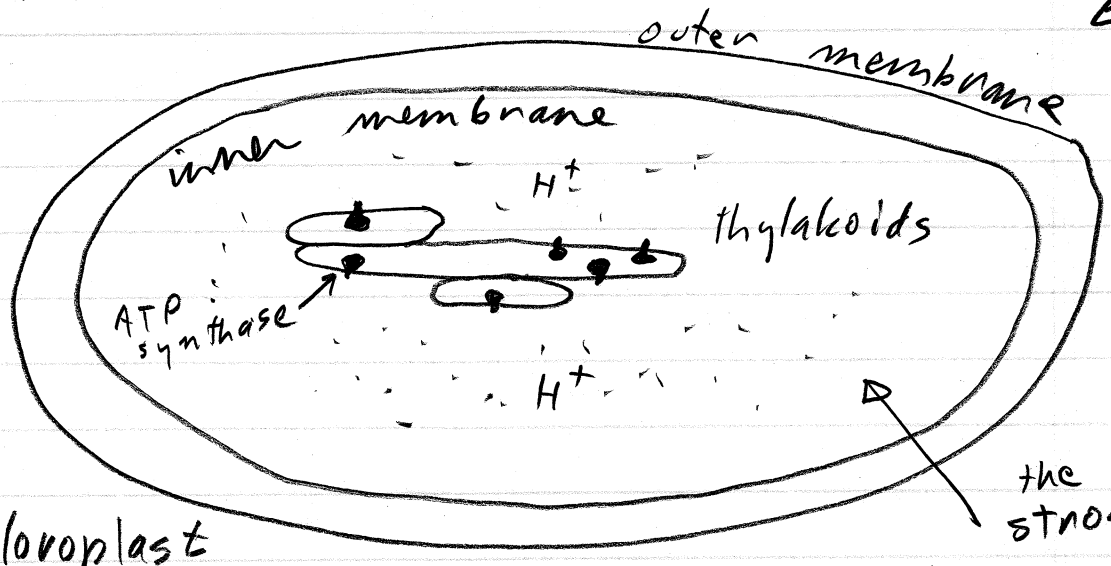
An electron-transport chain uses NADH and $FADH_2$ to reduce a sequence of electron acceptors, lastly O_2. It consists of several membrane proteins in the inner mitochondrial membrane. This chain pumps the protons that power ATP synthase. This chain, its suppliers of NADH and of $FADH_2$, and ATP synthase are a chemiosmotic mechanism. They do oxidative phosphorylation in that they use the energy they get from oxidizing food to add H^+ to a P_i^{2-} to ADP^{3-} making $ATP^{4-} + H_2O$.

Experiments have shown that oxidation and phosphorylation proceed almost independently. With acid in its intermembrane space, a mitochondrion can make ATP without a food supply.

Chloroplasts are organelles in plant cells. They resemble mitochondria, which also are organelles of plant cells. The chloroplasts use optical photons to energize electrons taken from H_2O, making O_2. They use an electron-transport process to pump H^+ out of sacs called <u>thylakoids</u>. The H^+ pumps and the ATP-synthase turbines are in the thylakoid membranes. A chloroplast



a chloroplast

Chloroplasts also absorb CO_2.

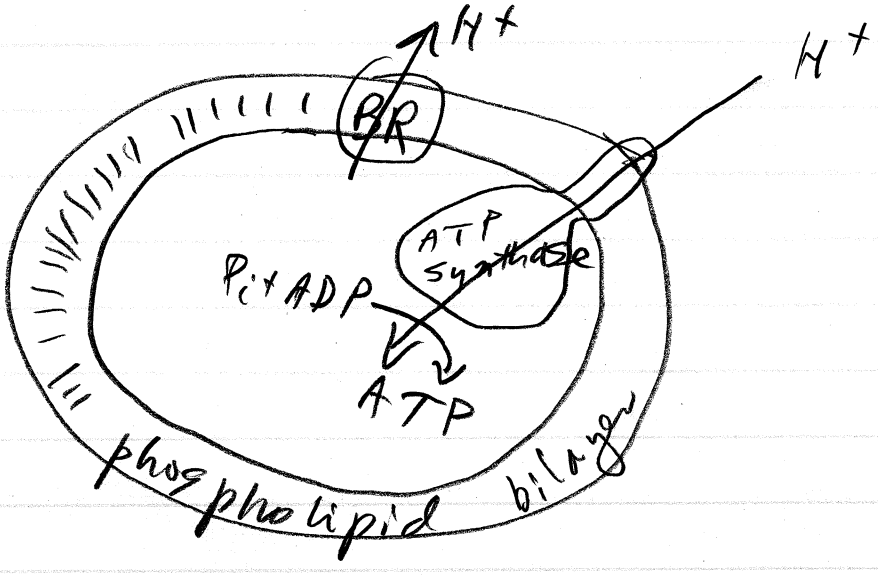
They use the H_2 extracted from the H_2O and the CO_2 to make sugars $(CH_2O)_n$ and other products.

$$h\nu + H_2O + CO_2 \rightarrow O_2 + CH_2O$$

Experiments show that H^+ in the stroma allows chloroplasts to make sugar without light.

Bacteriorhodopsin is a light-driven proton pump found in some archaea. (Archaea are members of one of the two major divisions of procaryotes, the other being the bacteria. (A procaryote is a single cell without a well-defined nucleus.))

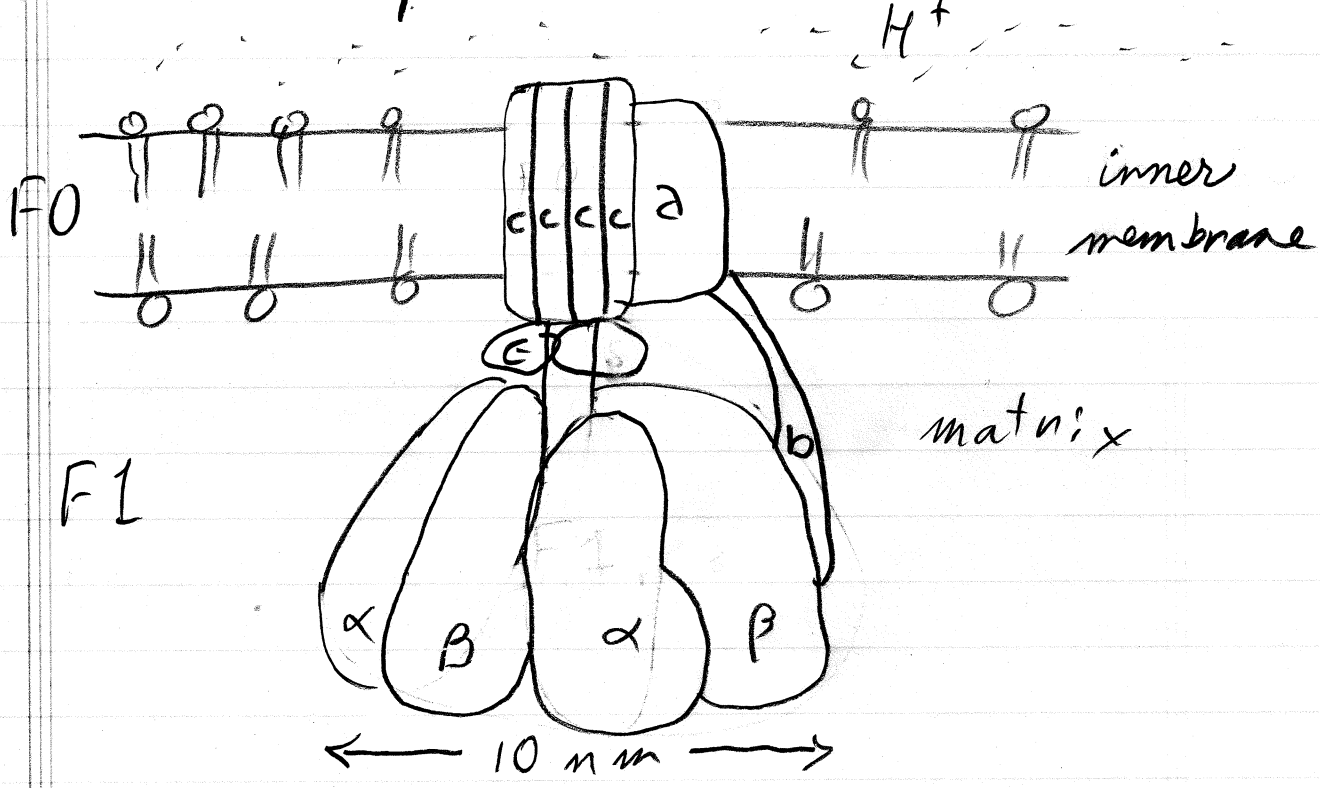
Experiments show that bacteriorhodopsin (BR) in an artificial lipid bilayer makes a pH gradient when exposed to light. When beef-heart ATP synthase is added to the membranes, they make ATP from ADP, P_i, and protons.



Ultrasound rips apart the inner membranes of mitochondria. Detergents like SDS, which are single-chain amphiphiles keep the inner membranes from reforming. These

disrupted membranes can oxidize NADH but can not make ATP, because the pumped H^+'s diffuse around them.

Also, membrane-channel proton pumps can short-circuit the mitochondrial membrane if they import protons. Animals do this to keep warm.



ATP synthase is an FO unit embedded in the inner membrane and

an F1 unit in the matrix. The 10-14 transmembrane units c rotate inside the units a, b, α, and β due to the passage of protons. Each time the rotating driveshaft passes one of the three β units, a P_i can be attached to an ADP making ATP. An ATP synthase can make over 100 molecules of ATP per second.

By itself, without a proton gradiant, the F1 unit catalyzes the hydrolysis of ATP to ADP + P_i.

Kinosita et al. attached a 1 μm, stiff actin filament to the c unit

and anchored the α,β units to a glass slide. When ATP was added to the solution, the actin filament rotated in 120° steps made visible by a fluorescent dye attached to the end of the filament. The filament got up to six revolutions per second. Kinosita et al. found the drag force f was

$$f \simeq 3.0\,\eta L v \qquad (11.17)$$

for a thin rod of length L dragged at speed v through a fluid of viscosity η.

11F (a) What is the torque needed to rotate a thin rod of length L at ω?

$\vec{\tau} = \vec{r} \times \vec{f}$ so here $v = \omega x$,

$|\vec{r}| = x$, and L is a sum of dx's:

$$\tau = 3\eta \int_0^L \omega x^2 dx = 3\eta\omega \frac{L^3}{3}$$

$$= \eta \omega L^3.$$

So if $\eta = 10^{-3}$ Pa s, and $\omega = 6 \cdot 2\pi\, s^{-1}$,

and $L = 10^{-6}$ m, then

$$\tau = 10^{-3}\ \text{Pa s}\ 12\pi\ s^{-1}\ 10^{-18}\ m^3$$

$$= 1.2\pi\ 10^{-20}\ N\, m^{-2} m^3$$

$$= 3.8 \cdot 10^{-20}\ N m = 38\ pN\, nm.$$

(b) $\Delta W = \tau \Delta\theta = \tau \frac{2\pi}{3} = 79\ pN\, nm.$

11G Suppose $c_{ATP} = 2\ mM$, $c_{ADP} = 10\ \mu M$, and $c_{P_i} = 10\ mM$. (a) What's ΔG for $ATP \rightarrow ADP + P_i$?

$$\Delta G = \mu_{ADP} + \mu_{P_i} - \mu_{ATP}$$

From problem 10.4 on p. 465, we find

$$\Delta G'^{0} = -7.3 \text{ kcal/mole}$$

$$= -7.3\ 10^{3} \cdot \frac{4.184\ J}{6\ 10^{23}} = -5.1\ 10^{-20}\ J,$$

$$\Delta G = \Delta G'^{0} + kT \ln \frac{[ADP][P_i]}{[ATP]}$$

$$= -5.086\ 10^{-20}\ J + kT \ln \frac{10^{-5}\ 10^{-2}}{2\ 10^{-3}}$$

$$= -5.086\ 10^{-20}\ J + 4.1\ 10^{-21}\ J \ln \frac{10^{-4}}{2}$$

$$= -5.086\ 10^{-20} + 4.1\ 10^{-21}(-9.9) \quad J$$

$$= (-5086 - 40.59)\ 10^{-21}\ J$$

$$= -91\ pN\ nm,$$

(b) So the efficiency is $79/91 = 87\%$, which is very high.

Cells pump ions because they

1) segregate (macro) molecules in vesicles

2) use negatively charged macromolecules to keep them from clumping

3) need to balance osmotic pressures.

Chemiosmosis is used in many ways. Plants have chloroplasts, which are like mitochondria. Bacteria and archaea pump protons using food or light as their energy source.

Cells use ATP to pump Ca^{2+} out. Lactose permease lets in a proton and a sugar. It's a <u>symport</u>. The sodium-calcium exchanger lets Na^+ in to force Ca^{2+} out; it's an antiport.

The flagellar motor, like FO,

spins at up to 100 revolutions per second

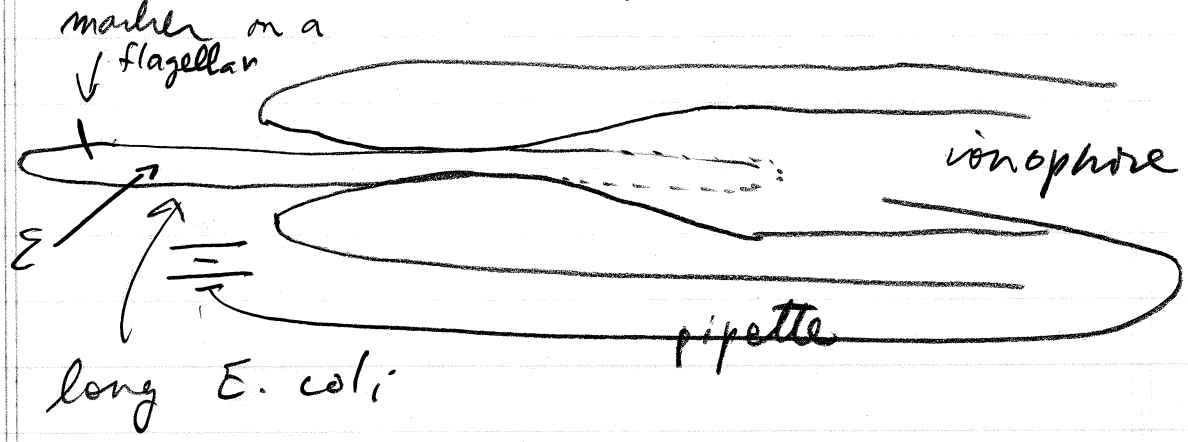
letting 1000 protons into the bacterium per revolution.

E. coli is 1 μm in diameter

and 2 μm long. Berg et al. grew

E. coli in cephalexin which prevents cell

division. The cells just grew longer.



The ionophore made the inner

membrane permeable to ions. They used

a voltage clamp to put up to 200 mV

across the intact membrane. The marker

spun at a speed that increased with increasing voltage, which forced more H^+ into the E. coli. When they reversed the polarity, the marker spun a few times and then stopped. A change back to the correct polarity got the flagellar spinning again.