ATP, the cell's energy currency, is produced by a rotating motor

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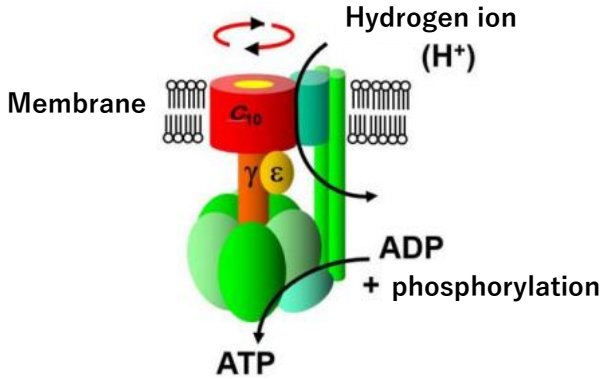
[About my research]

There is a small molecule called ATP. Most of the body's activities, such as muscle movement, synthesis of various molecules in the body, transport, and absorption of substances, are maintained by the energy created by the hydrolysis of ATP. ATP is like a 100-yen coin in money, and its energy is not very large. Cells do not give you change when you use energy (the change will be converted to heat), so a large energy currency like a 10,000-yen bill is wasteful. So, organisms have to synthesize a tremendous amount of ATP. For example, a human being synthesizes and consumes as much ATP as their body weight per day.

ATP synthase is the one to produce ATP. It is located in the membrane of mitochondria, the energy plant of the cell. ATP synthase, by the way, is a common enzyme in all living organisms, and it is this enzyme that produces ATP in the chloroplasts of plants and bacteria. Hydrogen extracted from sugars and amino acids is burned in the mitochondria and produces water. And during this process, hydrogen ions are pumped from the inside of the membrane to the outside by the energy of combustion, creating a hydrogen ion concentration difference (dam) between the inside and outside of the mitochondria. ATP synthase uses the energy of hydrogen ions flowing down inside mitochondria along a gradient to synthesize ATP.

So how can ATP synthase produce ATP with the flow of hydrogen ions? This is what I have been studying.

The structure of ATP synthase can be roughly summarized below. A long thin shaft is attached to a round ring-like structure embedded in a membrane, and a head like a bunch of oranges is attached at the end of the shaft (see figure). All of these are made of proteins.



Hydrogen ions flow through the base and rotate the shaft (C10 γ ε)
to form ATP at the head.

Hydrogen ions flow through the rings of the membrane, and their energy somehow travels down the thin shaft to synthesize ATP around the bunches of orange. Somehow? This was a mystery. And the answer was truly astonishing.

The membrane rings and narrow shafts were rotating.

The energy was transferred by rotation from the ring inside the membrane to the head outside the membrane. The ATP synthase was actually a motor. The ATP synthase was so small (1/100,000 of a millimeter) that we glued a rod, 100 times longer than the ring, to the shaft and examined it under a microscope. It was spinning in circles.

Hydrogen ions flowing down the dam turn into a turbine called ATP synthase, which is really like hydroelectric power generation. Living organisms are not good at spinning. Animals would run on wheels, fish would swim on screws, and birds would fly on propellers. It looks like they could be, but they are not. This was the first-ever discovery of a spinning enzyme. In our bodies, more than 100 million times and another 100 million times more than that number of motors are turning at a high speed of 300 times per second, day and night.