4·12–4·15 Cellular respiration converts food molecules into ATP, a universal source of energy for living organisms.

Watermelon powered! We extract energy from all the foods we eat.

4·12 How do living organisms fuel their actions? Cellular respiration: the big picture.

Food is fuel. And all the activities of life—growing, moving, reproducing—require fuel. Plants, most algae, and some bacteria obtain their fuel directly from the energy of sunlight, which they harness through photosynthesis. Less self-sufficient organisms, such as humans, alligators, and insects, must extract the energy they need from the food they eat. This energy comes from photosynthetic organisms either directly (from eating plants) or indirectly (from eating animals that eat plants) (**FIGURE 4-27**).

All living organisms extract energy from the chemical bonds of molecules (which can be considered "food") through a process

FIGURE 4-27 **Living organisms require fuel (in one form or another).**

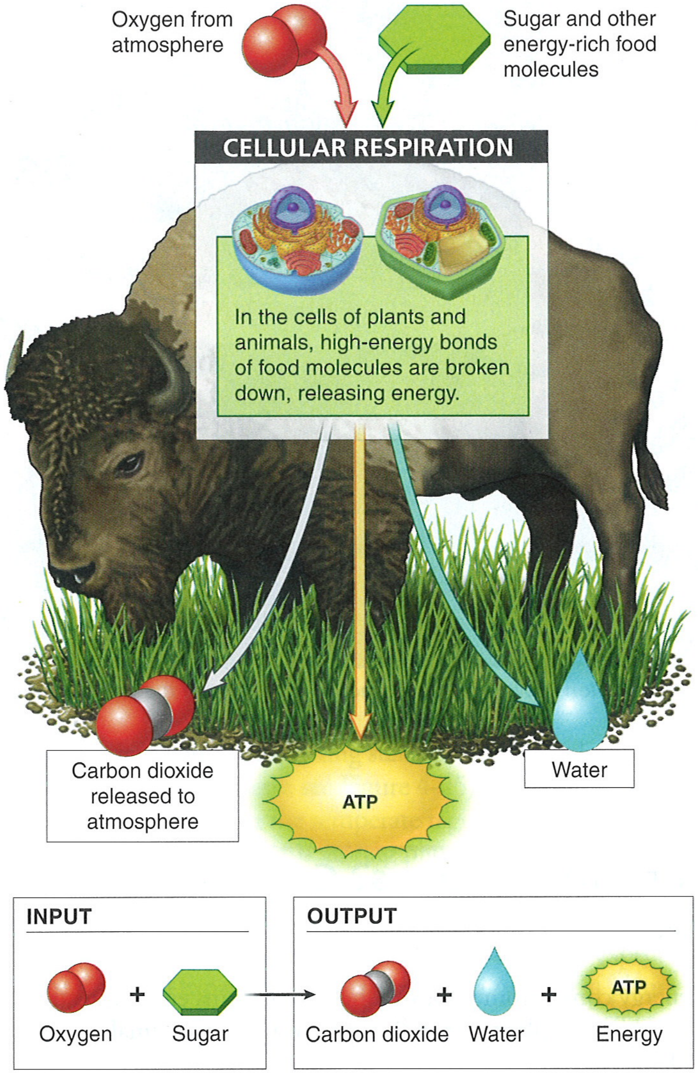

FIGURE 4-28 **Cellular respiration: the big picture.**

called cellular respiration (**FIGURE 4-28**). This process is a bit like photosynthesis in reverse. In photosynthesis, the energy of the sun is captured and used to build molecules of sugars, such as glucose. In cellular respiration, plants and animals break down the chemical bonds of sugar and other energy-rich food molecules (such as fats and proteins) to release the energy that went into creating them. (Don't confuse cellular respiration with the act of breathing, which is also called *respiration.*) As energy is released, cells capture and store it in the bonds of ATP molecules. This plentiful, readily available stored energy can then be tapped as needed to fuel the work of the life-sustaining activities and processes of all living organisms.

In humans and other animals, cellular respiration starts after we eat food, digest it, absorb the nutrient molecules into the bloodstream, and deliver them to the cells of our bodies. At this point, our cells begin to extract some of the energy stored in the bonds of the food molecules. We focus here on the breakdown of glucose, but later in this chapter we'll see that the process is similar for the breakdown of fats or lipids. Ultimately, when a food molecule has been completely processed, the cell has used the food molecule's stored energy (along with oxygen) to create a large number of high-energy-storing ATP molecules (which supply energy to power the cell's activities), water, and carbon dioxide (which is exhaled into the atmosphere).

TAKE-HOME MESSAGE 4·12

Living organisms extract energy through a process called cellular respiration, in which the high-energy bonds of sugar and other energy-rich molecules are broken, releasing the energy that went into creating them. The cell captures the food molecules' stored energy in the bonds of ATP molecules. This process requires fuel molecules and oxygen and it yields ATP molecules, water, and carbon dioxide.

4·13 The first step of cellular respiration: glycolysis is the universal energy-releasing pathway.

To generate energy, fuels such as glucose and other carbohydrates as well as proteins and fats are broken down in three steps: (1) glycolysis, (2) the Krebs cycle, and (3) the electron transport chain. **Glycolysis** means the splitting (*lysis*) of sugar (*glyco-*) and it is the first step that all organisms on the planet take in breaking down food molecules; for many single-celled organisms, this one step is sufficient to provide all of the energy they need (**FIGURE 4-29**).

As **FIGURE 4-30** illustrates, glycolysis is a sequence of chemical reactions (there are 10 in all) through which glucose is broken down, resulting in two molecules of a substance called **pyruvate.** Glycolysis has two distinct phases: an "uphill" preparatory phase and a "downhill" payoff phase.

Just as you sometimes have to spend money to make money, before any energy can be extracted from glucose, some energy

FIGURE 4-29 **Plants, animals, bacteria, and all other organisms use glycolysis to break down fuels.**

Every living organism, large or small, extracts energy through glycolysis!

must be added to the molecule. This addition occurs during the "uphill" phase. The additional energy (which comes from ATP) destabilizes the glucose molecule, making it ripe for chemical breakdown. Once the glucose can be broken down chemically, the energy stored in its bonds can be harnessed as the bonds are broken.

Three of the 10 steps in glycolysis yield energy. In two of these three, as bonds from the sugar are broken, and other lower-energy bonds are formed, the energy released is quickly harnessed by the attachment of phosphate groups to molecules of ADP to create energy-rich ATP molecules. In the third energy-yielding step of glycolysis, electrons originally from the glucose are transferred to NAD^+ to become the high-energy electron carrier NADH. Later (in an electron transport chain in the mitochondria) this energy will be converted to ATP. The net result of glycolysis is that each glucose molecule is broken down into two molecules of pyruvate. During this breakdown, some of the released energy is captured in the production of energy-rich ATP molecules and molecules of the high-energy electron carrier NADH. Two molecules of water are also produced during glycolysis.

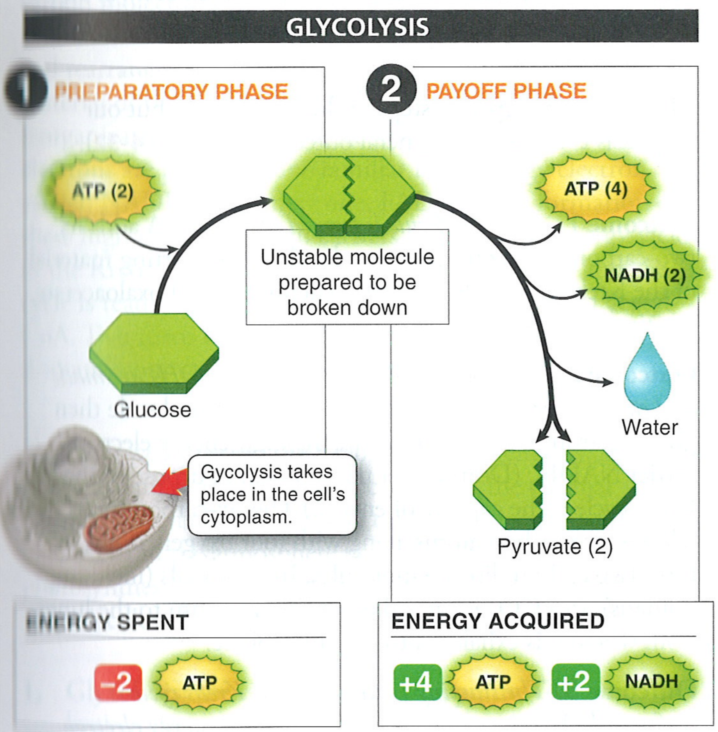

FIGURE 4-30 **Glycolysis up close.**

In the absence of oxygen and in many yeasts and bacteria, glycolysis is the only game in town for fueling activity. Because single-celled organisms have much lower energy needs, they can function solely on the yields of glycolysis. For many organisms (including humans), however, glycolysis is a springboard to further energy extraction. The additional energy payoffs come from the Krebs cycle and the electron transport chain.

TAKE-HOME MESSAGE 4·13

Glycolysis is the initial phase in the process by which all living organisms harness energy from food molecules. Glycolysis occurs in a cell's cytoplasm and uses the energy released from breaking chemical bonds in food molecules to produce high-energy molecules, ATP and NADH.