[**Endergonic/exergonic**] reactions are also said to be spontaneous reactions. Does this mean that if we don't keep glucose in tightly sealed containers it will spontaneously interact with atmospheric oxygen and turn into carbon dioxide and water? The answer is obviously no.

Spontaneous reactions rarely occur "spontaneously" because all chemical reactions, even those that release energy, require some addition of energy—the energy of activation—before they can occur. One way of supplying this energy is to add heat. An example is heating a marshmallow over a flame or campfire. When enough heat is added to reach (or overcome) the activation energy, the sugar in the marshmallow reacts by oxidizing. (Burning is a form of oxidation.) The marshmallow will continue to burn even if you remove it from the campfire. As the marshmallow burns, carbon dioxide and water are formed as products of the reaction, and the energy that was stored in the bonds of the sugar is released as heat.

If our cells used heat to overcome activation energies in metabolism, they would probably burn up like the marshmallow did. Instead, living systems use protein catalysts or enzymes to lower the energy of activation without adding heat. In addition, the metabolic breakdown of sugars is carried out in a controlled series of reactions. At each step or reaction in the sequence, a small amount of the total energy is released. Some of this energy is still lost as heat. The rest is converted to other forms that can be used in the cell to drive or fuel coupled endergonic reactions or to make ATP.

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Activity 9.2 Modeling cellular respiration: How can cells convert the energy in glucose to ATP?

Using your textbook, lecture notes, and the materials available in class (or those you devise at home), model both fermentation (an anaerobic process) and cellular respiration (an aerobic process) as they occur in a plant or animal cell. Each model should include a dynamic (working or active) representation of the events that occur in glycolysis.

Building the Model

- Use chalk on a tabletop or a marker on a large sheet of paper to draw the cell membrane and the mitochondrial membranes.
- Use playdough or cutout pieces of paper to represent the molecules, ions, and membrane transporters or pumps.
- Use the pieces you assembled to model the processes of fermentation and aerobic respiration. Develop a dynamic (claymation-type) model that allows you to manipulate or move glucose and its breakdown products through the various steps of both fermentation and aerobic respiration.
- When you feel you have developed a good working model, demonstrate and explain it to another student.

Be sure your model of **fermentation** includes and explains the actions and roles of the following:

glycolysis	ADP
cytoplasm	Ⓟ$_i$
electrons	ATP
protons	pyruvate
glucose	ethyl alcohol (or lactic acid)
NAD^+	substrate-level phosphorylation
NADH	

Be sure your model of **cellular respiration** includes and explains the actions and roles of the following:

glucose
oxygen
carbon dioxide
pyruvate
acetyl CoA
NAD^+
NADH
FAD
$FADH_2$
ADP
Ⓟi
ATP
water

electron transport chain
mitochondria
inner mitochondrial membrane
outer mitochondrial membrane
H^+
electrons (e^-)
chemiosmosis
ATP synthase (proton pumps)
cristae
proton gradients
oxidative phosphorylation
substrate-level phosphorylation
oxidative phosphorylation

Use your models to answer the questions.

1. The summary formula for cellular respiration is

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{Energy}$$

a. At what stage(s) in the overall process is each of the reactants used?		b. At what stage(s) in the overall process is each of the products produced?		
$C_6H_{12}O_6$ +	$6\ O_2$ →	$6\ CO_2$ +	$6\ H_2O$ +	Energy

Be sure your model of **cellular respiration** includes and explains the actions and roles of the following:

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carbon dioxide
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2. In cellular respiration, the oxidation of glucose is carried out in a controlled series of reactions. At each step or reaction in the sequence, a small amount of the total energy is released. Some of this energy is lost as heat. The rest is converted to other forms that can be used by the cell to drive or fuel coupled endergonic reactions or to make ATP.

a. What is/are the overall function(s) of glycolysis?	b. What is/are the overall function(s) of the Krebs cycle?	c. What is/are the overall function(s) of oxidative phosphorylation?

3. Are the compounds listed here *used* or *produced* in:	Glycolysis?	The Krebs cycle?	Oxidative phosphorylation?
Glucose			
O_2			
CO_2			
H_2O			
ATP			
ADP + Ⓟi			
NADH			
NAD^+			

4. The cell's supply of ADP, Ⓟi, and NAD^+ is finite (limited). What happens to cellular respiration when all of the cell's NAD^+ has been converted to NADH?

5. If the Krebs cycle does not require oxygen, why does cellular respiration stop after glycolysis when no oxygen is present?

6. Many organisms can withstand periods of oxygen debt (anaerobic conditions). Yeast undergoing oxygen debt converts pyruvic acid to ethanol and carbon dioxide. Animals undergoing oxygen debt convert pyruvic acid to lactic acid. Pyruvic acid is fairly nontoxic in even high concentrations. Both ethanol and lactic acid are toxic in even moderate concentrations. Explain why this conversion occurs in organisms.

7. How efficient is fermentation? How efficient is cellular respiration? Remember that efficiency is the amount of useful energy (as ATP) gained during the process divided by the total amount of energy available in glucose. Use 686 kcal as the total energy available in 1 mole of glucose and 8 kcal as the energy available in 1 mol of ATP.

Efficiency of fermentation	Efficiency of aerobic respiration

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Efficiency of fermentation	Efficiency of aerobic respiration

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8. a. Why can't cells store large quantities of ATP? (*Hint:* Consider both the chemical stability of the molecule and the cell's osmotic potential.)

b. Given that cells can't store ATP for long periods of time, how do they store energy?

c. What are the advantages of storing energy in these alternative forms?

9. To make a 5 *M* solution of hydrochloric acid, we add 400 mL of 12.5 *M* hydrochloric acid to 600 mL of distilled water. Before we add the acid, however, we place the flask containing the distilled water into the sink because this solution can heat up so rapidly that the flask breaks. How is this reaction similar to what happens in chemiosmosis? How is it different?

a. Similarities	b. Differences