Although it may not seem so during the holiday season, we do not have to eat continually throughout the day. Our cells do require a constant supply of sugars and other nourishment, but fortunately our bodies contain a mechanism for storing sugar during meals and then metering it out for the rest of the day. The sugars are stored in glycogen, a large molecule that contains up to 10,000 glucose molecules connected in a dense ball of branching chains. Your muscles store enough glycogen to power your daily activities, and your liver stores enough to feed your nervous system and other tissues all through the day and on through the night.

**Sweet Tooth**
Sugar is released from glycogen by the enzyme glycogen phosphorylase. It clips glucose from the chains on the surface of a glycogen granule. The enzyme is a dimer of two identical subunits (colored green and blue in the structure here, from PDB entry 6gpb). In the upper illustration, two nucleotides, in red, are bound at the entrance to the active site, which is found in a deep cleft. The yellow molecules are short chains of sugars similar to the ends of glycogen chains, which bind into another cleft that the enzyme uses to grip the glycogen granule. In its cleavage reaction, glycogen phosphorylase uses a phosphate molecule, connecting it to the sugar as it is released.
December 2001: Glycogen Phosphorylase

A second enzyme, phosphoglucomutase, then shifts the position of the phosphate to a neighboring carbon atom in the sugar, making the sugar ready for breakdown by glycolysis.

Moderation

As you might imagine, this process is highly regulated. Traffic of sugar into and out of storage in glycogen is used to control the level of glucose in the blood, so glycogen phosphorylase must be activated when sugar is needed and quickly shut down when sugar is plentiful. It is controlled in several ways. First, the enzyme is activated by adding a phosphate molecule to a serine amino acid (serine 14) on the back side of the enzyme. The phosphate causes a large shift in the shape of the enzyme, shifting it into the active conformation. Two special enzymes control the addition and removal of this phosphate, based on levels of the sugar-monitoring hormones insulin and glucagon, and other hormones such as epinephrine (adrenaline). Also, binding of other molecules can modify the activity of the molecule. For instance, AMP (adenine monophosphate) binds to a different site on the back side of the molecule, causing the same shift to the active conformation. This is useful, because AMP is a product of ATP breakdown and will be more plentiful when energy levels are low and more sugar is needed.
December 2001: Glycogen Phosphorylase

Shape-shifting
Glycogen phosphorylase is activated by a change of shape. The structure on the left (PDB entry 8gpb) is in the inactive T state and the structure on the right (PDB entry 1gpa) is in the active R state. (T stands for tense and R for relaxed, a notation developed when the first allosteric enzymes were being studied, although structures such as these have shown that the idea of tension does not really apply at the molecular level). The shift between the two shapes is controlled by phosphorylation of serine 14 or binding of AMP to the regulatory site. The R-state structure shown here has phosphates attached to the serines (colored pink) and a sulfate group in the site that binds to AMP (colored yellow).
Exploring the Structure

Glycogen is used in many organisms, from humans to yeast. Much of the scientific work on the enzyme has been done with rabbit glycogen phosphorylase. You can look at the slightly different enzyme from yeast in PDB entry 1ygp. This file contains the two protein chains (colored blue and green here) and several small molecules. The molecule labeled PLP is the cofactor pyridoxal phosphate, a reactive molecule which binds tightly in the active site and is used to assist in the reaction. A phosphate is bound in each subunit next to the key threonine amino acid that is used for regulation, controlling an allosteric change similarly to serine 14 in the rabbit form. As you are looking at this enzyme, notice how the two protein chains wrap arms around one another. This allows the subunits to work together when responding to the small changes in shape that are used for control.