March 2002: Bacteriorhodopsin

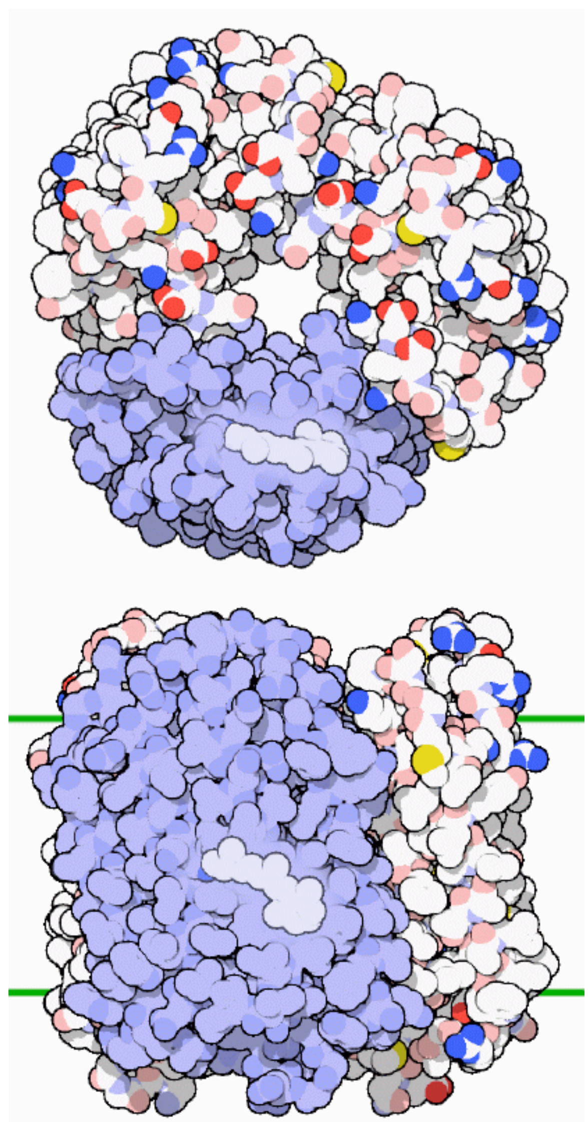
Sunlight powers the biological world. Through photosynthesis, plants capture sunlight and build sugars. These sugars then provide all of the starting materials for our growth and energy needs. As seen in the Molecule of Month last October, photosynthesis requires a complex collection of molecular antennas and photosystems. However, some archaebacteria have found a simpler solution to capturing sunlight.

A Light-driven Pump

Bacteriorhodopsin is a compact molecular machine that pumps protons across a membrane powered by green sunlight. It is built by halophilic (salt loving) archaebacteria, found in high-temperature brine pools. They use sunlight to pump protons outwards across their cell membranes, making the inside 10,000-fold more alkaline than the outside. These protons are then allowed to flow back inwards through another protein, ATP synthase, building much of the ATP that powers the cell.

Capturing Light

Bacteriorhodopsin, shown here from PDB entry 1fbb, is composed of three protein chains. It is found embedded in dense arrays in the membranes of the archaebacteria. The area spanning the membrane is shown in the lower picture between the two green lines. At the heart of each protein chain is a molecule of retinal, which is bound deep inside the protein and connected through a lysine amino acid. In these pictures, one of the three protein chains is shown in blue and the retinal molecule, which is buried inside, is shown in white. Retinal contains a string of carbons that strongly absorb light. When a photon is absorbed, it causes a change in the conformation of the molecule. In bacteriorhodopsin, this is a change from a straight form to a bent form, as shown on a later page. This change in shape powers the pumping of protons.



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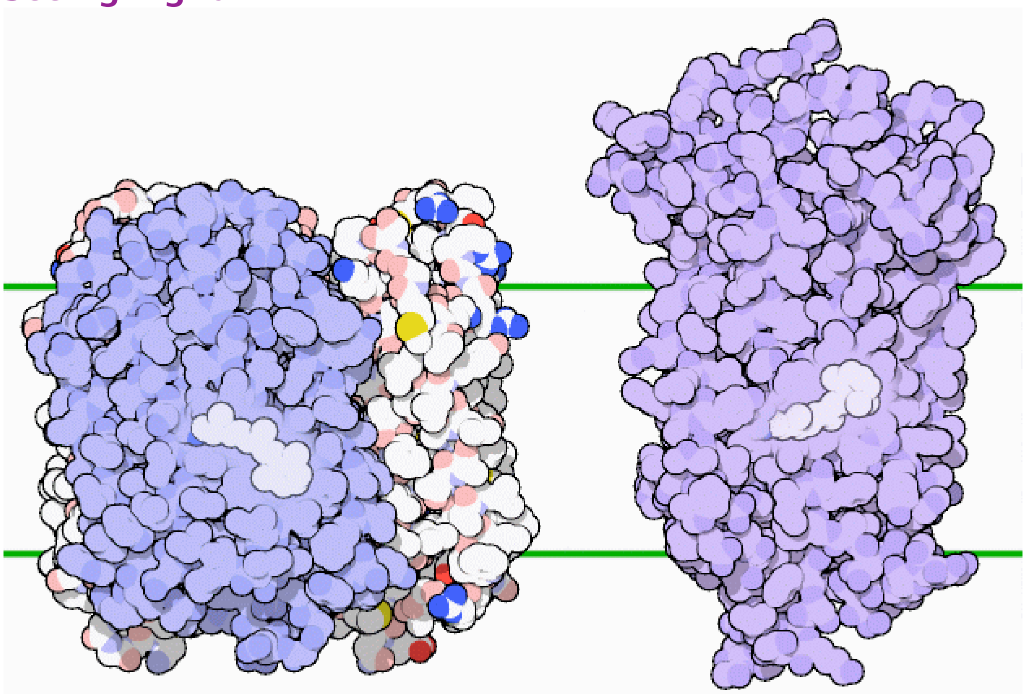
Many Uses

The capturing of light is so useful that these salt-loving archaebacteria actually build four different types of rhodopsins. Bacteriorhodopsin is used to generate energy. Halorhodopsin, which may be seen in PDB entry 1e12, is also a pump that funnels chloride ions instead of protons. It is in charge of keeping the internal concentration of chloride at high levels that match the salty conditions outside the cell. The other two rhodopsins are sensory rhodopsins, such as the ones in PDB entries 1h68 or 1jgj. These rhodopsins sense bluish light and send signals to the cell to move, finding an area with more useful, greenish light. All four of these rhodopsins are built along similar lines, with a retinal molecule securely held inside a compact container of protein.

Seeing Light



We also build several forms of rhodopsin and use them in our eyes for seeing light. As in bacteriorhodopsin, our rhodopsin also contains a molecule of retinal. (Bacteriorhodopsin is shown on the left, from PDB entry 1fbb, and rhodopsin from cows is shown on the right, from PDB entry 1f88). Retinal is made in our bodies from retinol, or vitamin A, which is essential in the diet, since we cannot synthesize vitamin A on our own. When it absorbs a photon, the retinal in rhodopsin changes shape from bent to straight--just the opposite of retinal in bacteriorhodopsin! This change of shape then pushes the surrounding protein into a slightly different shape, which is sensed by proteins inside the cell. Then, the message is passed through a cascade of proteins, each sending the message to the next, finally launching a nerve signal to the brain. The process is so sensitive that the eye can sense as few as 5 photons.

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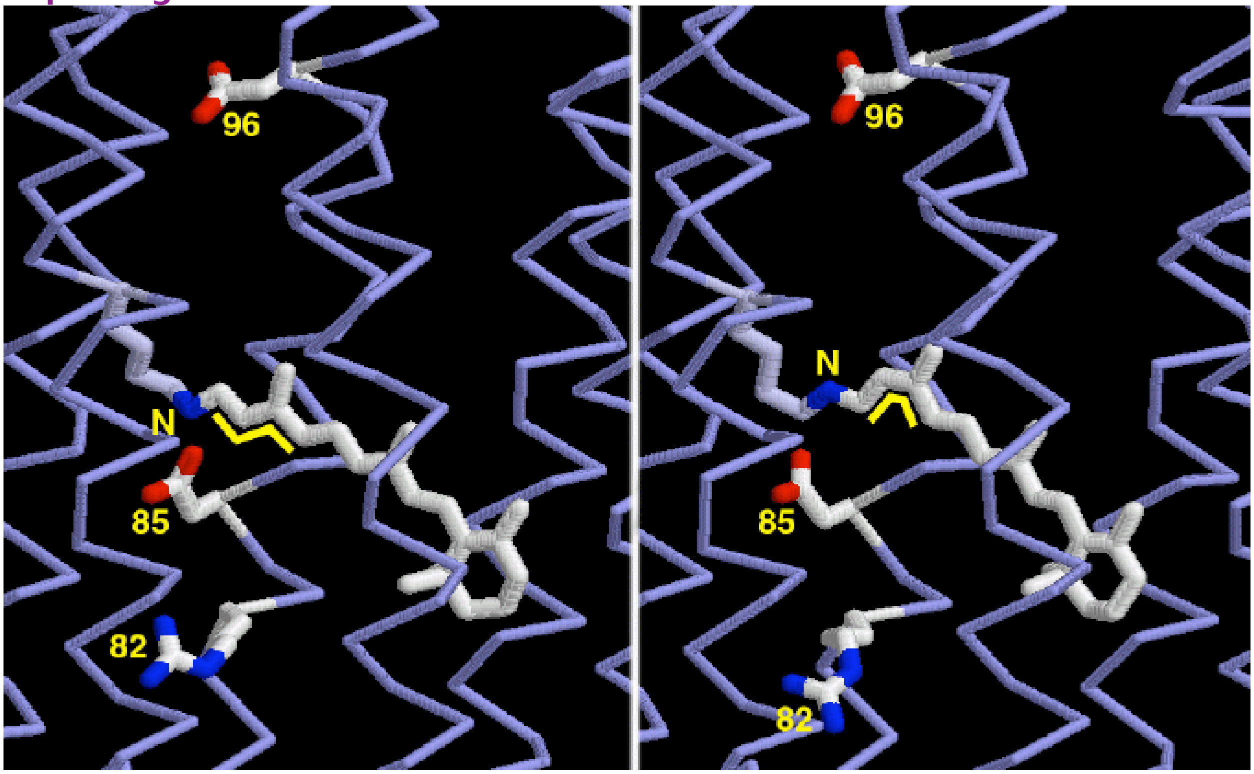
Exploring the Structure



Many structures of bacteriorhodopsin are available in the PDB, showing many of the steps in the process of absorbing light and pumping protons. Two snapshots are shown here. The structure on the left, from PDB entry 1c3w, is in the ground state, before it has absorbed light. The retinal (the long molecule in white crossing through the center) is in the straight trans form, as shown by the little zig-zag yellow lines. The structure on the right, from PDB entry 1dze, shows the molecule after absorbing light. Notice that the retinal now has a bent cis shape at the site indicated by the yellow lines. This new shape has changed the orientation of the nitrogen at the end of the retinal, indicated by the yellow N. It has also shifted the position of several protein amino acids that are along the pathway of proton transfer, indicated by the numbers. In particular, notice the large shift of arginine 82 at the bottom. Researchers are working to discover how these changes in shape power the transfer of a proton from the top to the bottom, through the middle of bacteriorhodopsin and across the archaebacterial membrane.