical reactions; \/ represents energy transfer between coupled reactions

**2.** The chart below shows that both anaerobic fermentation and aerobic respiration begin with the breakdown of glucose to 2 pyruvate molecules; this reaction provides the energy to produce \_\_\_\_\_ ATP molecules per glucose molecule.

Aerobic respiration includes additional processes in the mitochondria; these processes use 2 pyruvate and 6 O2 and provide the energy to produce \_\_\_\_\_\_ additional ATP per glucose molecule.

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| **Anaerobic****Fermentation** |  glucose 2 pyruvate  \/  \/ 2 ADP + 2 P 2 ATP |  2 lactic acid |
| **Aerobic****Respiration** |   glucose 2 pyruvate \/  \/ 2 ADP + 2 P 2 ATP  |  In mitochondria 2 pyruvate-  + 6 O2- 6 CO2 + 6 H2O \/  \/ ~27 ADP + ~27 P ~27 ATP  |

**3.** Use the information in this chart to finish writing in the names of the molecules in the first chemical equation in each box in question 1.

**4.** During vigorous physical activity a person breathes faster and deeper. This increases the supply of O2 for the muscles. How does this contribute to better athletic performance?

General Principles

* Energy can be transformed from one type to another (e.g. the stored chemical energy in ATP can be transformed to the kinetic energy of muscle motion). Energy is *not* created or destroyed by biological processes.
* All types of energy transformation are inefficient and result in the production of heat. For example, when ATP provides the energy for muscle contraction, only about 20-25% of the chemical energy released from the ATP molecules is captured in the kinetic energy of muscle contraction. The rest of the energy from the ATP is converted to heat.
* The atoms in molecules can be rearranged into other molecules, but matter (atoms in molecules) is *not* created or destroyed.

**5.** Complete this chart to show how energy and matter are transformed during aerobic respiration:

|  |  |  |
| --- | --- | --- |
| **Inputs****Type of Energy**Chemical energy stored in the bonds of glucose molecules**Matter** (input molecules) |  >>>>>>>> | **Outputs****Types of Energy****Matter** (output molecules)  |

**6.** A website claims that "The mitochondria in muscle cells make the energy needed for athletic activity." Explain what is wrong with this sentence, and give a more accurate sentence.

**7.** Explain why your body gets warmer when you are physically active.

You have seen that the breakdown of glucose provides the energy to produce ATP, and ATP provides the energy for muscle contraction. The obvious next question is "How does glucose get to the muscles?"

As shown in this chart, glucose can be derived from:

* carbohydrates in food (e.g. starch or sugars such as sucrose)
* glycogen (a polymer of glucose used to store glucose in muscles and in the liver).

|  |  |  |
| --- | --- | --- |
| **Digestive System** Mouth, stomach and small intestine - carbohydrates in food glucose  |  | **Respiratory System** - air in lungs O2  blood |
|  |  blood |  |  |
|  Liver  - glycogen many glucose   |  | **Muscles** - many glucose glycogen  - anaerobic fermentation and aerobic respiration of glucose provides the energy to produce ATP  |

Notice that the energy supply for muscle contraction depends on the cooperation of:

* the digestive system (to provide glucose)
* the respiratory system (to provide O2)
* the circulatory system (since the blood pumped by the heart carries glucose and O2 to the muscles).

**8a.** In the above chart, draw arrows to show the transport of glucose and O2 by the circulatory system.

**8b.** The chart shows that at some times many glucose molecules are combined to form glycogen, and at other times glycogen is broken down to release glucose. Which of these reactions occurs at a higher rate during vigorous exercise? Mark the arrows for this reaction with an X. Which of these reactions occurs at a higher rate during rest after a meal? Mark the arrows for this reaction with an M.

|  |  |
| --- | --- |
| During exercise, fat molecules stored in muscles and in adipose tissue are broken down to fatty acids which muscle cells can use as another input for aerobic respiration. | **Aerobic Respiration of Fatty Acids** fatty acids+ multiple O2  multiple CO2 + H2O  \/  \/ multiple ADP + P multiple ATP |

**9.** Regular aerobic exercise such as walking, running or swimming results in changes in the body called training effects. Complete the following table to explain how each listed training effect contributes to an increased capacity for aerobic respiration in muscle cells.

|  |  |
| --- | --- |
| **Training Effect Produced by Regular Aerobic Exercise** | **Explain how this training effect contributes to** **an increase in the rate of aerobic respiration in muscle cells.** |
| The heart can pump more blood per second and the muscles have more capillaries (small blood vessels where O2, glucose, and fatty acids move from the blood to the muscle cells). |  |
| Muscle cells have more and larger mitochondria and more enzymes for aerobic respiration. |  |
| Muscle cells have more stored glycogen and more of the molecules that facilitate uptake of glucose and fatty acids into cells. |  |

In active muscle, both anaerobic fermentation and aerobic respiration provide energy for the production of ATP. In addition, the breakdown of creatine phosphate can provide the energy needed to produce ATP. The relative importance of these three energy sources varies depending on the intensity and duration of the physical activity. To learn how the primary source of muscle ATP differs for races of different lengths, read the following information and answer questions 10-12.

* The breakdown of creatine phosphate can provide energy for the production of ATP more rapidly than anaerobic fermentation or aerobic respiration. Muscle cells typically have enough creatine phosphate for ~10 seconds of intense activity.
* Anaerobic fermentation is faster than aerobic respiration and does not require O2, so anaerobic fermentation can provide a lot of ATP for brief intense athletic events. However, anaerobic fermentation can only be a major source of energy for a minute or two, in part because anaerobic fermentation produces lactic acid and too much lactic acid has harmful effects.
* Aerobic respiration is the slowest of these processes, but aerobic respiration produces more ATP per glucose molecule than anaerobic fermentation and aerobic respiration can continue for hours.

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| --- | --- | --- |
| **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. |

**10.** What do you think is the primary source of ATP for muscles during a marathon?

 aerobic respiration \_\_ anaerobic fermentation \_\_ creatine phosphate \_\_

Explain your reasoning.

**11.** Explain why creatine phosphate is the most important source of the energy needed to produce ATP during a 100 m race and less important for longer races.

**12.** Explain why, for a 400 m race, anaerobic fermentation supplies more of the ATP than aerobic respiration.

**13.** Complete this table concerning two of the recovery processes that occur after an athletic event.

|  |  |
| --- | --- |
| **Recovery Process** | **Explain why this recovery process is useful after a marathon which ended with an intense sprint.** |
| In muscle cells and liver cells, glycogen is synthesized from glucose derived from food molecules. |  |
| In liver cells, lactic acid is converted back to glucose. |  |

1. By Dr. Ingrid Waldron, Biology Dept, Univ Pennsylvania, ©2014. The most recent version of this Student Handout and Teacher Notes with instructional suggestions and background information are available at <http://serendip.brynmawr.edu/exchange/bioactivities>/energyathlete. [↑](#footnote-ref-1)