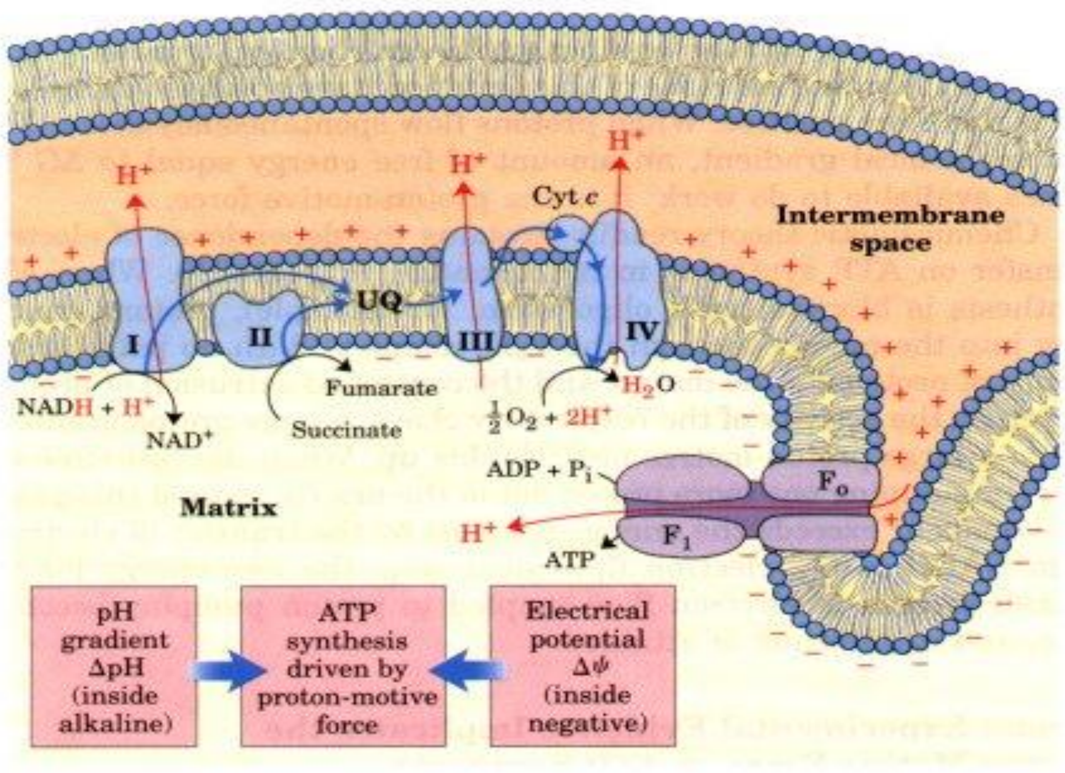
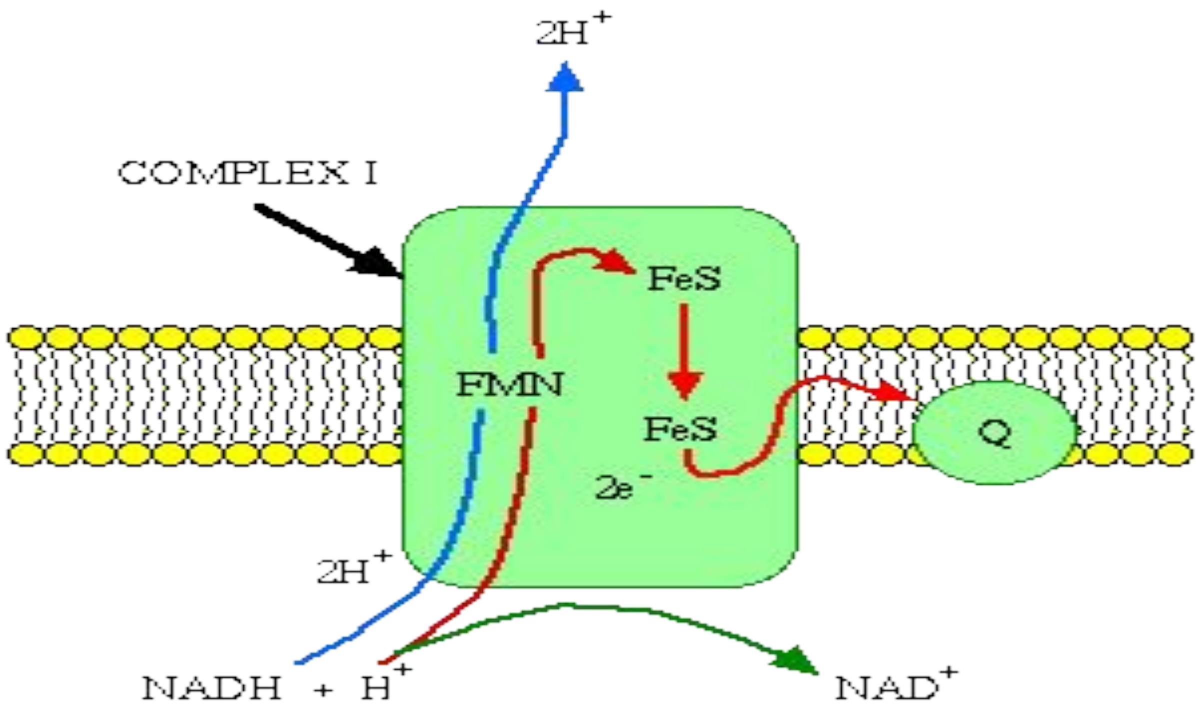
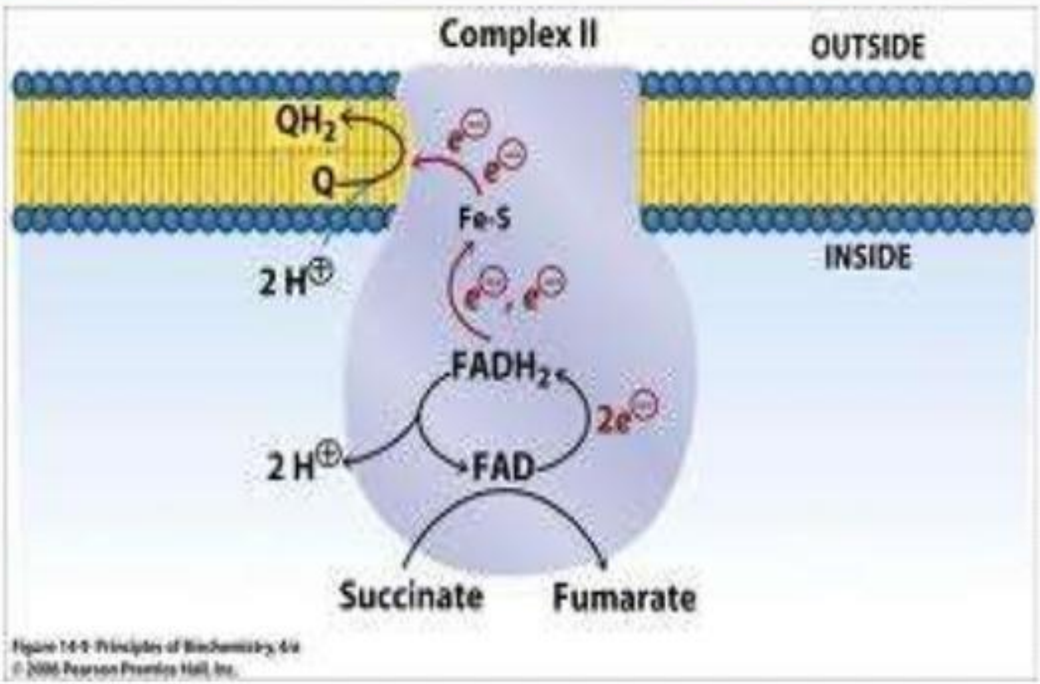
Oxidative Phosphorylation

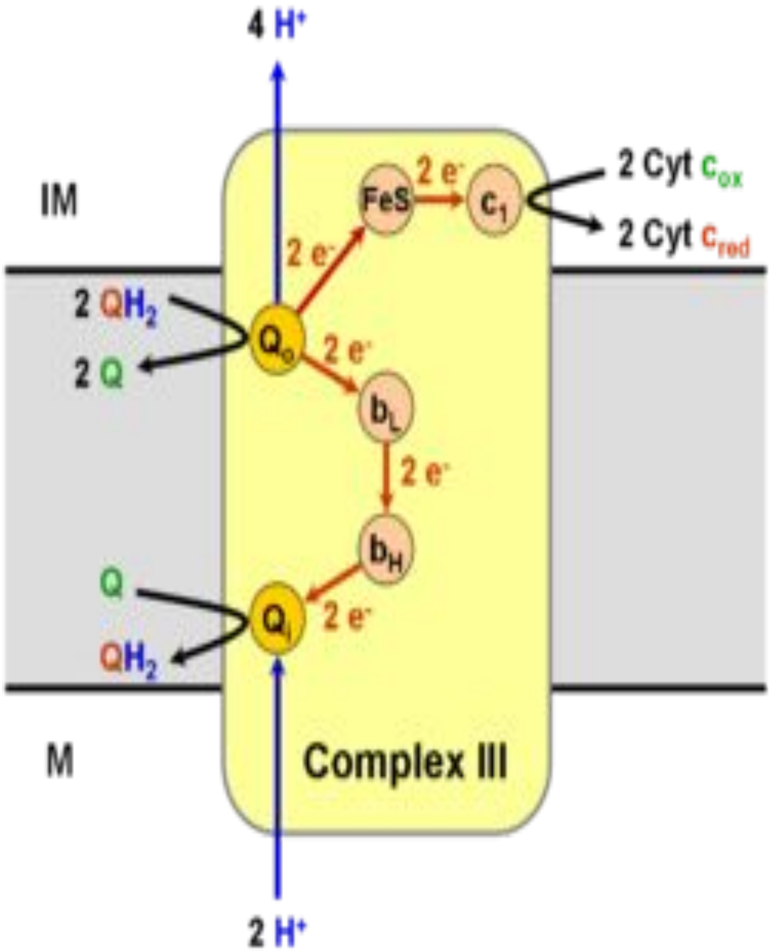



2H+
COMPLEX I
FeS
FMN
FeS
Q
2e-
2H+
NADH + H+
NAD+

PATHWAY OF ELECTRON TRANSFER THROUGH COMPLEX II



✓No transfer of protons from the matrix to intermembrane space.



4 H+
IM
2 Cyt c_ox
2 Cyt c_red
FeS
2 e-
c1
2 e-
2 QH2
Qo
2 e-
2 Q
bL
2 e-
bH
Q
Qi
2 e-
QH2
M
Complex III
2 H+

Q cycle

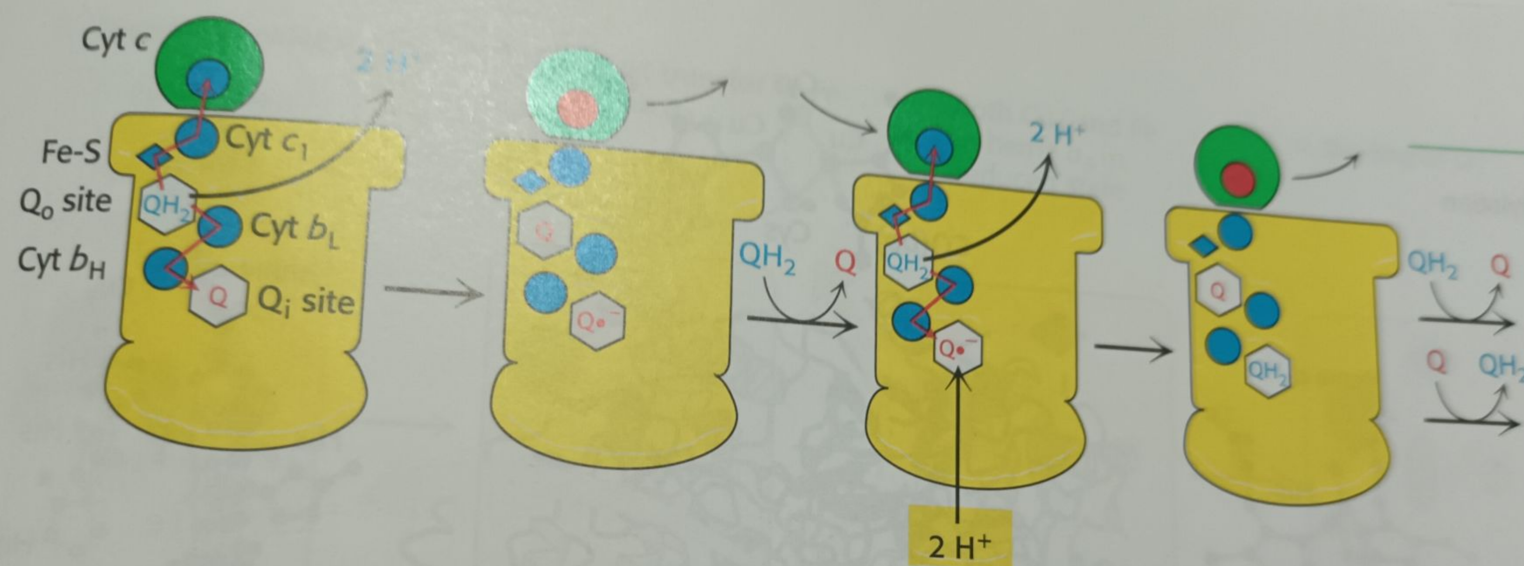
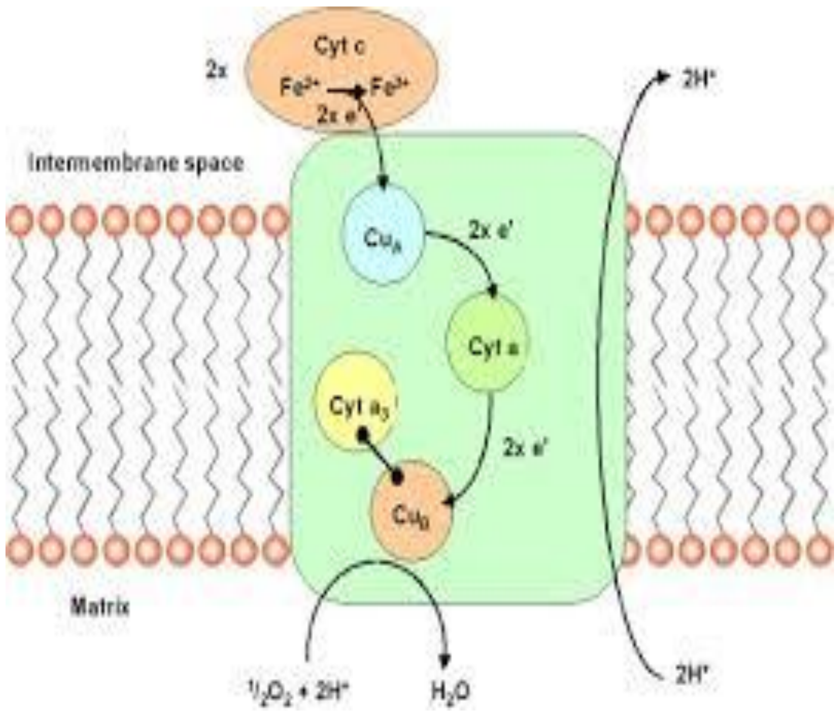


FIGURE 18.17 Q cycle. The two electrons of a bound QH_2 are transferred, one to cytochrome *c* and the other to a bound Q to form the semiquinone $Q\cdot^-$. The newly formed Q dissociates and is replaced by a second QH_2, which also gives up its electrons, one to a second molecule of cytochrome *c* and the other to reduce $Q\cdot^-$ to QH_2. This second electron transfer results in the uptake of two protons from the matrix. Prosthetic groups are shown in their oxidized forms in blue and in their reduced forms in red.

Mechanism of Q Cycle

18.3.4 Transmembrane Proton Transport: The Q Cycle

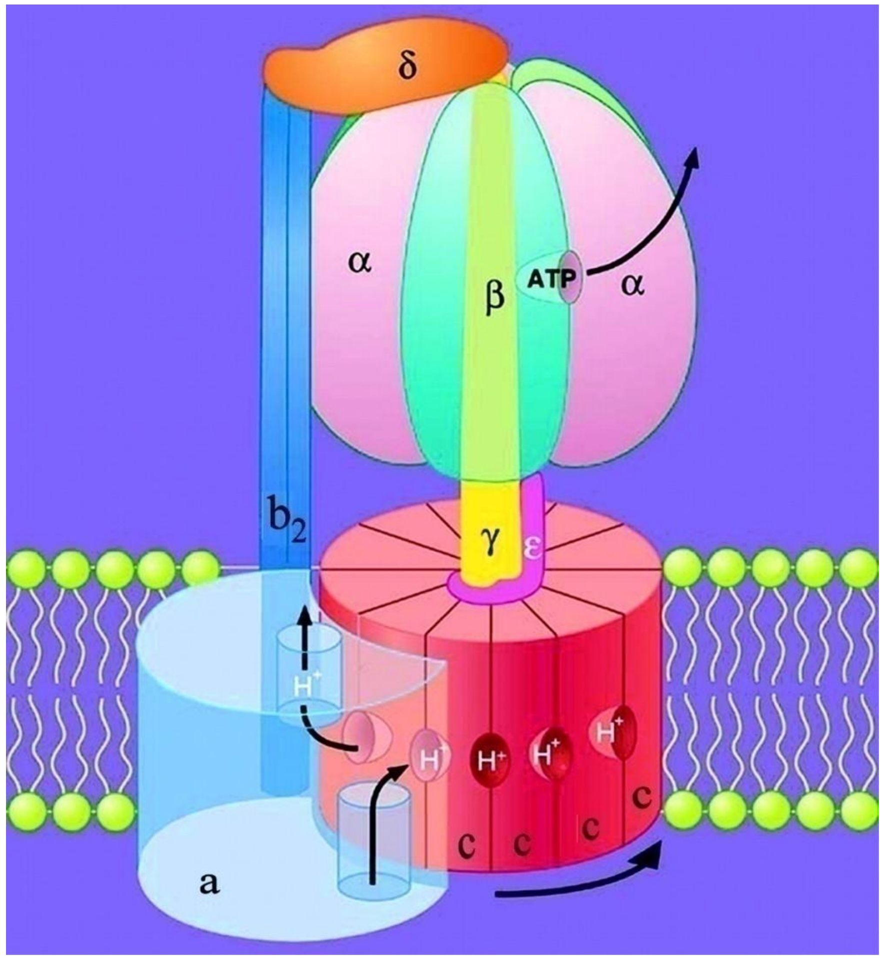
The mechanism for the coupling of electron transfer from Q to cytochrome *c* to transmembrane proton transport is known as the *Q cycle* (Figure 18.17). The Q cycle also facilitates the switch from the two-electron carrier ubiquinol to the one-electron carrier cytochrome *c*. The cycle begins as ubiquinol (QH_2) binds in the Q_o site. Ubiquinol transfers its electrons, one at a time. One electron flows first to the Rieske 2Fe-2S cluster, then to cytochrome c_1, and finally to a molecule of oxidized cytochrome *c*, converting it into its reduced form. The reduced cytochrome *c* molecule is free to diffuse away from the enzyme. The second electron is transferred first to cytochrome b_L, then to cytochrome b_H, and finally to an oxidized uniquinone bound in the Q_i site. This quinone (Q) molecule is reduced to a semiquinone anion ($Q\cdot^-$). Importantly, as the QH_2 in the Q_o site is oxidized to Q, its protons


Cyt c
2x
Fe^{2+} → Fe^{3+}
2x e⁻
Intermembrane space
Cu_A
2x e⁻
Cyt a
Cyt a_3
2x e⁻
Cu_B
Matrix
$^1/_2O_2$ + $2H^+$
H_2O
$2H^+$
$2H^+$

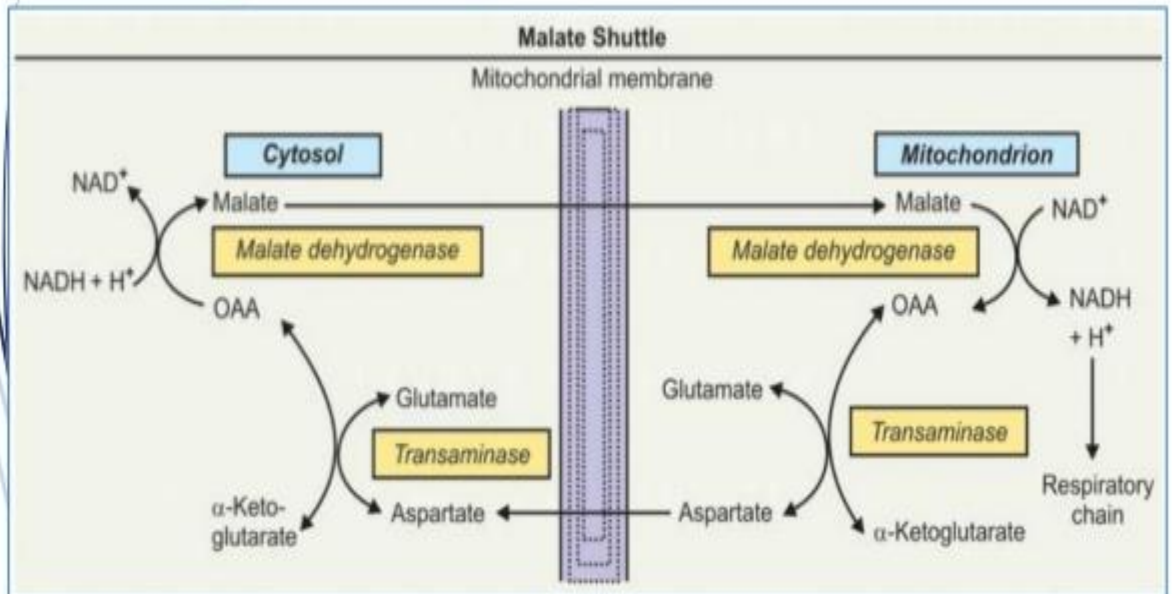
- NADH dehydrogenase
- Succinate dehydrogenase
- Ubiquinone cytochrome C oxidoreductase
- Cytochrome oxidase

Electron Carriers

- NAD/NADH
- Iron-sulfur protein, Rieske protein
- Ubiquinone
- Cytochrome b
- Cytochrome c_1
- Cytochrome c
- Cytochrome a
- Cytochrome a_3
- O_2/H_2O


δ
α
β
ATP
α
b2
γ
ε
H+
H+
H+
H+
H+
c
c
c
c
a

Malate-Aspartate shuttle



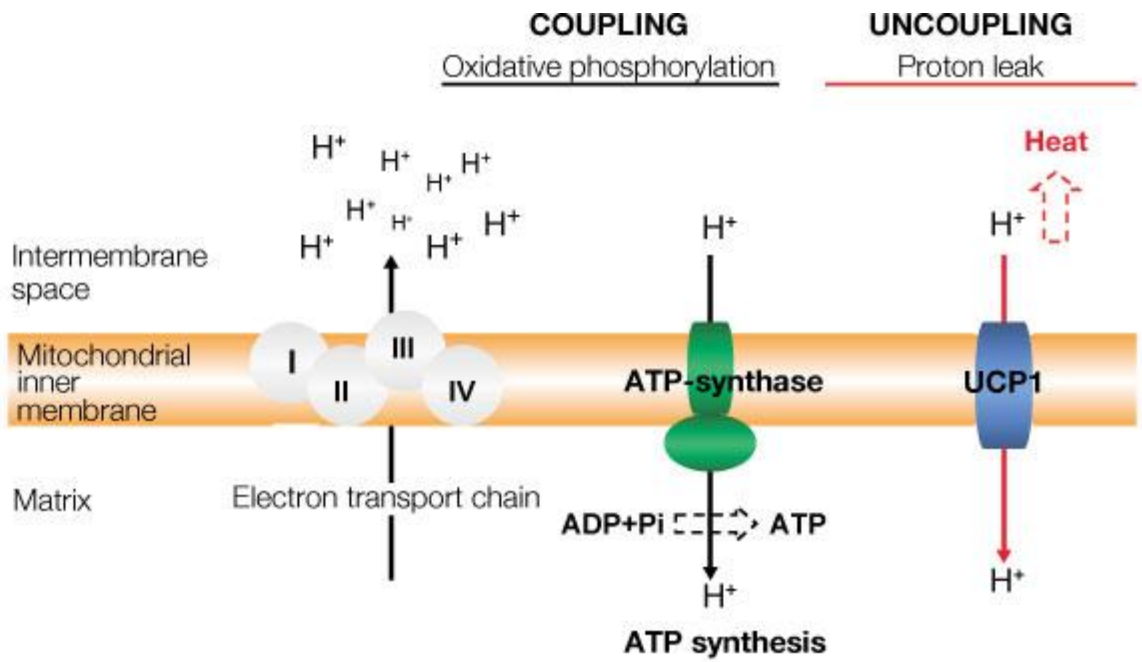


Figure 1. UCP1 location and function in the mitochondrial respiratory chain (MRC). Numbers I-IV corresponds to the MRC complexes. ATP-synthase is the fifth complex of the MRC. During respiration, protons are pumped through the MRC complexes, and a proton gradient is generated. The energy of the proton gradient drives the synthesis of ATP by the ATP-synthase complex. UCP1 catalyzes a regulated re-entry of protons into the matrix, uncoupling the MRC and, consequently, reducing ATP synthesis and generating heat.

Inhibitors and Uncouplers

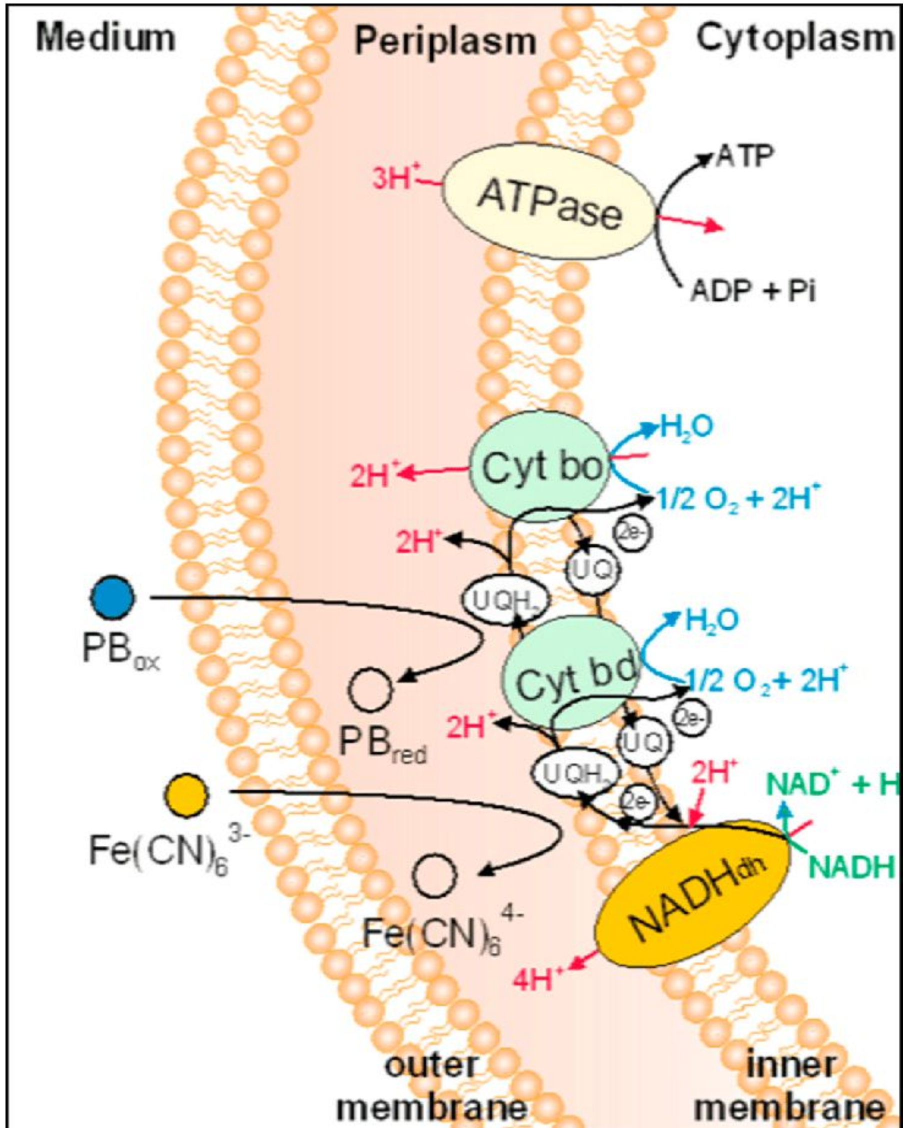
Table 1. Inhibitors of Respiration and Oxidative Phosphory

Site-Specific	Target Complex
Carbon monoxide	IV
Cyanide	IV
Sodium Azide	IV
Rotenone	I
Antimycin A	III
Amytal	I
Phosphorylation	
Oligomycin	F_o
Uncouplers	
2,4-Dinitrophenol (DNP)	Proton gradient
Trifluorocarbonylcyanide Phenylhydrazone (FCCP)	Proton gradient

Any compound that stops electron transport will stop respiration…this means you stop breathing

Electron transport can be stopped by inhibiting ATP synthesis

An uncoupler breaks the connection between ATP synthesis and electron transport



Medium
Periplasm
Cytoplasm
3H+
ATPase
ATP
ADP + Pi
H2O
2H+
Cyt bo
1/2 O2 + 2H+
2H+
2e-
UQ
UQH2
PBox
H2O
Cyt bd
1/2 O2+ 2H+
PBred
2H+
2e-
UQ
UQH2
2H+
NAD+ + H
2e-
Fe(CN)6 3-
NADH
NADHdh
Fe(CN)6 4-
4H+
outer membrane
inner membrane

Transport of Electron

- A,B,C and D are electron Carriers
- A= 0.32 V
- B = 0.75 V
- C= 0.66 V
- D = 1.05 V
- State the direction of electron flow

- Direction Of electron flow is from lower reduction potential to higher reduction potential

- Proton Motive Force: The electrochemical energy inherent in the difference in proton concentration and separation of charge represents a temporary conservation of much of the energy of electron transfer . The energy stored in such a gradient is termed as proton motive force. This force has two components:
- Chemical Potential energy
- Electrical potential Energy

Aerobic respiration in *E.coli*

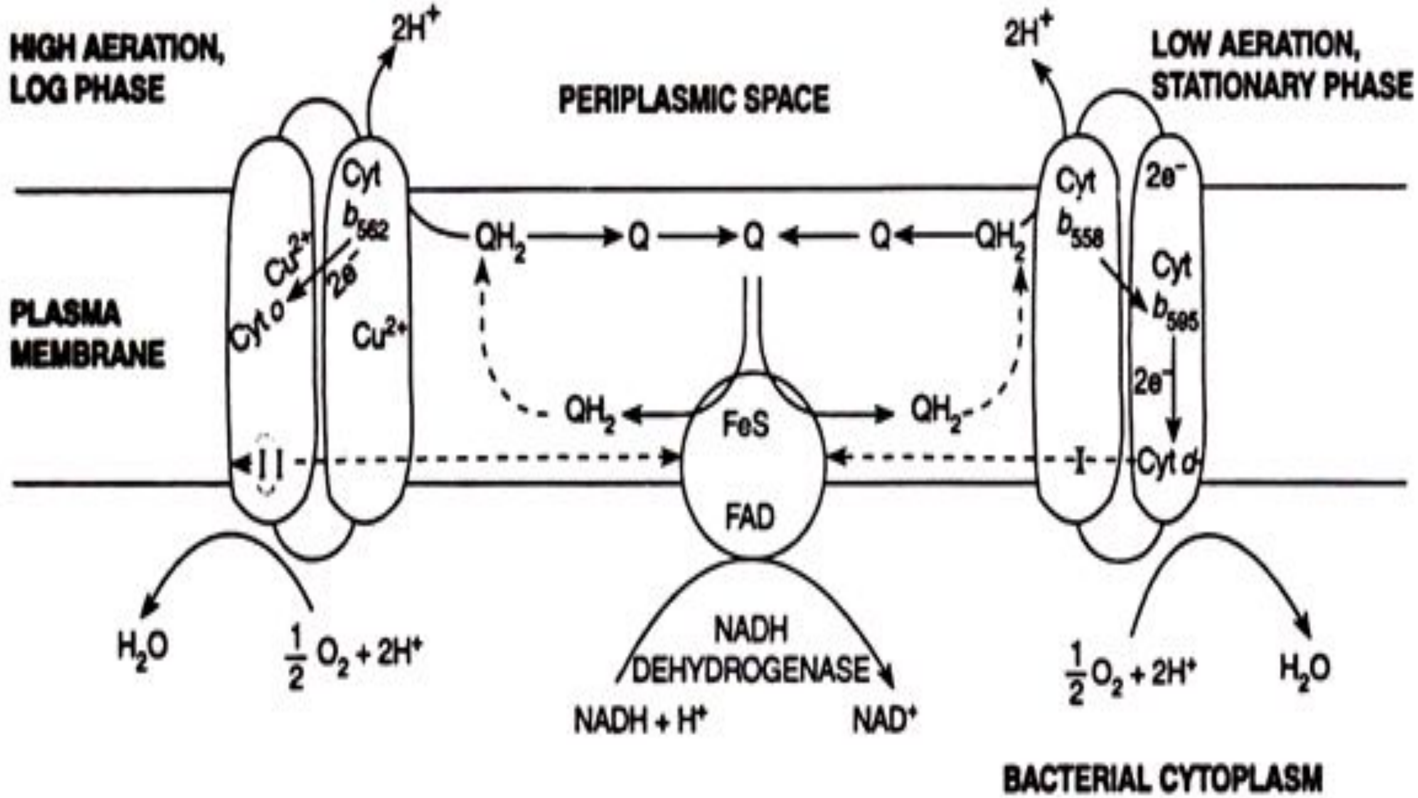
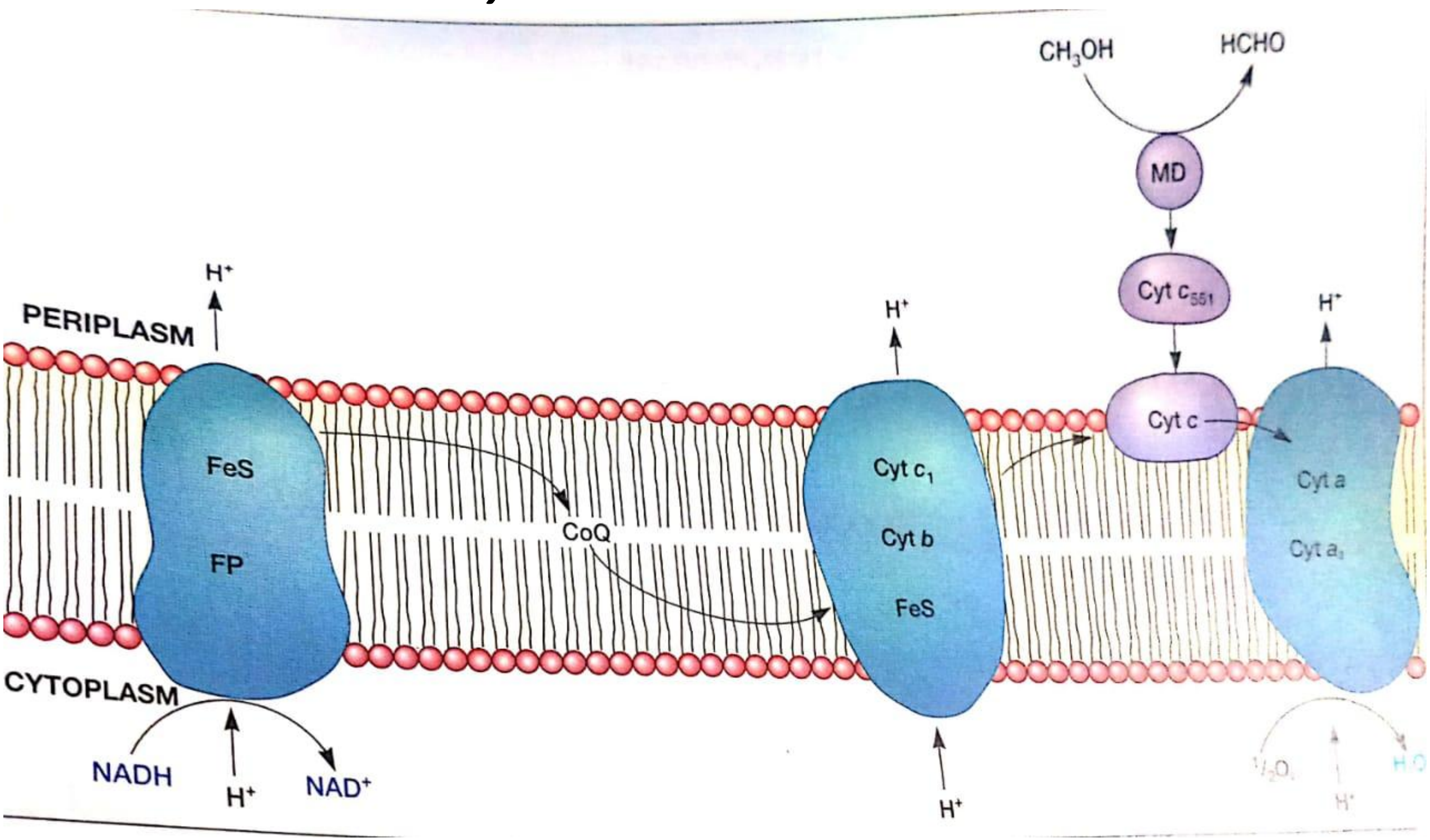


FIG. 24.7. Electron transport chain of *E. coli* that operates in aerobic conditions. NADH is the electron donor. Ubiquinone (Q) is the connecting link between NADH dehydrogenase with two terminal oxidase systems of the two branches, cytochrome *d* branch (shown as I) and cytochrome *o* branch (shown as II).

Aerobic respiration in *Paracoccus denitrificans* (*Methanol and methyamine can contribute electrons at the cytochrome C level*

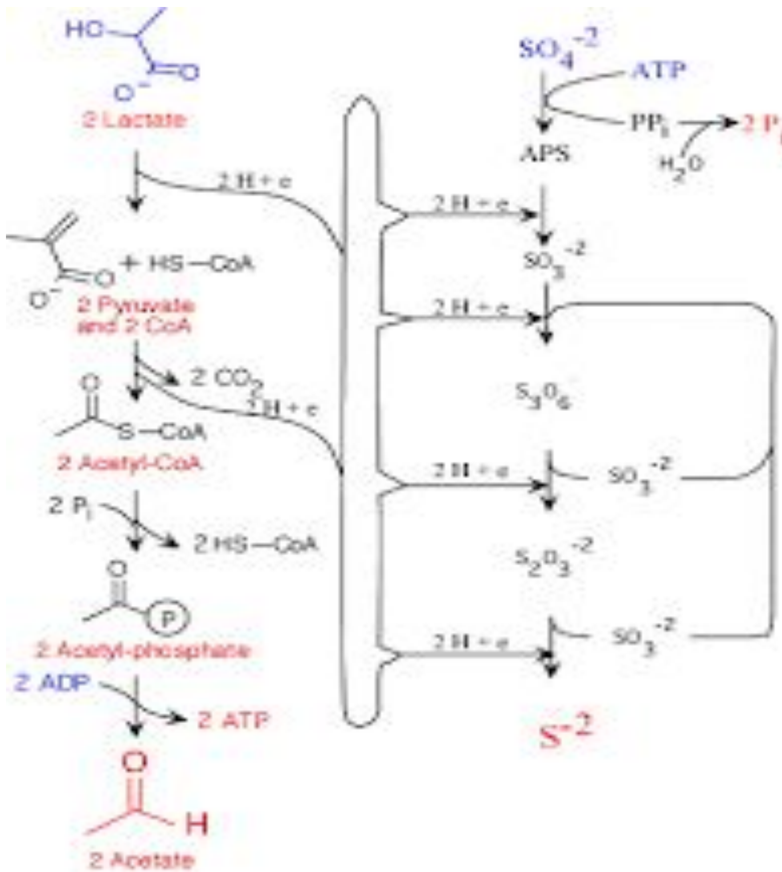


P/O ratio

- **P/O ratio (phosphorus:oxygen ratio)** The number of atoms of phosphorus (i.e. as phosphate) incorporated as ATP per molecule of oxygen (O_2) consumed during oxidative phosphorylation in aerobically respiring cells

Chemiosmotic Theory

- Trans membrane difference in proton concentration are the reservoir for the energy extracted from biological oxidation reaction. This theory is introduced by Peter mitchell



HO
O⁻
2 Lactate
2 H + e
+ HS—CoA
O⁻
2 Pyruvate
and 2 CoA
2 CO2
2 H + e
O
S—CoA
2 Acetyl-CoA
2 Pi
2 HS—CoA
O
P
2 Acetyl-phosphate
2 ADP
2 ATP
O
H
2 Acetate
SO4-2
ATP
PPi
2 Pi
H2O
APS
2 H + e
SO3-2
2 H + e
S3O6
2 H + e
SO3-2
S2O3-2
2 H + e
SO3-2
S-2

Anaerobic respiration

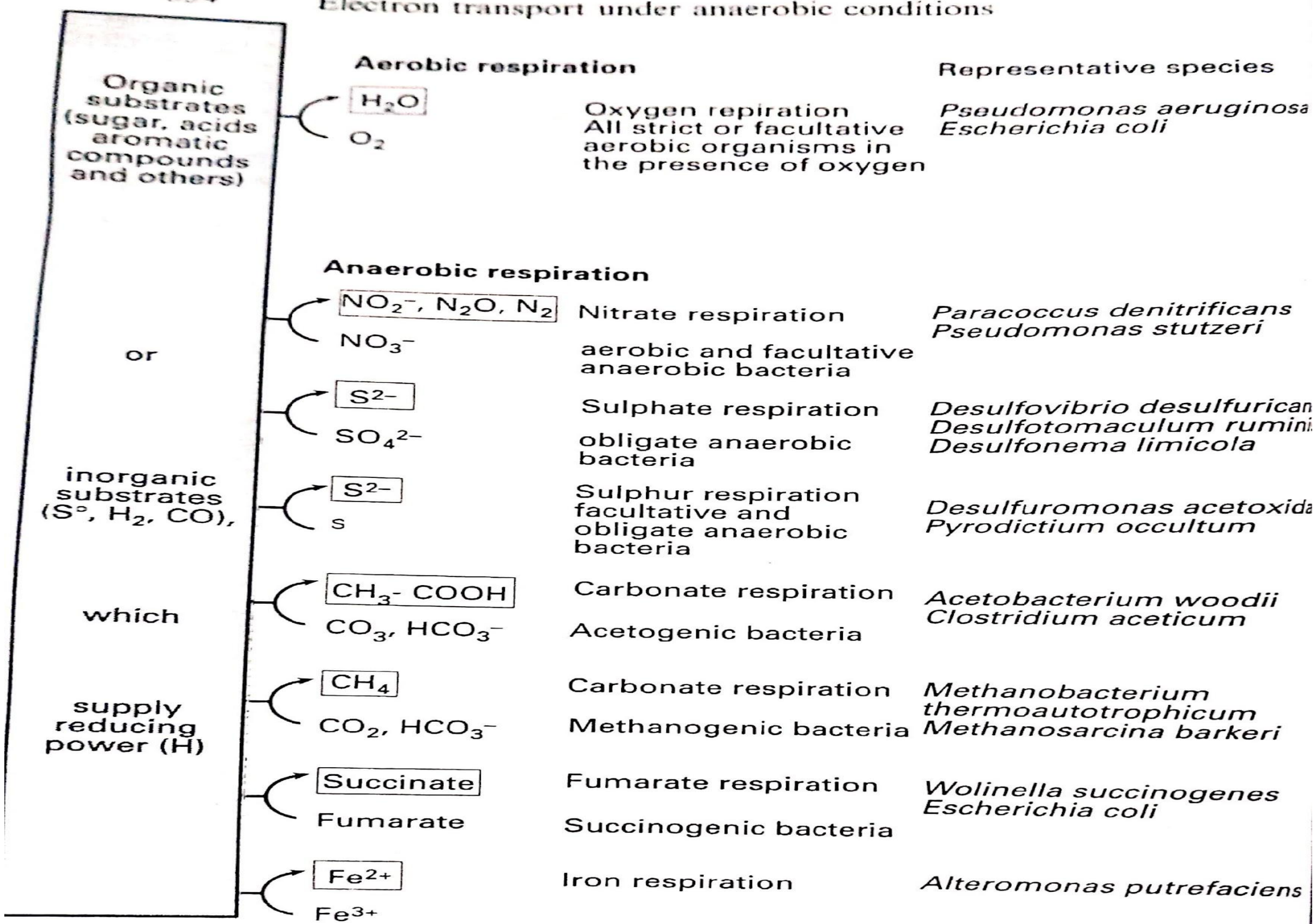


Fig. 9.1. *Processes that yield energy by electron transport phosphorylation under aerobic and anaerobic conditions.*

(Also called aerobic and anaerobic respiration.)

Dissimilatory Nitrate reduction

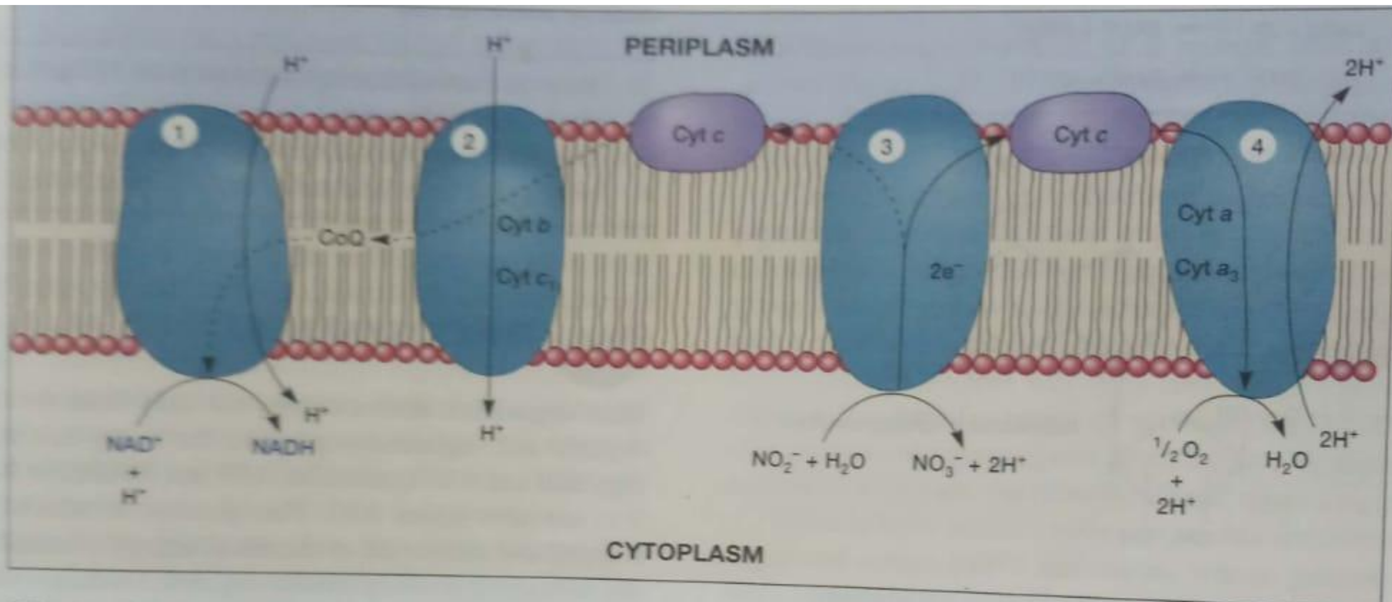


Figure 9.24 Electron Flow in *Nitrobacter* Electron Transport Chain. *Nitrobacter* oxidizes nitrite and carries out normal electron transport to generate proton motive force for ATP synthesis. This is the right-hand branch of the diagram. Some of the proton motive force also is used to force electrons to flow up the reduction potential gradient from nitrite to NAD^+ (left-hand branch). Cytochrome *c* and four complexes are involved: NADH-ubiquinone oxidoreductase (1), ubiquinol-cytochrome *c* oxidoreductase (2), nitrite oxidase (3), and cytochrome aa_3 oxidase (4).

Anaerobic respiration with nitrate

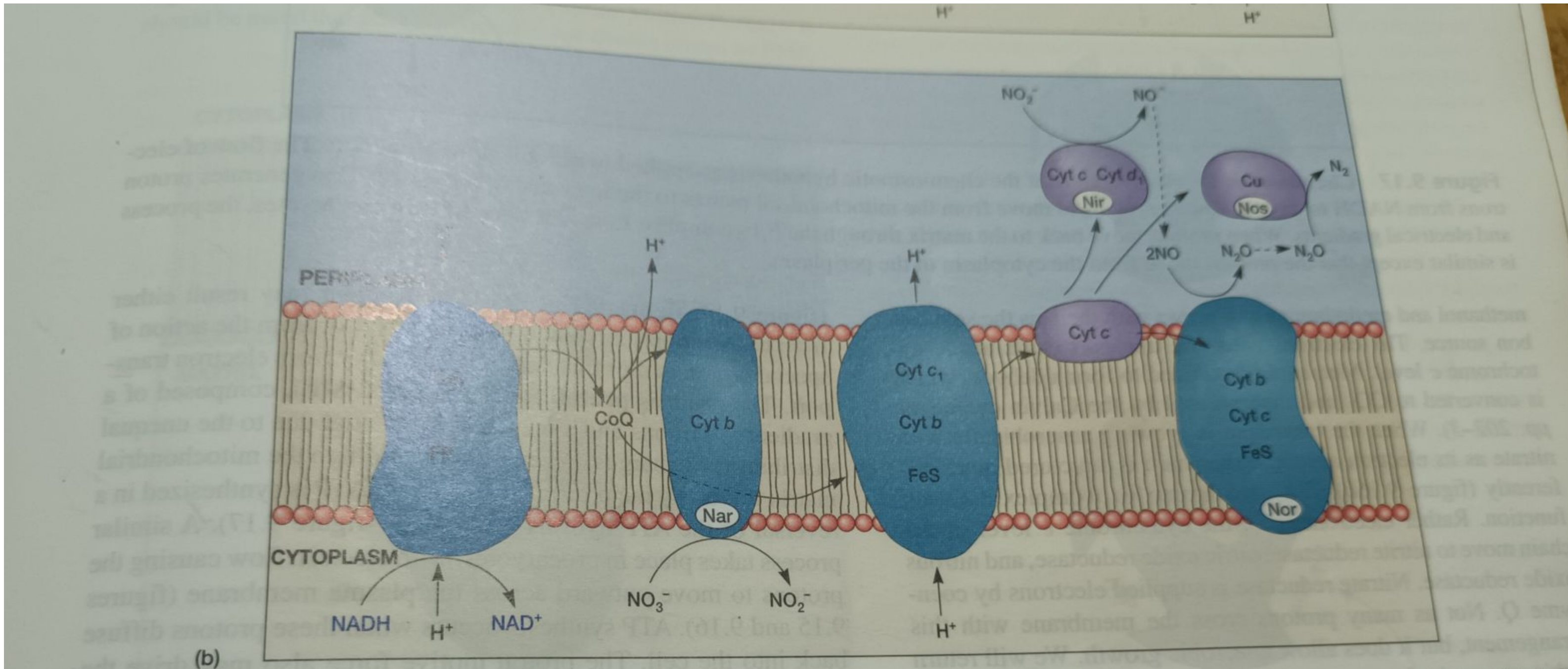


Figure 9.16 ***Paracoccus denitrificans*** **Electron Transport Chains.** (**a**) The aerobic transport chain resembles a mitochondrial elec tron transport chain and uses oxygen as its acceptor. Methanol and methylamine can contribute electrons at the cytochrome *c* lev (**b**) The highly branched anaerobic chain is made of both membrane and periplasmic proteins. Nitrate is reduced to diatomic nitrogen the collective action of four different reductases that receive electrons from CoQ and cytochrome *c*. Locations of proton movement shown, but the number of protons involved has not been indicated. Abbreviations used: flavoprotein (FP), methanol dehydroger (MD), nitrate reductase (Nar), nitrite reductase (Nir), nitric oxide reductase (Nor), and nitrous oxide reductase (Nos).

Table 18-5 Coenzymes of Methanogenic Bacteria

Component	Type of Molecule	Function
Coenzyme F_{420}	Flavin-containing coenzyme	Transfers $2H^+$ and $2e^-$
Coenzyme F_{430}	Nickel-containing tetrapyrrole	Involved in terminal step of reduction to methane
Methanofuran	Phenol-glutamate-dicarboxylic acid-furan complex	Binds CO_2 in the initial stage of methanogenesis
Methanopterin	Pterin-containing coenzyme	C1 carrier for most of the reductive pathway of methanogenesis
Coenzyme M	Mercapto-containing coenzyme	Methyl carrier involved in terminal step of reduction to methane
HS-HTP	7-Mercaptoheptanoylthreonine phosphate	e^- donor involved in terminal step of reduction to methane

Anaerobic respiration with carbonate

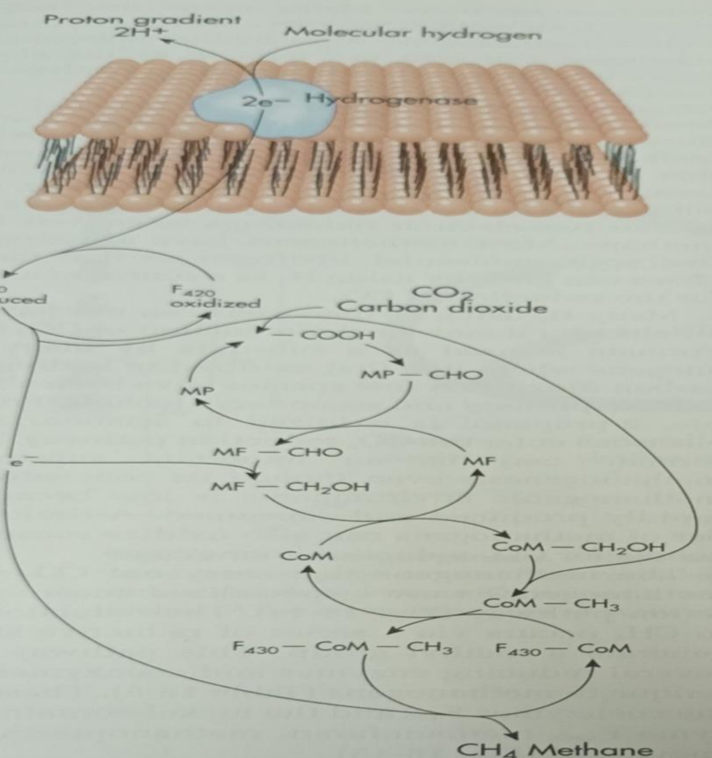


Fig. 18-14 Methanogenesis—CO_2 Reduction Pathway. The conversion of CO_2 to CH_4 (methane) is carried out by methanogenic archaea. This is a strictly anaerobic pathway involving the flow of electrons from a hydrogen donor. Several unique electron carriers are involved in the transfer of electrons in this pathway, including factor 420 (F_{420}), factor 430 (F_{430}), coenzyme M (CoM), methanopterin (MP), and methanofuran (MF). The oxidation of hydrogen, which occurs outside of the cell, produces hydrogen ions and supplies electrons for the reduction of F_{420}, which occurs inside the cell. Because the reduction of F_{420} inside the cell consumes protons, and the oxidation of hydrogen produces protons outside the cell, the net result is the establishment of a proton gradient (protonmotive force) across the membrane.

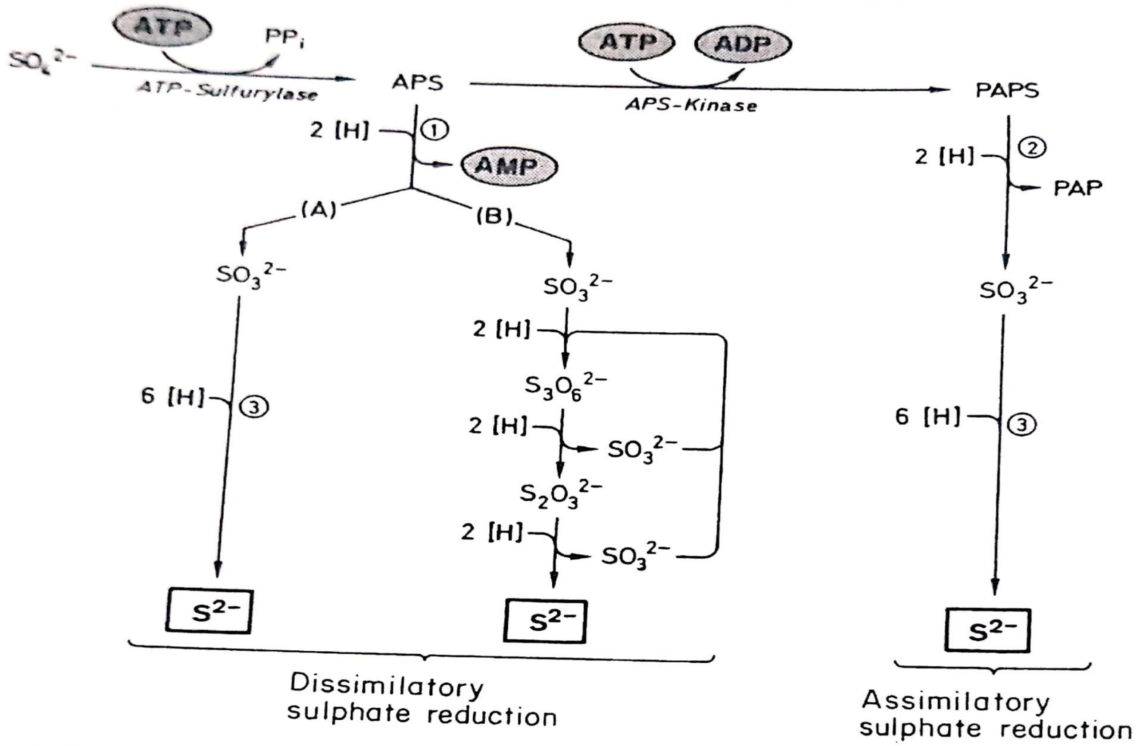


Fig. 9.3. *Diagrams of dissimilatory sulphate reduction (sulphate respiration) and assimilatory sulphate reduction.*

APS, adenosine-5'-phosphosulphate; PAPS, phosphoadenosine-5'-phosphosulphate; PAP, phospho-adenosine-5'-phosphate.

Enzymes: (!) APS reductase; (2) PAPS reductase; (3) sulphite reductase (bisulphite reductase).

Role of uncoupler: Thermogenin

- The uncoupling protein (UCP) or thermogenin is a 33 kDa inner-membrane mitochondrial protein exclusive to brown adipocytes in mammals that **functions as a proton transporter, allowing the dissipation as heat of the proton gradient generated by the respiratory chain and thereby uncoupling oxidative phosphorylation**.