Electron Transport Chain (ETC)

Respiratory Chain (RC)

Coupling the oxidation of food
to the synthesis of ATP

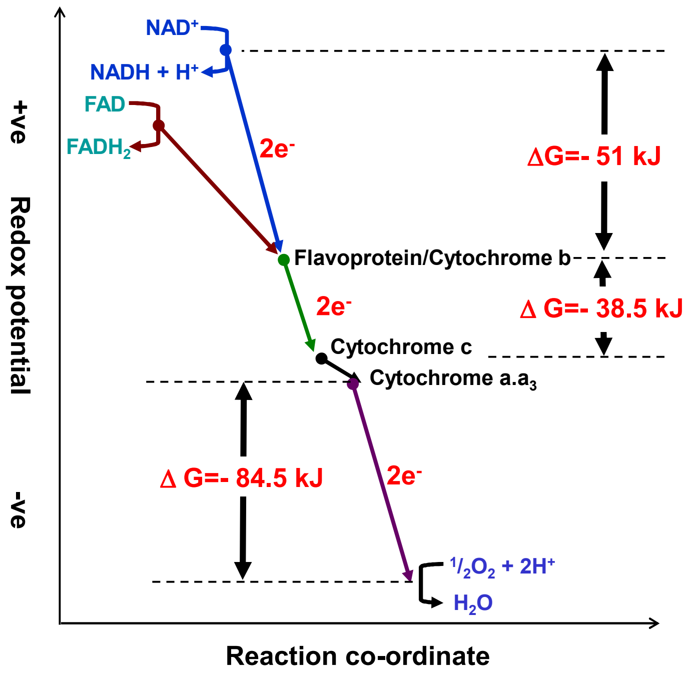
Natural Electron Acceptors

Nicotinamide Adenine Dinucleotide (**NAD**)
Flavine Adenine Dinucleotide (**FAD**)

$$NAD^+ + 2H^+ + 2e^- \underset{\textbf{Oxidation}}{\overset{\textbf{Reduction}}{\rightleftharpoons}} NADH + H^+$$

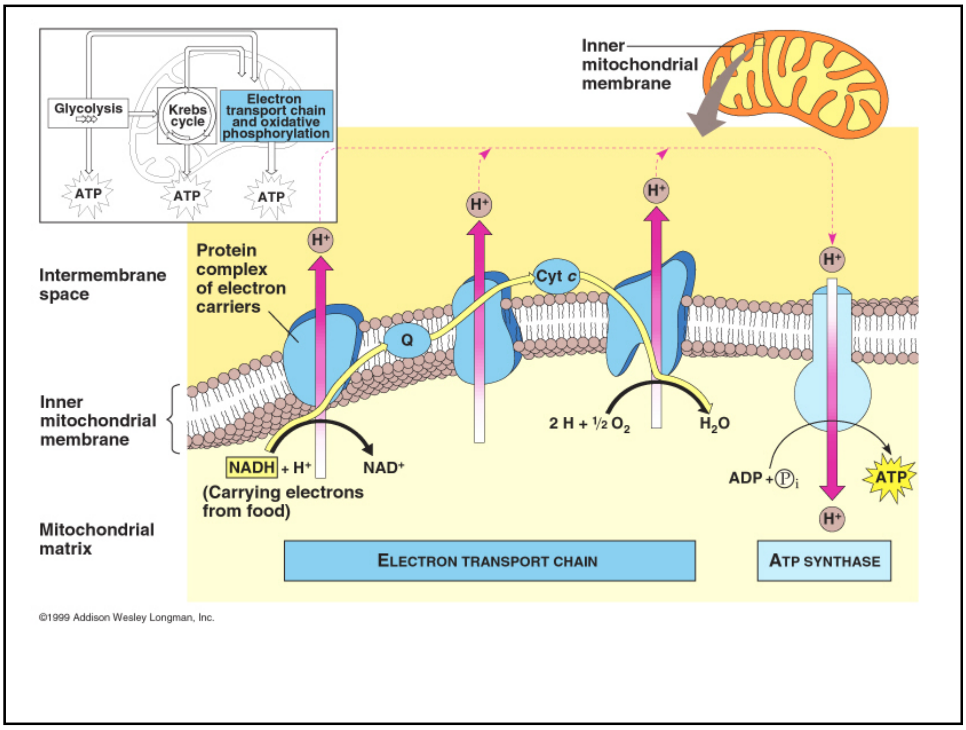
Cytochromes Conjugate proteins which contain a haem group.
The iron atom undergoes redox reactions

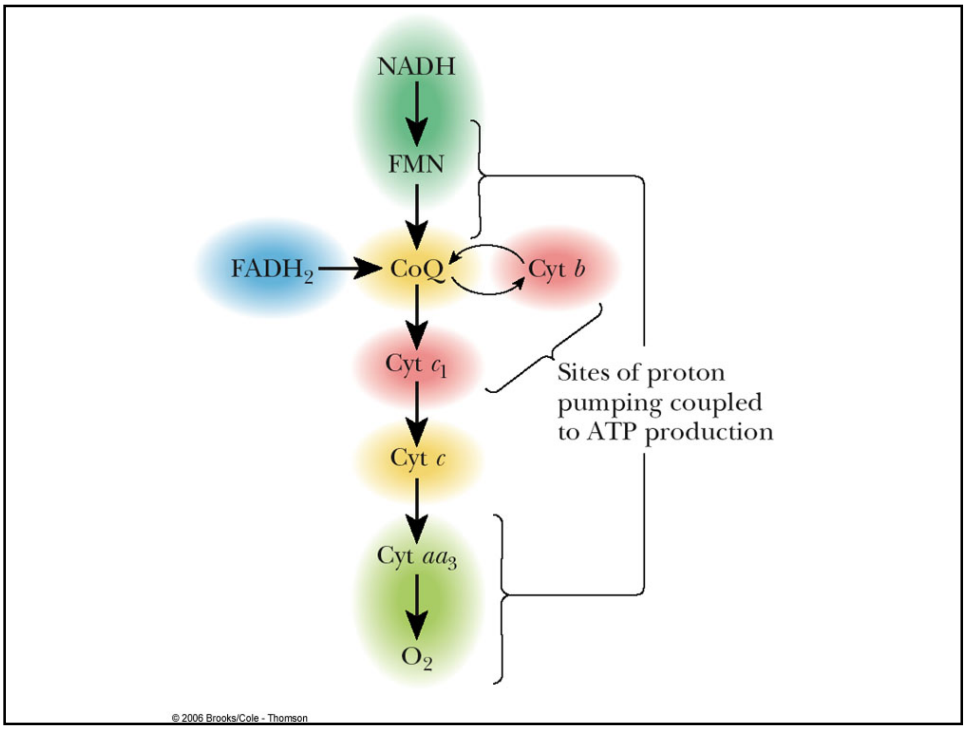
$$Fe^{3+} + e^- \underset{\textbf{Oxidation}}{\overset{\textbf{Reduction}}{\rightleftharpoons}} Fe^{2+}$$



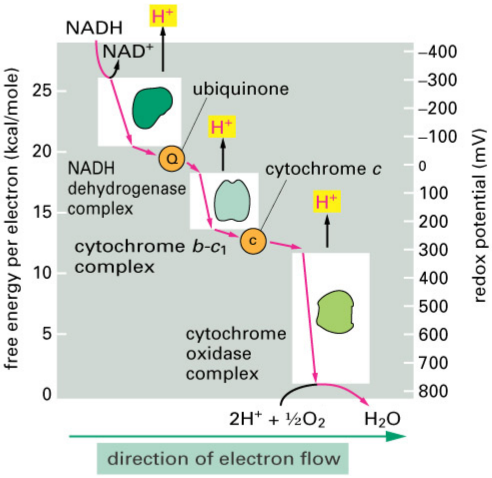
The location of the ETC

- The mitochondrial inner membrane of eukaryotes
- the plasma membrane of prokaryotes


Glycolysis
Krebs cycle
Electron transport chain and oxidative phosphorylation
ATP
ATP
ATP
Inner mitochondrial membrane
Intermembrane space
Protein complex of electron carriers
H+
Q
Cyt c
Inner mitochondrial membrane
NADH + H+
NAD+
(Carrying electrons from food)
2 H + 1/2 O2
H2O
ADP + Pi
ATP
Mitochondrial matrix
ELECTRON TRANSPORT CHAIN
ATP SYNTHASE
©1999 Addison Wesley Longman, Inc.

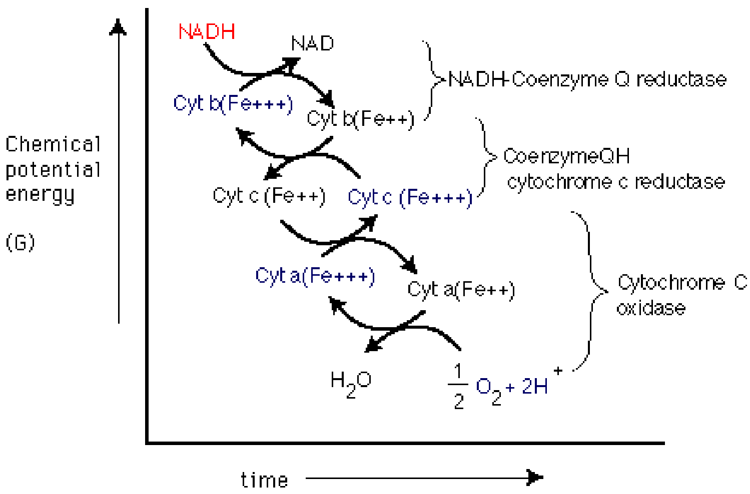

NADH
FMN
FADH2
CoQ
Cyt b
Cyt c1
Cyt c
Cyt aa3
O2
Sites of proton pumping coupled to ATP production
© 2006 Brooks/Cole - Thomson

Gibbs energy „G“



Redox potential „E“

Figure 14-21 Essential Cell Biology, 2/e. (© 2004 Garland Science)

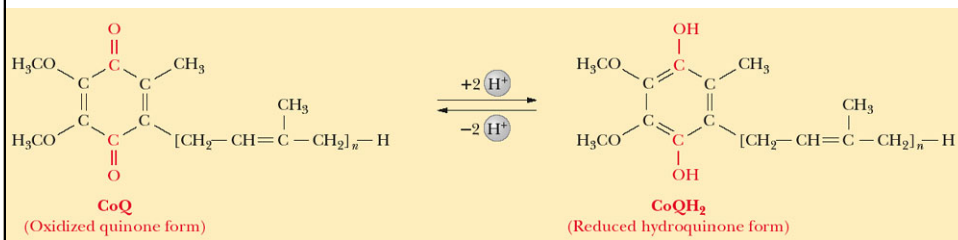


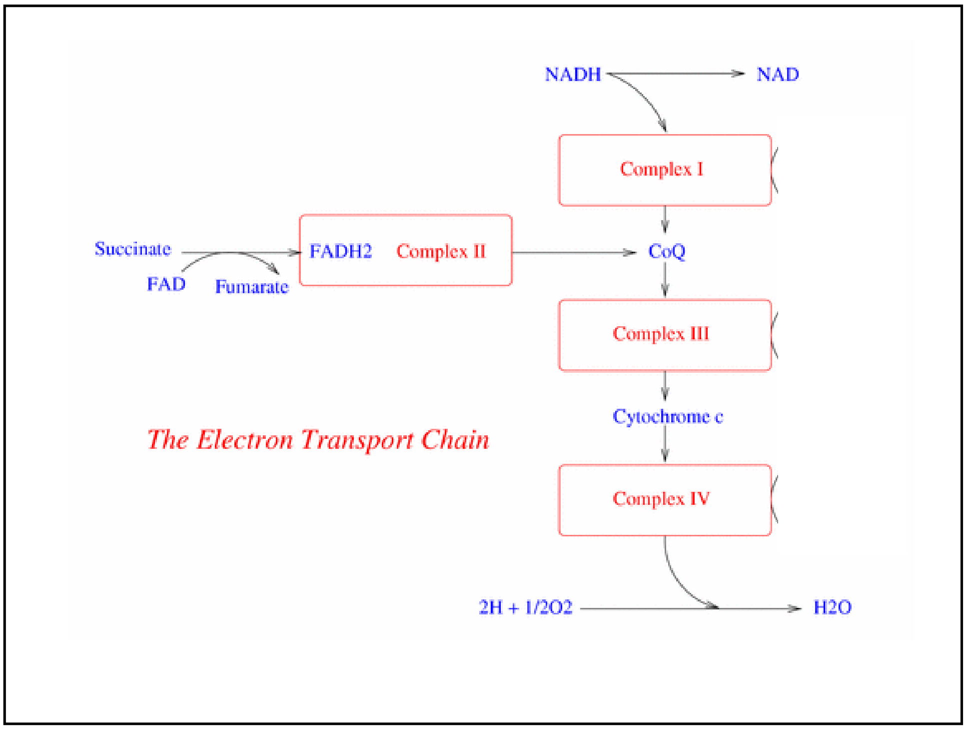
The figure is found at http://academic.brooklyn.cuny.edu/biology/bio4fv/page/mito_ox.htm (December 2006)

Table 20.1

Standard Reduction Potentials for Several Biological Reduction Half-Reactions

Reduction Half-Reaction	$E^{\circ\prime}$ (V)
$\frac{1}{2} O_2 + 2 H^+ + 2 e^- \rightarrow H_2O$	0.816
$Fe^{3+} + e^- \rightarrow Fe^{2+}$	0.771
Cytochrome $a_3(Fe^{3+}) + e^- \rightarrow$ Cytochrome $a_3(Fe^{2+})$	0.350
Cytochrome $a(Fe^{3+}) + e^- \rightarrow$ Cytochrome $a(Fe^{2+})$	0.290
Cytochrome $c(Fe^{3+}) + e^- \rightarrow$ Cytochrome $c(Fe^{2+})$	0.254
Cytochrome $c_1(Fe^{3+}) + e^- \rightarrow$ Cytochrome $c_1(Fe^{2+})$	0.220
$CoQH^{\cdot} + H^+ + e^- \rightarrow CoQH_2$ (coenzyme Q)	0.190
$CoQ + 2 H^+ + 2 e^- \rightarrow CoQH_2$	0.060
Cytochrome $b_H(Fe^{3+}) + e^- \rightarrow$ Cytochrome $b_H(Fe^{2+})$	0.050
Fumarate $+ 2 H^+ + 2 e^- \rightarrow$ Succinate	0.031
$CoQ + H^+ + e^- \rightarrow CoQH^{\cdot}$	0.030
$[FAD] + 2 H^+ + 2 e^- \rightarrow [FADH_2]$	0.003–0.091*
Cytochrome $b_L(Fe^{3+}) + e^- \rightarrow$ Cytochrome $b_L(Fe^{2+})$	−0.100
Oxaloacetate $+ 2 H^+ + e^- \rightarrow$ Malate	−0.166
Pyruvate $+ 2 H^+ + 2 e^- \rightarrow$ Lactate	−0.185
Acetaldehyde $+ 2 H^+ + 2 e^- \rightarrow$ Ethanol	−0.197
$FMN + 2 H^+ + 2 e^- \rightarrow FMNH_2$	−0.219
$FAD + 2 H^+ + 2 e^- \rightarrow FADH_2$	−0.219
1,3-*bis*phosphoglycerate $+ 2 H^+ + 2 e^- \rightarrow$ Glyceraldehyde-3-phosphate $+ P_i$	−0.290
$NAD^+ + 2 H^+ + 2 e^- \rightarrow NADH + H^+$	−0.320
$NADP^+ + 2 H^+ + 2 e^- \rightarrow NADPH + H^+$	−0.320
α-Ketoglutarate $+ CO_2 + 2 H^+ + 2 e^- \rightarrow$ Isocitrate	−0.380
Succinate $+ CO_2 + 2 H^+ + 2 e^- \rightarrow$ α-Ketoglutarate $+ H_2O$	−0.670




NADH
NAD
Complex I
Succinate
FAD
Fumarate
FADH2
Complex II
CoQ
Complex III
Cytochrome c
Complex IV
2H + 1/2O2
H2O
The Electron Transport Chain

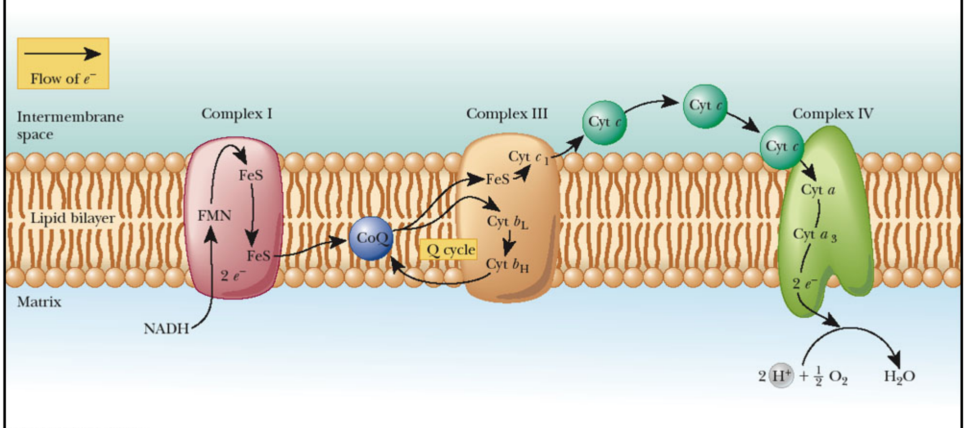
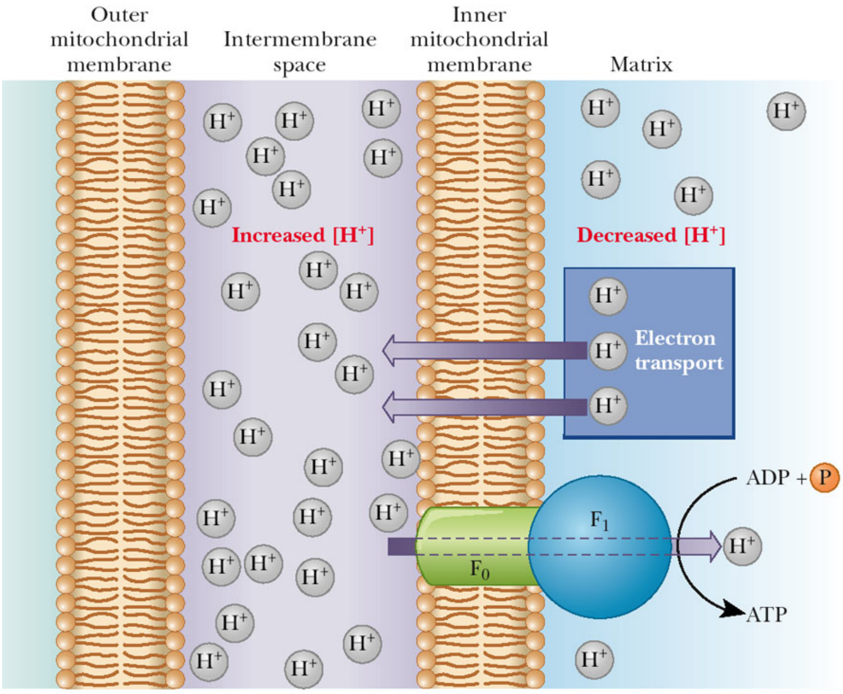

Flow of e⁻
Intermembrane space
Complex I
Complex III
Complex IV
Lipid bilayer
Matrix
NADH
FMN
FeS
2 e⁻
CoQ
Q cycle
Cyt c
Cyt a
Cyt a3
H2O

Table 20.2

The Energetics of Electron Transport Reactions

Reaction	$\Delta G^{\circ\prime}$ *kJ* (mol NADH)$^{-1}$	$\Delta G^{\circ\prime}$ *kcal* (mol NADH)$^{-1}$
$NADH + H^+ + E\text{—}FMN \rightarrow NAD^+ + E\text{—}FMNH_2$	−38.6	−9.2
$E\text{—}FMNH_2 + CoQ \rightarrow E\text{—}FMN + CoQH_2$	−42.5	−10.2
$CoQH_2 + 2\ Cyt\ b[Fe(III)] \rightarrow CoQ + 2\ H^+ + 2\ Cyt\ b[Fe(II)]$	+11.6	+2.8
$2\ Cyt\ b[Fe(II)] + 2\ Cyt\ c_1[Fe(III)] \rightarrow 2\ Cyt\ c_1[Fe(II)] + 2\ Cyt\ b[Fe(III)]$	−34.7	−8.3
$2\ Cyt\ c_1[Fe(II)] + 2\ Cyt\ c[Fe(III)] \rightarrow 2\ Cyt\ c[Fe(II)] + 2\ Cyt\ c_1[Fe(III)]$	−5.8	−1.4
$2\ Cyt\ c[Fe(II)] + 2\ Cyt\ (aa_3)\ [Fe(III)] \rightarrow 2\ Cyt\ (aa_3)\ [Fe(II)] + 2\ Cyt\ c[Fe(III)]$	−7.7	−1.8
$2\ Cyt\ (aa_3)[Fe(II)] + \frac{1}{2}O_2 + 2\ H^+ \rightarrow 2\ Cyt\ (aa_3)[Fe(III)] + H_2O$	−102.3	−24.5
Overall reaction: $NADH + H^+ + \frac{1}{2}O_2 \rightarrow NAD^+ + H_2O$	−220	−52.6



OXIDATIVE PHOSPHORYLATION

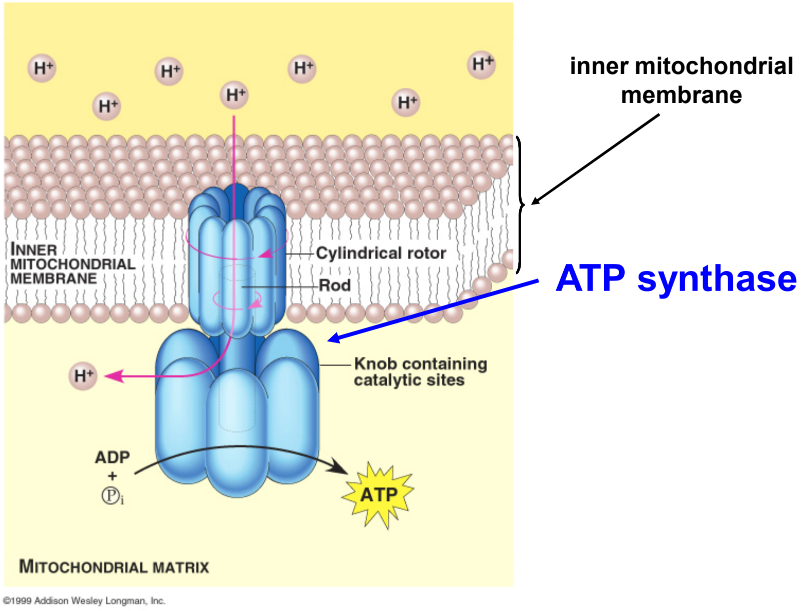


Table 20.3

Yield of ATP from Glucose Oxidation

Pathway	ATP Yield per Glucose: Glycerol–Phosphate Shuttle	ATP Yield per Glucose: Malate–Aspartate Shuttle	NADH	$FADH_2$
Glycolysis: glucose to pyruvate (cytosol)				
Phosphorylation of glucose	−1	−1		
Phosphorylation of fructose-6-phosphate	−1	−1		
Dephosphorylation of 2 molecules of 1,3-BPG	+2	+2		
Dephosphorylation of 2 molecules of PEP	+2	+2		
Oxidation of 2 molecules of glyceraldehyde-3-phosphate yields 2 NADH			+2	
Pyruvate conversion to acetyl-CoA (mitochondria)				
2 NADH produced			+2	
Citric acid cycle (mitochondria)				
2 molecules of GTP from 2 molecules of succinyl-CoA	+2	+2		
Oxidation of 2 molecules each of isocitrate, α-ketoglutarate, and malate yields 6 NADH			+6	
Oxidation of 2 molecules of succinate yields 2 $FADH_2$				+2
Oxidative phosphorylation (mitochondria)				
2 NADH from glycolysis yield 1.5 ATP each if NADH is oxidized by glycerol–phosphate shuttle; 2.5 ATP by malate–aspartate shuttle	+3	+5	−2	
Oxidative decarboxylation of 2 pyruvate to 2 acetyl-CoA: 2 NADH produce 2.5 ATP each	+5	+5	−2	
2 $FADH_2$ from each citric acid cycle produce 1.5 ATP each	+3	+3		−2
6 NADH from citric acid cycle produce 2.5 ATP each	+15	+15	−6	
Net Yield	+30	+32	0	0