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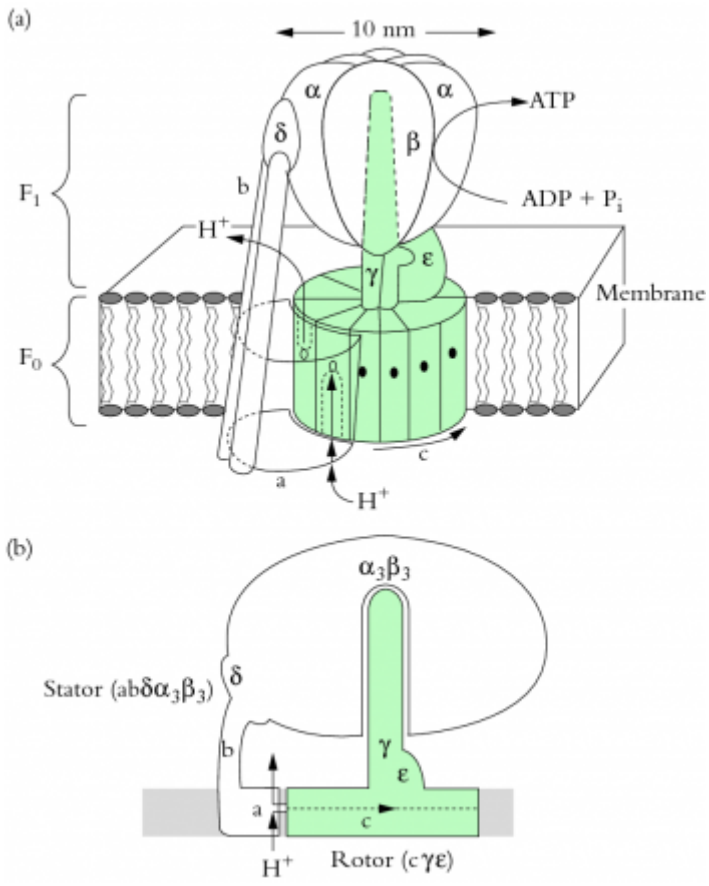
CASE STUDY 2.1??Knobs and ATP synthase



[1]

Figure 1 Nature's tiniest rotary motor shown here as a highly diagrammatic version of an ATP synthase complex — a device for generating ATP from free energy stored as a transmembrane protonmotive force (a gradient in electrochemical potential of protons, consisting of a pH gradient and a gradient in electric potential). The ATP synthase complex of chloroplasts was referred to earlier as a 'coupling factor' (Figure 1.11). (a) In mitochondria, an asymmetric portion F_0 spans the inner membrane and provides a conduit for proton movement across this inner membrane (from intermembrane space to matrix), movement that imparts a torque between two adjacent subunits 'a' and 'c'.Torque so generated is transmitted to F1 via the shaft '?' plus the '?' subunit. (b) 'a', 'b' and '?' subunits are linked to

the F1 hexainer (?$_3$?$_3$) and constitute the 'stator' of this rotary motor. The 'rotor' itself is represented here as a shaded portion of the overall complex, and comprises 'c', '?' and '?' subunits. The '?' subunit behaves as a rotating shaft that mediates an exchange of energy derived from proton flow through F_0 for ATP synthesis via the cooperative activity of three catalytic sites within F_1 (three ATP are generated for every 12 protons that pass through this rotary motor).

In a widely acclaimed technical achievement, Hiroyuki Noji and colleagues at Yokohama (Noji et. al. 1997) attached a fluorescent actin filament to the tip of a '?' subunit and recorded continuous rotation during synthesis of ATP, thus confirming a rotary motion that had been predicted on biophysical grounds. Unrestrained by a long actin filament, rotation rate *in vivo* would peak around 150 revs per second. Significantly, when provided with a source of ATR this self same device (an ATP synthase complex) can draw energy from ATP hydrolysis to pump protons against a gradient. Now working as an ATPase, these rotary motors sustain energy-dependent processes including nutrient ion uptake and salt exclusion by plant roots. (Based on Elston et al. 1998; reproduced with permission of Nature)

During the mid-1950s Marjorie Wilkins and I, both of CSIRO Food Preservation and Transport, were collaborating with John Farrant, CSIRO Industrial Chemistry. Using his electron microscope, we had seen what we then called 'knobs' protruding from the inner surfaces of plant mitochondria (Farrant *et al* . 1956).

Happily, the molecular structure of such bodies is now so well understood, thanks to the experiments of many workers around the world, that we have a good understanding of their function at a molecular level. As a retired plant physiologist, I have become specially interested in the membrane-bound F_0F_1 ATPase of *E. coli*, also an ATP synthase. Here my thanks are due to the Frank Gibson (1991) and Graham Cox Group in John Curtain School at ANU, whose work led to my understanding the hypothesis of its structure and function.

The 'knobs' attached to a membrane-bound portion (Figure 1) are thought to be analogous to motors, with internal subunits that rotate at about 150 times per second relative to adjacent subunits, and with the stalk complex acting as a kind of 'stator'. According to this rotational model, protons are pumped across the membrane. Proton pumping in one direction results in formation of ATP from ADP and phosphate; in the other direction, ATP is hydrolysed to ADP, liberating H^+ ions, to which the movement of other ions is linked. Thanks to the techniques of molecular biology and to many workers, much of the structure is now understood. The 'knobs' in chloroplast membranes are similar in structure to those in mitochondria, but point the opposite way.
