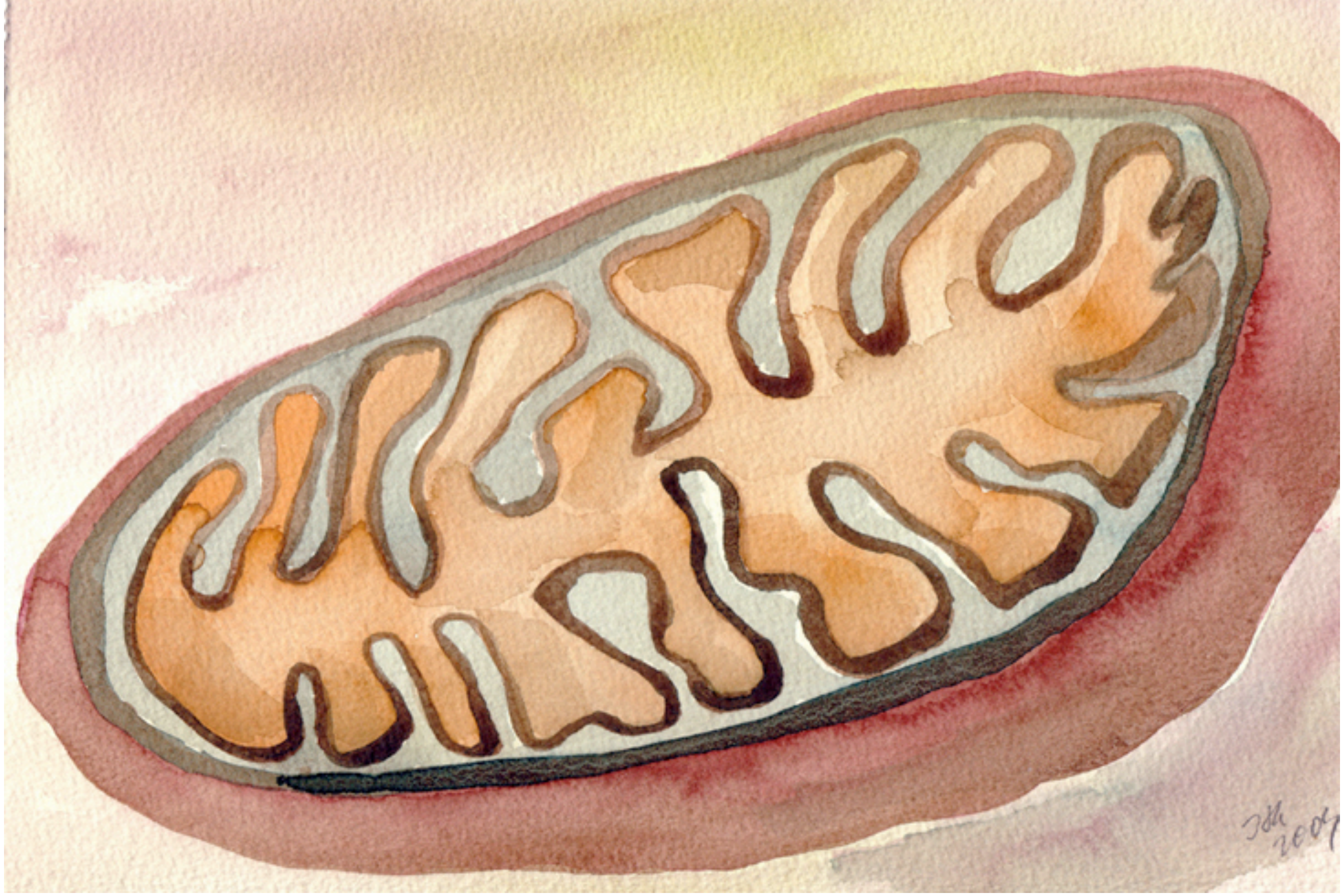

JSK
2004

A mitochondrion—one of many tiny power-houses within cells that control our lives in surprising ways



Mitochondria are tiny organelles inside cells that generate almost all our energy in the form of ATP. On average there are 300–400 in every cell, giving ten million billion in the human body. Essentially all complex cells contain mitochondria. They look like bacteria, and appearances are not deceptive: they were once free-living bacteria, which adapted to life inside larger cells some two billion years ago. They retain a fragment of a genome as a badge of former independence. Their tortuous relations with their host cells have shaped the whole fabric of life, from energy, sex, and fertility, to cell suicide, ageing, and death.

Membrane Proteins

Mitochondria and respiratory chains

John F. Allen

School of Biological and Chemical Sciences,
Queen Mary, University of London

Queen Mary
University of London

Some references

Nicholls DJ, Ferguson, SJ. Bioenergetics3. Academic Press/Elsevier Science 2002

Some references

Nicholls DJ, Ferguson, SJ. Bioenergetics3. Academic Press/Elsevier Science 2002

Molecular Biology of the Cell Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter. Fifth edition. 2007.Garland publishing.

Some references

Nicholls DJ, Ferguson, SJ. Bioenergetics3. Academic Press/Elsevier Science 2002

Molecular Biology of the Cell Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter. Fifth edition. 2007.Garland publishing.

Lane N. Power, Sex, Suicide. Mitochondria and the Meaning of Life. Oxford University Press. October 2005.

Presentations

and

supplementary information

jfallen.org/lectures/

Queen Mary
University of London

Lectures in Membrane Proteins

References

- Nicholls DJ, Ferguson, SJ. Bioenergetics3. Academic Press/Elsevier Science 2002
- Molecular Biology of the Cell Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter. 2002. Garland Science
- Lane N. Power, Sex, Suicide. Mitochondria and the Meaning of Life. Oxford University Press. October 2005

Specialist web sites

- Complex I Home Page
- News on the 3D structure from the Complex I Home Page
- Complex III Home Page
- Cytochrome oxidase home page. Complex IV, the subject of the lecture by Professor Peter Rich

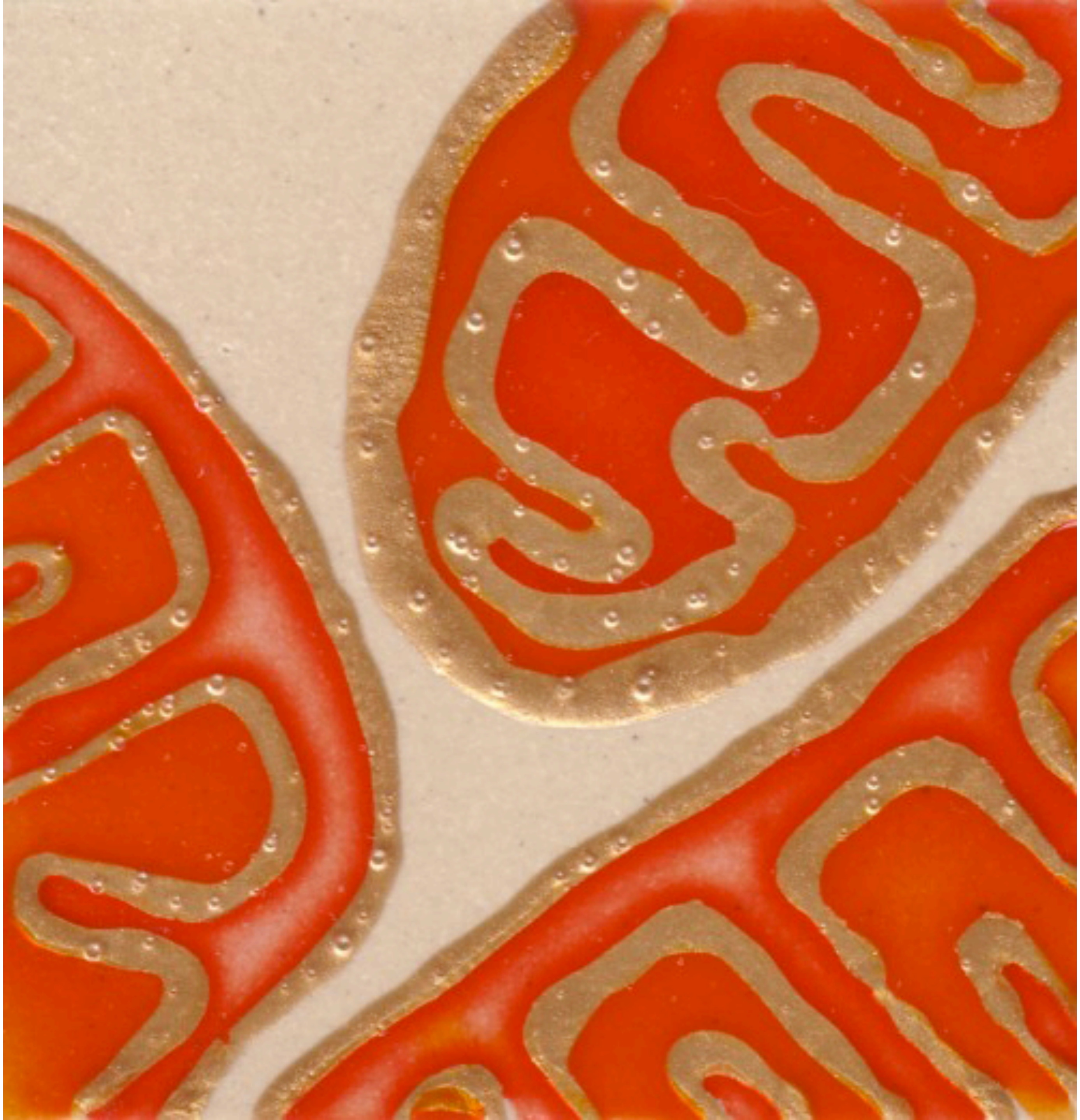
---

Qo. The movie

- Qo.mov

Molecule of the Month

- ATP Synthase
- Bacteriorhodopsin
- Cytochrome c
- Cytochrome c Oxidase
- Photosystem I
- Photosystem II
- Potassium Channels



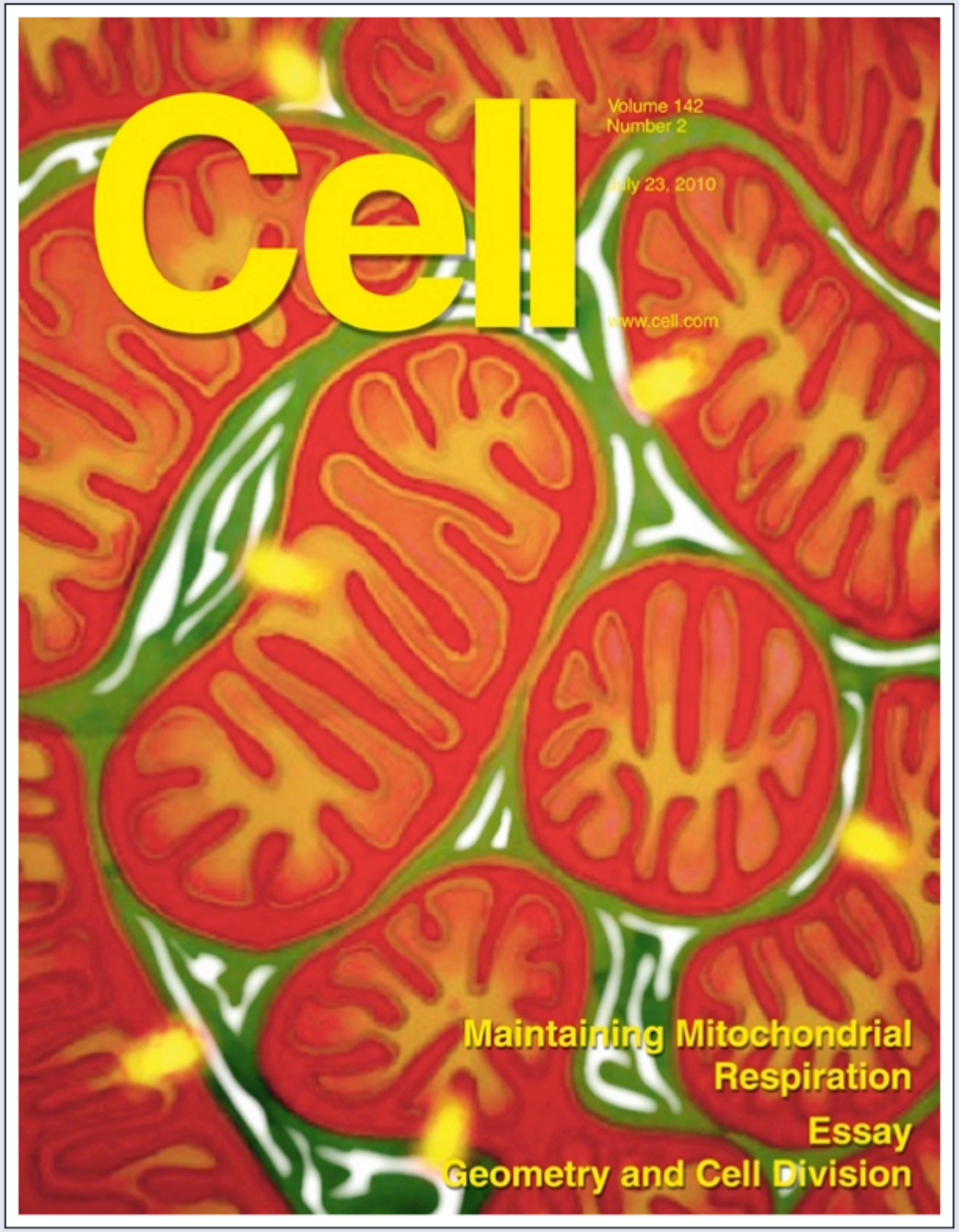
Mitochondrial membranes and chemiosmotic coupling

The elementary particles of life—energy generating proteins in the mitochondrial membranes


JSK
2004

The way in which mitochondria generate energy is one of the most bizarre mechanisms in biology. Its discovery has been compared with those of Darwin and Einstein. Mitochondria pump protons across a membrane to generate an electric charge with the power, over a few nanometres, of a bolt of lightning. This proton power is harnessed by the elementary particles of life—mushroom-shaped proteins in the membranes—to generate energy in the form of ATP. This radical mechanism is as fundamental to life as DNA itself, and gives an insight into the origin of life on Earth


GBE
Genome Biology and Evolution



Volume 142, Issue 2

On the cover: Eukaryotic cells rely on aerobic mitochondrial metabolism to generate ATP. Here, Cárdenas et al. (pp. 270–283) demonstrate that constitutive low-level Ca2+ release through endoplasmic reticulum InsP3 receptor release channels (yellow flashes), in close proximity to mitochondria, is essential for mitochondria to produce sufficient ATP and to maintain normal cell bioenergetics. The image is modified from the original artwork of Odra Noel, with her permission (http://www.odranoel.eu).

Does life inherently become more complex? There may be nothing in the genes to push life up a ramp of ascending complexity, but one force lies outside the genes. Size and complexity are usually linked, for larger size requires greater genetic and anatomical complexity. But there is an immediate advantage to being bigger: more mitochondria means more power and greater metabolic efficiency. It seems that two revolutions were powered by mitochondria—the accumulation of DNA and genes in eukaryotic cells, giving an impetus to complexity, and the evolution of warm-blooded animals, which inherited the earth

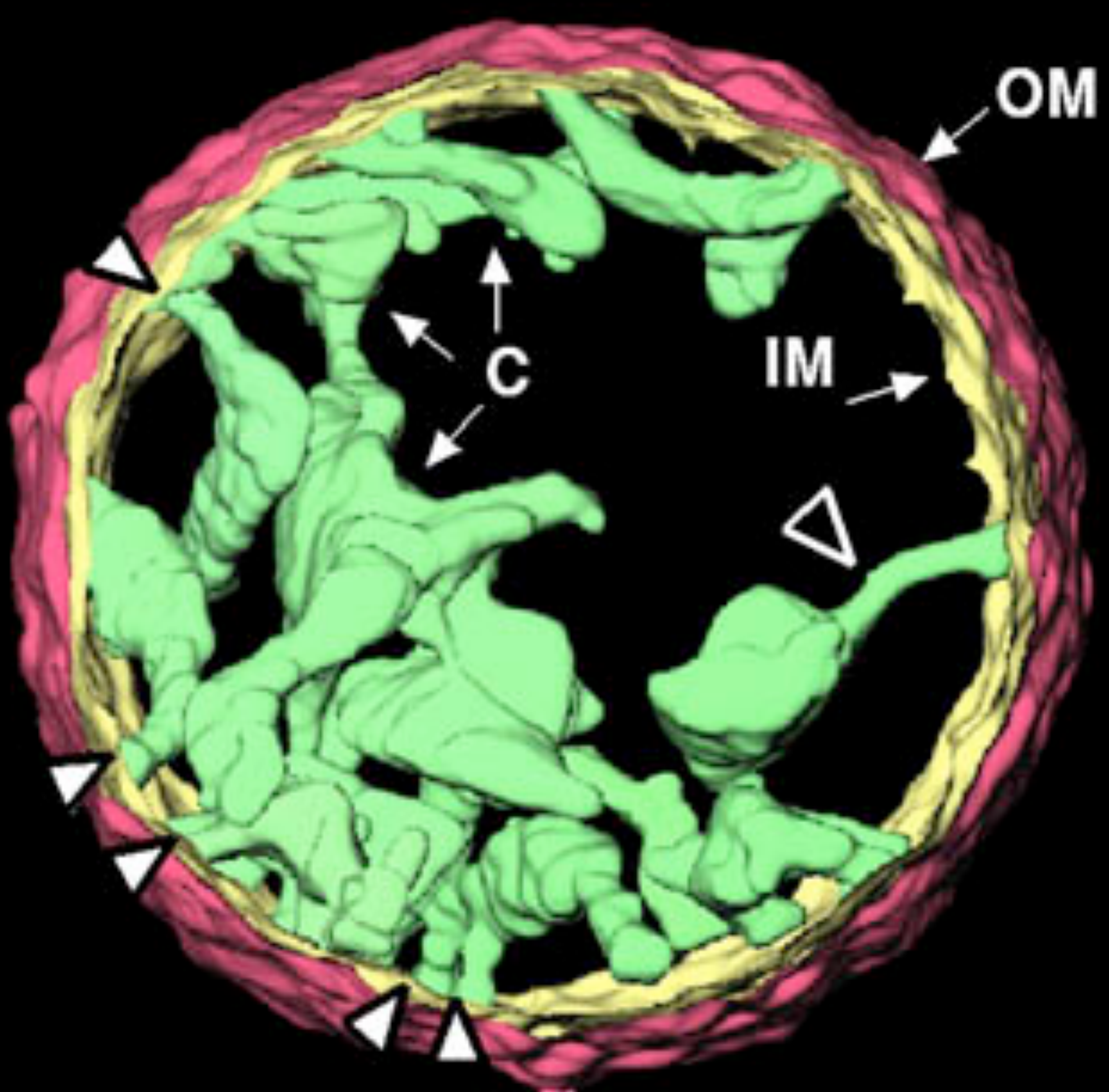
Why do chloroplasts and mitochondria have genomes?
(Acrobat, .pdf file)

From:
Lectures in Cell Biology and Developmental Genetics

Tomograph of rat liver mitochondrion

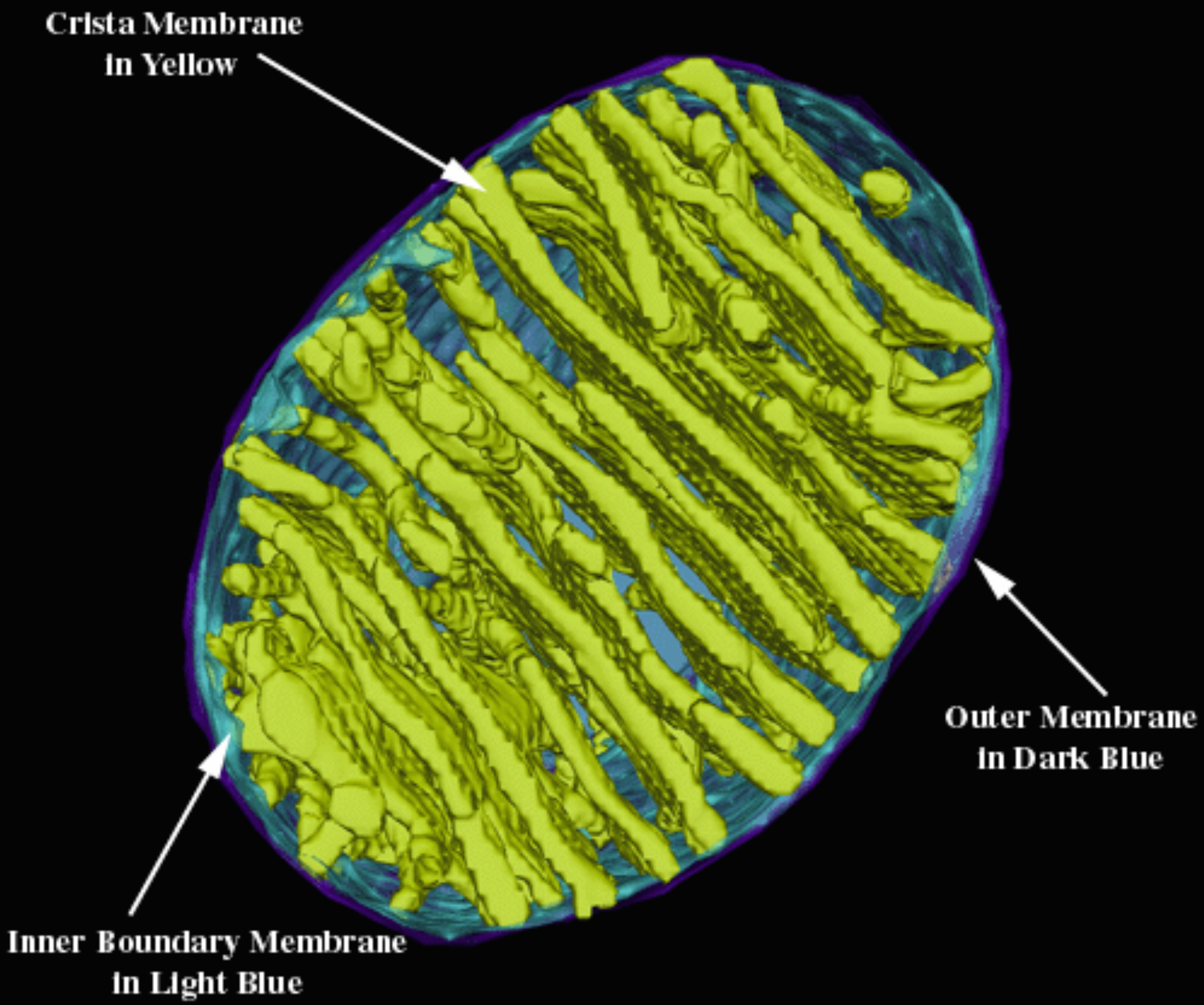
C.A. Mannella, Wadsworth Center

http://www.wadsworth.org/BMS/SCBlinks/channels2.htm

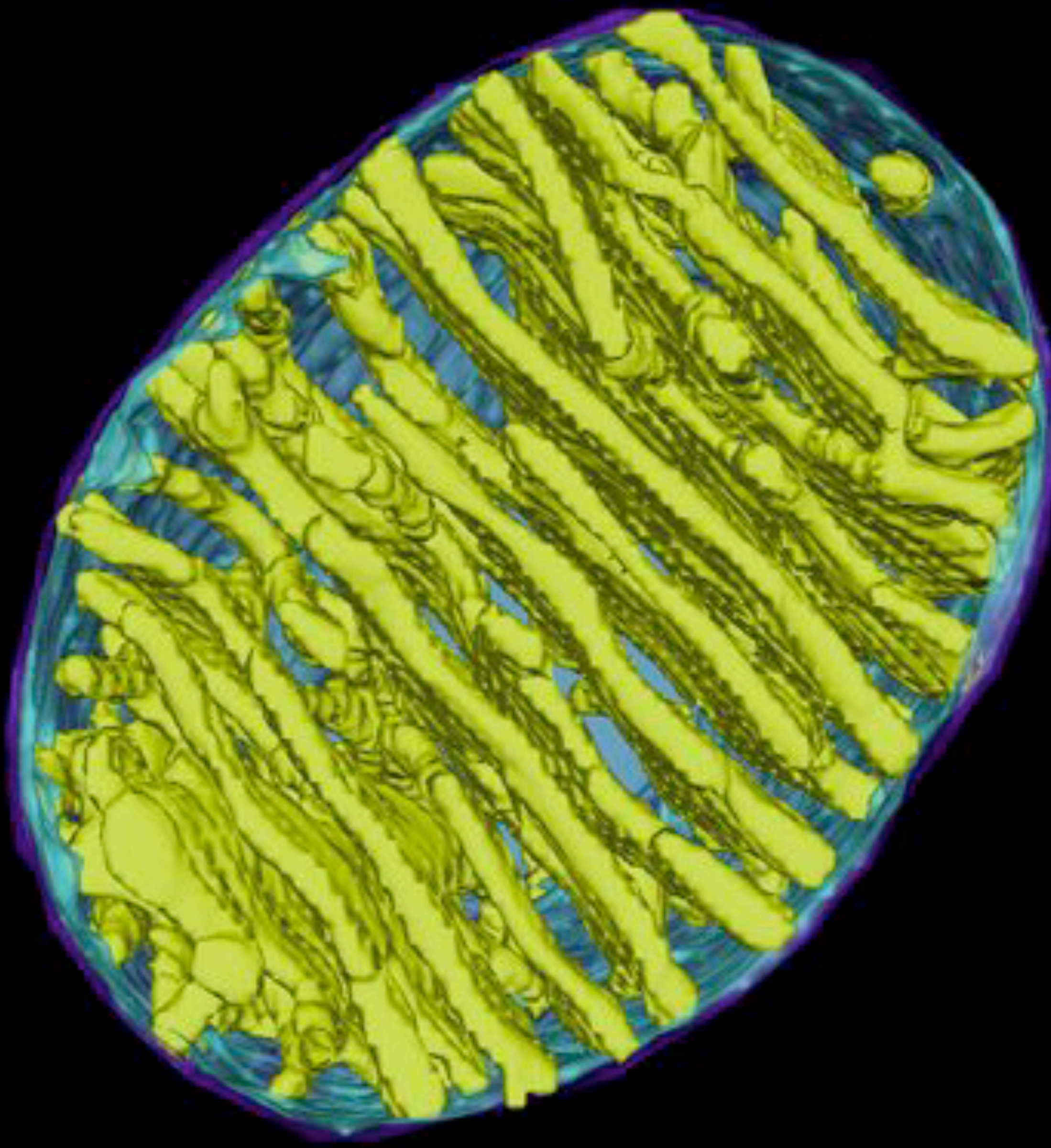


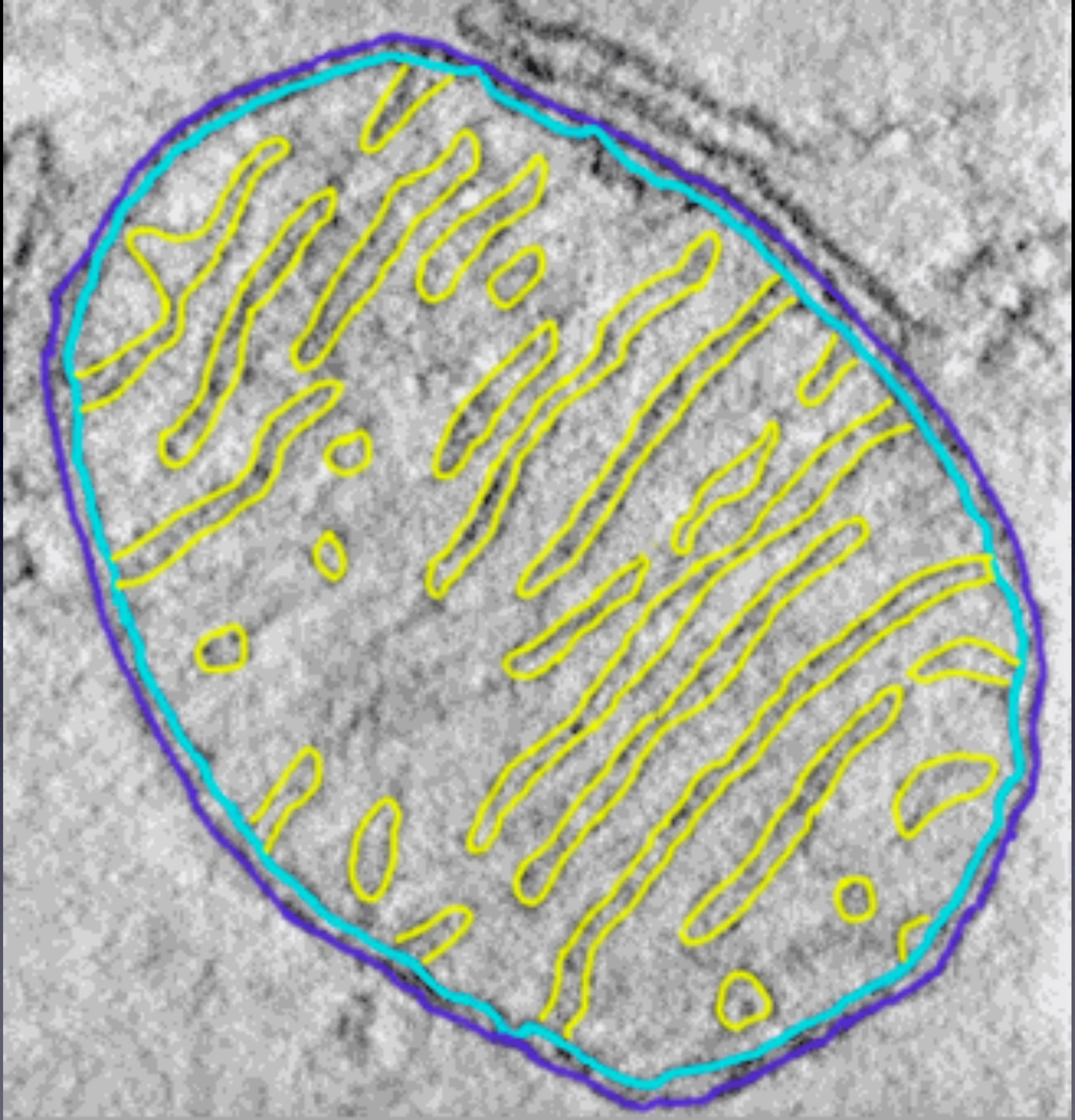
This is a look inside an isolated mitochondrion, showing the outer membrane (OM), inner peripheral membrane (IM), and some of the internal compartments called cristae (C) formed by infolding of the inner membrane. Arrows point to narrow tubular regions of the IM that connect cristae to periphery and to each other.

Mitochondrial morphology

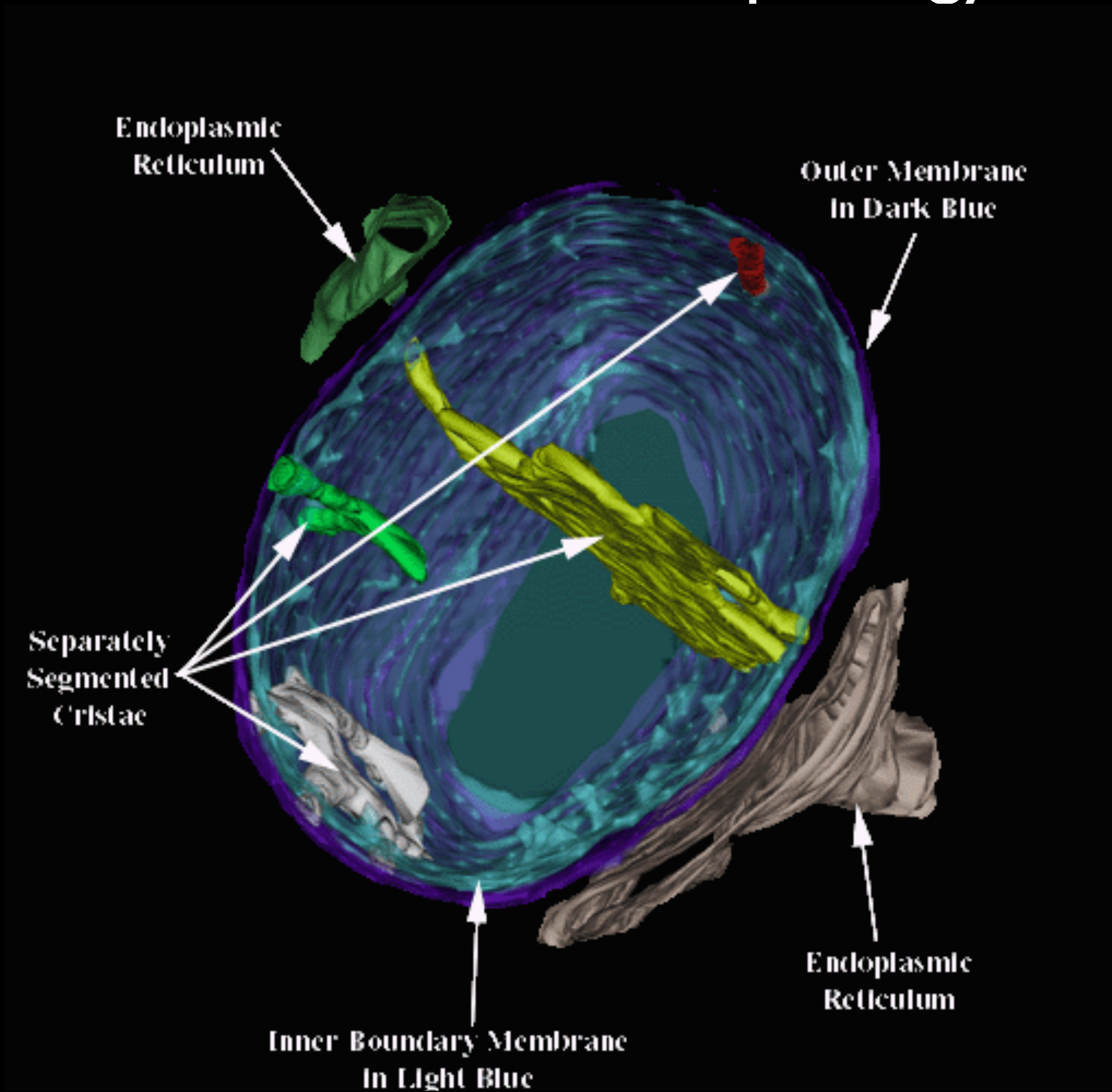


Terry Frey (San Diego State Univ.)

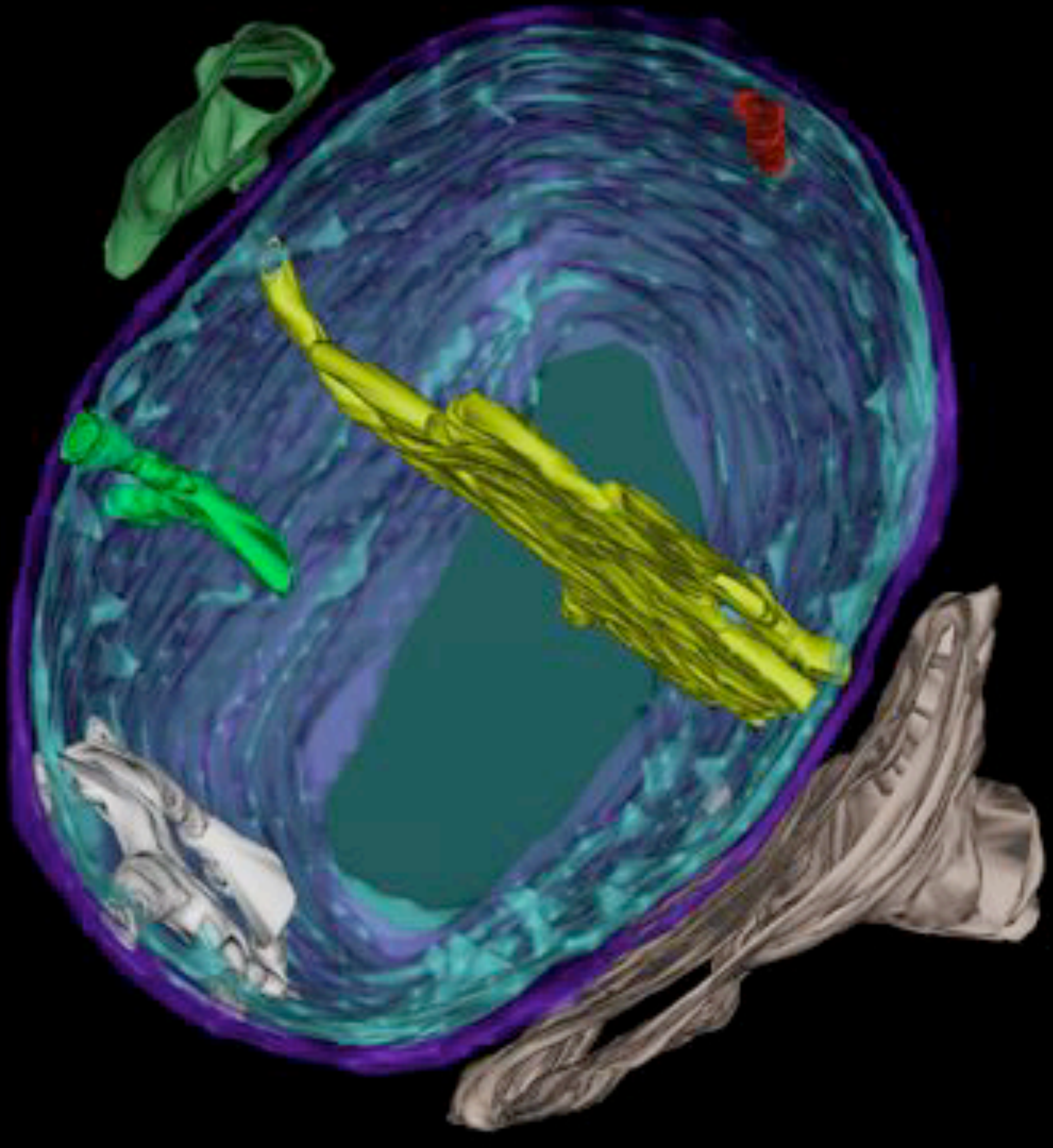




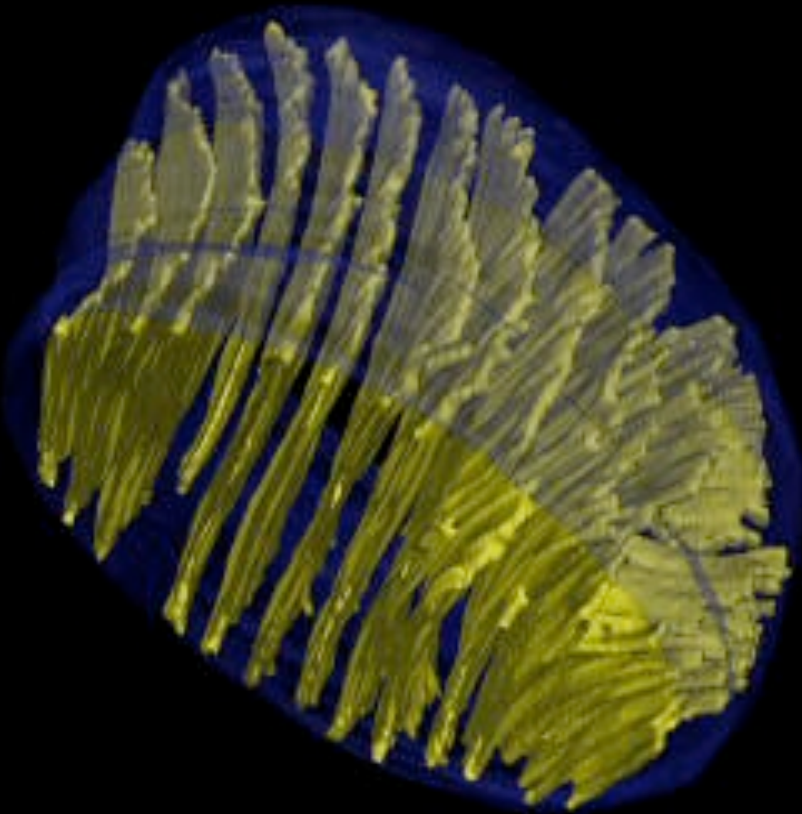
Mitochondrial morphology



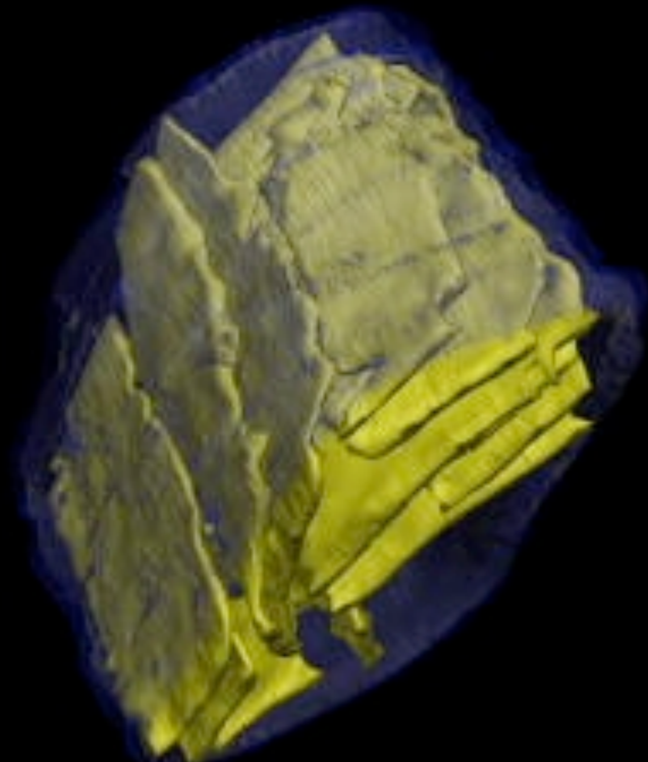
Terry Frey (San Diego State Univ.)



Mitochondrial morphology



Brown fat adipose tissue



Terry Frey (San Diego State Univ.)
Guy Perkins (UCSD)

Neurospora

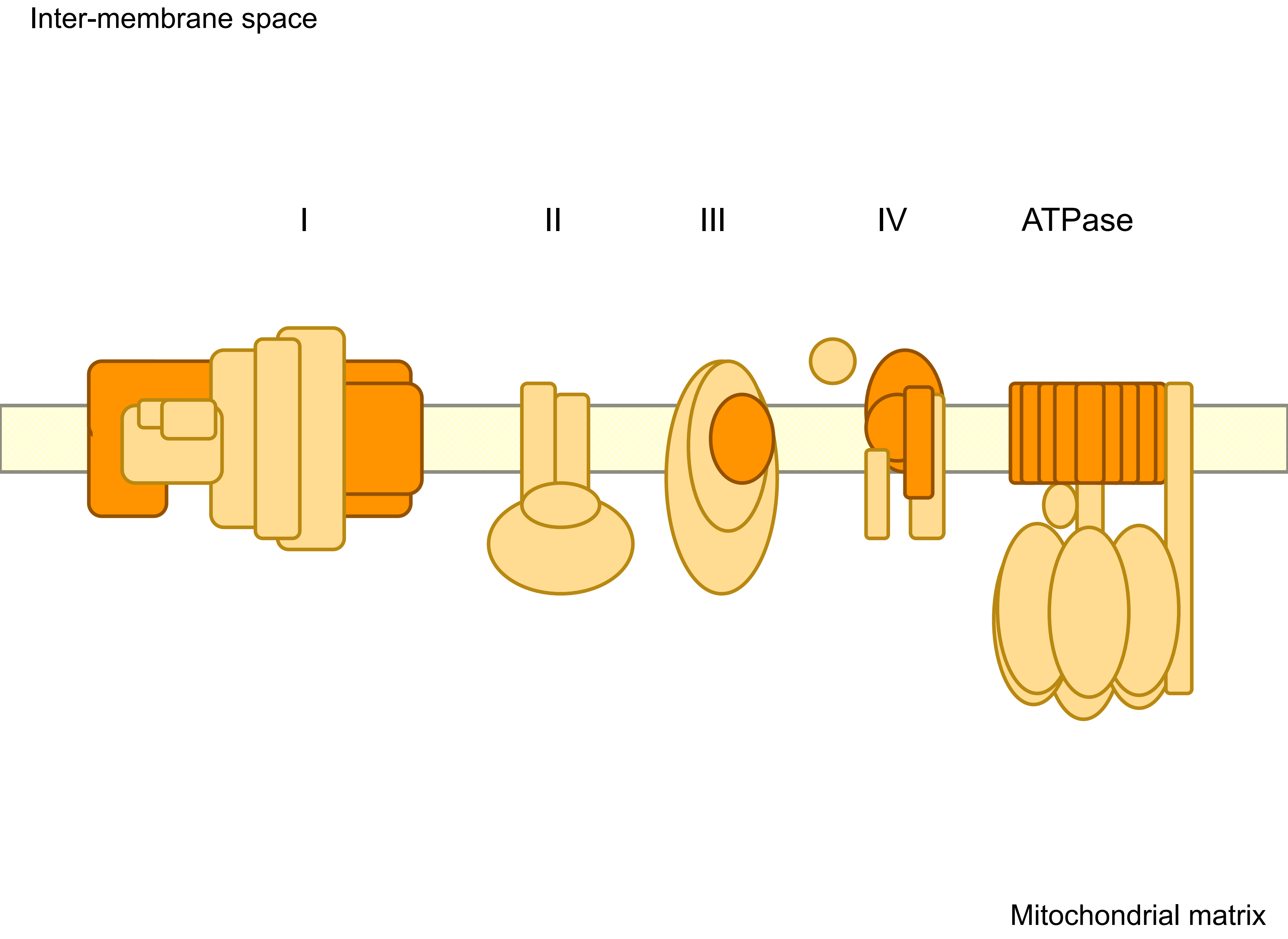
Protein subunit encoded in mitochondrial DNA

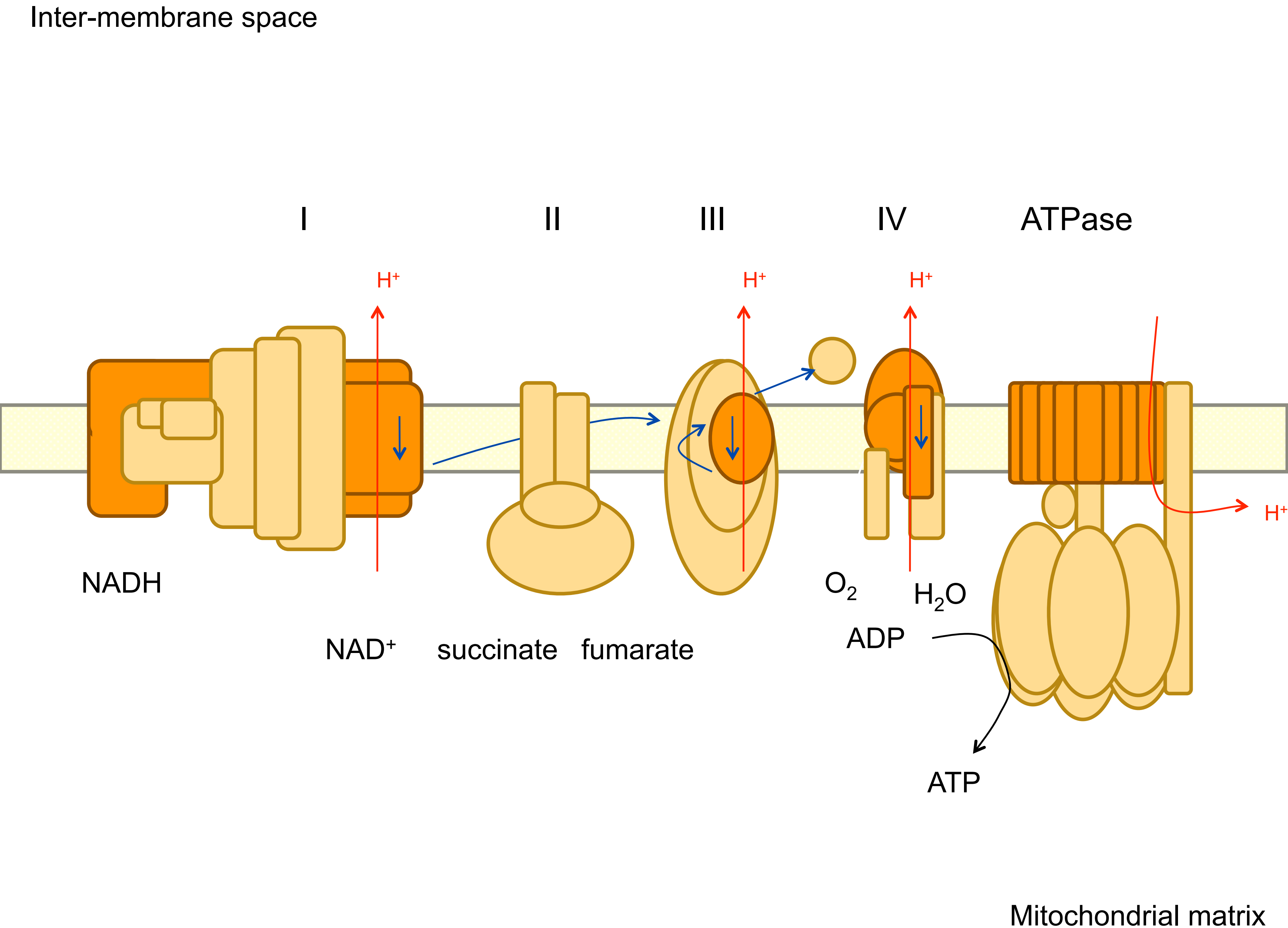
Protein subunit encoded in nuclear DNA

Mitochondrial inner membrane

Direction of vectorial proton translocation

Direction of electron transfer


Inter-membrane space
I
II
III
IV
ATPase
Mitochondrial matrix



Inter-membrane space
I
II
III
IV
ATPase
H+
H+
H+
H+
NADH
NAD+
succinate
fumarate
O2
H2O
ADP
ATP
Mitochondrial matrix

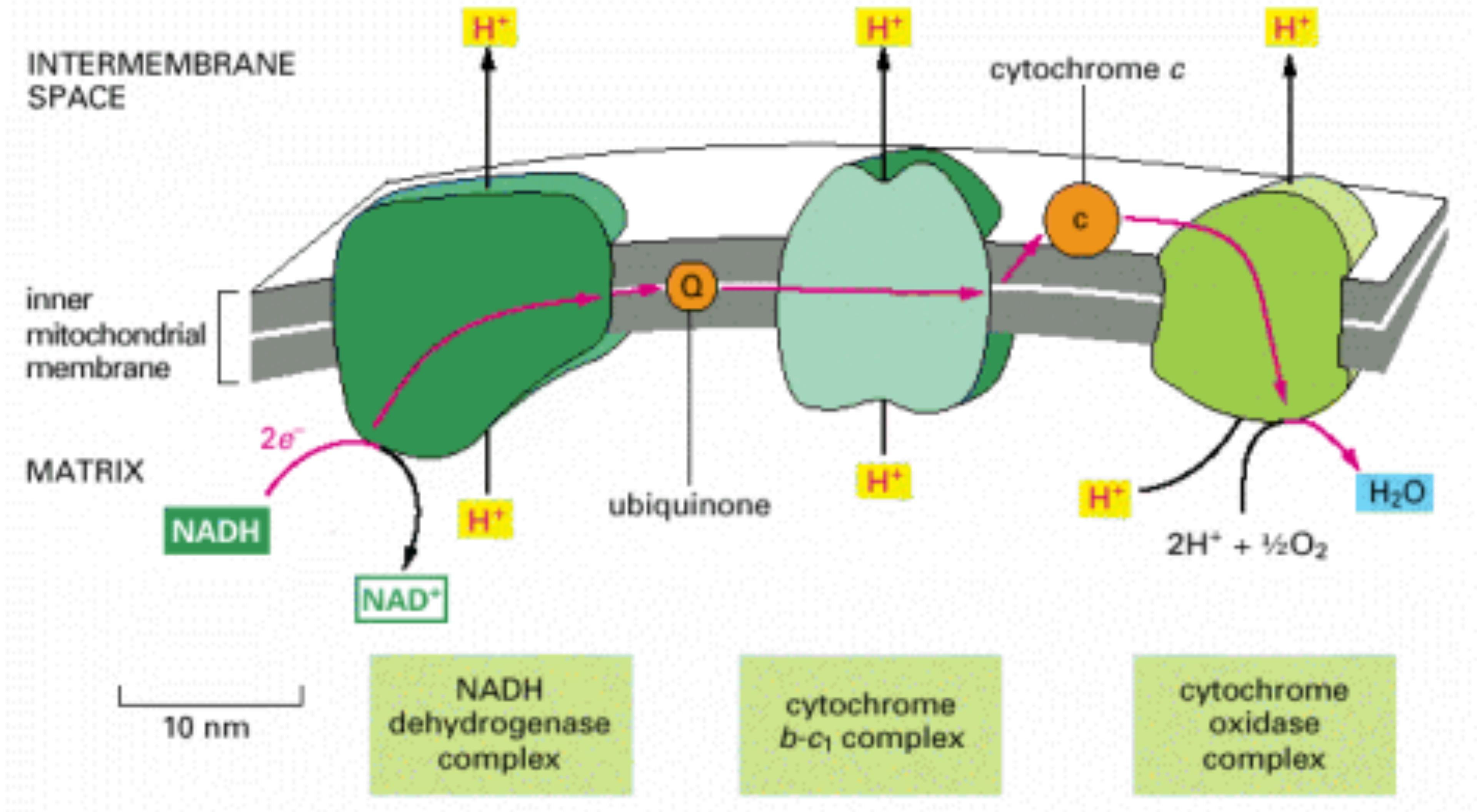


Figure 14-26. The path of electrons through the three respiratory enzyme complexes. The relative size and shape of each complex are shown. During the transfer of electrons from NADH to oxygen *(red lines),* ubiquinone and cytochrome *c* serve as mobile carriers that ferry electrons from one complex to the next. As indicated, protons are pumped across the membrane by each of the respiratory enzyme complexes.

Molecular Biology of the Cell Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter. 2007

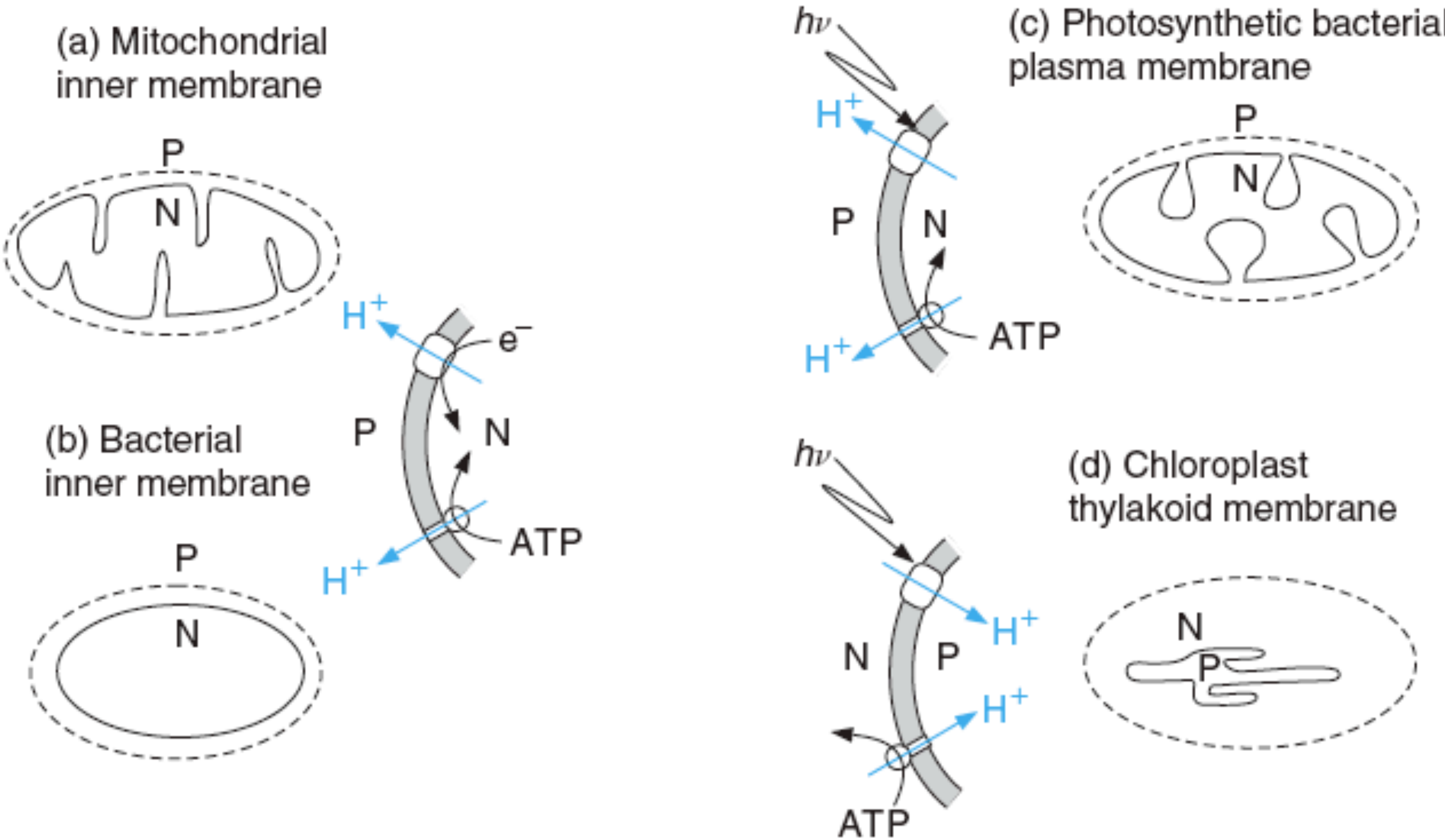


Figure 1.1 Energy-transducing membranes contain pairs of proton pumps with the same orientation.
In each case the primary pump utilizing either electrons (e^-) or photons ($h\nu$) pumps protons from the N (negative) compartment to the P (positive) compartment. Note that the ATP synthase in each case is shown acting in the direction of ATP hydrolysis, when it would also pump protons from the N- to the P-phase.

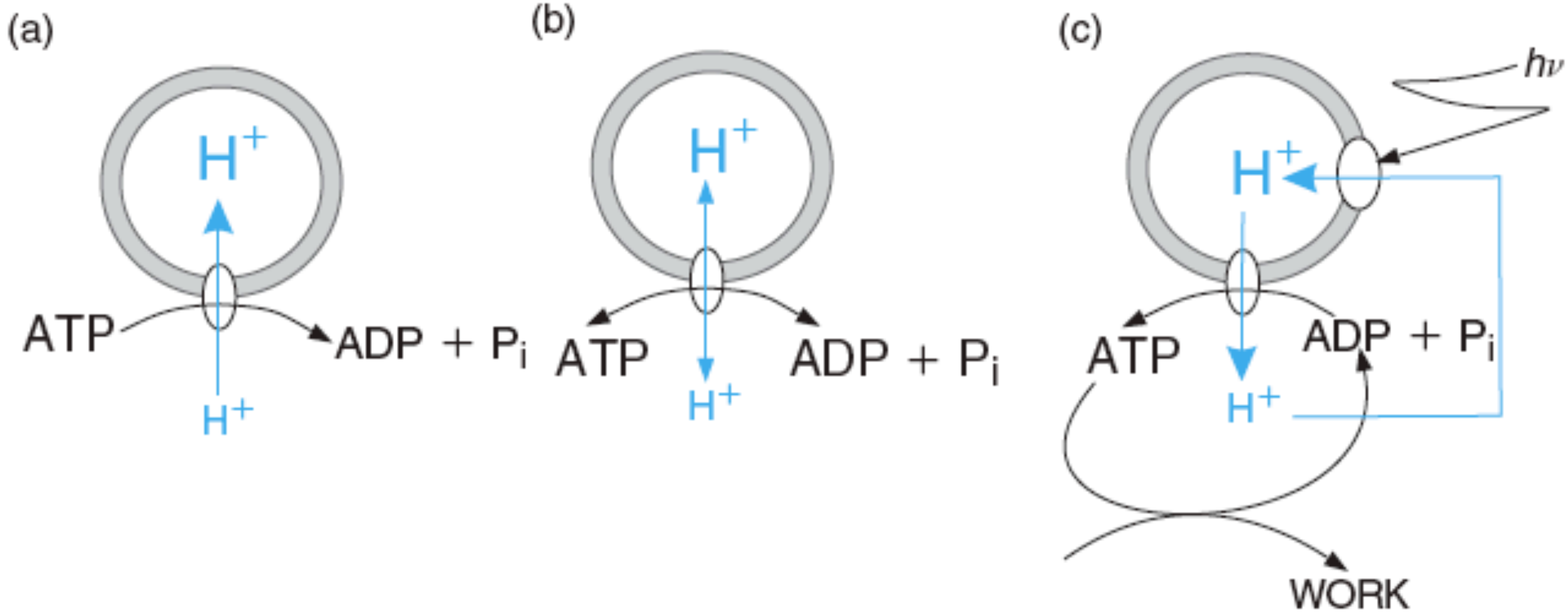


Figure 1.2 A hypothetical 'thylakoid' to demonstrate chemiosmotic coupling. An ATP synthase complex is incorporated into a phospholipid membrane such that the ATP binding site is on the outside. (a) ATP is added, the nucleotide starts to be *hydrolysed* to ADP + P_i and protons are pumped into the vesicle lumen. As ATP is converted to ADP + P_i the energy available from the hydrolysis steadily decreases, while the energy required to pump further protons against the gradient which has already been established steadily increases. (b) Eventually an equilibrium is attained. (c) If this equilibrium is now disturbed, for example, by removing ATP, the ATP synthase will reverse and attempt to re-establish the equilibrium by *synthesizing* ATP. Net synthesis, however, would be very small as the gradient of protons would rapidly collapse and a new equilibrium would be established. For continuous ATP synthesis, a primary proton pump, driven in this example by photons ($h\nu$), is required to pump protons across the same membrane and replenish the gradient of protons. *A proton circuit has now been established.*

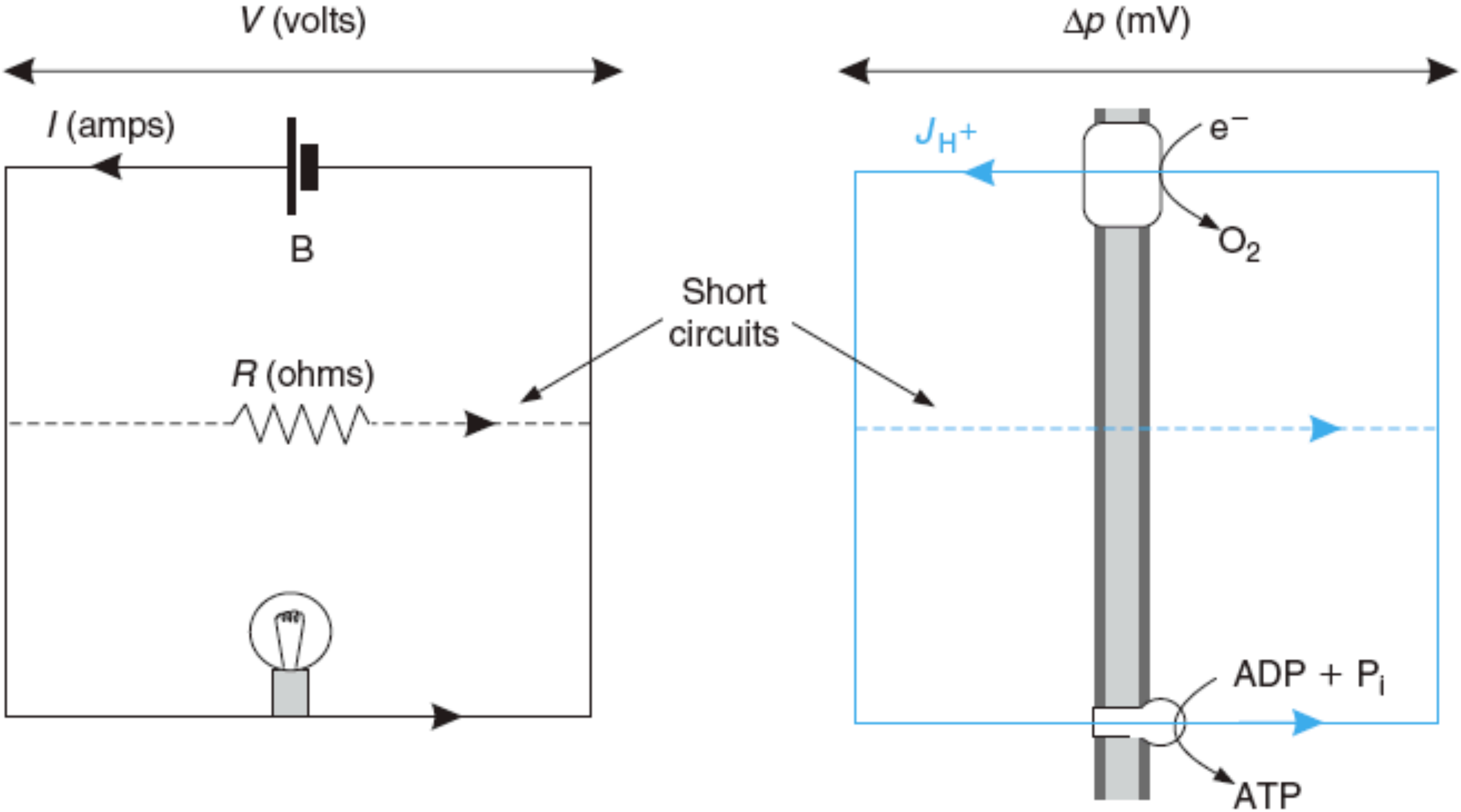


Figure 1.3 Proton circuits and electrical circuits are analogous. A simple electrical circuit comprising battery and light bulb is analogous to a basic proton circuit. Voltage (Δp equivalent to V), current (J_{H^+} equivalent to I) and conductance C_MH^+ (equivalent to electrical conductance – reciprocal ohms) terms can be derived. Short-circuits have similar effects and more complex circuits with parallel batteries can be devised to mimic the multiple proton pumps in the mitochondrion (see Chapter 4).

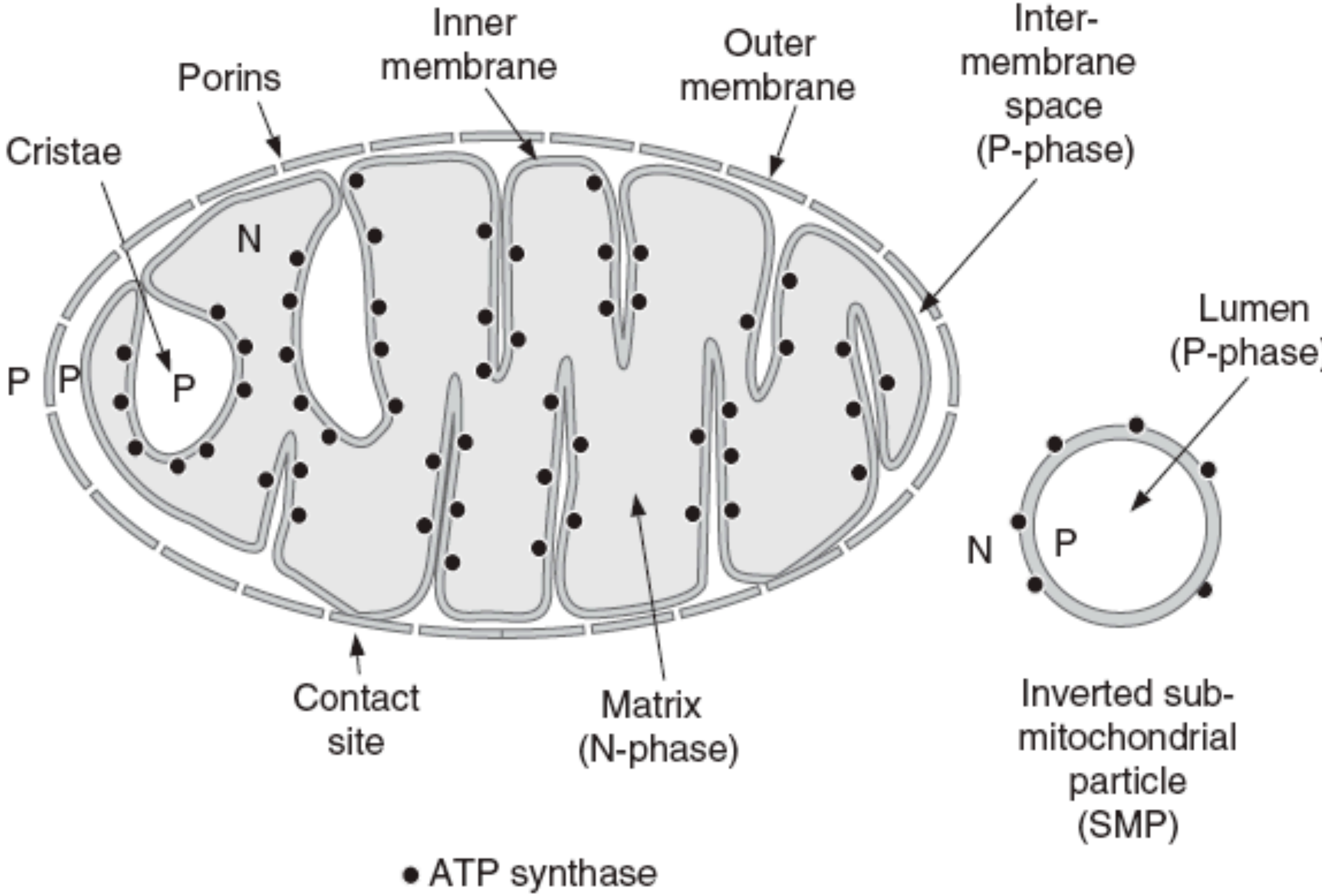


Figure 1.4 Schematic representation of a typical mitochondrion and sub-mitochondrial particle.
P and N refer to the positive and negative compartments. Note that the shape of the cristae is highly variable and that communication between cristae and inter-membrane space may be restricted.

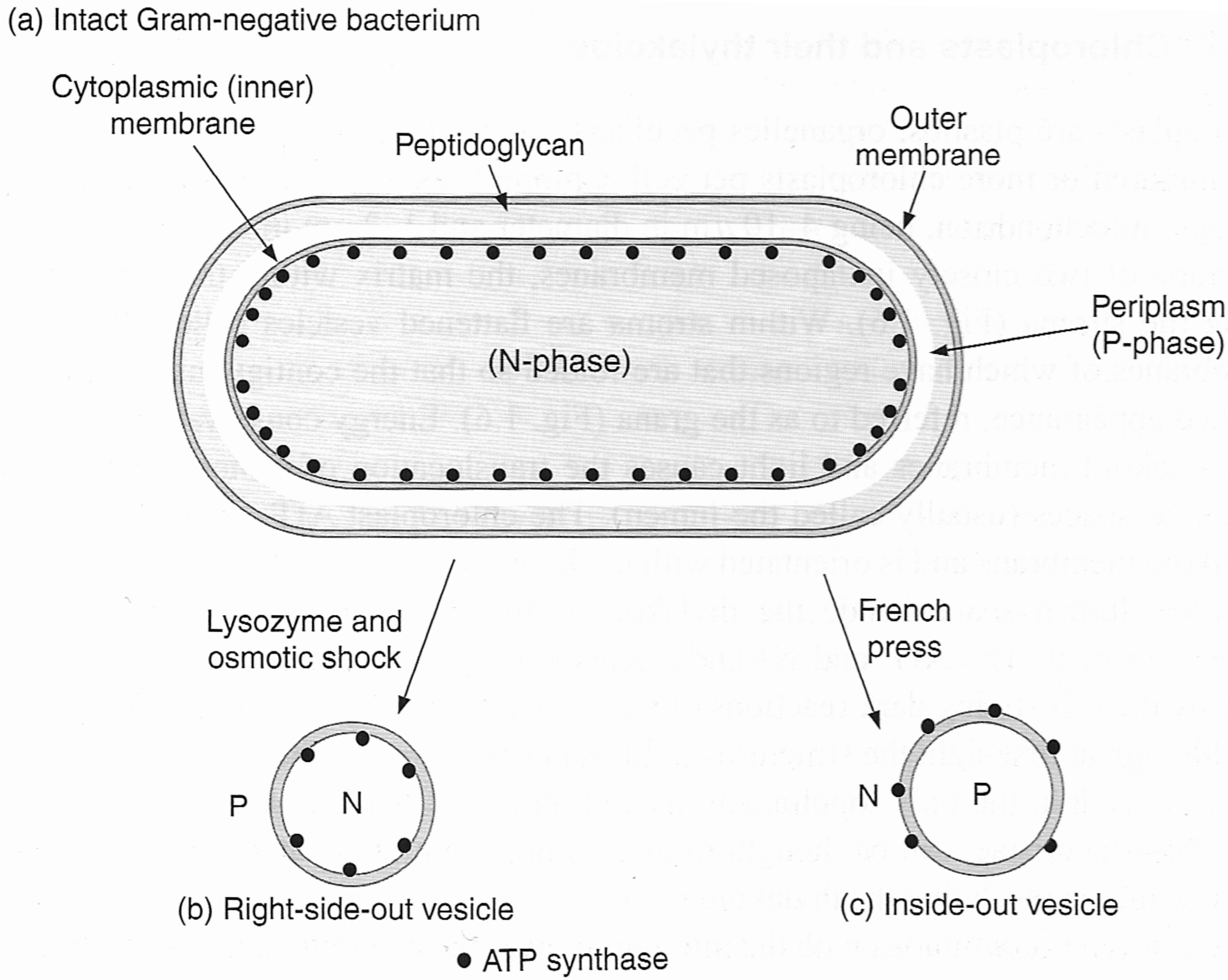


Figure 1.5 Gram-negative bacteria and vesicle preparations. P and N refer to positive and negative compartments. The periplasm is part of the P-phase, which also includes the bulk external medium, since the outer membrane is freely permeable to ions. Note that Gram-positive bacteria differ by lacking an outer membrane and a periplasm. Nevertheless, similar vesicle preparations can be made from these organisms as is also the case for the archaea.

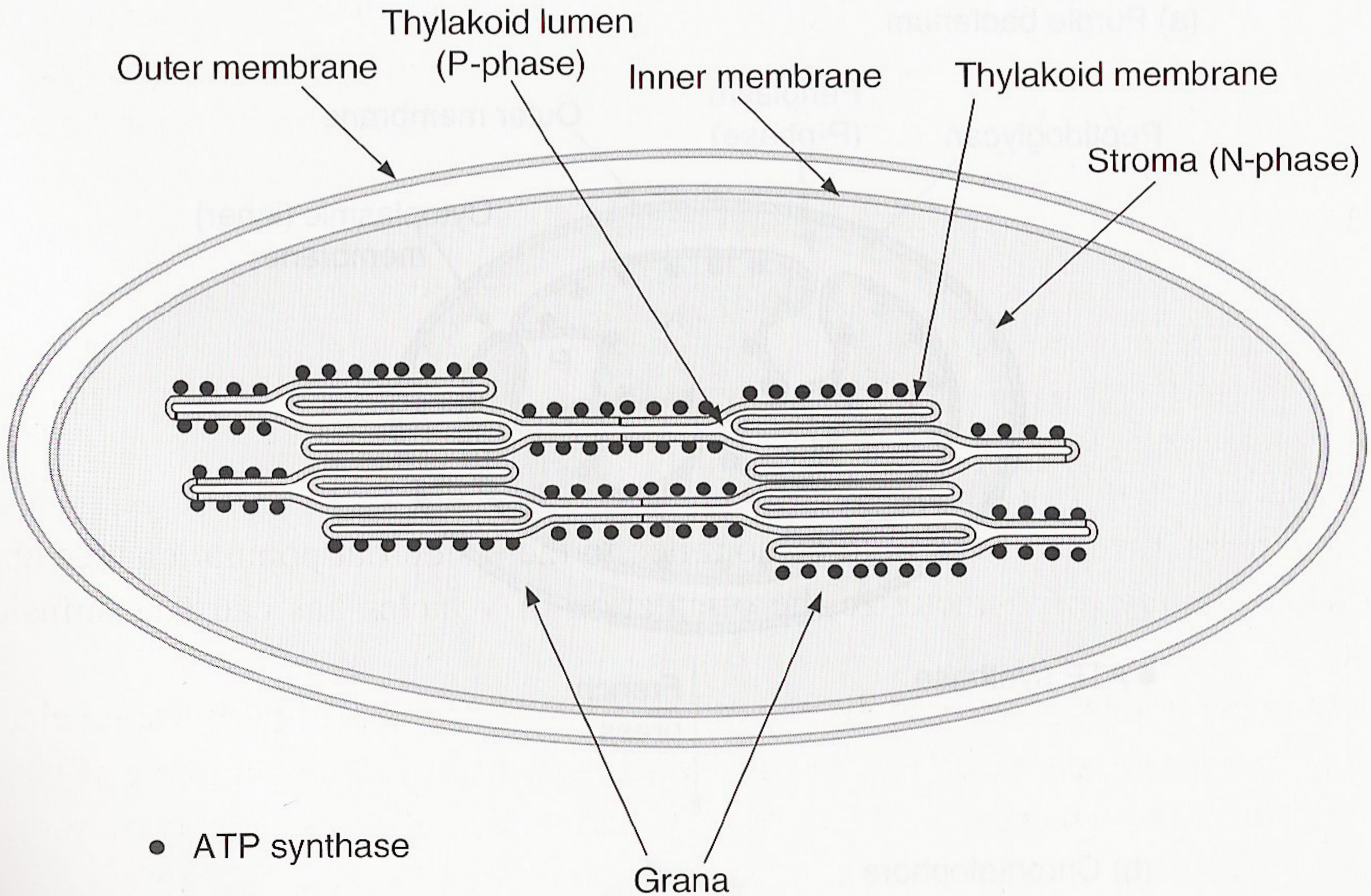


Figure 1.6 Chloroplasts and their thylakoids.
Note it is probable that there is a single continuous lumen (the internal thylakoid space). The thylakoid membrane is heterogeneous with, for example, the ATP synthase being excluded from the grana (appressed regions) where the membrane is closely stacked (see Chapter 6). Light-driven proton pumping occurs from the N- to the P-phase (note, however, that in steady-state light the membrane potential across a thylakoid membrane is negligible and that the pH gradient dominates – see Chapter 6).

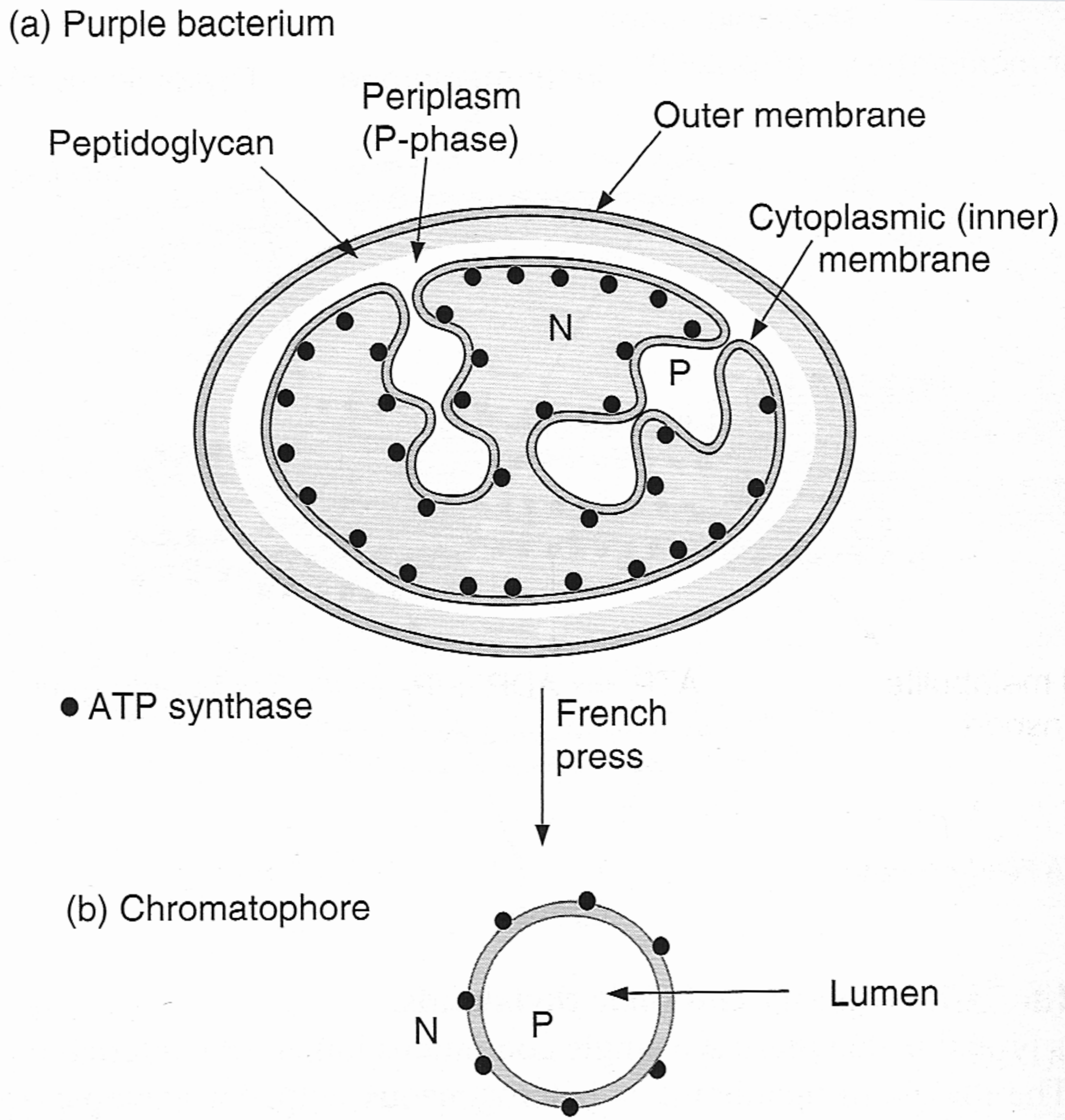


Figure 1.7 Photosynthetic bacteria and chromatophores. The cytoplasmic membrane of photosynthetically grown organisms such as *Rhodobacter sphaeroides* is highly invaginated. When the cells are forced through a narrow orifice at high pressure (the French press), the membranes pinch off as shown to give chromatophores.

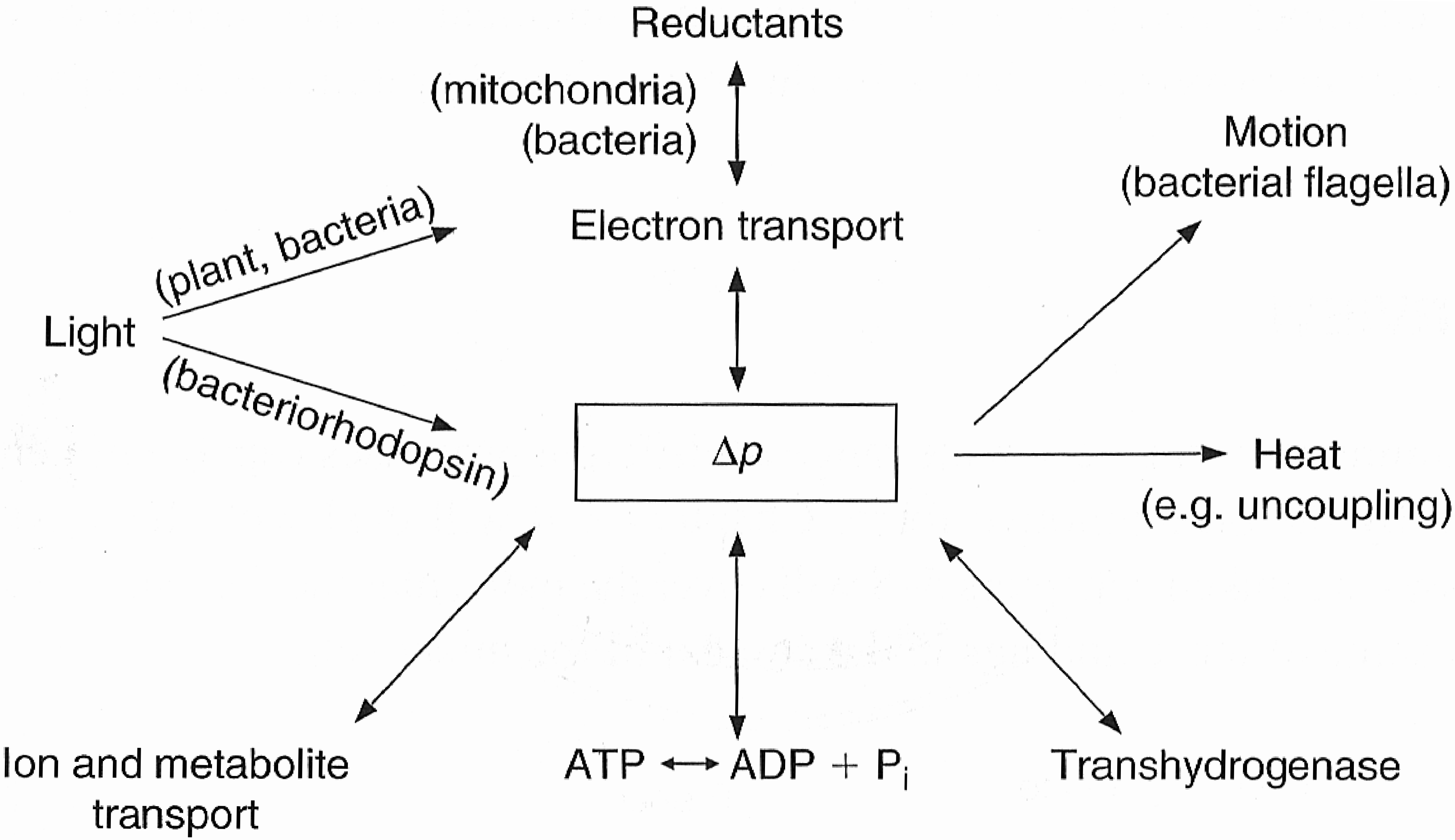
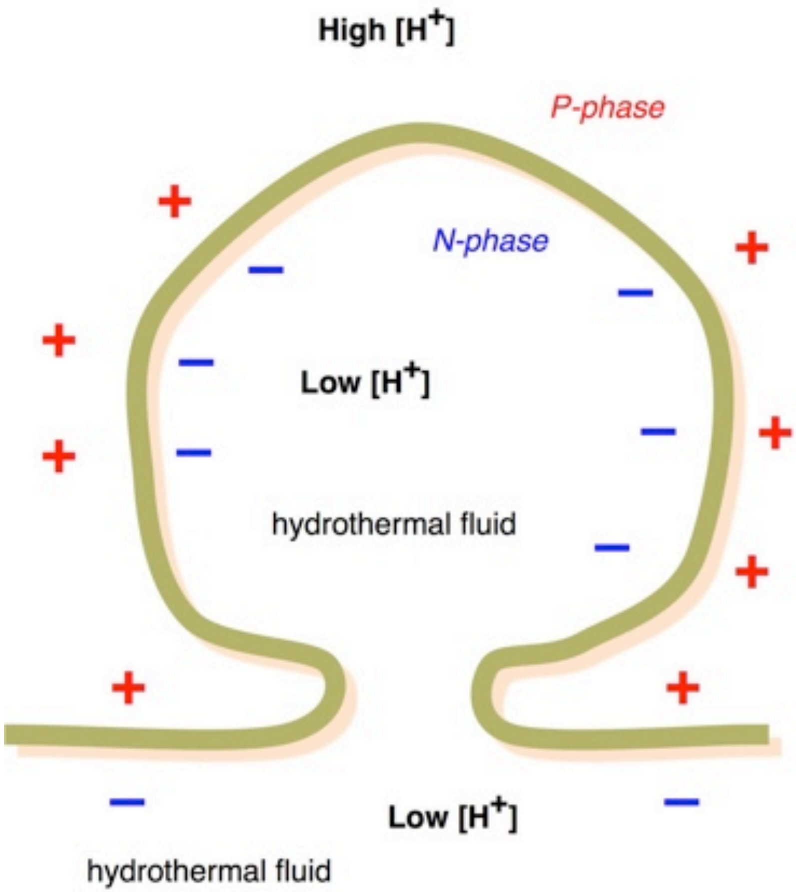
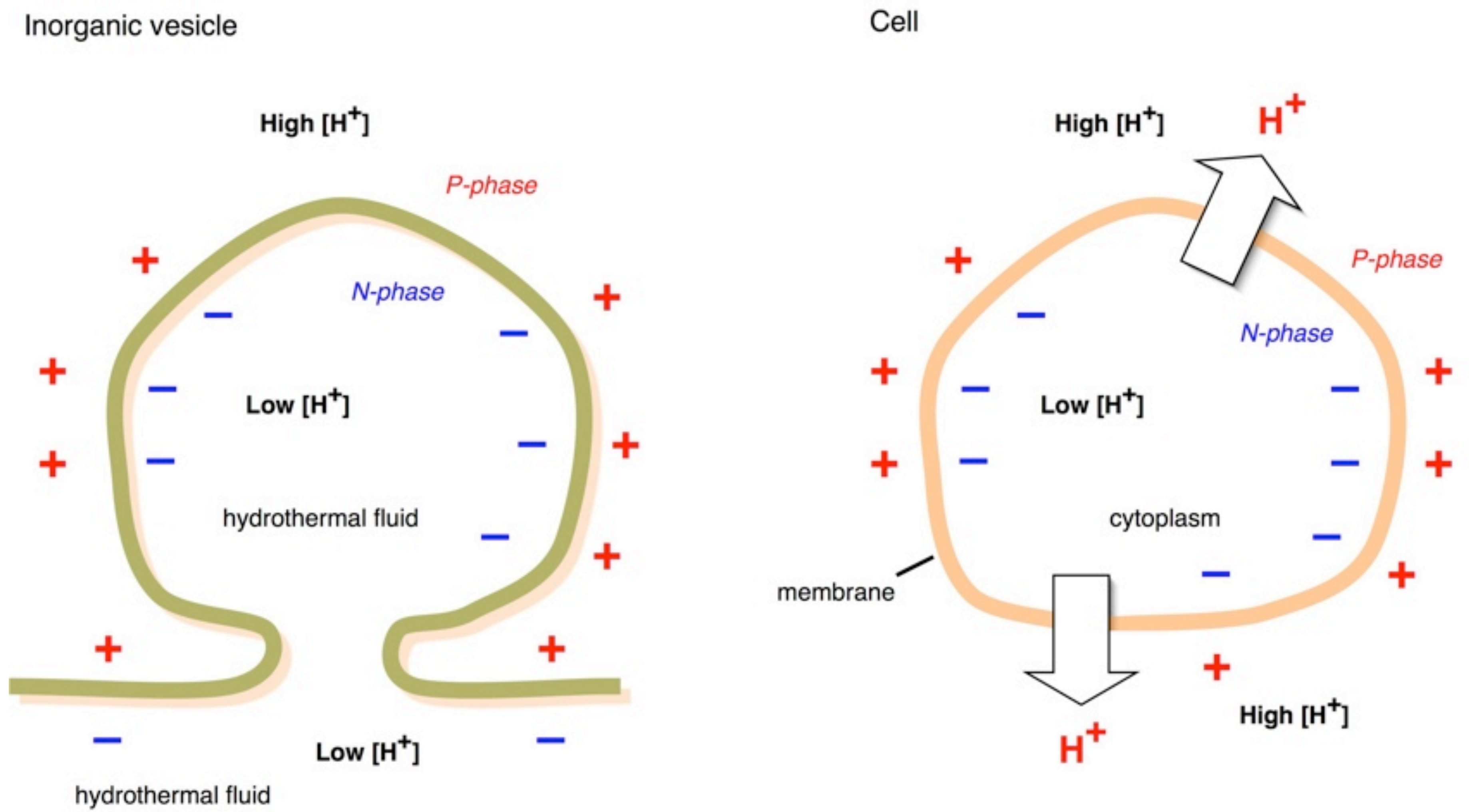


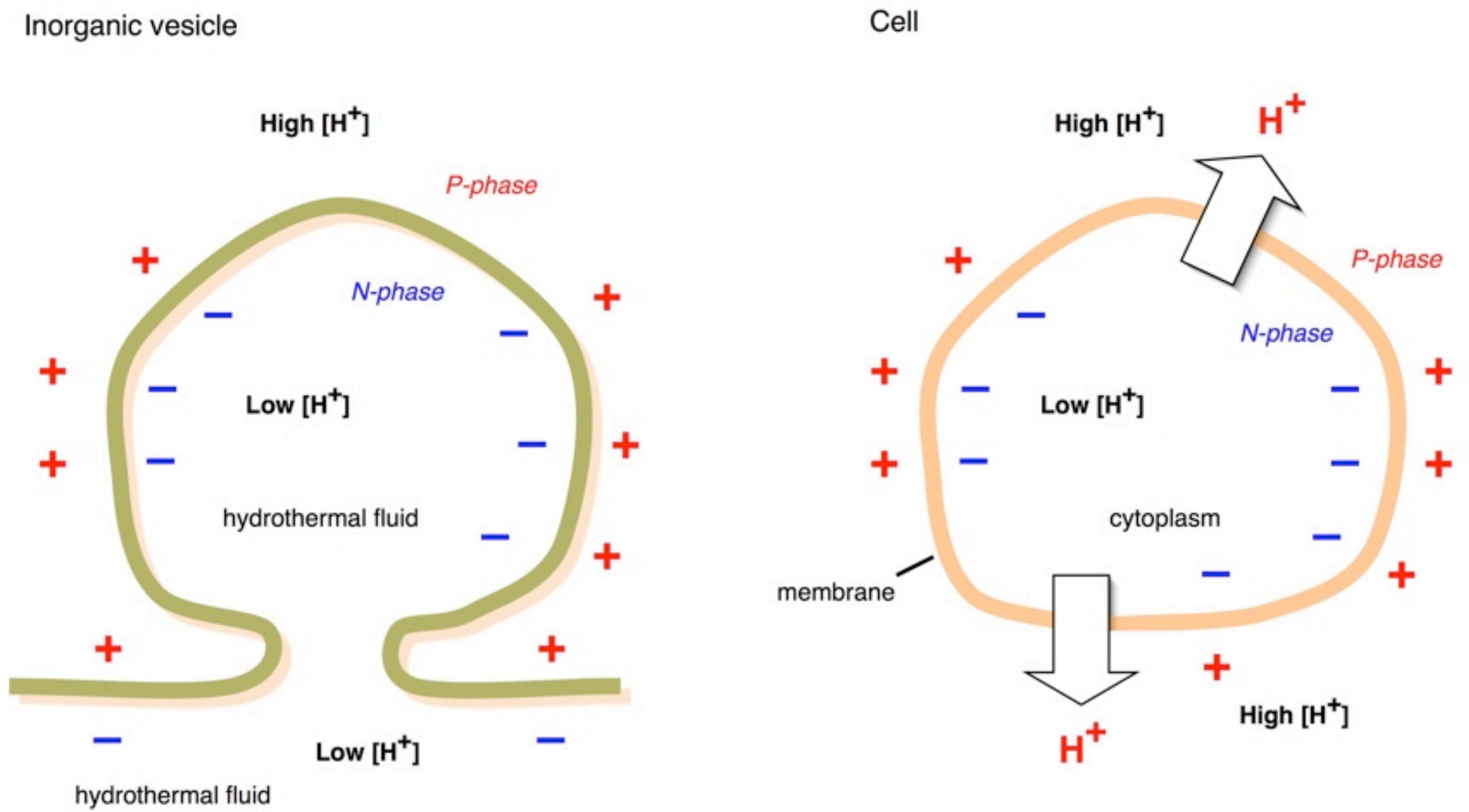
Figure 1.8 Pathways of energy transduction.
The protonmotive force interconnects multiple forms of energy.

Inorganic vesicle

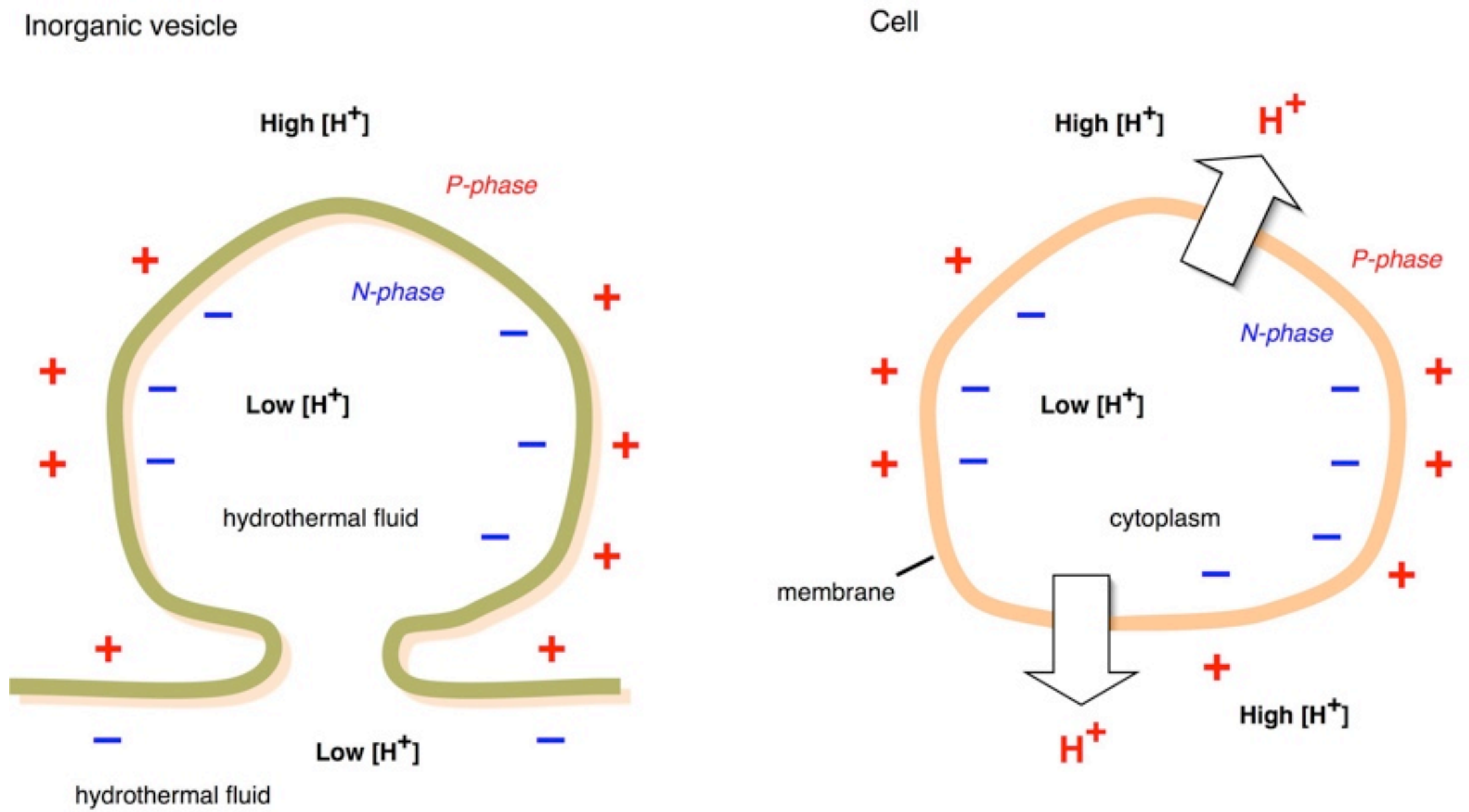




Inorganic vesicle
High $[H^+]$
P-phase
N-phase
Low $[H^+]$
hydrothermal fluid
Low $[H^+]$
hydrothermal fluid
Cell
High $[H^+]$
H^+
P-phase
N-phase
Low $[H^+]$
cytoplasm
membrane
H^+
High $[H^+]$

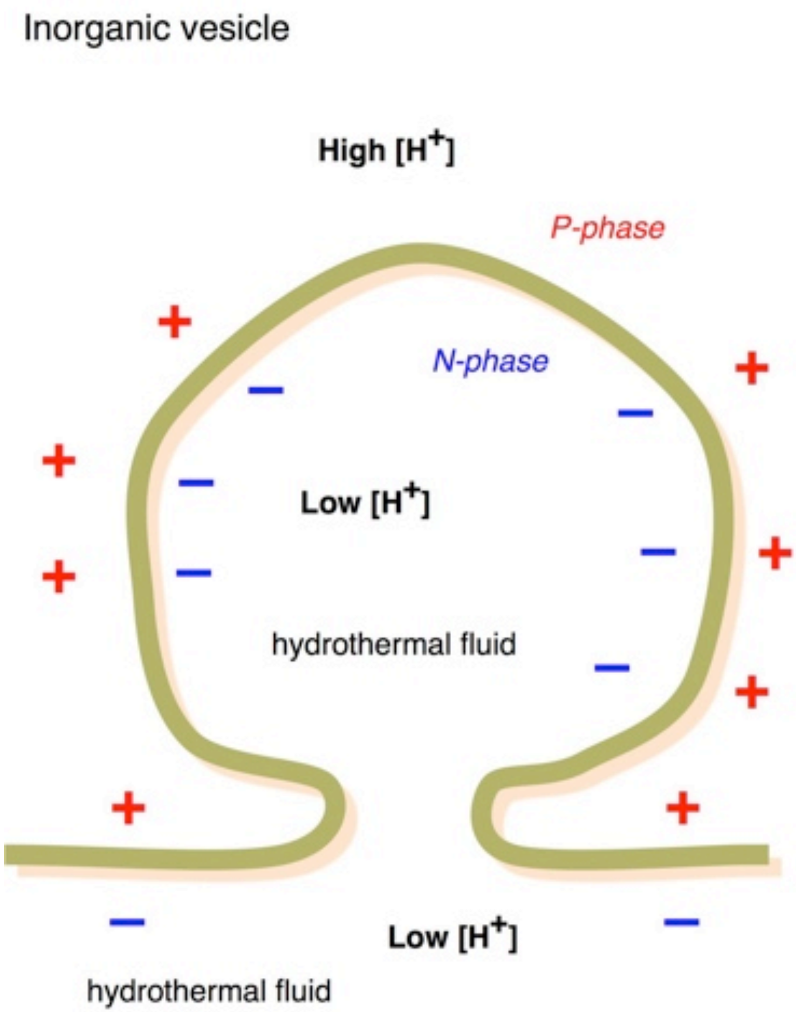


A. The proton motive force across the boundary of LUCA. The pmf is a gradient of H+ concentration and electrical potential that stores energy and makes it available for synthesis and transport. The pmf is made by an alkaline (high pH) internal effluent from LUCA's founding hydrothermal vent and by an acidic (low pH) external environment of carbonic acid solution.

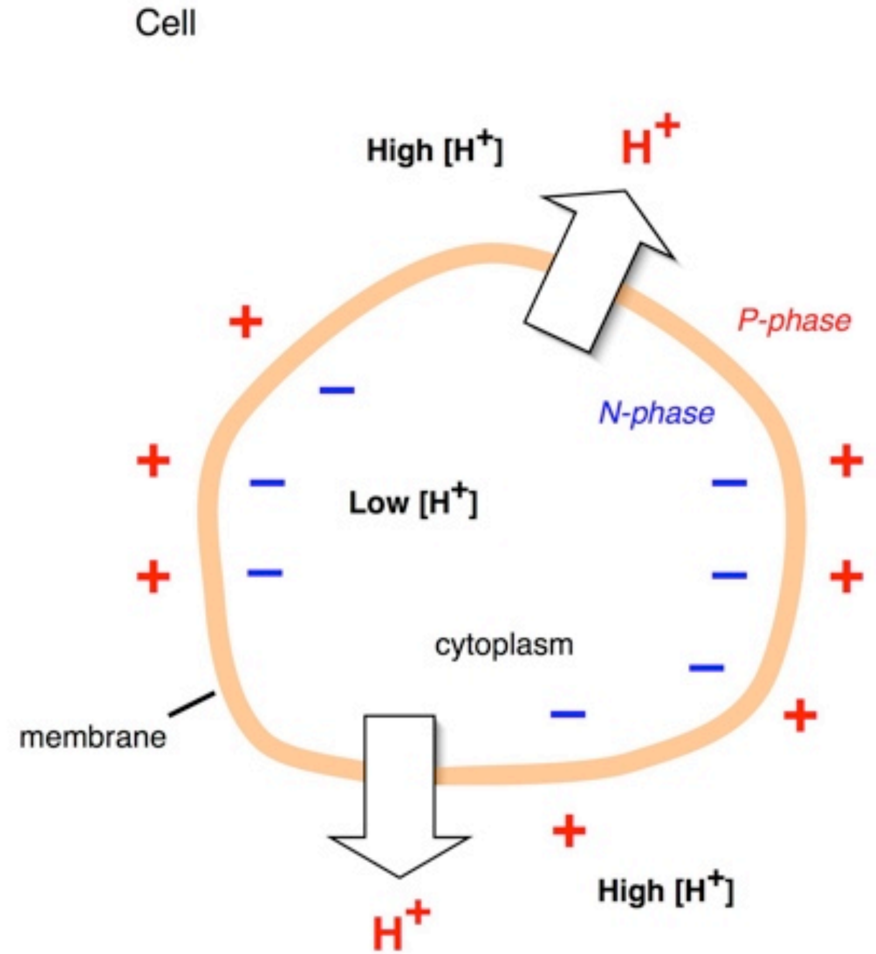


A. The proton motive force across the boundary of LUCA. The pmf is a gradient of H+ concentration and electrical potential that stores energy and makes it available for synthesis and transport. The pmf is made by an alkaline (high pH) internal effluent from LUCA's founding hydrothermal vent and by an acidic (low pH) external environment of carbonic acid solution.

B. The proton motive force of living cells descended from LUCA. The pmf is a gradient of H+ concentration and electrical potential that stores energy and makes it available for synthesis and transport. The pmf is made by an alkaline (high pH) cytoplasm and by an acidic (low pH) extracellular environment. The gradient is continuously replenished by electrons flowing across the membrane from donors to acceptors.



A. The proton motive force across the boundary of LUCA. The pmf is a gradient of H+ concentration and electrical potential that stores energy and makes it available for synthesis and transport. The pmf is made by an alkaline (high pH) internal effluent from LUCA's founding hydrothermal vent and by an acidic (low pH) external environment of carbonic acid solution.



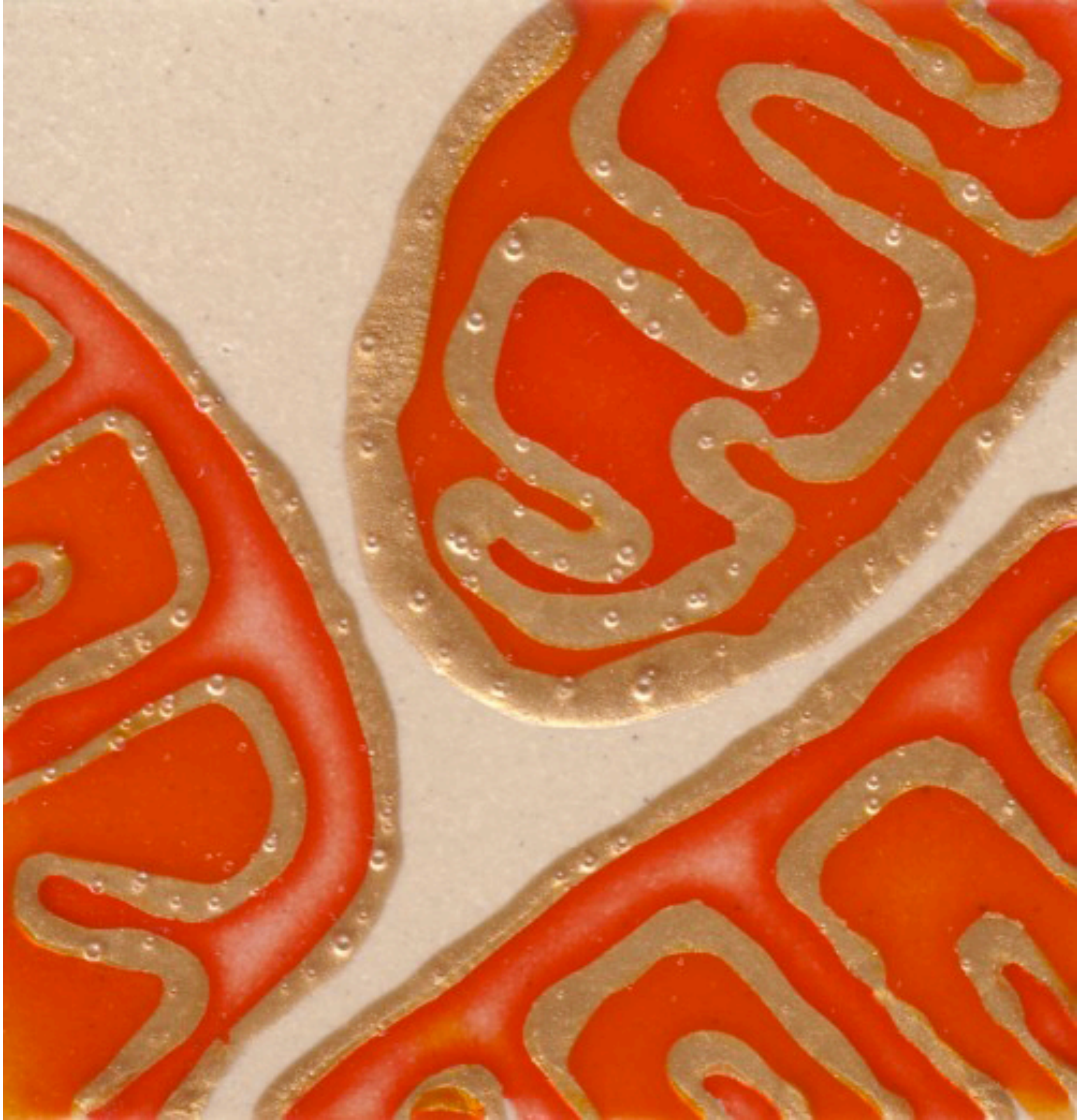
B. The proton motive force of living cells descended from LUCA. The pmf is a gradient of H+ concentration and electrical potential that stores energy and makes it available for synthesis and transport. The pmf is made by an alkaline (high pH) cytoplasm and by an acidic (low pH) extracellular environment. The gradient is continuously replenished by electrons flowing across the membrane from donors to acceptors.

Nick Lane, John F. Allen and William Martin (2010) **How did LUCA make a living? Chemiosmosis in the origin of life**. Bioessays 32: 271-280

Next lecture

Redox carriers

jfallen.org/lectures/




Thank you for listening


2004