Mitochondria and Peroxisome

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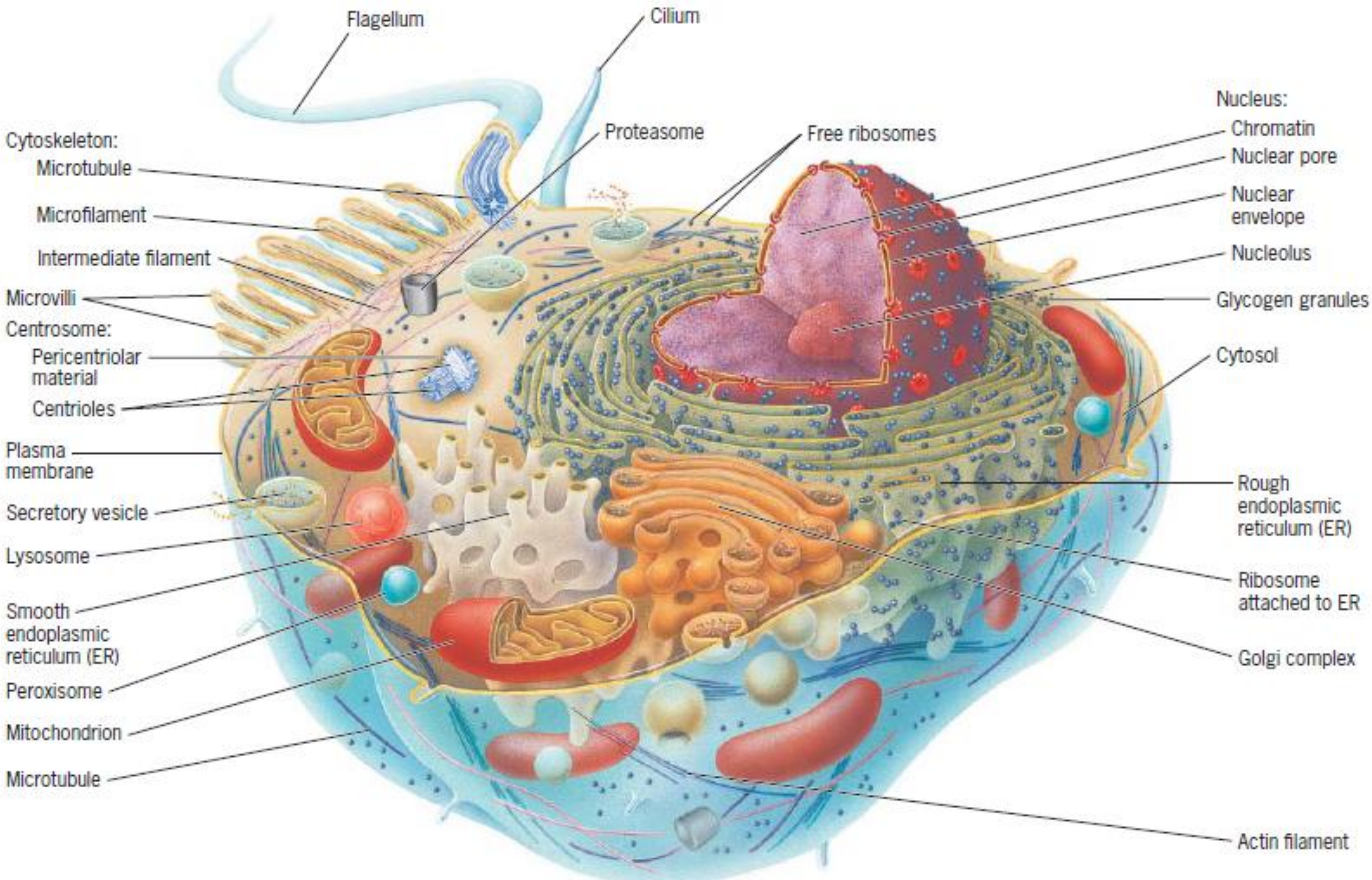
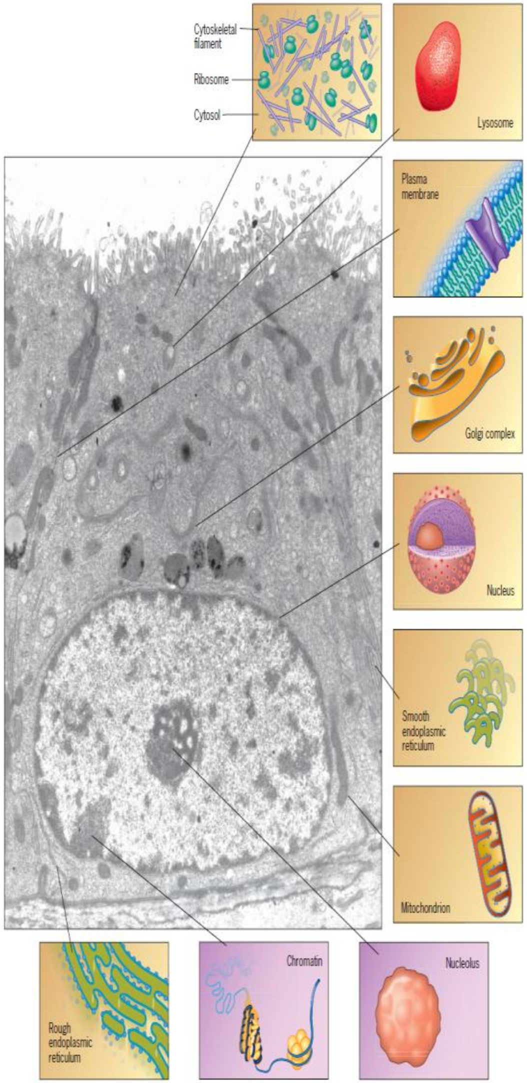
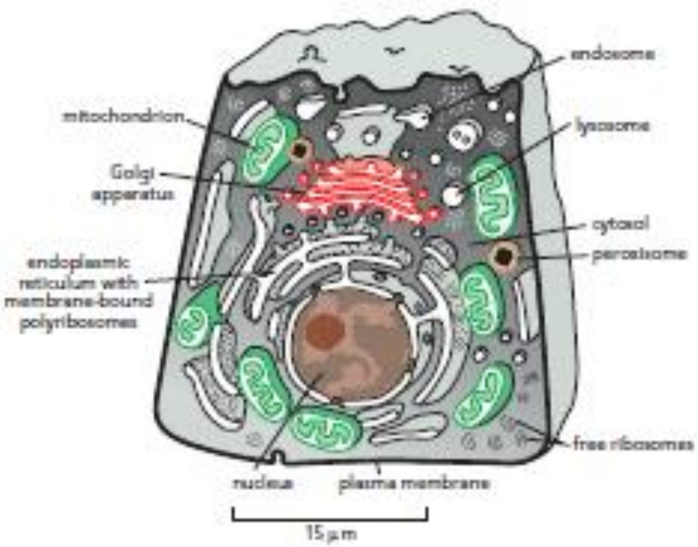
Ultrastructure of an animal cell

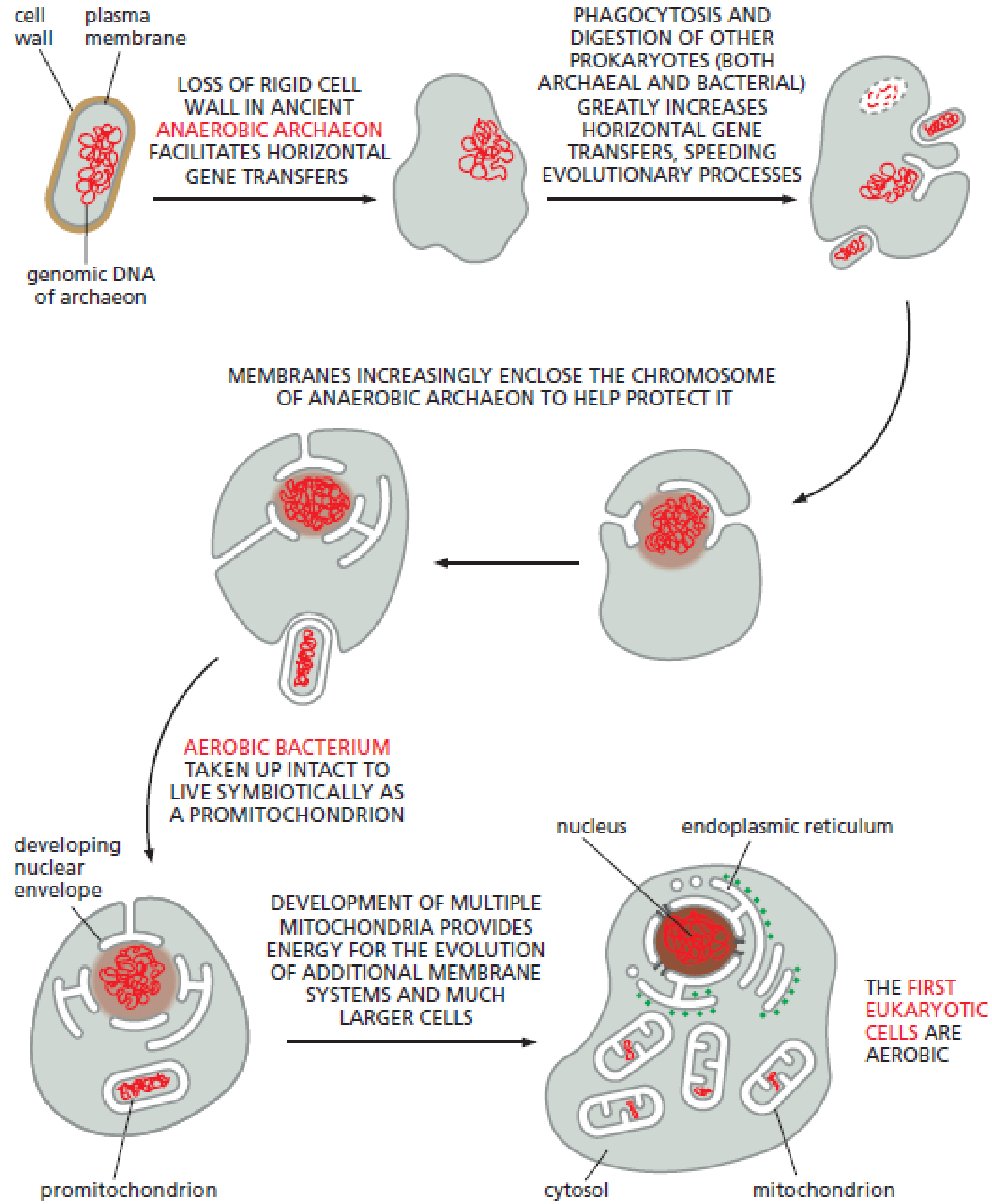




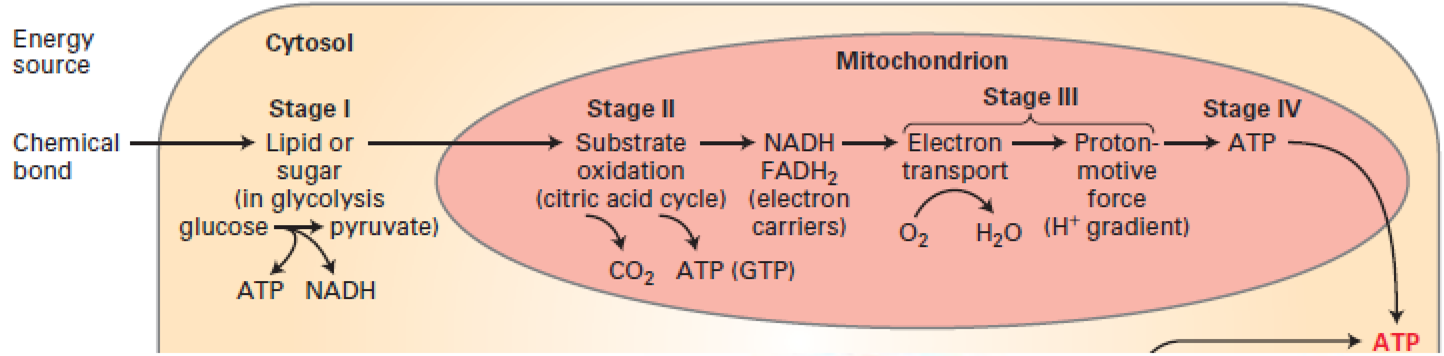
Cytoplasm Component	Structure	Function
MEMBRANOUS ORGANELLES		
Endoplasmic Reticulum	Extensive, continuous membranous network of fluid-filled tubules and flattened sacs, partially studded with ribosomes	Forms new cell membrane and other cell components and manufactures products for secretion
Golgi Complex	Sets of stacked, flattened membranous sacs	Modifies, packages, and distributes newly synthesized proteins
Lysosomes	Membranous sacs containing hydrolytic enzymes	Serve as cell's digestive system, destroying foreign substances and cellular debris
Peroxisomes	Membranous sacs containing oxidative enzymes	Perform detoxification activities
Mitochondria	Rod- or oval-shaped bodies enclosed by two membranes, with the inner membrane folded into cristae that project into an interior matrix	Act as energy organelles; major site of ATP production; contain enzymes for citric acid cycle, proteins of electron transport system, and ATP synthase
NONMEMBRANOUS ORGANELLES		
Ribosomes	Granules of RNA and proteins—some attached to rough ER, some free in cytosol	Serve as workbenches for protein synthesis
Proteosomes	Tunnel-like protein complexes	Serve to break down unwanted proteins
Vaults	Shaped like hollow octagonal barrels	Serve as cellular trucks for transport from nucleus to cytoplasm
Centrosome/ Centrioles	A pair of cylindrical structures at right angles to each other (centrioles) surrounded by an amorphous mass	Form and organize the microtubule cytoskeleton
CYTOSOL		
Intermediary Metabolism Enzymes	Dispersed within the cytosol	Facilitate intracellular reactions involving degradation, synthesis, and transformation of small organic molecules
Transport, Secretory, and Endocytic Vesicles	Transiently formed, membrane-enclosed products synthesized within or engulfed by the cell	Transport and/or store products being moved within, out of, or into the cell, respectively
Inclusions	Glycogen granules, fat droplets	Store excess nutrients
Cytoskeleton		As an integrated whole, serves as the cell's "bone and muscle"
Microtubules	Long, slender, hollow tubes composed of tubulin molecules	Maintain asymmetric cell shapes and coordinate complex cell movements, specifically serving as highways for transport of secretory vesicles within cell, serving as main structural and functional component of cilia and flagella, and forming mitotic spindle during cell division
Microfilaments	Intertwined helical chains of actin molecules; microfilaments composed of myosin molecules also present in muscle cells	Play a vital role in various cellular contractile systems, including muscle contraction and amoeboid movement; serve as a mechanical stiffener for microvilli
Intermediate Filaments	Irregular, threadlike proteins	Help resist mechanical stress

Evolution of an eukaryotic cell

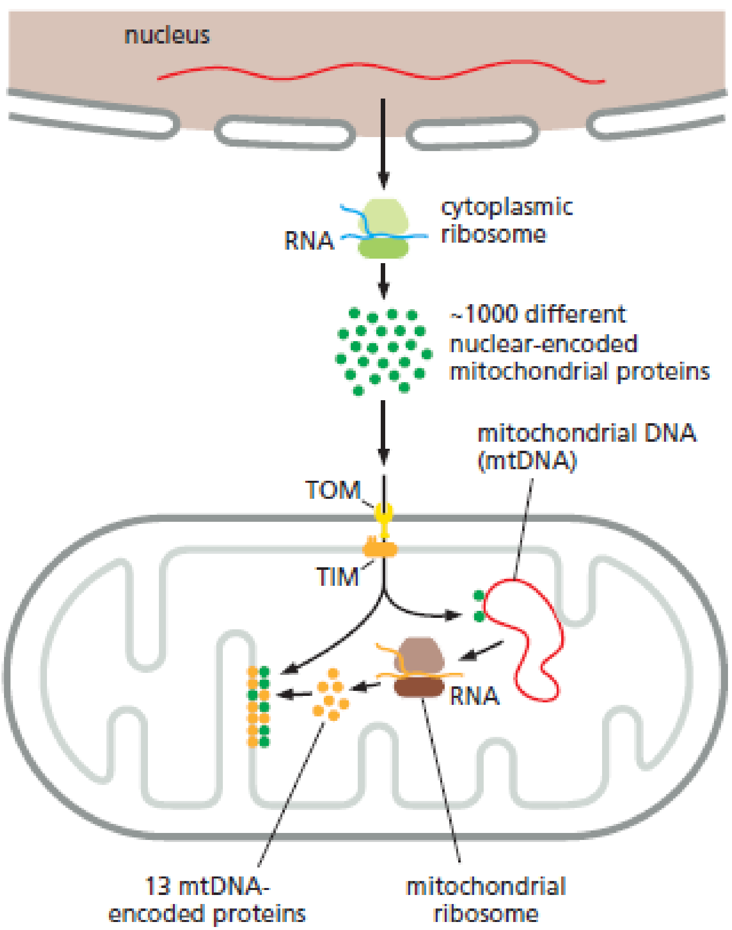




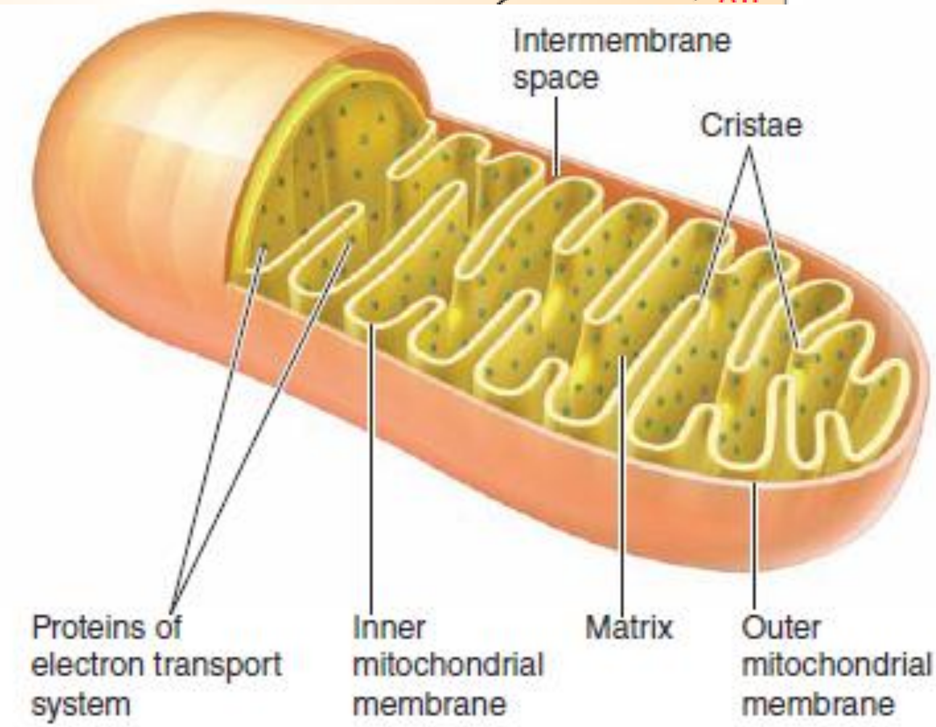
MITOCHONDRIA



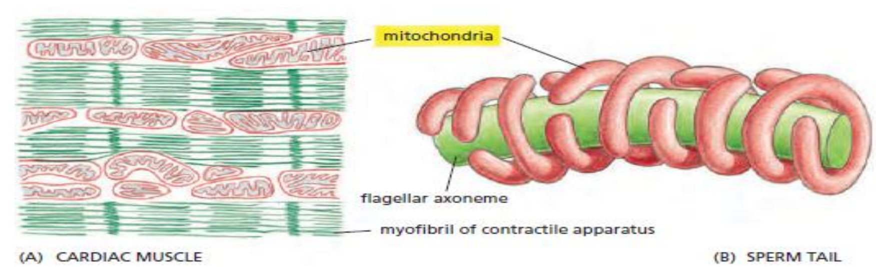
Energy source
Cytosol
Mitochondrion
Chemical bond
Stage I
Lipid or sugar (in glycolysis glucose → pyruvate)
ATP
NADH
Stage II
Substrate oxidation (citric acid cycle)
CO_2
ATP (GTP)
NADH $FADH_2$ (electron carriers)
Stage III
Electron transport
O_2
H_2O
Proton-motive force (H^+ gradient)
Stage IV
ATP
ATP



nucleus
RNA
cytoplasmic ribosome
~1000 different nuclear-encoded mitochondrial proteins
mitochondrial DNA (mtDNA)
TOM
TIM
RNA
13 mtDNA-encoded proteins
mitochondrial ribosome



Intermembrane space
Cristae
Proteins of electron transport system
Inner mitochondrial membrane
Matrix
Outer mitochondrial membrane



mitochondria
flagellar axoneme
myofibril of contractile apparatus
(A) CARDIAC MUSCLE
(B) SPERM TAIL

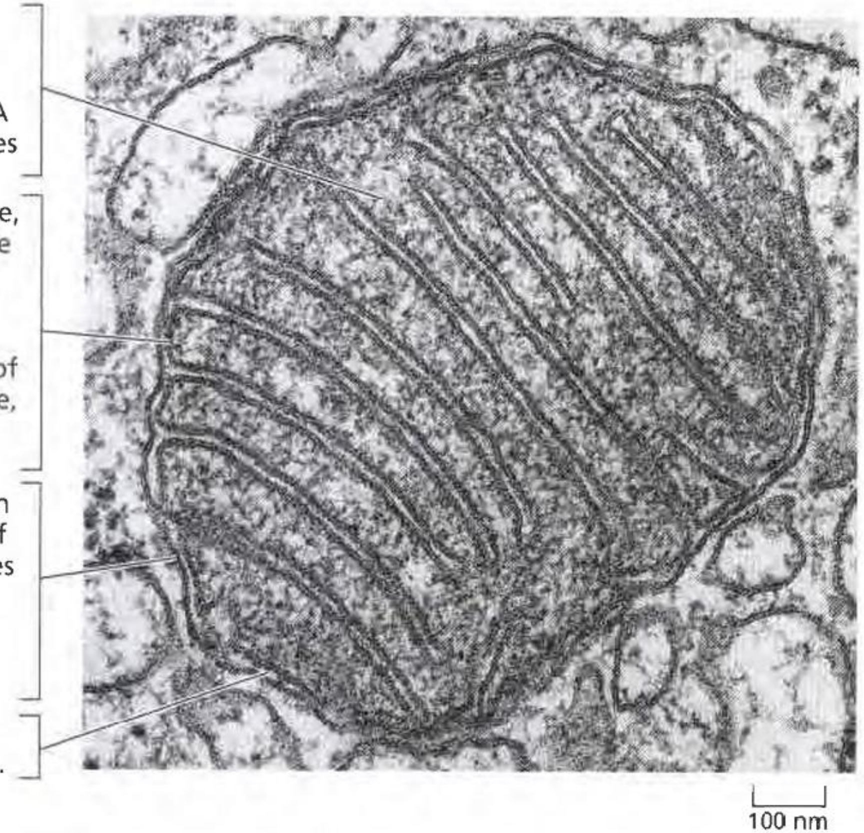
MITOCHONDRIAL COMPARTMENTS

Matrix. This large internal space contains a highly concentrated mixture of hundreds of enzymes, including those required for the oxidation of pyruvate and fatty acids and for the citric acid cycle. The matrix also contains several identical copies of the mitochondrial DNA genome, special mitochondrial ribosomes, tRNAs, and various enzymes required for expression of the mitochondrial genes.

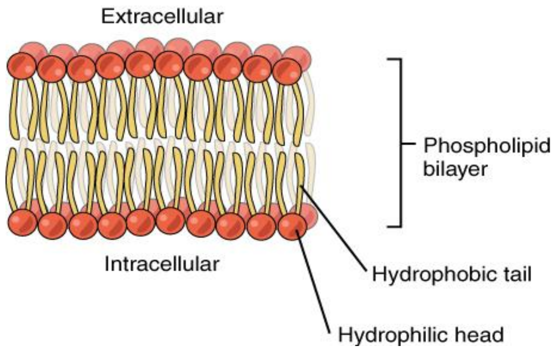
Inner membrane. The inner membrane is folded into numerous cristae, greatly increasing its total surface area. It contains proteins with three types of functions: (1) those that carry out the oxidation reactions of the electron-transport chain, (2) the ATP synthase that makes ATP in the matrix, and (3) transport proteins that allow the passage of metabolites into and out of the matrix. An electrochemical gradient of H^+, which drives the ATP synthase, is established across this membrane, so the membrane must be impermeable to ions and most small charged molecules.

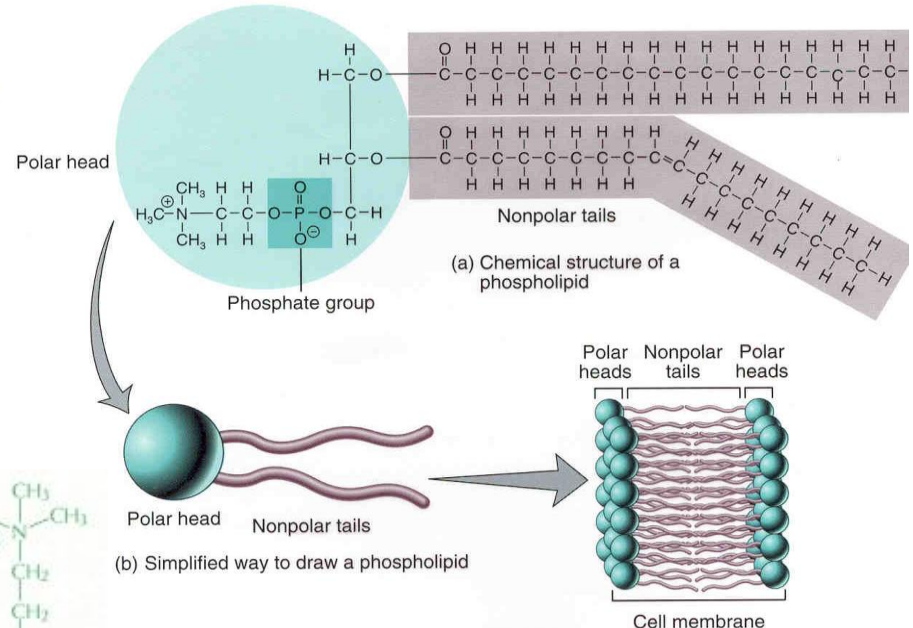
Outer membrane. Because it contains a large channel-forming protein (a porin, VDAC), the outer membrane is permeable to all molecules of 5000 daltons or less. Other proteins in this membrane include enzymes involved in mitochondrial lipid synthesis and enzymes that convert lipid substrates into forms that are subsequently metabolized in the matrix, import receptors for mitochondrial proteins, and enzymatic machinery for division and fusion of the organelle.

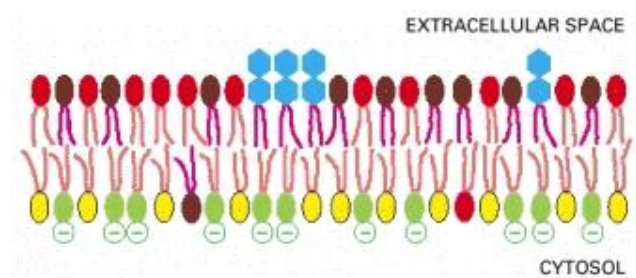
Intermembrane space. This space contains several enzymes that use the ATP passing out of the matrix to phosphorylate other nucleotides.

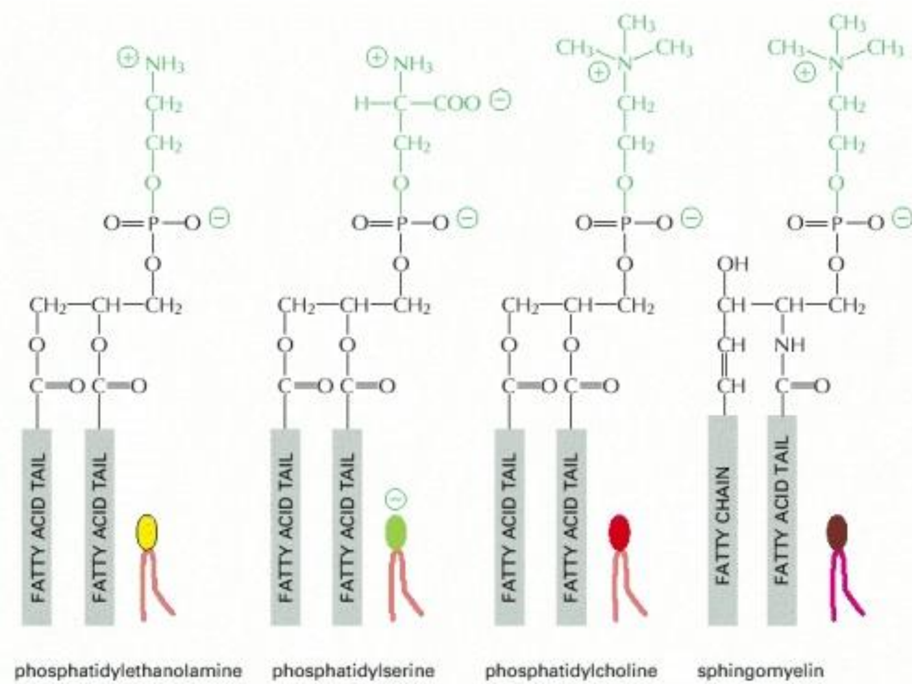


MITOCHONDRIAL MEMBRANE

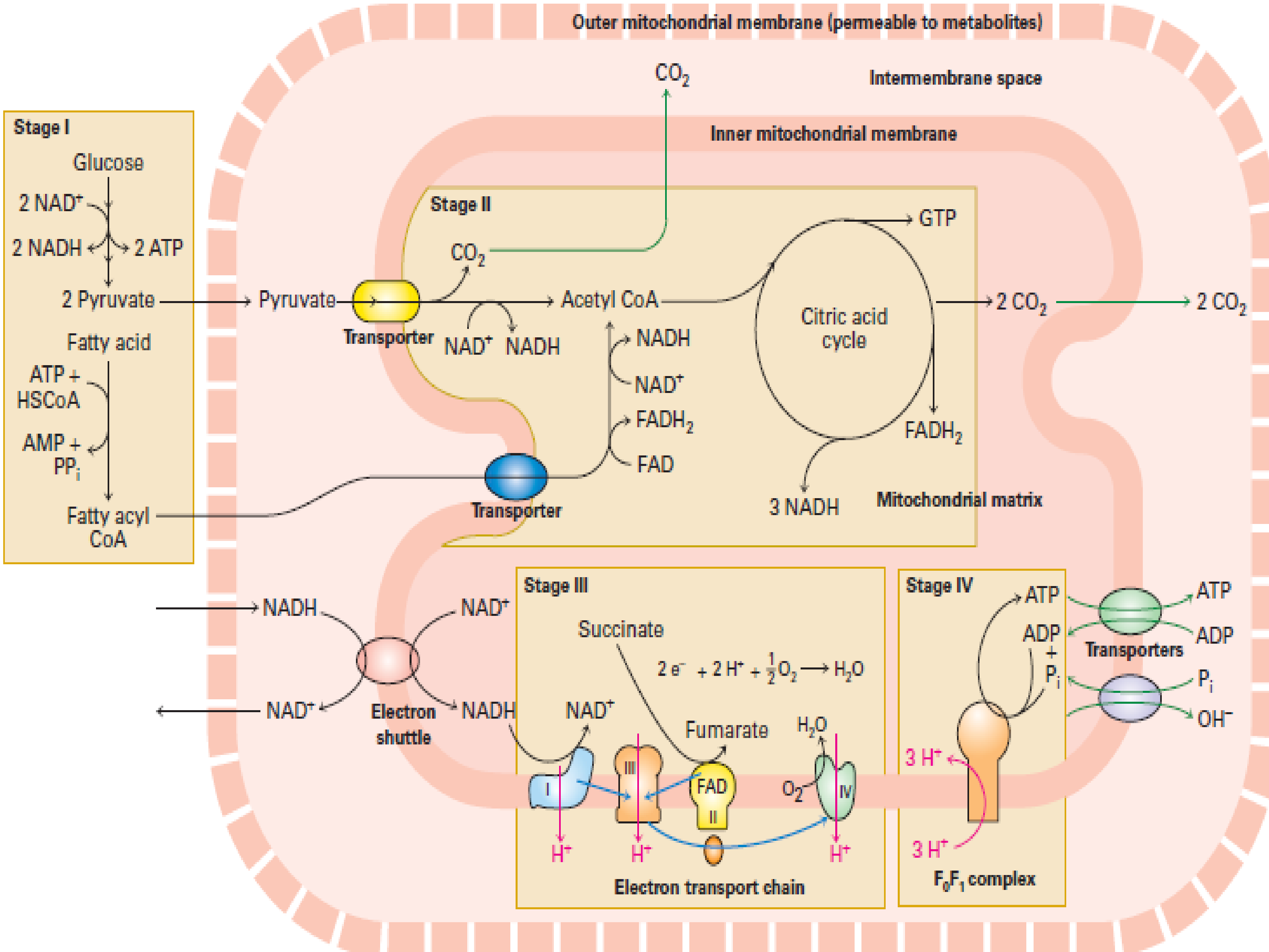




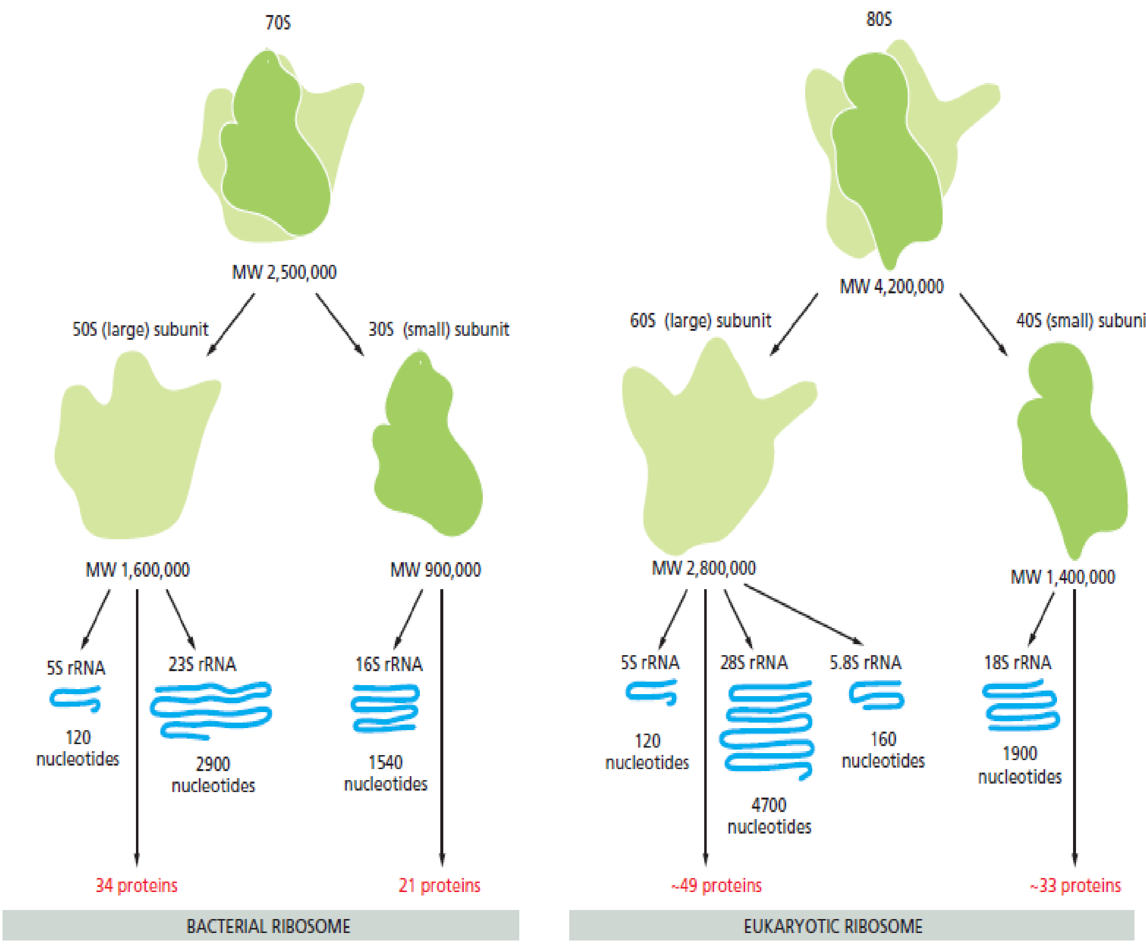




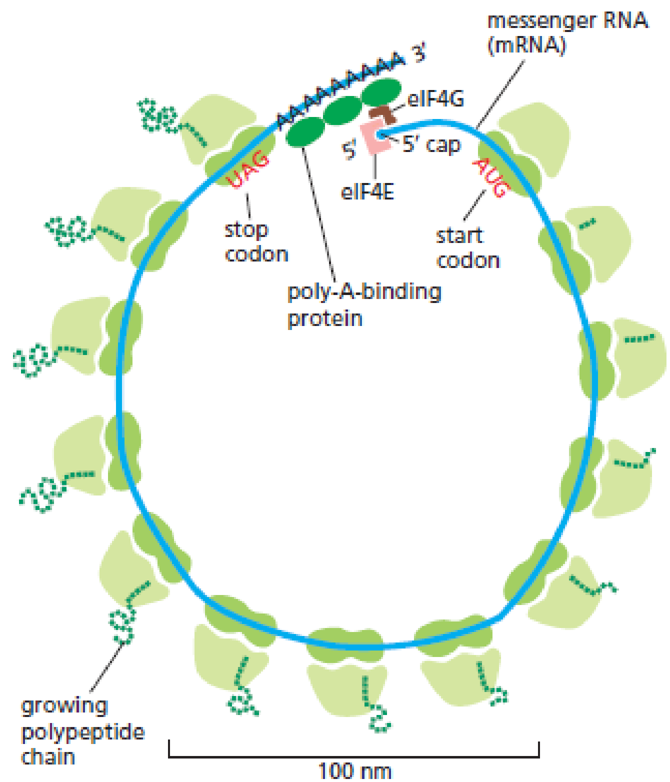
OVERVIEW OF BIOCHEMICAL REACTIONS IN MITOCHONDRIA



RIBOSOME



70S
MW 2,500,000
50S (large) subunit
30S (small) subunit
MW 1,600,000
MW 900,000
5S rRNA
120 nucleotides
23S rRNA
2900 nucleotides
16S rRNA
1540 nucleotides
34 proteins
21 proteins
BACTERIAL RIBOSOME
80S
MW 4,200,000
60S (large) subunit
40S (small) subunit
MW 2,800,000
MW 1,400,000
5S rRNA
120 nucleotides
28S rRNA
4700 nucleotides
5.8S rRNA
160 nucleotides
18S rRNA
1900 nucleotides
~49 proteins
~33 proteins
EUKARYOTIC RIBOSOME



messenger RNA (mRNA)
AAAAAAAAA 3'
eIF4G
5'
5' cap
eIF4E
UAG
stop codon
AUG
start codon
poly-A-binding protein
growing polypeptide chain
100 nm

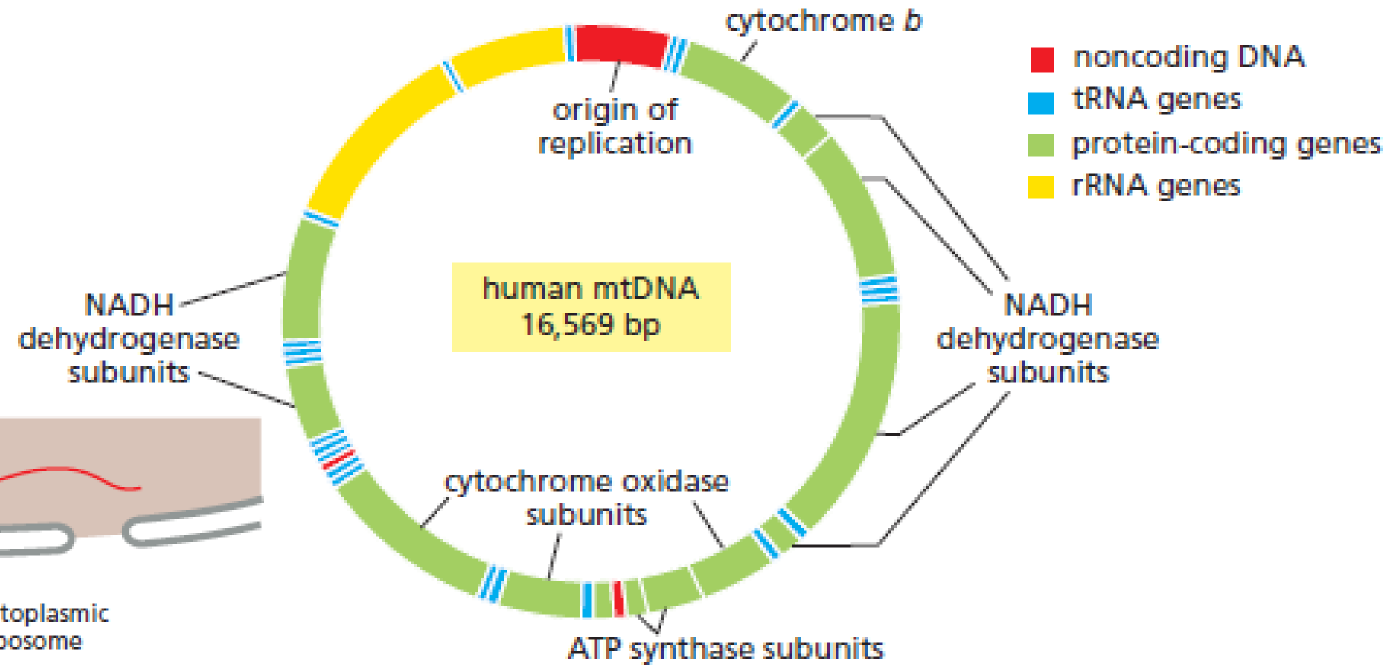
Mitoribosome

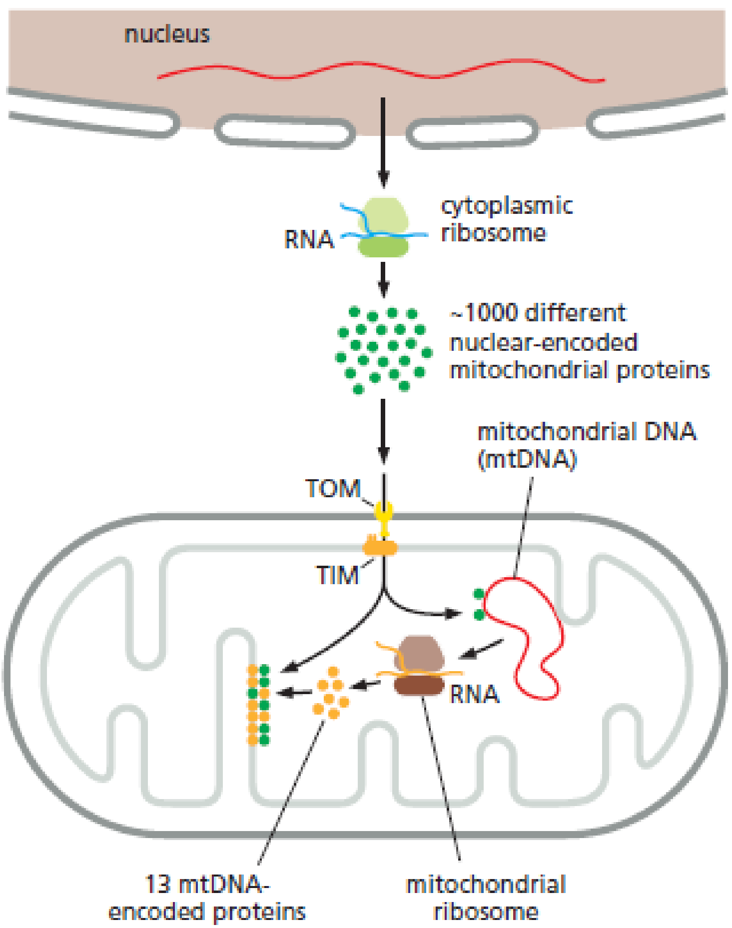
Table 1 Overview of the composition of bacterial, eukaryotic cytosolic, and mitochondrial ribosomes

	Bacteria (*Escherichia coli*) (154)	Eukaryotic cytosol (154)	Mammalian mitochondria (62, 63)	Yeast mitochondria (21, 57)
Ribosome				
Sedimentation coefficient	70S	80S	55S	74S
Molecular weight	2.3 MDa	3.3–4.3 MDa	2.7 MDa	3–3.3 MDa
Number of rRNAs	3	4	3	2
Number of proteins	54	79–80	82	∼82[a]
Large subunit				
Sedimentation coefficient	50S	60S	39S	54S
rRNAs	23S (2,904 nt)	26S–28S (3,396–5,034 nt)	16S (1,569 nt)	21S (3,296 nt)
		5.8S (156–158 nt)		
	5S (120 nt)	5S (120–121 nt)	CP tRNA (73–75 nt)	
Number of proteins	33	46–47	52	46
Small subunit				
Sedimentation coefficient	30S	40S	28S	37S
rRNAs	16S (1,534 nt)	18S (1,800–1,870 nt)	12S (962 nt)	15S (1,649 nt)
Number of proteins	21	33	30	∼36[a]

Abbreviations: CP, central protuberance; nt, nucleotide; rRNA, ribosomal RNA; tRNA, transfer RNA.
[a]The high-resolution structure of the 37S subunit has not been determined. Therefore, the protein count might change.

MITOCHONDRIAL GENOME





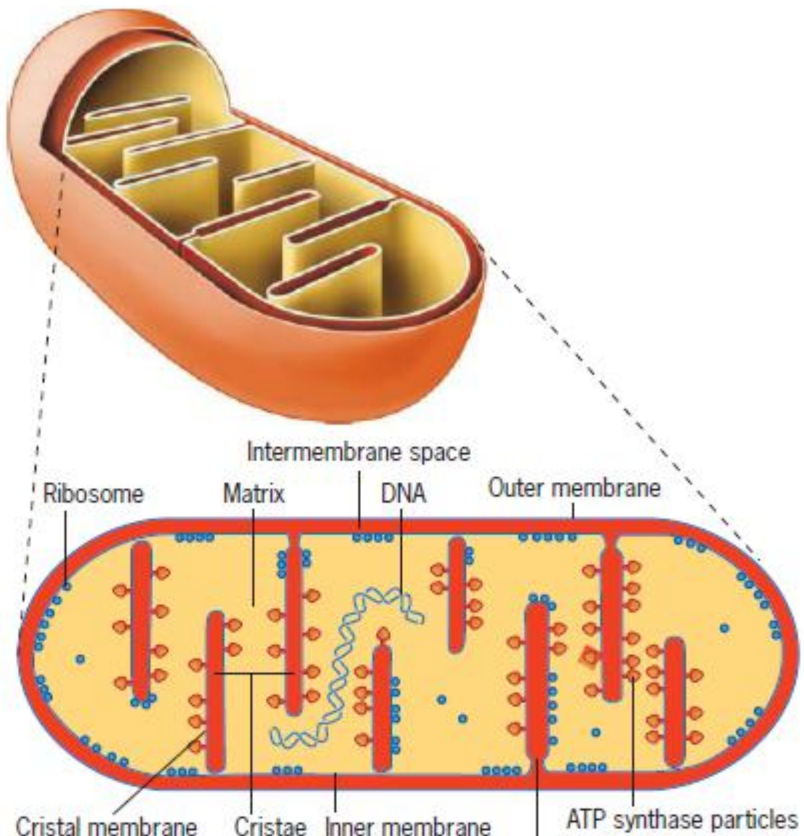
MITOCHONDRIA

FUNCTION

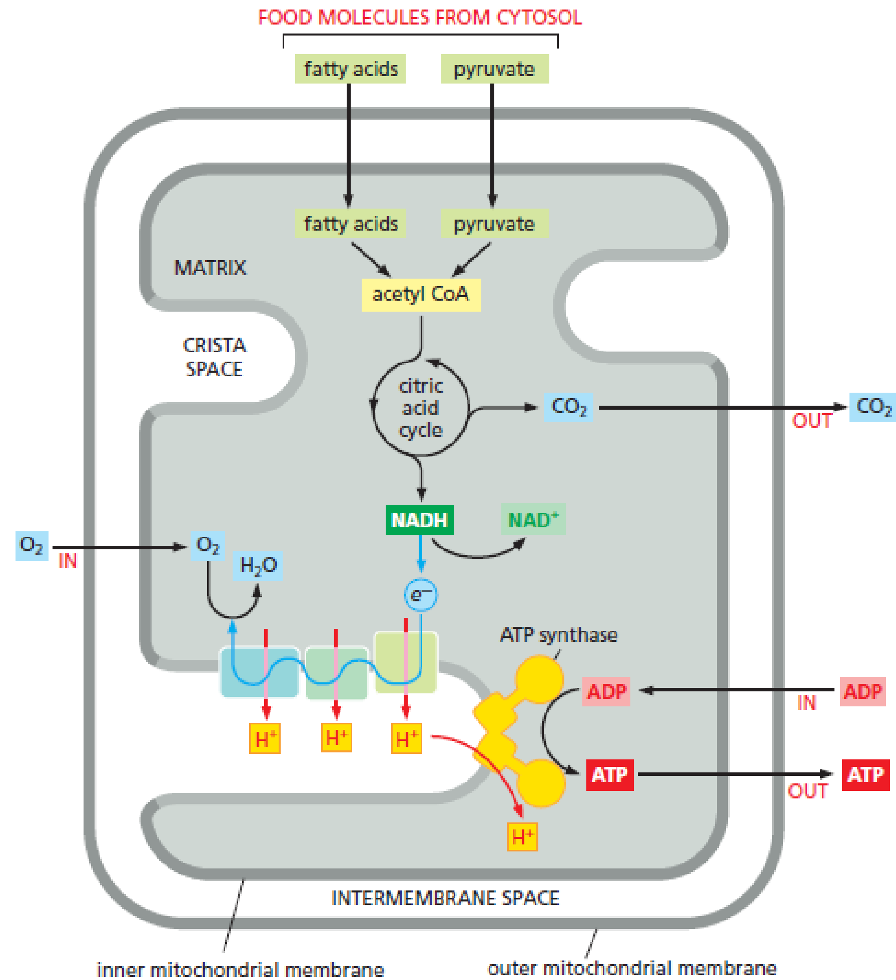
TABLE 12-1 Multiple Functions of Mitochondria
Biosynthesis or processing of small molecules
Fatty acids
Steroid hormones
Pyrimidines
Iron-sulfur clusters
Heme
Phospholipids (phosphatidylethanolamine, phosphatidylglycerol, cardiolipin)
Ubiquinone
Amino acids (synthesis, interconversion, and catabolism)
Other mitochondrial functions
Oxidative phosphorylation and ATP synthesis
Reactive oxygen species (ROS) homeostasis
Ion homeostasis (e.g., calcium)
Ammonia detoxification
Fatty acid oxidation
Thermogenesis (heat generation) in brown fat
Contributions to innate immunity and inflammation
Regulated cell death pathways (e.g., apoptosis)
Cellular processes influenced by mitochondria-associated membranes (MAMs)
Mitochondrial shape and dynamics
PINK1/Parkin-dependent mitophagy (initiated at MAMs)
Calcium transport into the mitochondria
Calcium homeostasis and calcium-mediated signaling
Glucose and energy metabolism
Mitochondrial import from the ER of lipids, including phosphatidylserine and possibly cholesterol
Mitochondrial biosynthesis of lipids, including phosphatidylethanolamine and steroid hormones
Responses to stress
Cell survival via regulated cell death (see Chapter 21)
Inflammatory responses via the inflammasome and innate immune responses (see Chapter 23)
Pathways implicated in viral infections (cytomegalovirus, hepatitis C virus)
Neurodegenerative pathology (Alzheimer's and Parkinson's diseases)

TABLE 12-3 Net Result of the Glycolytic Pathway and the Citric Acid Cycle

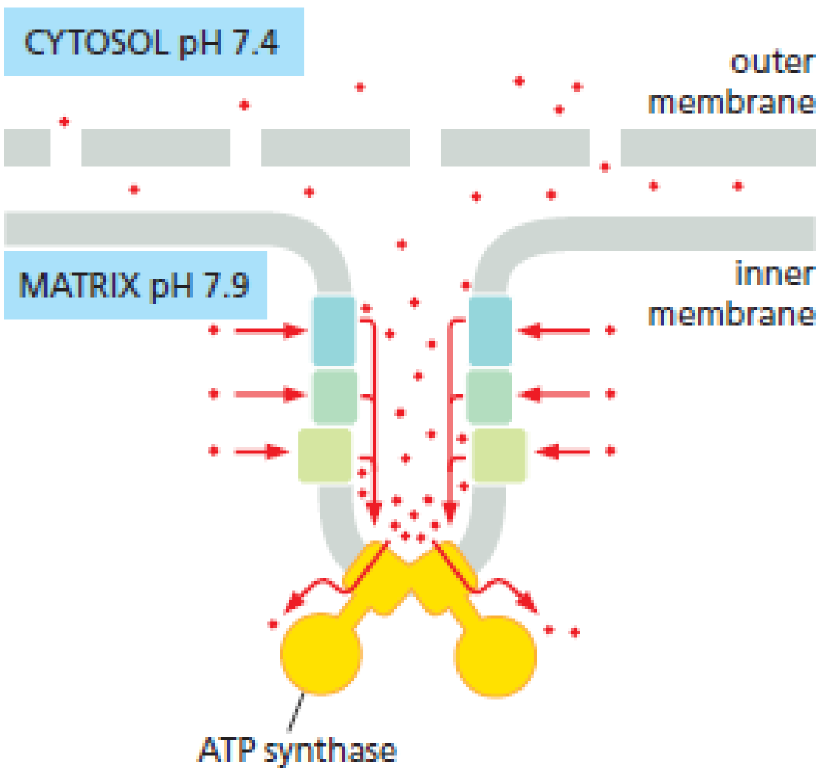
Reaction	CO_2 Molecules Produced	NAD^+ Molecules Reduced to NADH	FAD Molecules Reduced to $FADH_2$	ATP (or GTP)
1 glucose molecule to 2 pyruvate molecules	0	2	0	2
2 pyruvates to 2 acetyl CoA molecules	2	2	0	0
2 acetyl CoA to 4 CO_2 molecules	4	6	2	2
Total	6	10	2	4

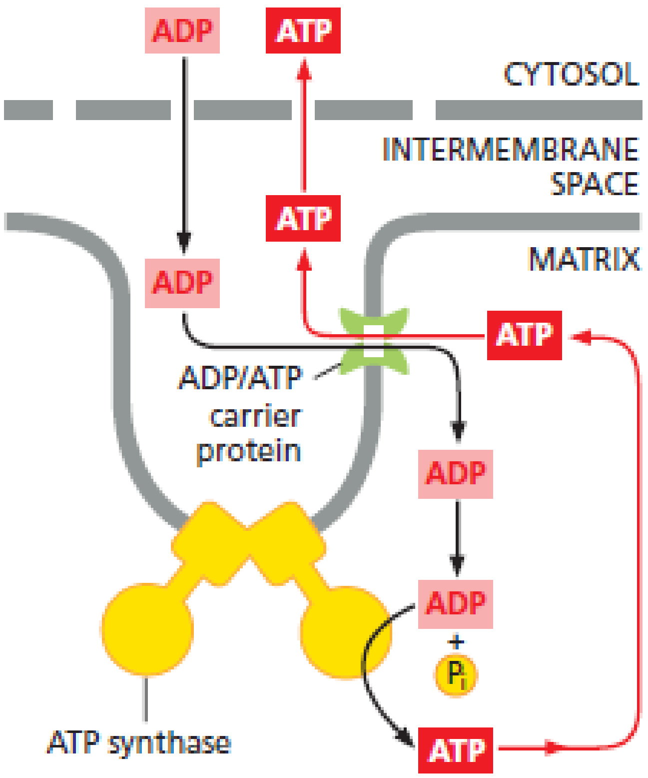


(c)

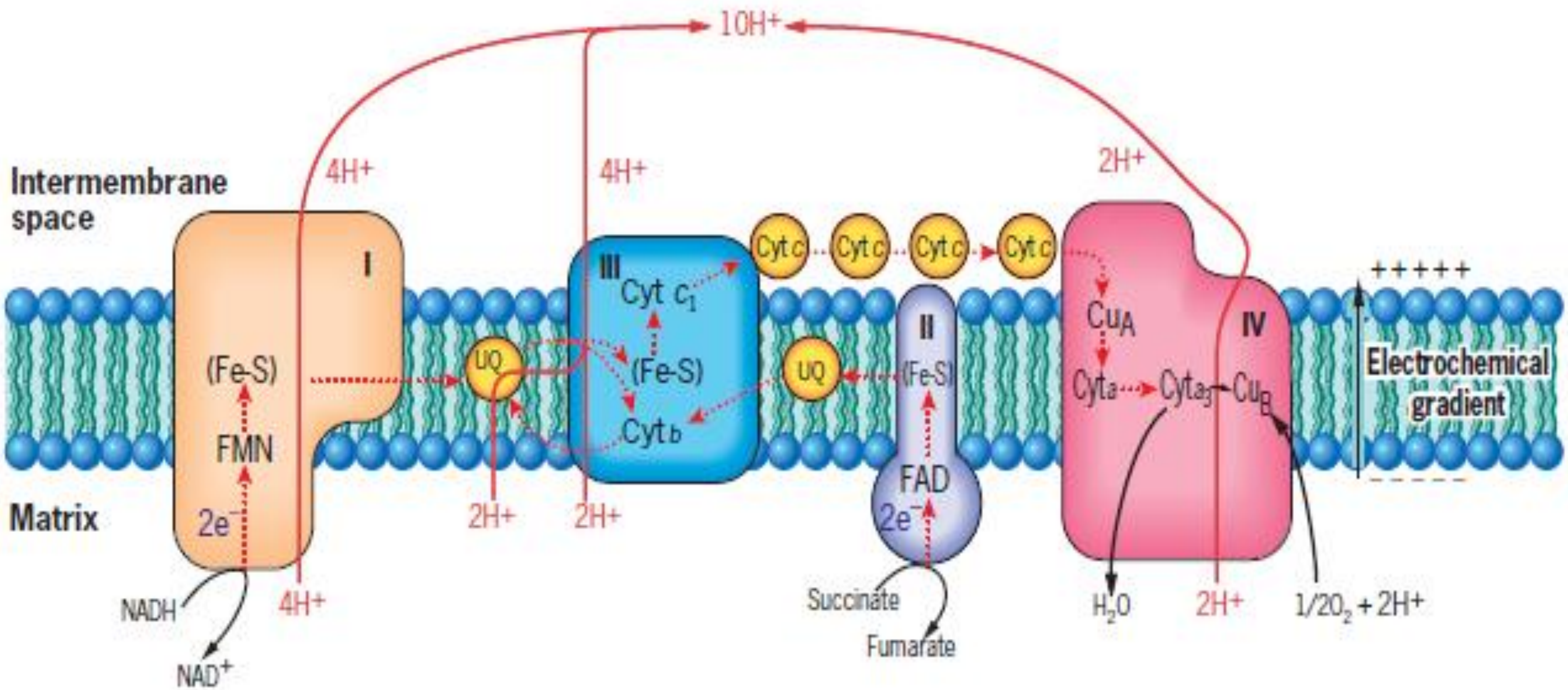


CHEMIOSMOTIC COUPLING

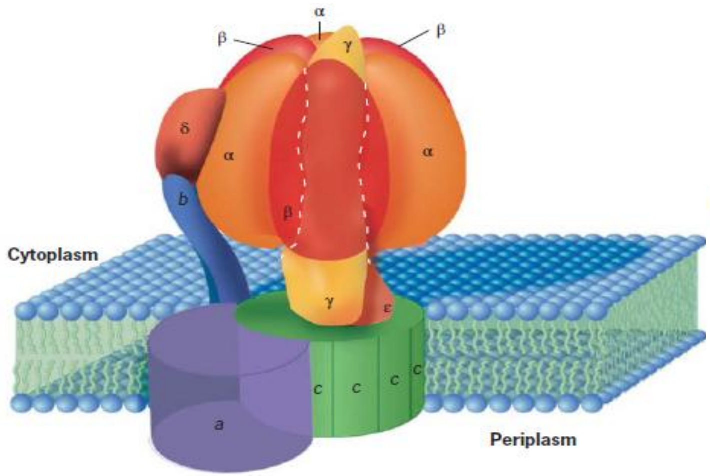


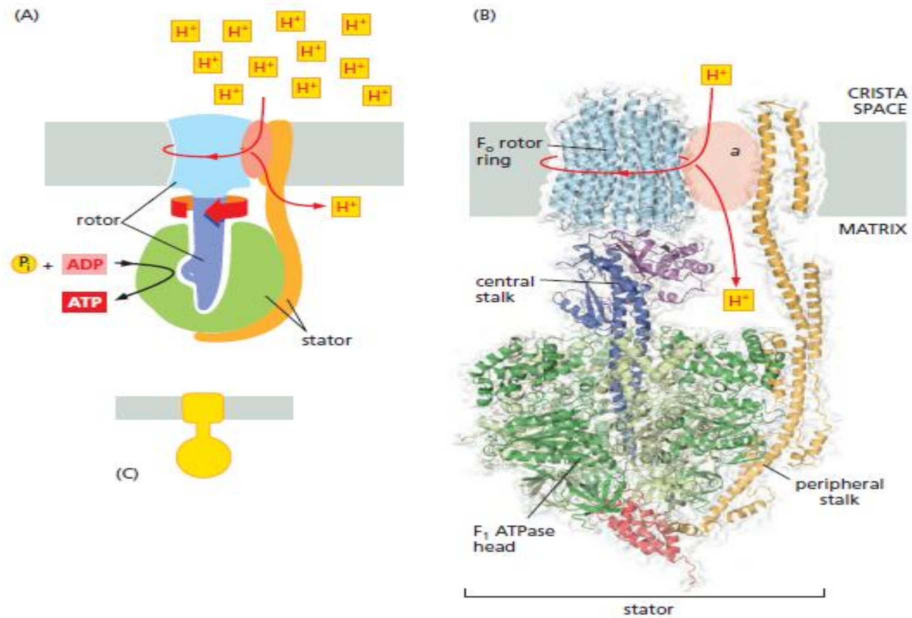


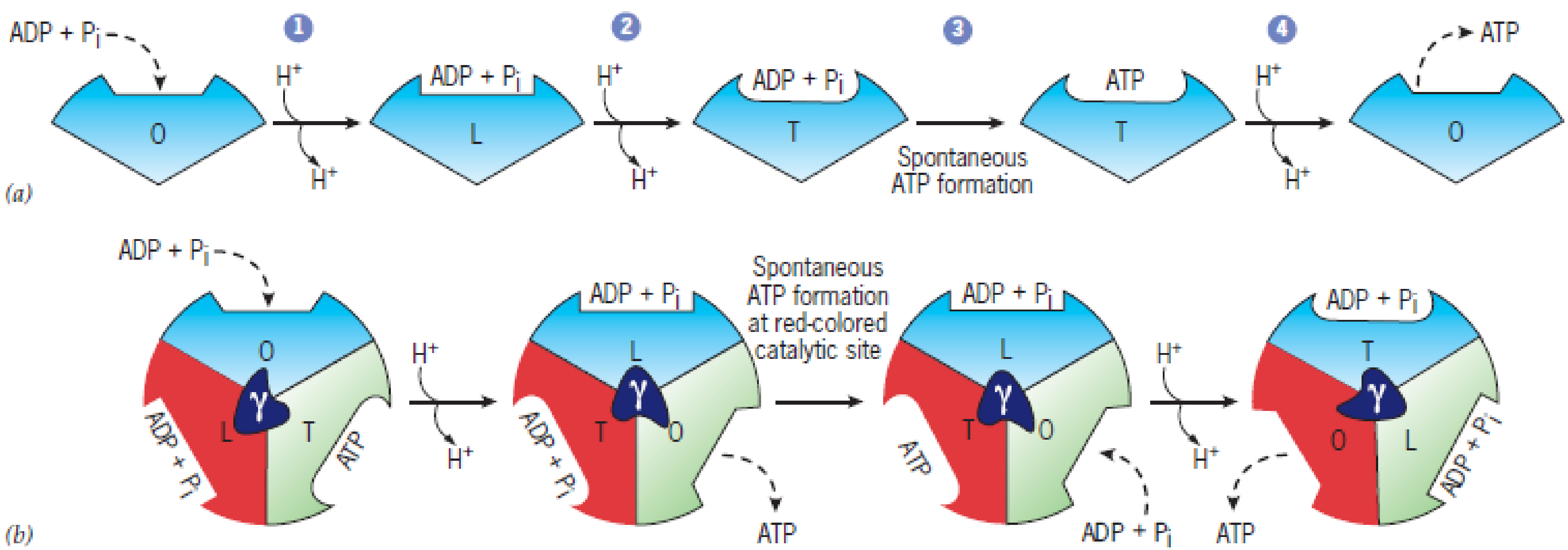
ELECTRON TRANSPORT SYSTEM & ATP SYNTHASE



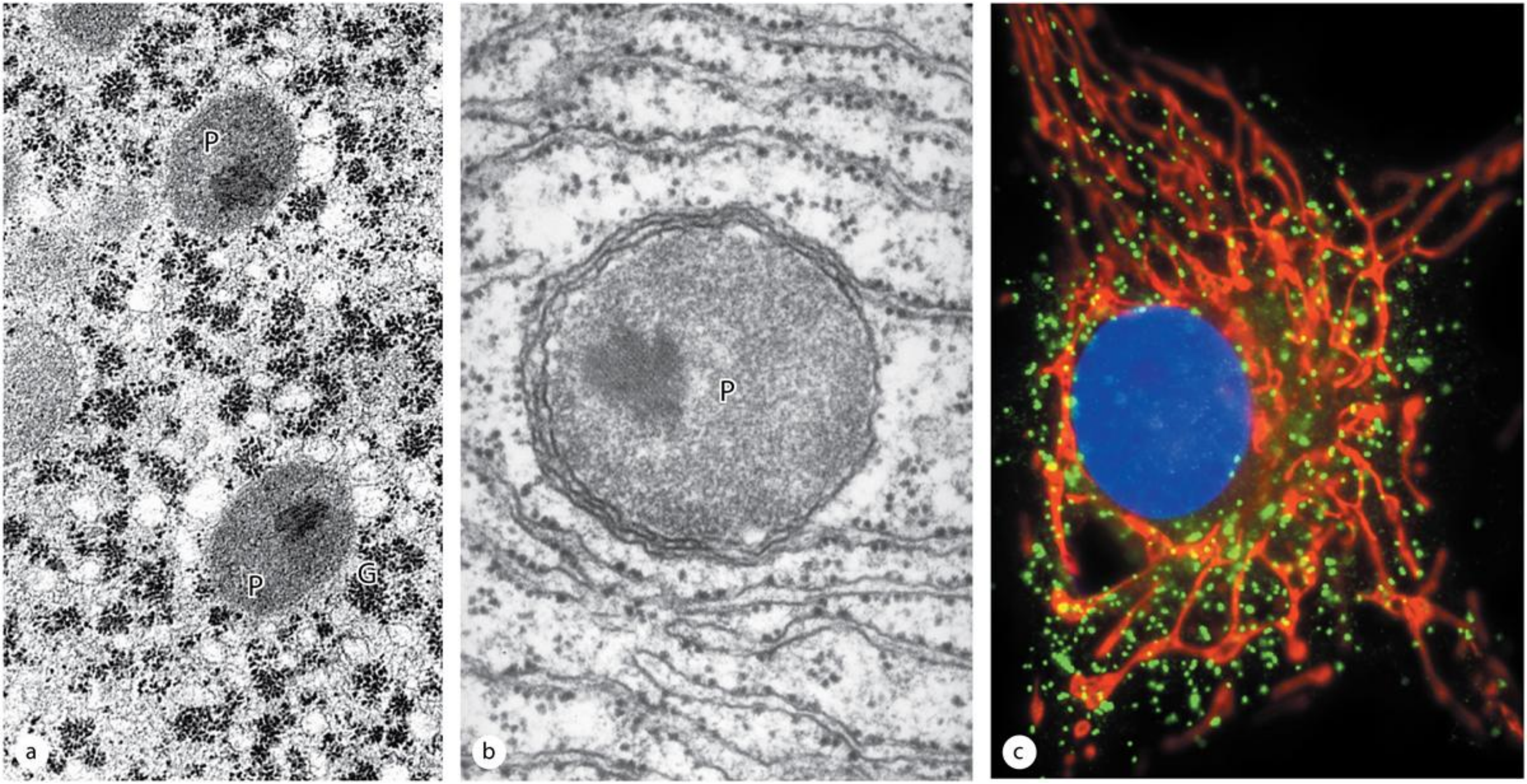
ATP SYNTHESIS

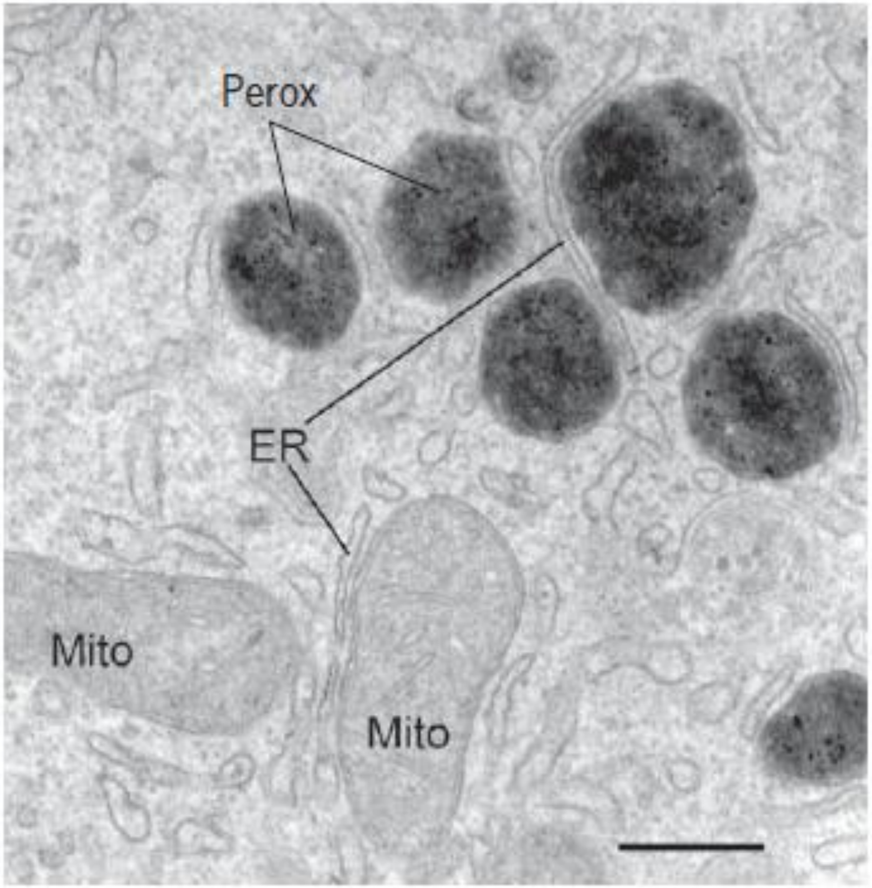




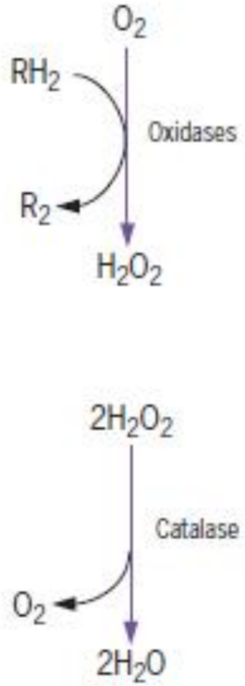


PEROXISOME

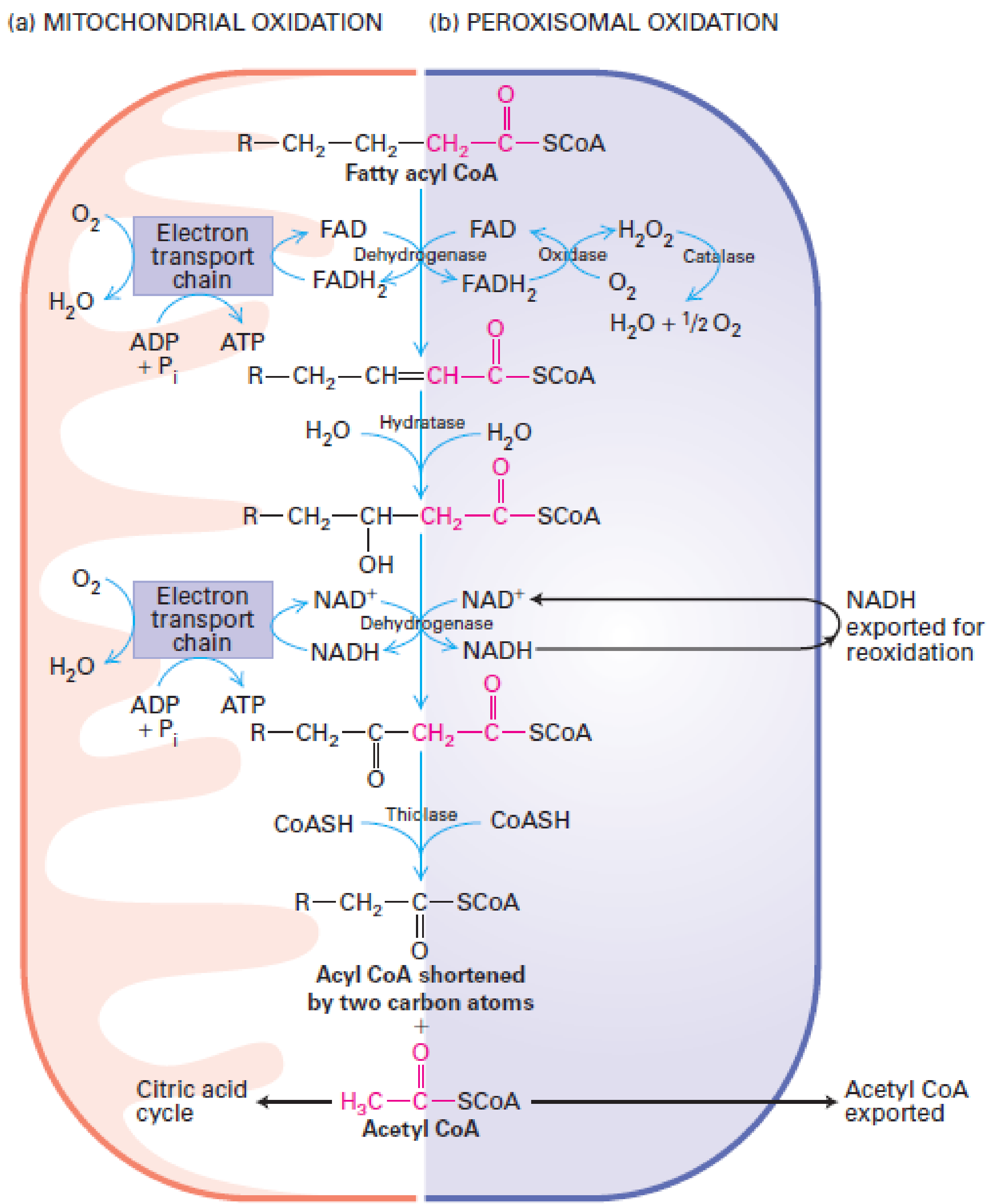

P
P
G
a
P
b
c


Perox
ER
Mito
Mito

(a)


O_2
RH_2
Oxidases
R_2
H_2O_2
$2H_2O_2$
Catalase
O_2
$2H_2O$

(b)


(a) MITOCHONDRIAL OXIDATION
(b) PEROXISOMAL OXIDATION
R—CH2—CH2—CH2—C—SCoA
Fatty acyl CoA
O2
Electron transport chain
H2O
ADP + Pi
ATP
FAD
FADH2
Dehydrogenase
Oxidase
H2O2
Catalase
O2
H2O + 1/2 O2
R—CH2—CH═CH—C—SCoA
H2O
Hydratase
R—CH2—CH—CH2—C—SCoA
OH
NAD+
NADH
NADH exported for reoxidation
R—CH2—C—CH2—C—SCoA
CoASH
Thiolase
R—CH2—C—SCoA
Acyl CoA shortened by two carbon atoms
H3C—C—SCoA
Acetyl CoA
Citric acid cycle
Acetyl CoA exported