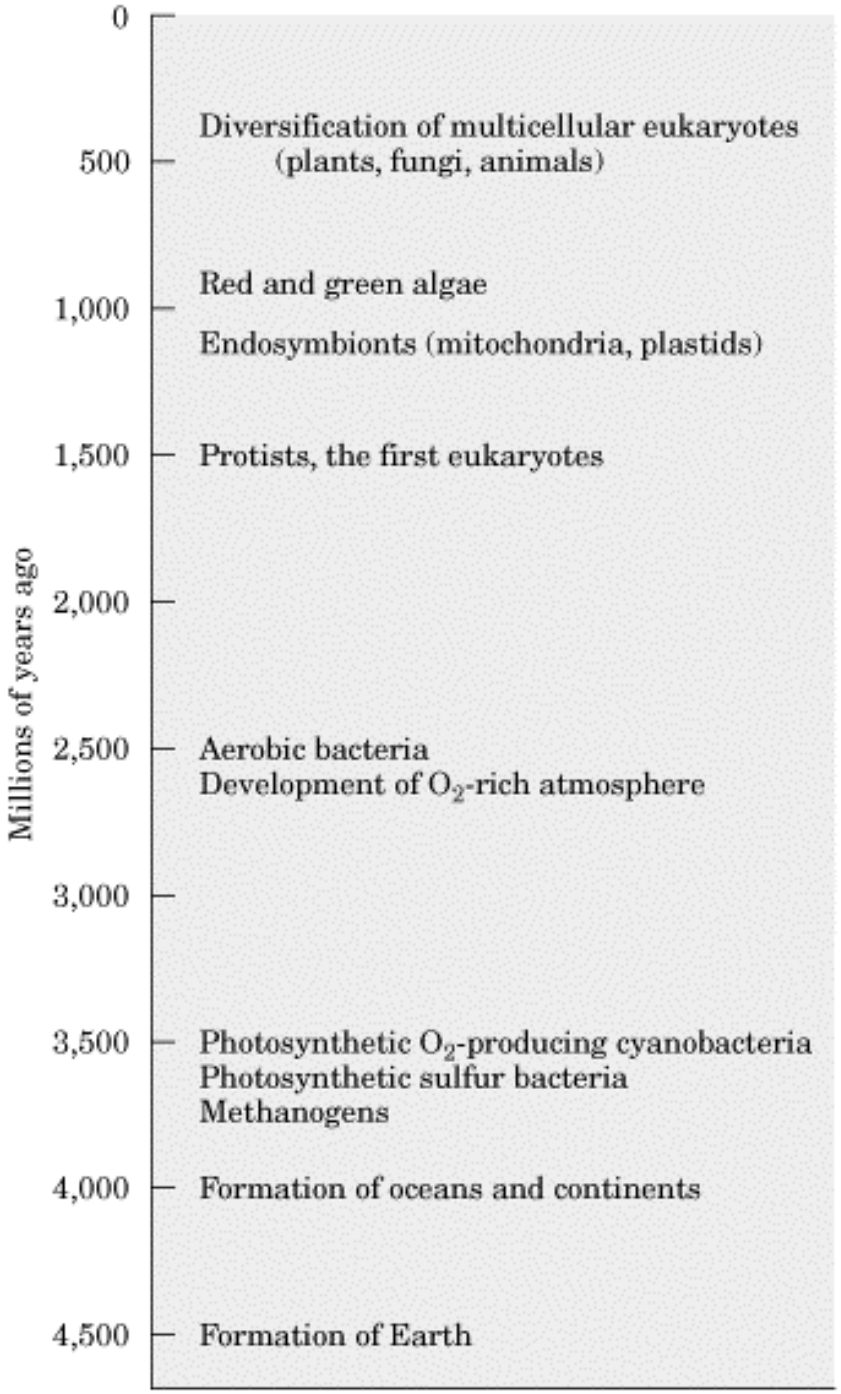

Millions of years ago
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
Diversification of multicellular eukaryotes (plants, fungi, animals)
Red and green algae
Endosymbionts (mitochondria, plastids)
Protists, the first eukaryotes
Aerobic bacteria
Development of O_2-rich atmosphere
Photosynthetic O_2-producing cyanobacteria
Photosynthetic sulfur bacteria
Methanogens
Formation of oceans and continents
Formation of Earth

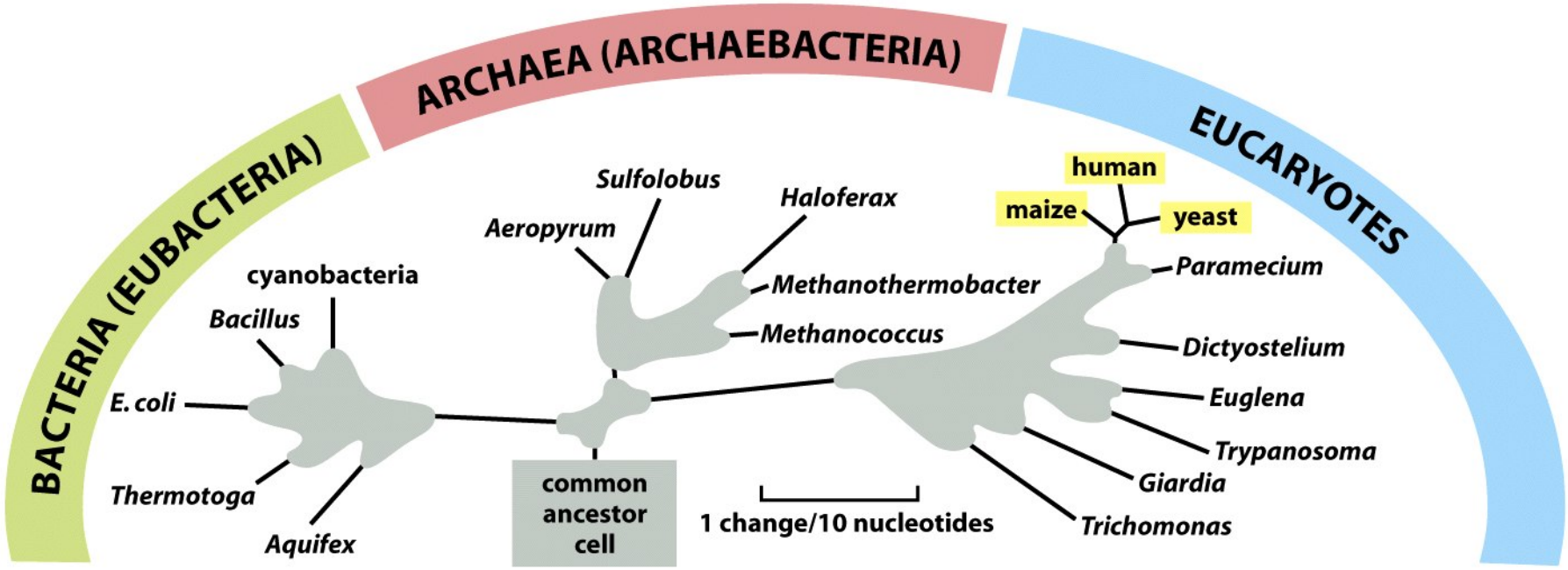


Figure 1-21 *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)

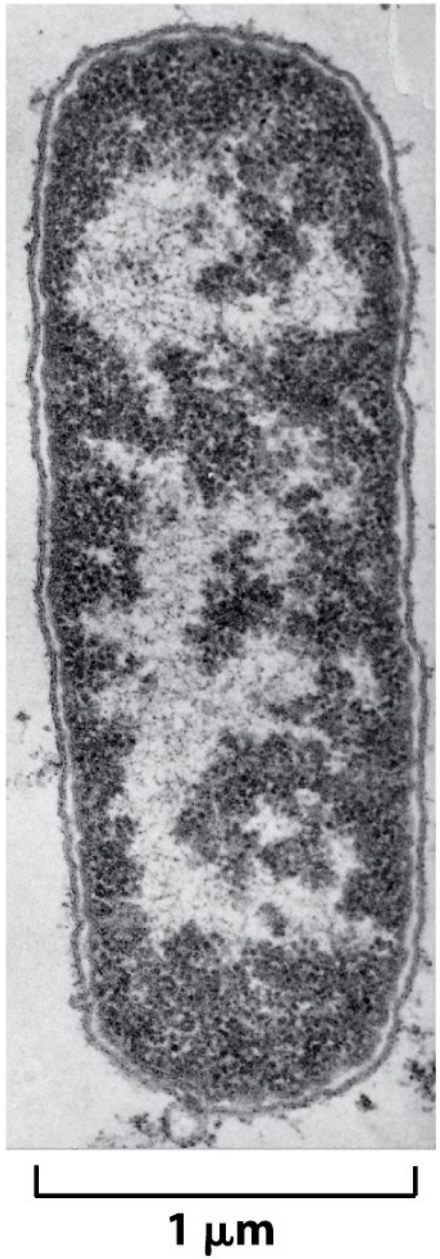


Figure 1-18b *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)

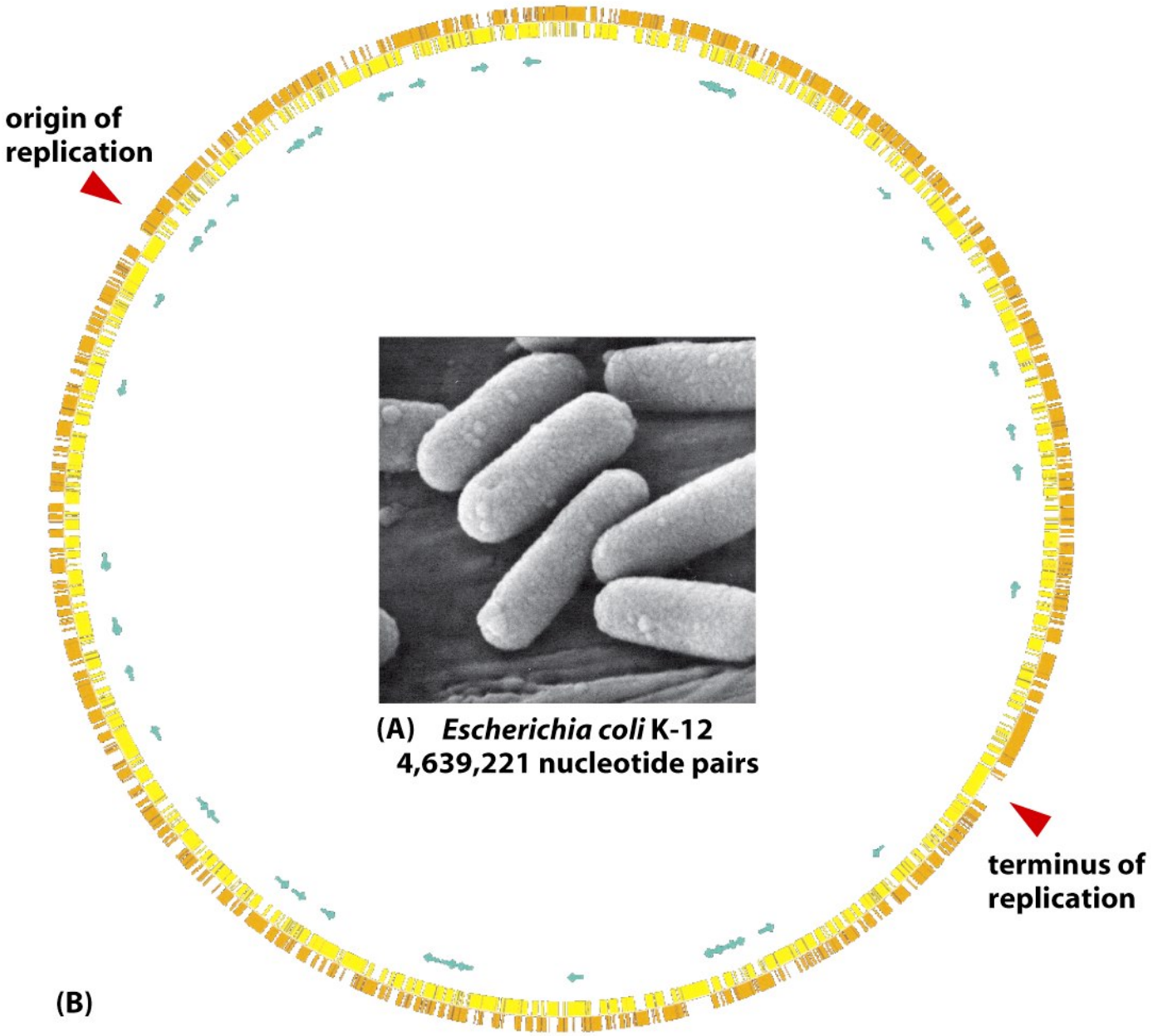
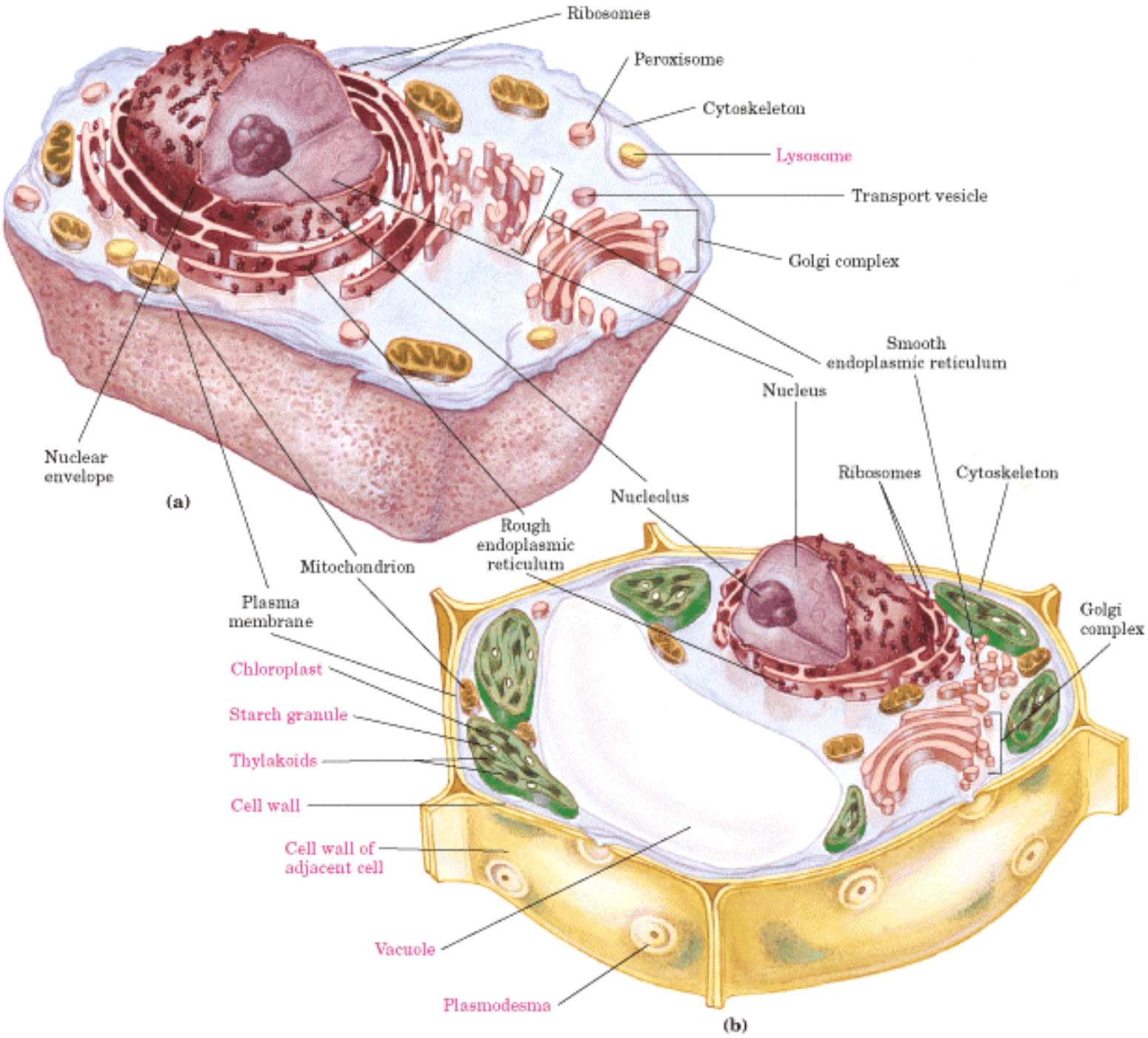
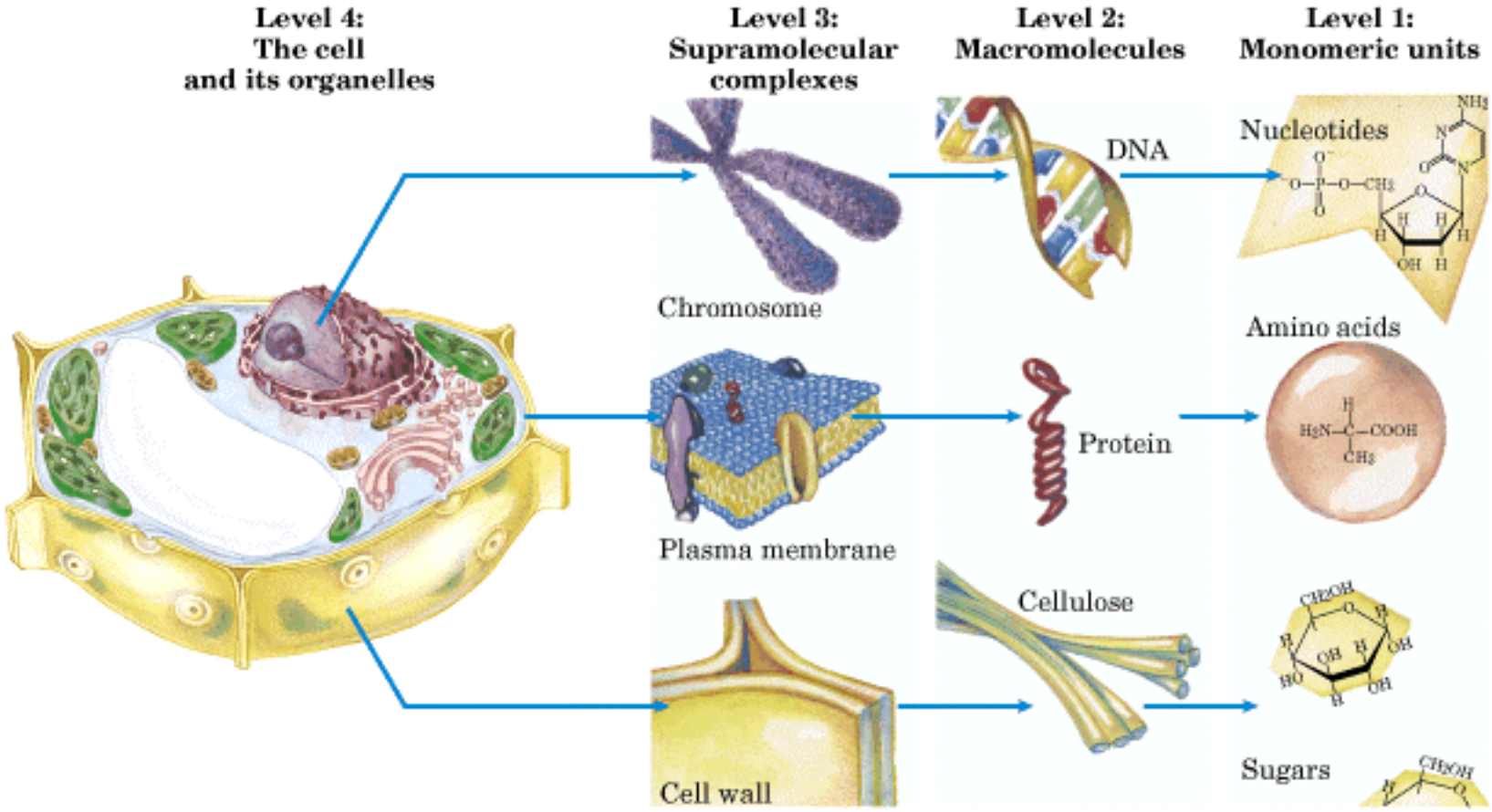


Figure 1-29 *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)


Ribosomes
Peroxisome
Cytoskeleton
Lysosome
Transport vesicle
Golgi complex
Smooth endoplasmic reticulum
Nucleus
Nuclear envelope
(a)
Nucleolus
Ribosomes
Cytoskeleton
Rough endoplasmic reticulum
Mitochondrion
Plasma membrane
Golgi complex
Chloroplast
Starch granule
Thylakoids
Cell wall
Cell wall of adjacent cell
Vacuole
Plasmodesma
(b)


Level 4:
The cell
and its organelles
Level 3:
Supramolecular
complexes
Level 2:
Macromolecules
Level 1:
Monomeric units
Chromosome
DNA
Nucleotides
Amino acids
Plasma membrane
Protein
Cellulose
Cell wall
Sugars

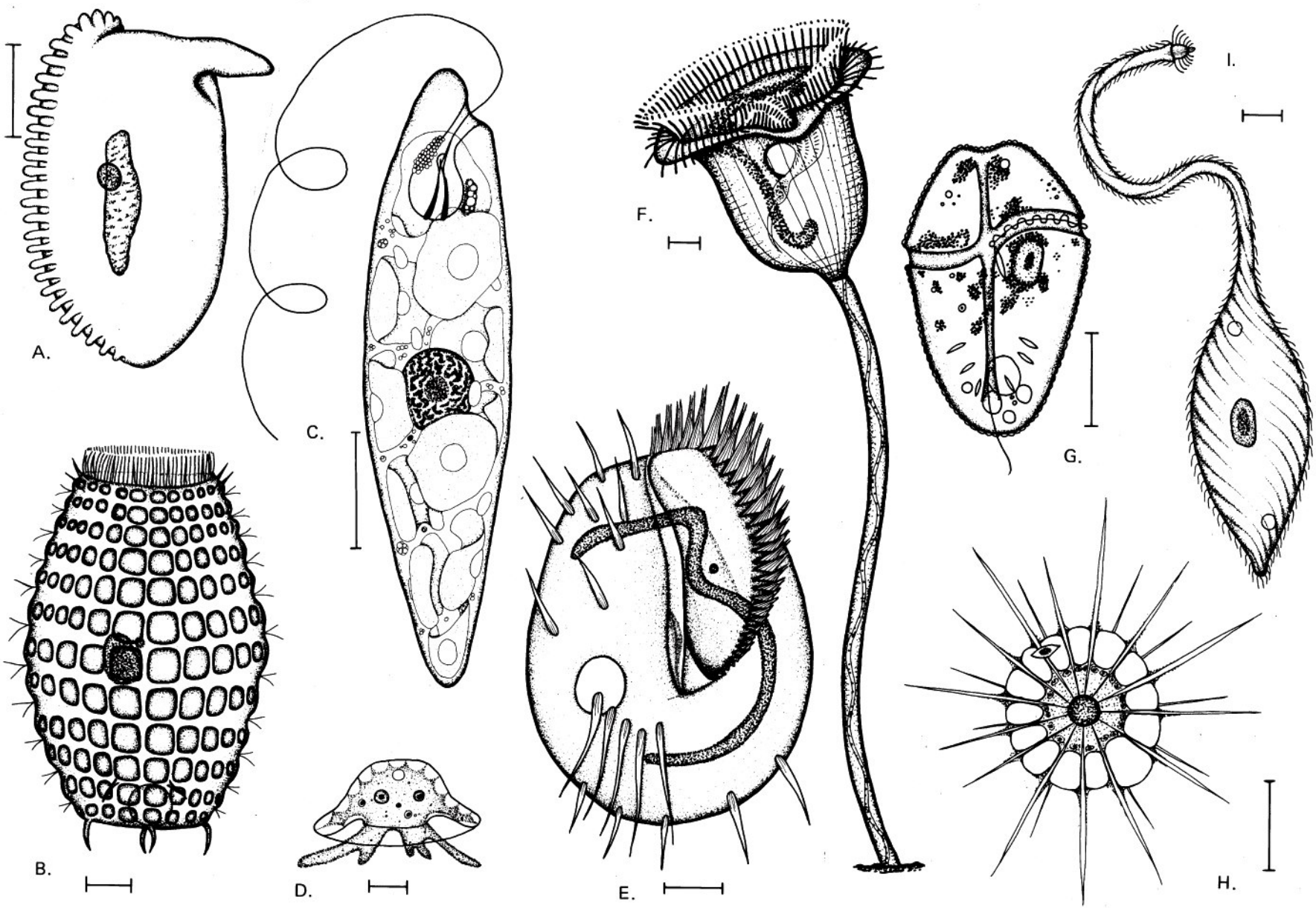


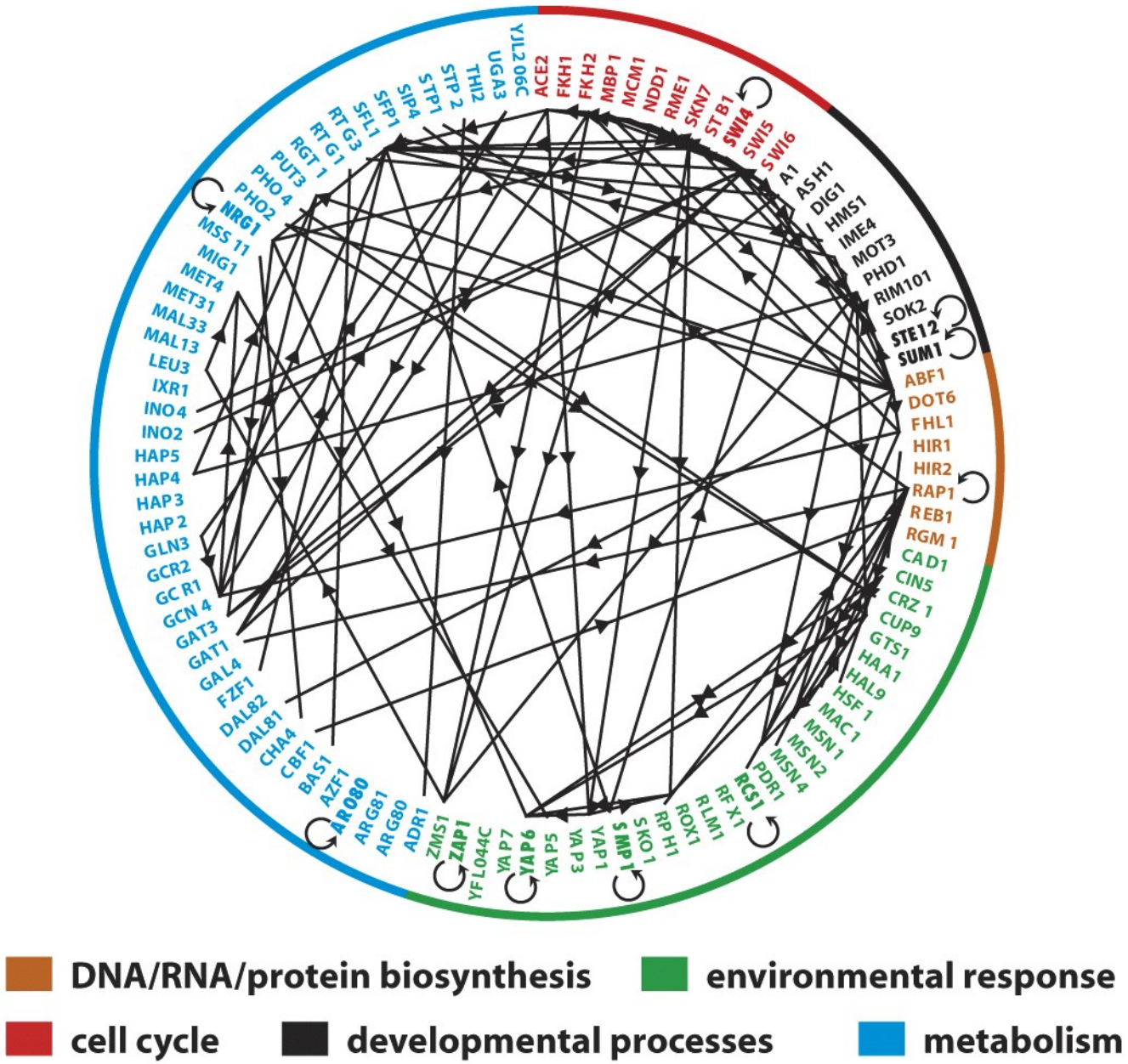
Figure 1-41 *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)

table 2–1

Comparison of Prokaryotic and Eukaryotic Cells

Characteristic	Prokaryotic cell	Eukaryotic cell
Size	Generally small (1–10 μm)	Generally large (5–100 μm)
Genome	DNA with nonhistone protein; genome in nucleoid, not surrounded by membrane	DNA complexed with histone and nonhistone proteins in chromosomes; chromosomes in nucleus with membranous envelope
Cell division	Fission or budding; no mitosis	Mitosis including mitotic spindle; centrioles in many species
Membrane-bounded organelles	Absent	Mitochondria, chloroplasts (in plants, some algae), endoplasmic reticulum, Golgi complexes, lysosomes (in animals), etc.
Nutrition	Absorption; some photosynthesis	Absorption, ingestion; photosynthesis in some species
Energy metabolism	No mitochondria; oxidative enzymes bound to plasma membrane; great variation in metabolic pattern	Oxidative enzymes packaged in mitochondria; more unified pattern of oxidative metabolism
Cytoskeleton	None	Complex, with microtubules, intermediate filaments, actin filaments
Intracellular movement	None	Cytoplasmic streaming, endocytosis, phagocytosis, mitosis, vesicle transport

Source: Modified from Hickman, C.P., Roberts, L.S., & Hickman, F.M. (1990) *Biology of Animals*, 5th edn, p. 30, Mosby–Yearbook, Inc., St. Louis, MO.



DNA/RNA/protein biosynthesis

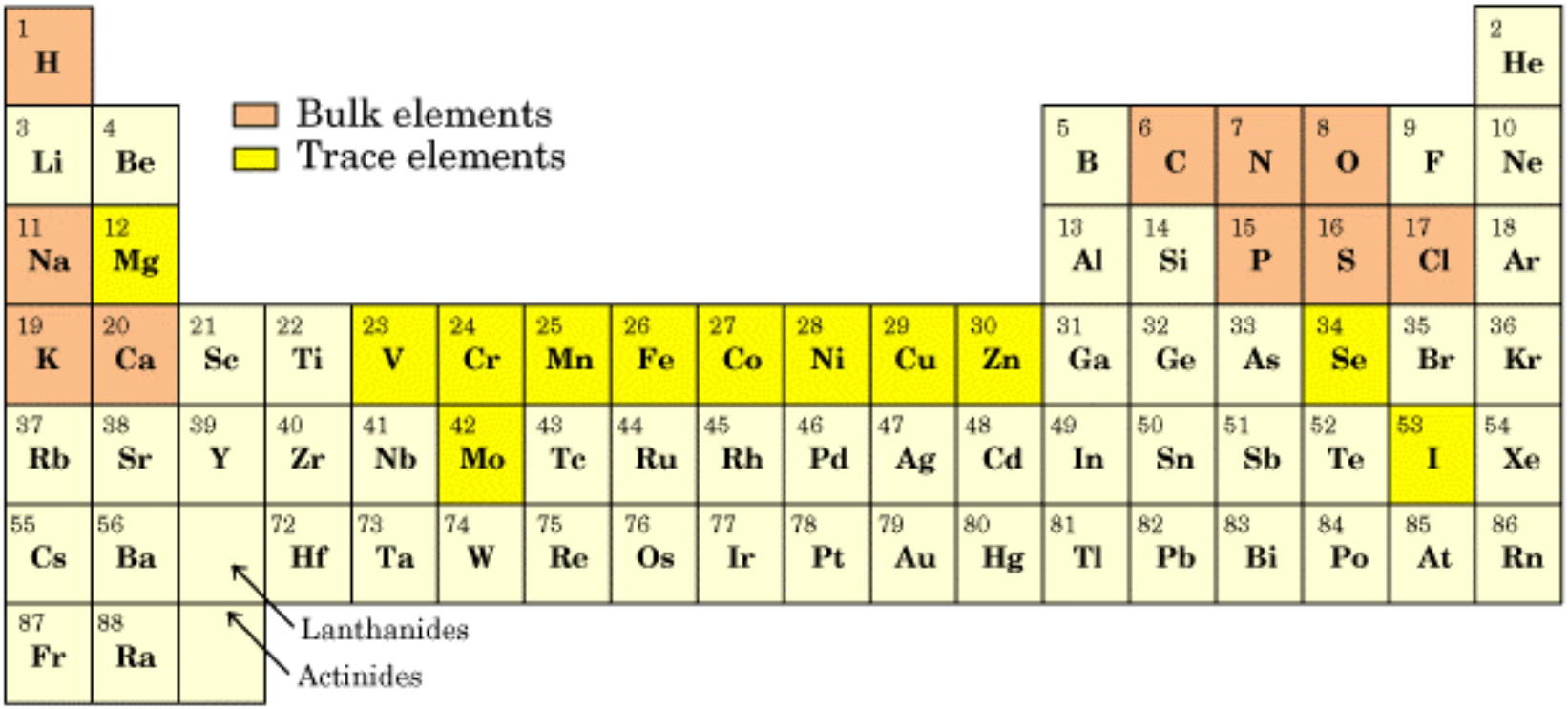
environmental response

cell cycle

developmental processes

metabolism

Figure 1-44 *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)


Bulk elements
Trace elements
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
Lanthanides
Actinides

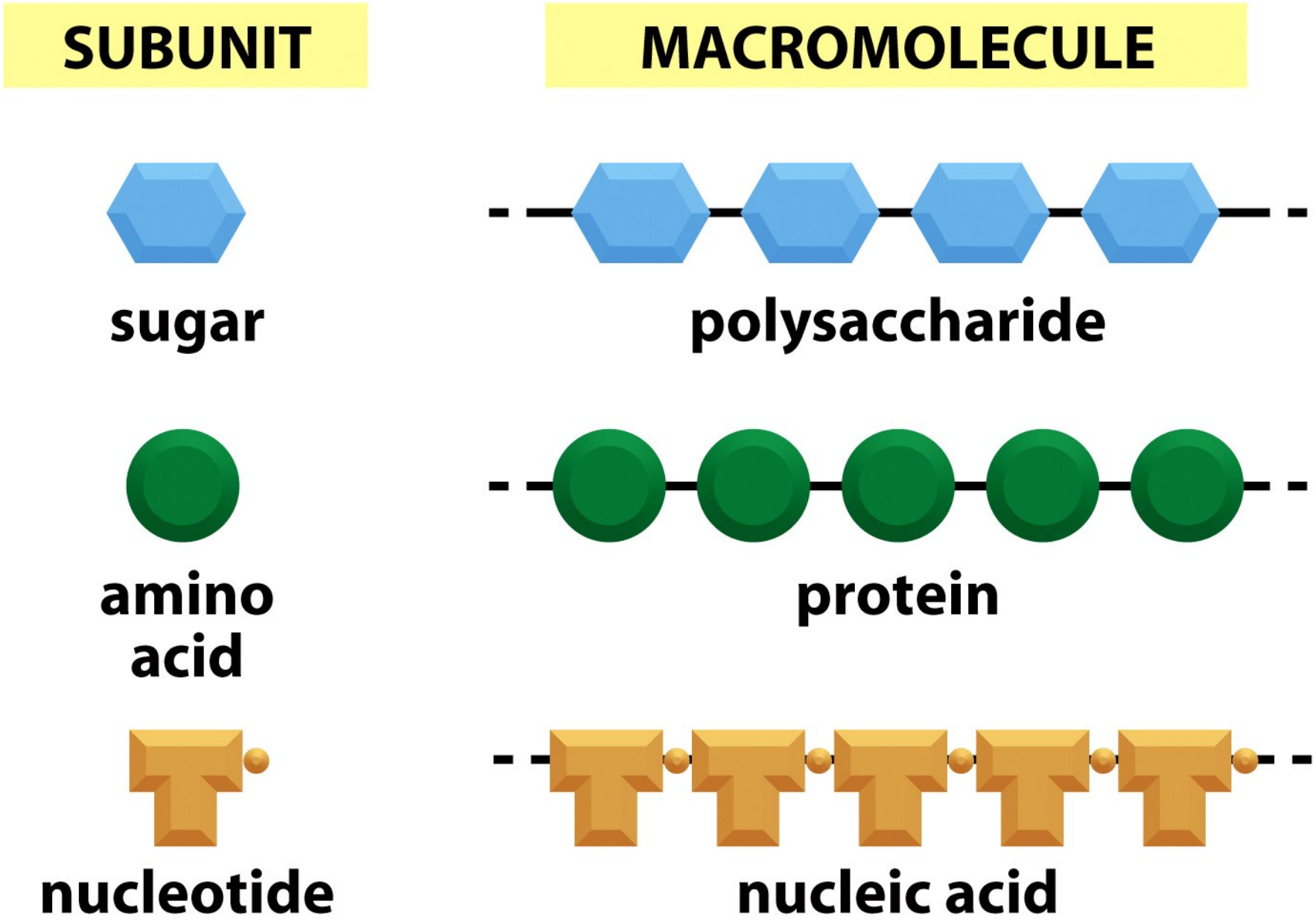


Figure 2-30 *Molecular Biology of the Cell* (© Garland Science 2008)

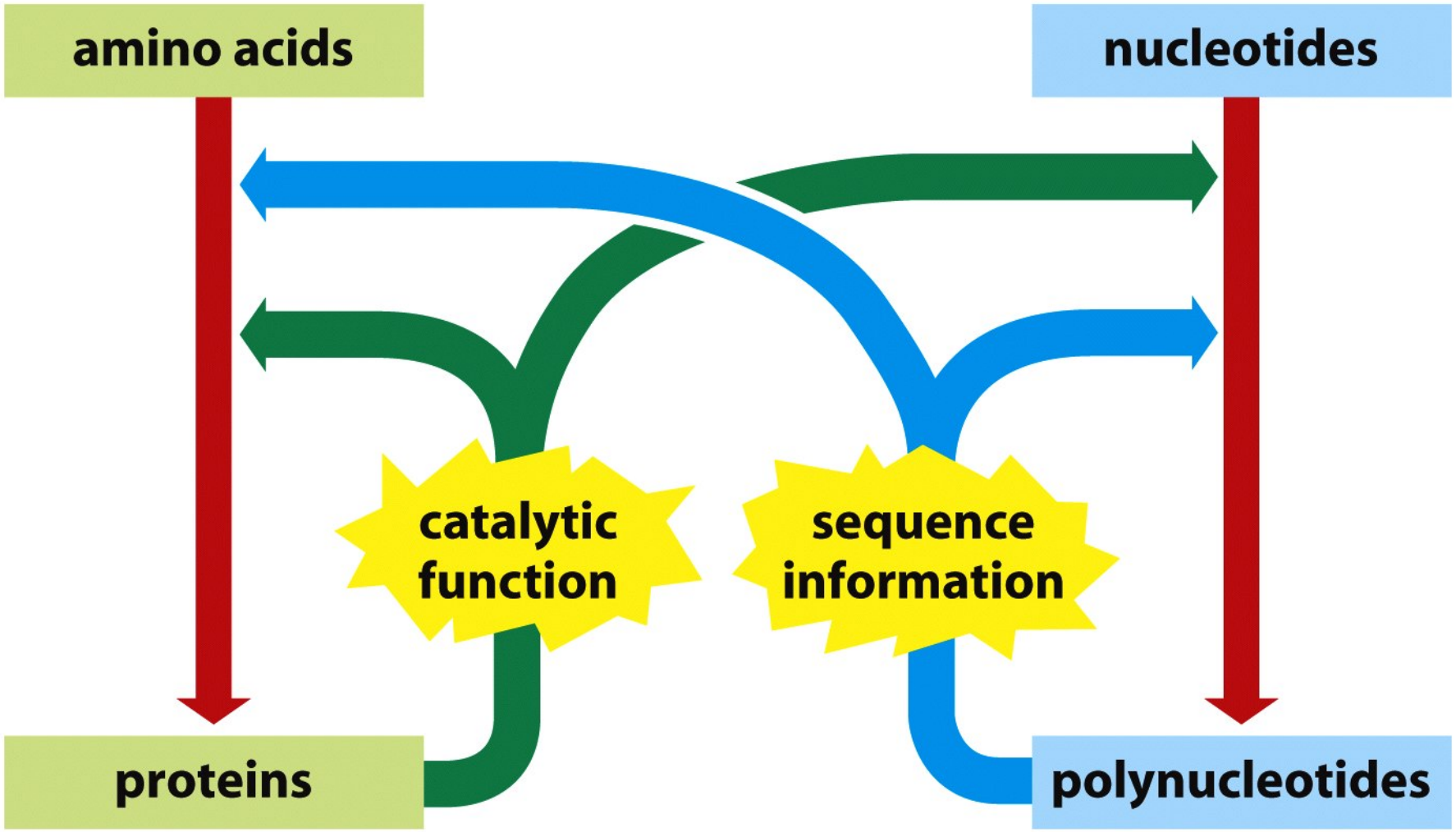
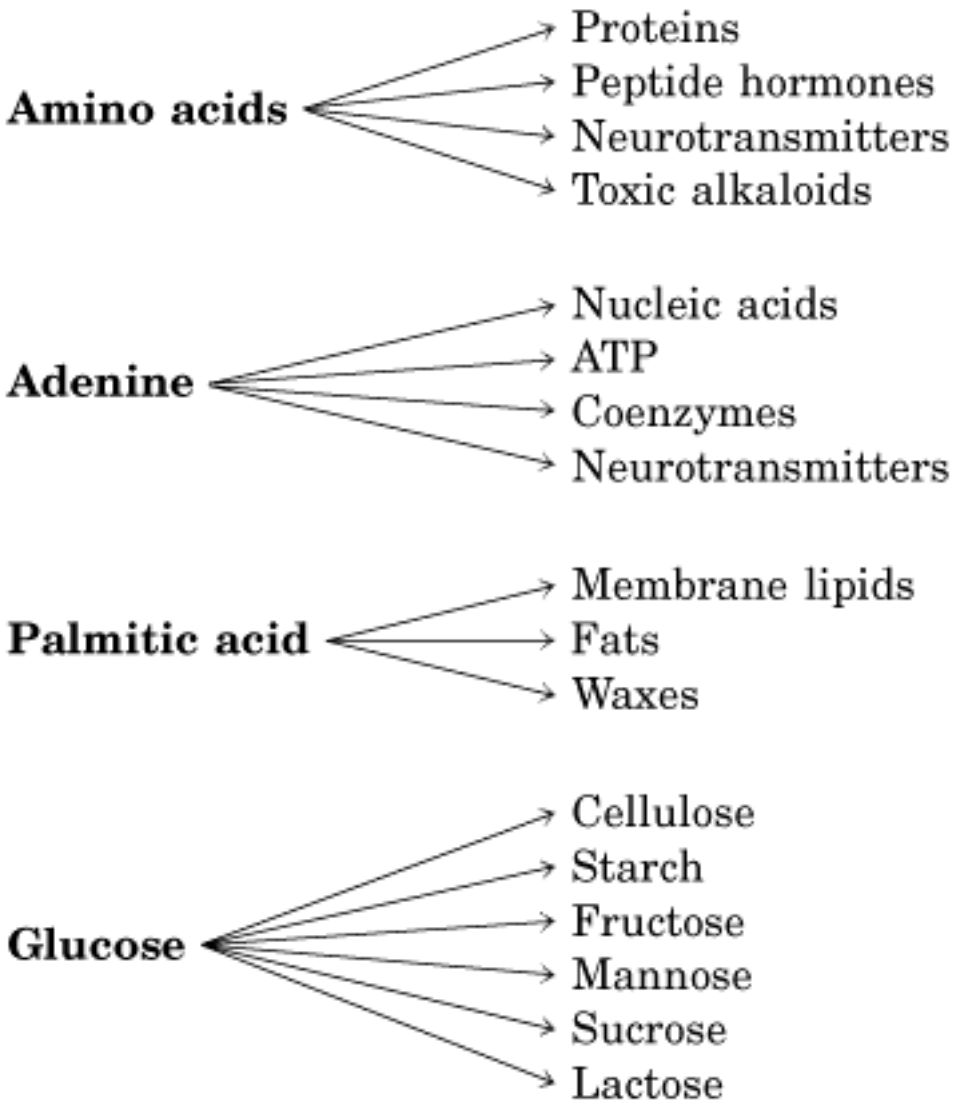


Figure 1-8 *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)


Amino acids
Proteins
Peptide hormones
Neurotransmitters
Toxic alkaloids
Adenine
Nucleic acids
ATP
Coenzymes
Neurotransmitters
Palmitic acid
Membrane lipids
Fats
Waxes
Glucose
Cellulose
Starch
Fructose
Mannose
Sucrose
Lactose

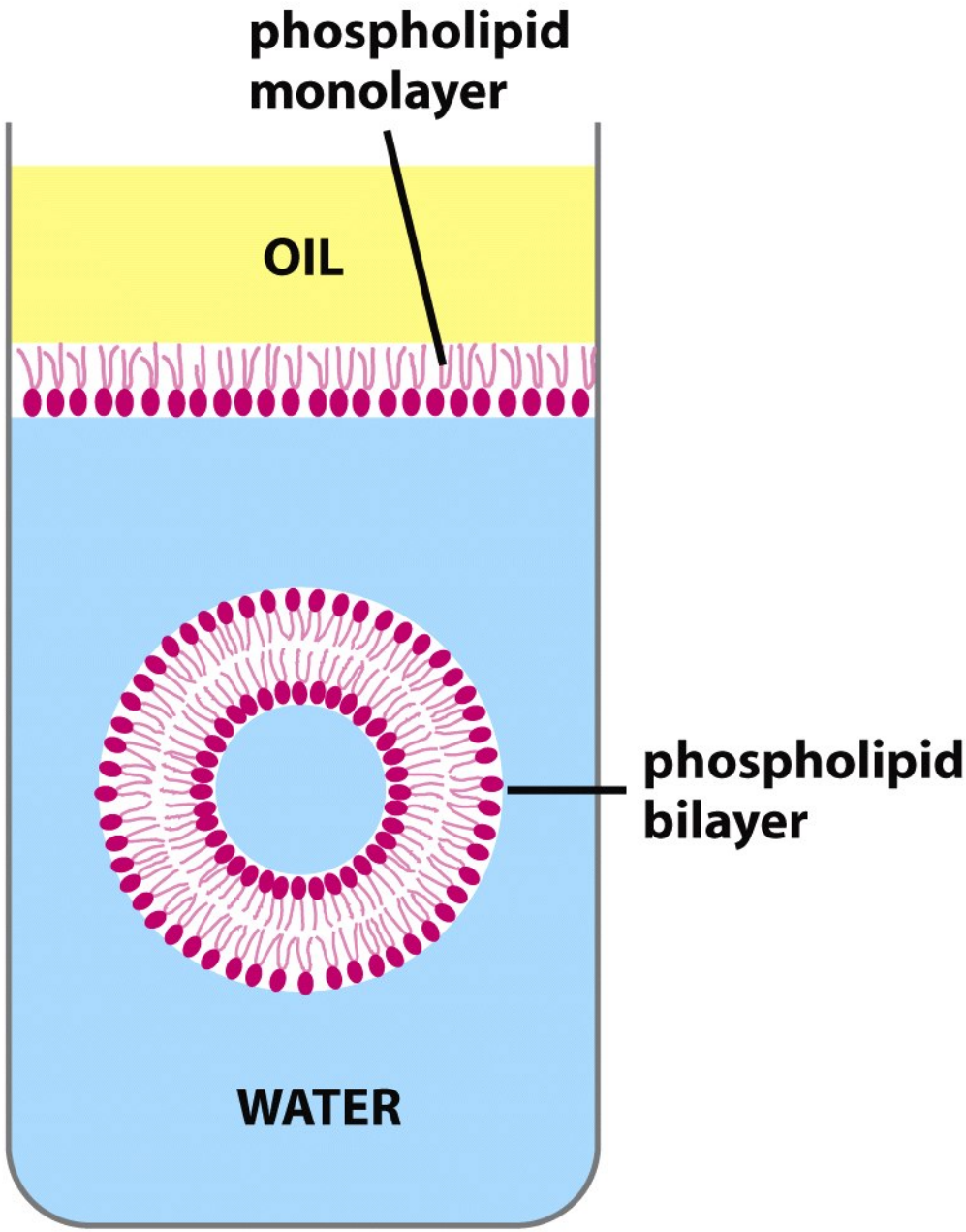


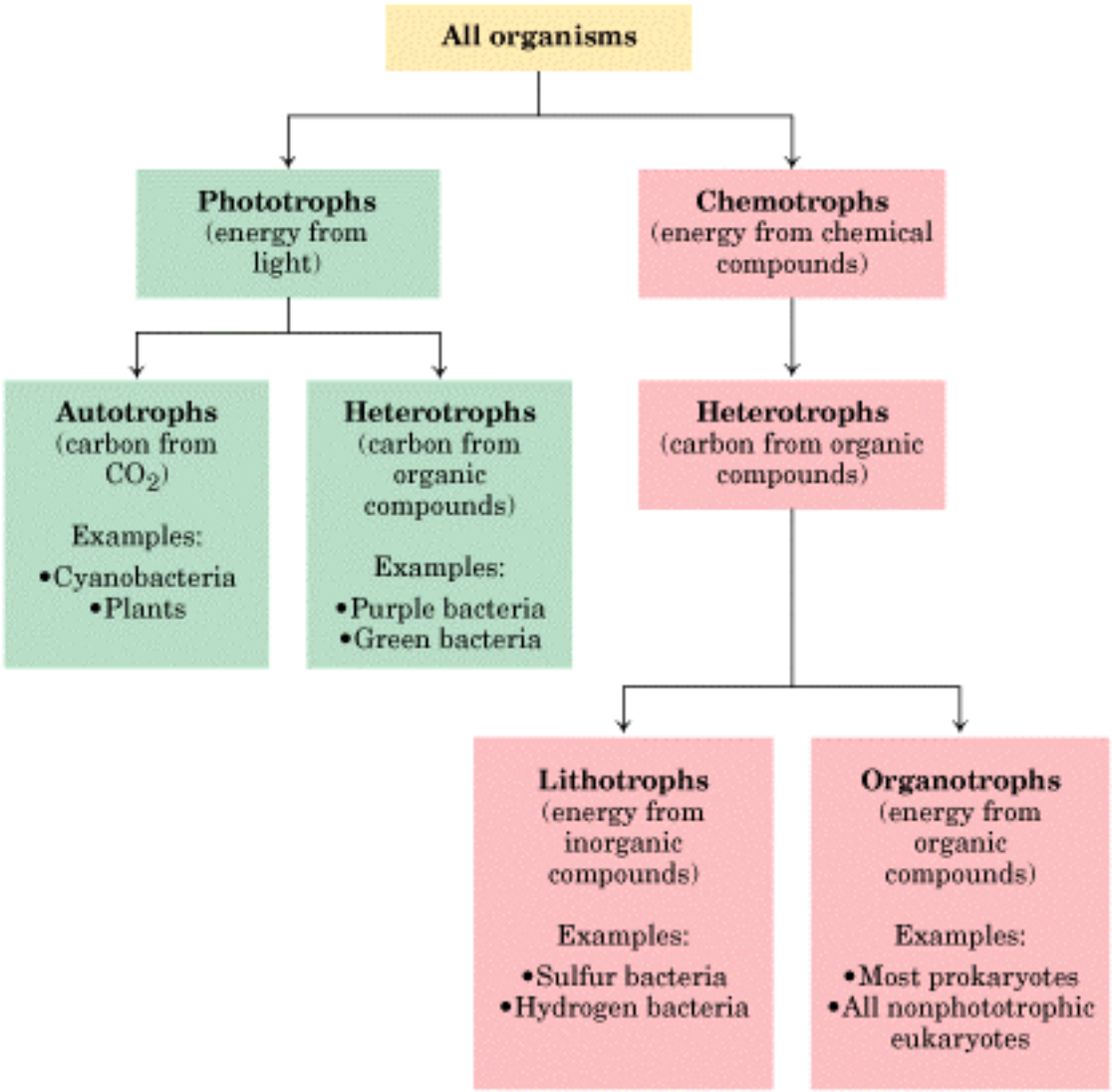
Figure 1-12 *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)

Table 2–3 Approximate Chemical Compositions of a Typical Bacterium and a Typical Mammalian Cell

COMPONENT	PERCENT OF TOTAL CELL WEIGHT	
	E. COLI BACTERIUM	MAMMALIAN CELL
H_2O	70	70
Inorganic ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, etc.)	1	1
Miscellaneous small metabolites	3	3
Proteins	15	18
RNA	6	1.1
DNA	1	0.25
Phospholipids	2	3
Other lipids	–	2
Polysaccharides	2	2
Total cell volume	2×10^{-12} cm^3	4×10^{-9} cm^3
Relative cell volume	1	2000

Proteins, polysaccharides, DNA, and RNA are macromolecules. Lipids are not generally classed as macromolecules even though they share some of their features; for example, most are synthesized as linear polymers of a smaller molecule (the acetyl group on acetyl CoA), and they self-assemble into larger structures (membranes). Note that water and protein comprise most of the mass of both mammalian and bacterial cells.

Table 2-3 *Molecular Biology of the Cell* (© Garland Science 2008)


All organisms
Phototrophs
(energy from light)
Chemotrophs
(energy from chemical compounds)
Autotrophs
(carbon from CO_2)
Examples:
•Cyanobacteria
•Plants
Heterotrophs
(carbon from organic compounds)
Examples:
•Purple bacteria
•Green bacteria
Heterotrophs
(carbon from organic compounds)
Lithotrophs
(energy from inorganic compounds)
Examples:
•Sulfur bacteria
•Hydrogen bacteria
Organotrophs
(energy from organic compounds)
Examples:
•Most prokaryotes
•All nonphototrophic eukaryotes

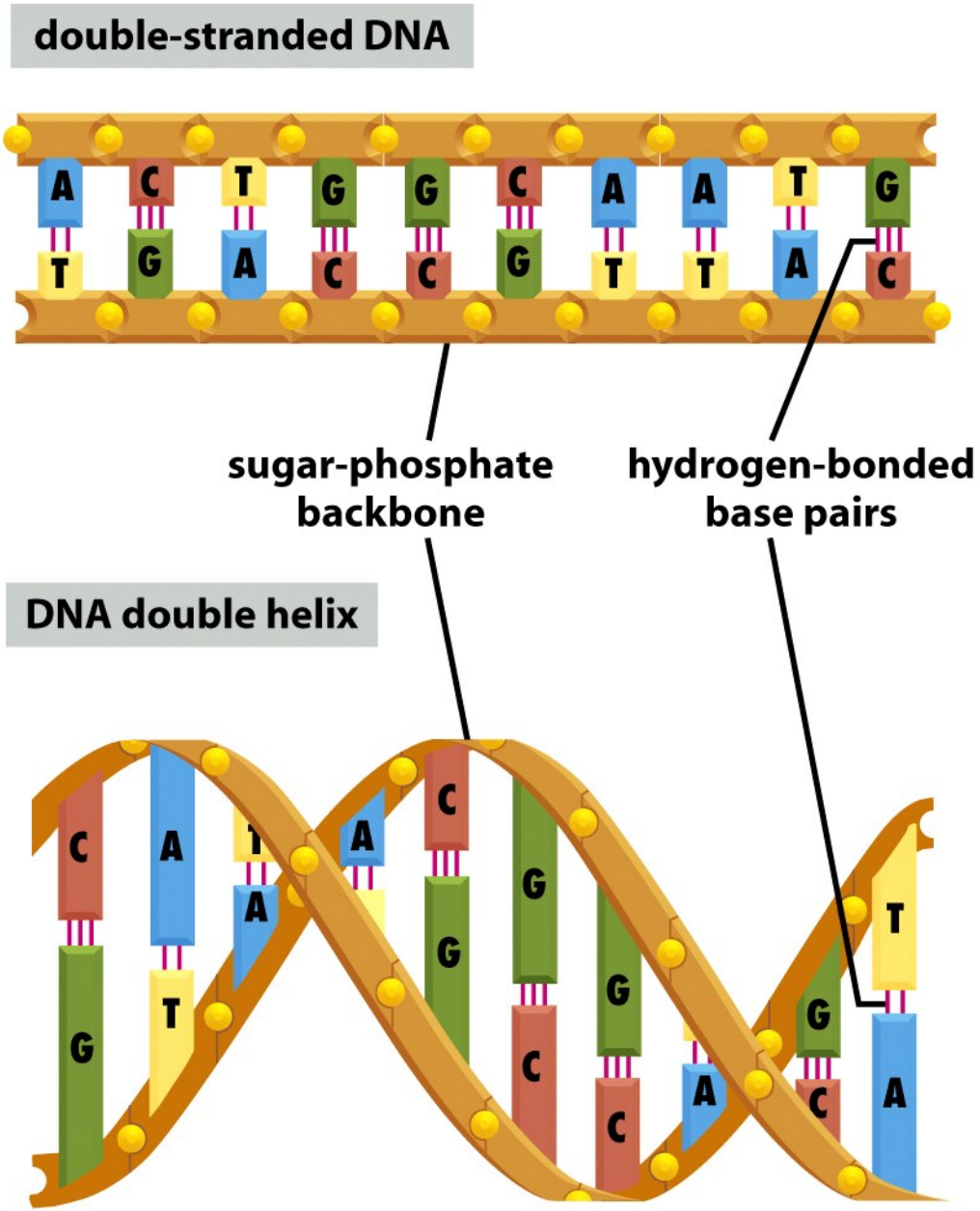


Figure 1-2d,e *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)

Figure 1-22 *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)

Table 1–1 Some Genomes That Have Been Completely Sequenced

SPECIES	SPECIAL FEATURES	HABITAT	GENOME SIZE (1000s OF NUCLEOTIDE PAIRS PER HAPLOID GENOME)	ESTIMATED NUMBER OF GENES CODING FOR PROTEINS
BACTERIA				
Mycoplasma genitalium	has one of the smallest of all known cell genomes	human genital tract	580	468
Synechocystis sp.	photosynthetic, oxygen-generating (cyanobacterium)	lakes and streams	3573	3168
Escherichia coli	laboratory favorite	human gut	4639	4289
Helicobacter pylori	causes stomach ulcers and predisposes to stomach cancer	human stomach	1667	1590
Bacillus anthracis	causes anthrax	soil	5227	5634
Aquifex aeolicus	lithotrophic; lives at high temperatures	hydrothermal vents	1551	1544
Streptomyces coelicolor	source of antibiotics; giant genome	soil	8667	7825
Treponema pallidum	spirochete; causes syphilis	human tissues	1138	1041
Rickettsia prowazekii	bacterium most closely related to mitochondria; causes typhus	lice and humans (intracellular parasite)	1111	834
Thermotoga maritima	organotrophic; lives at very high temperatures	hydrothermal vents	1860	1877

Genome size and gene number vary between strains of a single species, especially for bacteria and archaea. The table shows data for particular strains that have been sequenced. For eucaryotes, many genes can give rise to several alternative variant proteins, so that the total number of proteins specified by the genome is substantially greater than the number of genes.

Table 1-1 (part 1 of 2) *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)

Table 1–1 Some Genomes That Have Been Completely Sequenced

SPECIES	SPECIAL FEATURES	HABITAT	GENOME SIZE (1000s OF NUCLEOTIDE PAIRS PER HAPLOID GENOME)	ESTIMATED NUMBER OF GENES CODING FOR PROTEINS
ARCHAEA				
Methanococcus jannaschii	lithotrophic, anaerobic, methane-producing	hydrothermal vents	1664	1750
Archaeoglobus fulgidus	lithotrophic or organotrophic, anaerobic, sulfate-reducing	hydrothermal vents	2178	2493
Nanoarchaeum equitans	smallest known archaean; anaerobic; parasitic on another, larger archaean	hydrothermal and volcanic hot vents	491	552
EUCARYOTES				
Saccharomyces cerevisiae (budding yeast)	minimal model eucaryote	grape skins, beer	12,069	~6300
Arabidopsis thaliana (Thale cress)	model organism for flowering plants	soil and air	~142,000	~26,000
Caenorhabditis elegans (nematode worm)	simple animal with perfectly predictable development	soil	~97,000	~20,000
Drosophila melanogaster (fruit fly)	key to the genetics of animal development	rotting fruit	~137,000	~14,000
Homo sapiens (human)	most intensively studied mammal	houses	~3,200,000	~24,000

Genome size and gene number vary between strains of a single species, especially for bacteria and archaea. The table shows data for particular strains that have been sequenced. For eucaryotes, many genes can give rise to several alternative variant proteins, so that the total number of proteins specified by the genome is substantially greater than the number of genes.

Table 1-1 (part 2 of 2) *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)

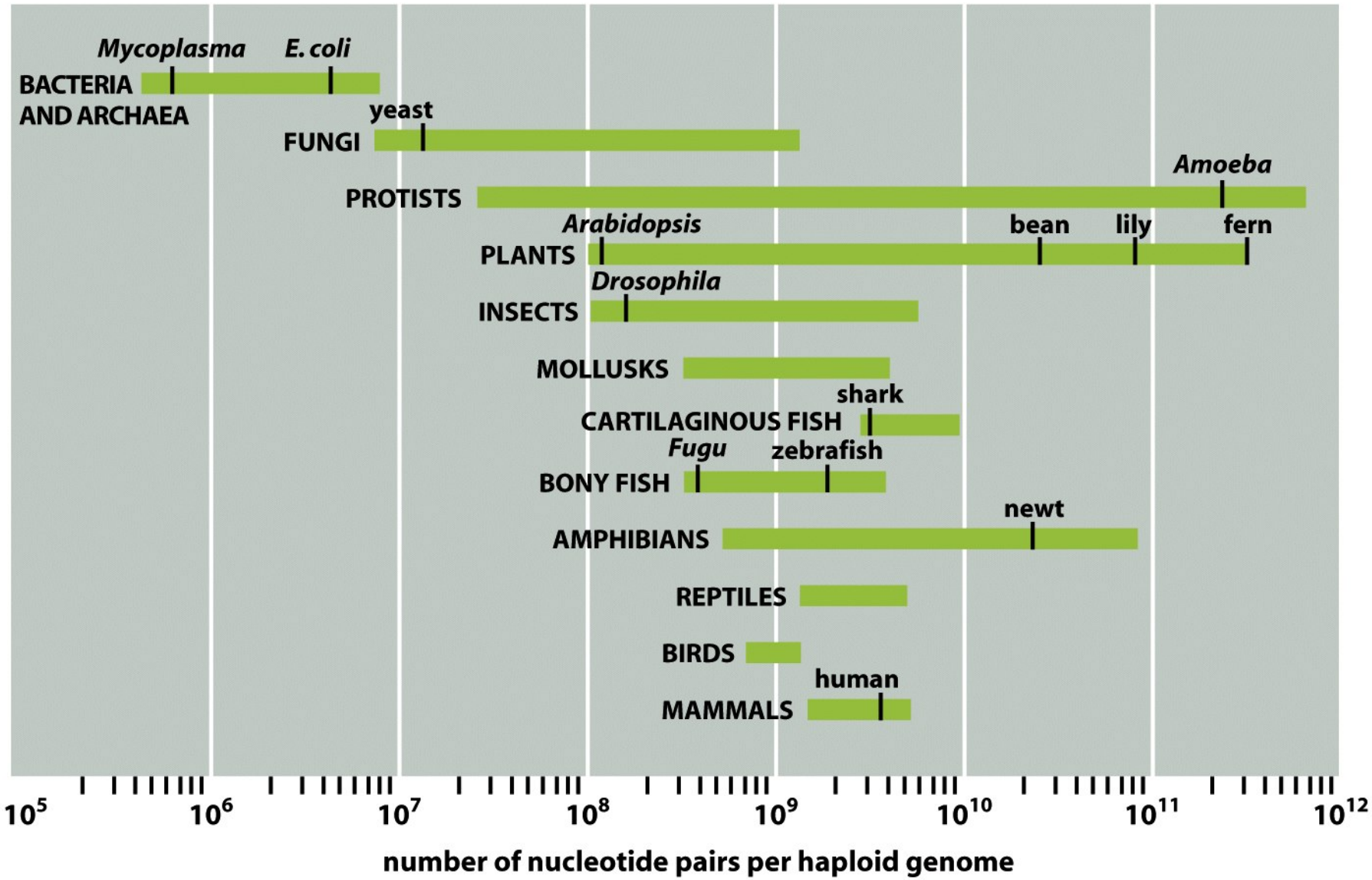
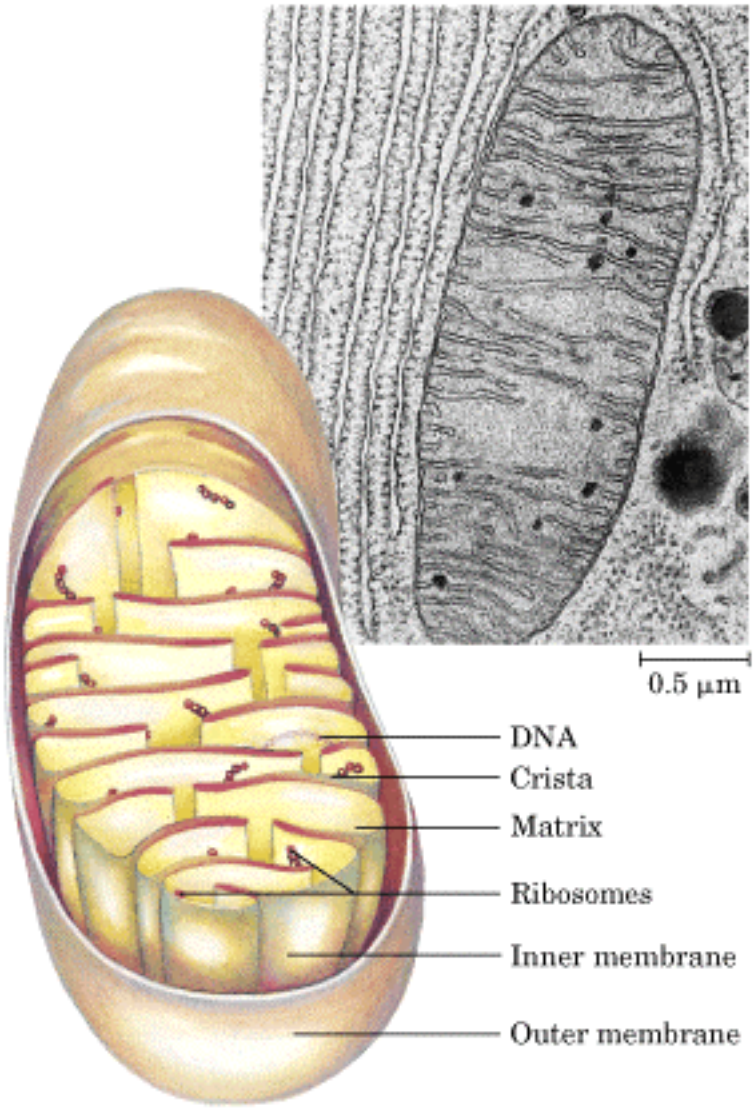


Figure 1-37 *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)


0.5 μm
DNA
Crista
Matrix
Ribosomes
Inner membrane
Outer membrane

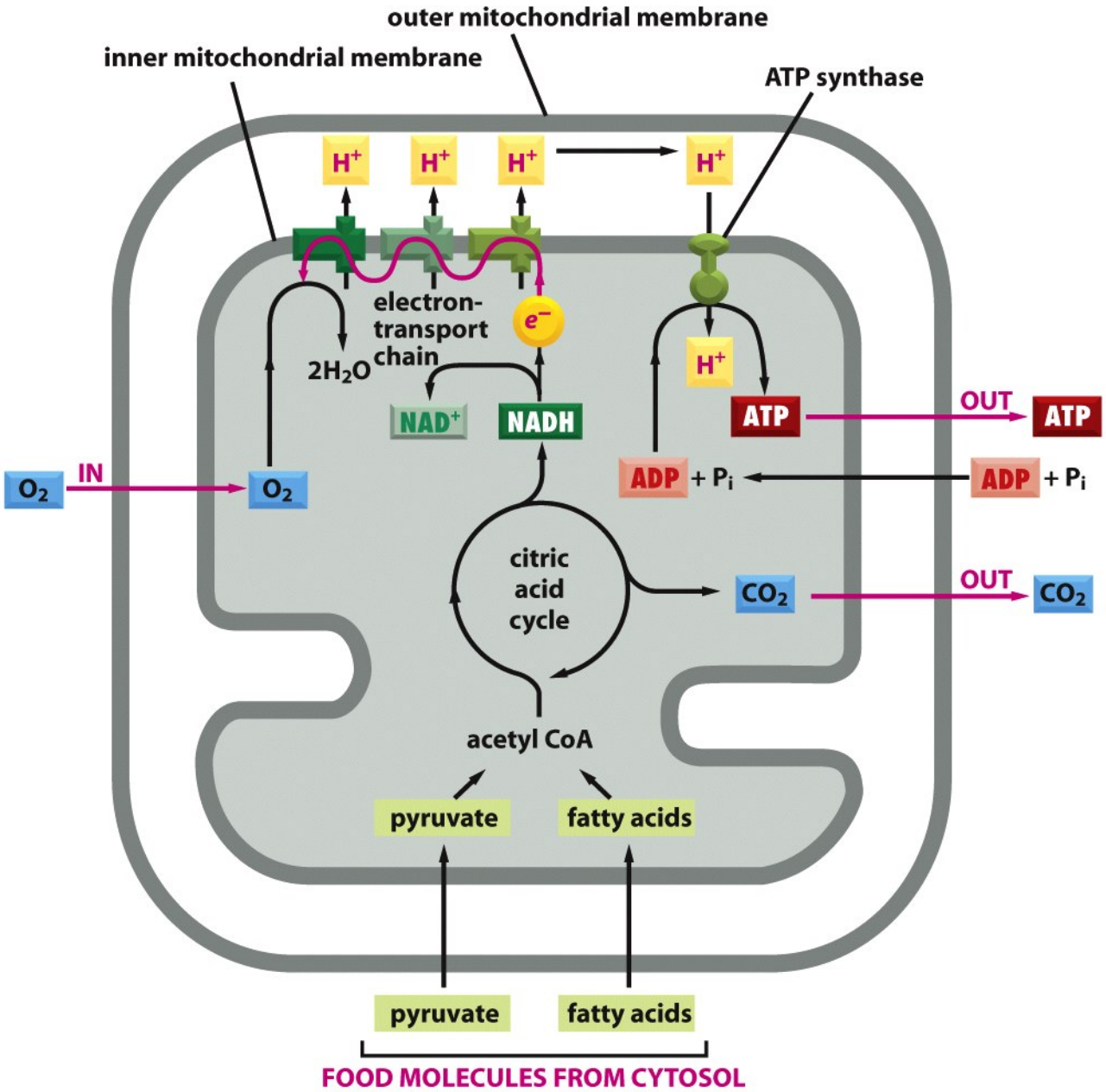
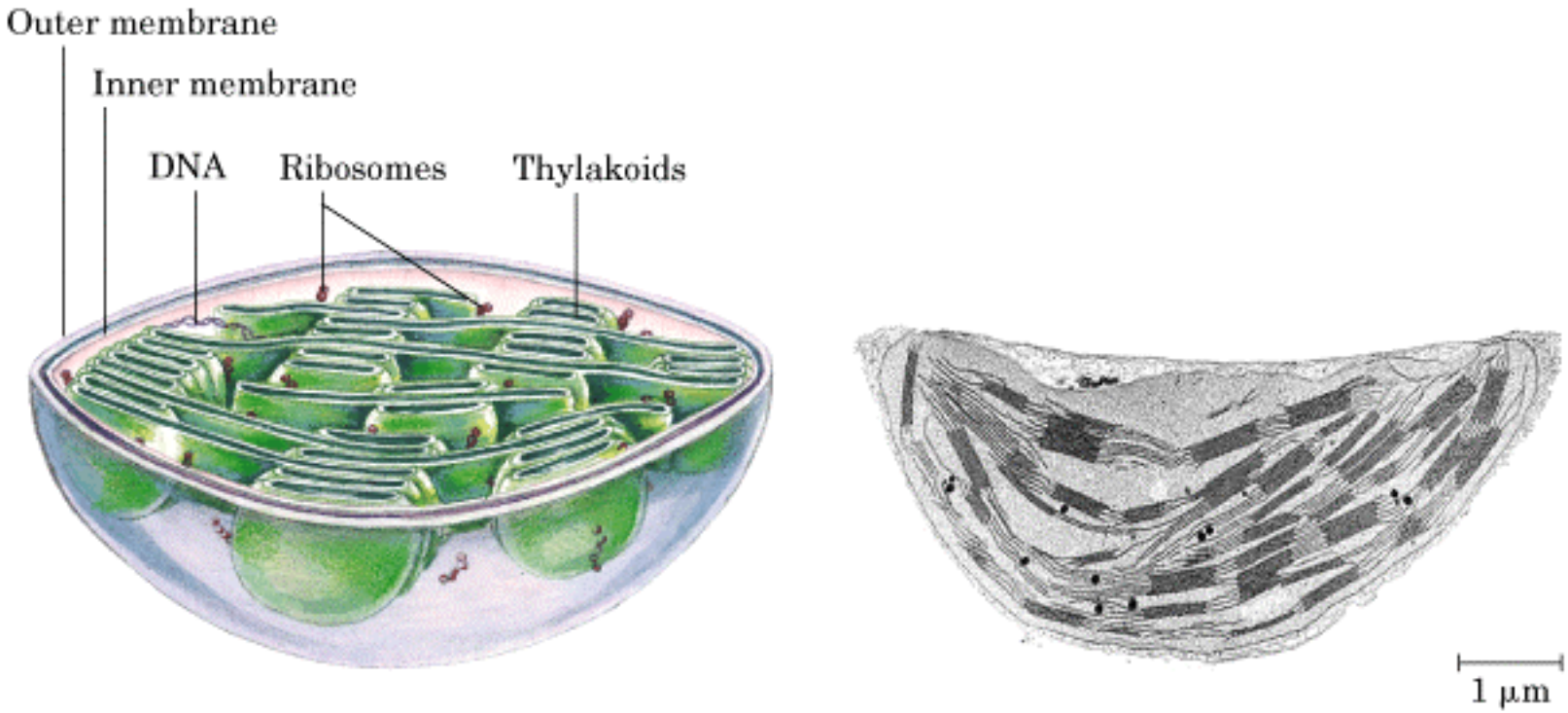


Figure 14-10 *Molecular Biology of the Cell* (© Garland Science 2008)


Outer membrane
Inner membrane
DNA
Ribosomes
Thylakoids
1 μm

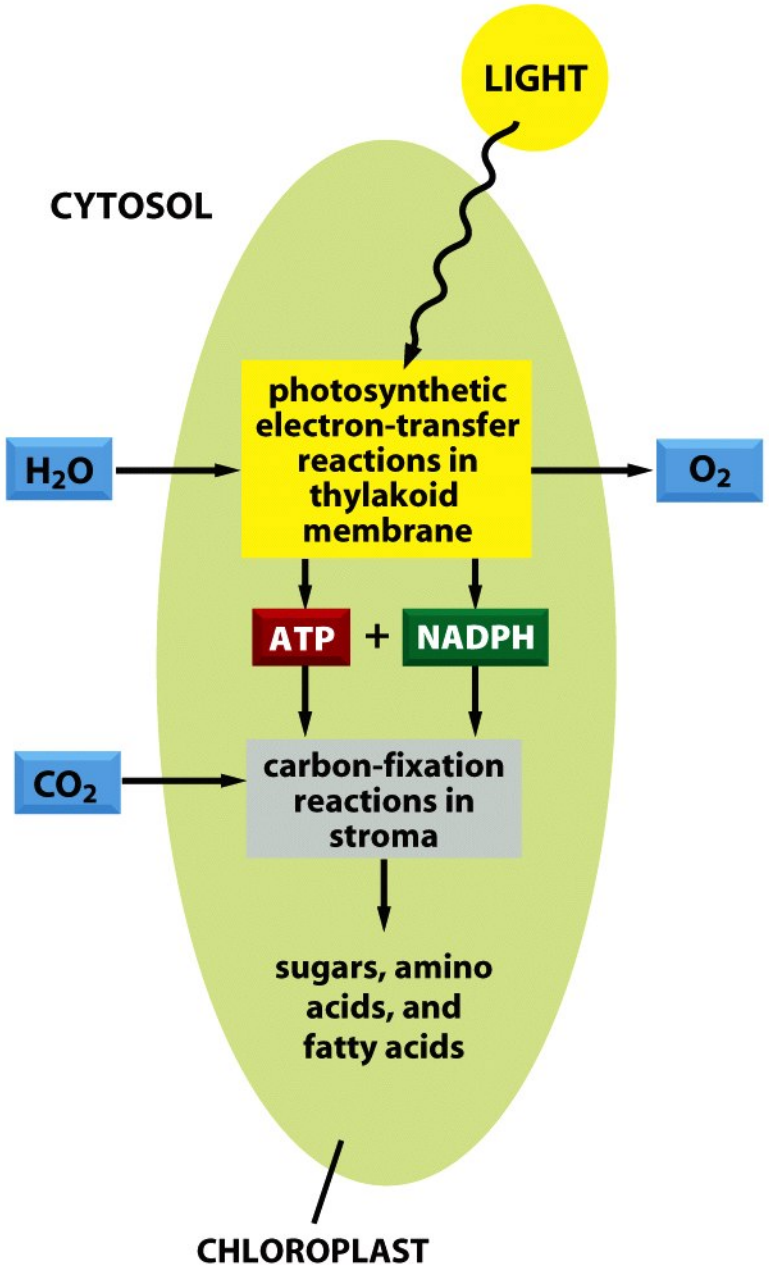
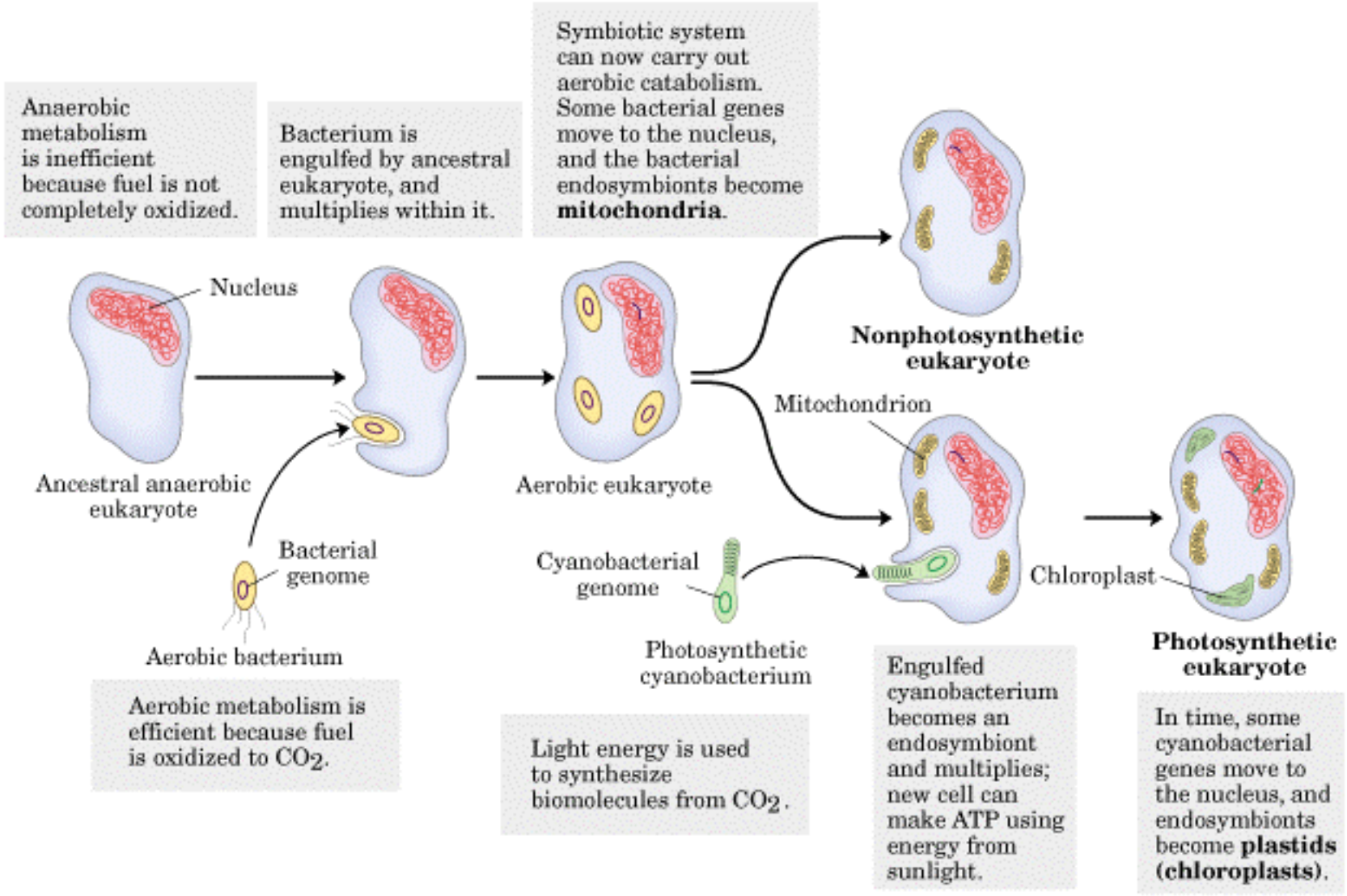
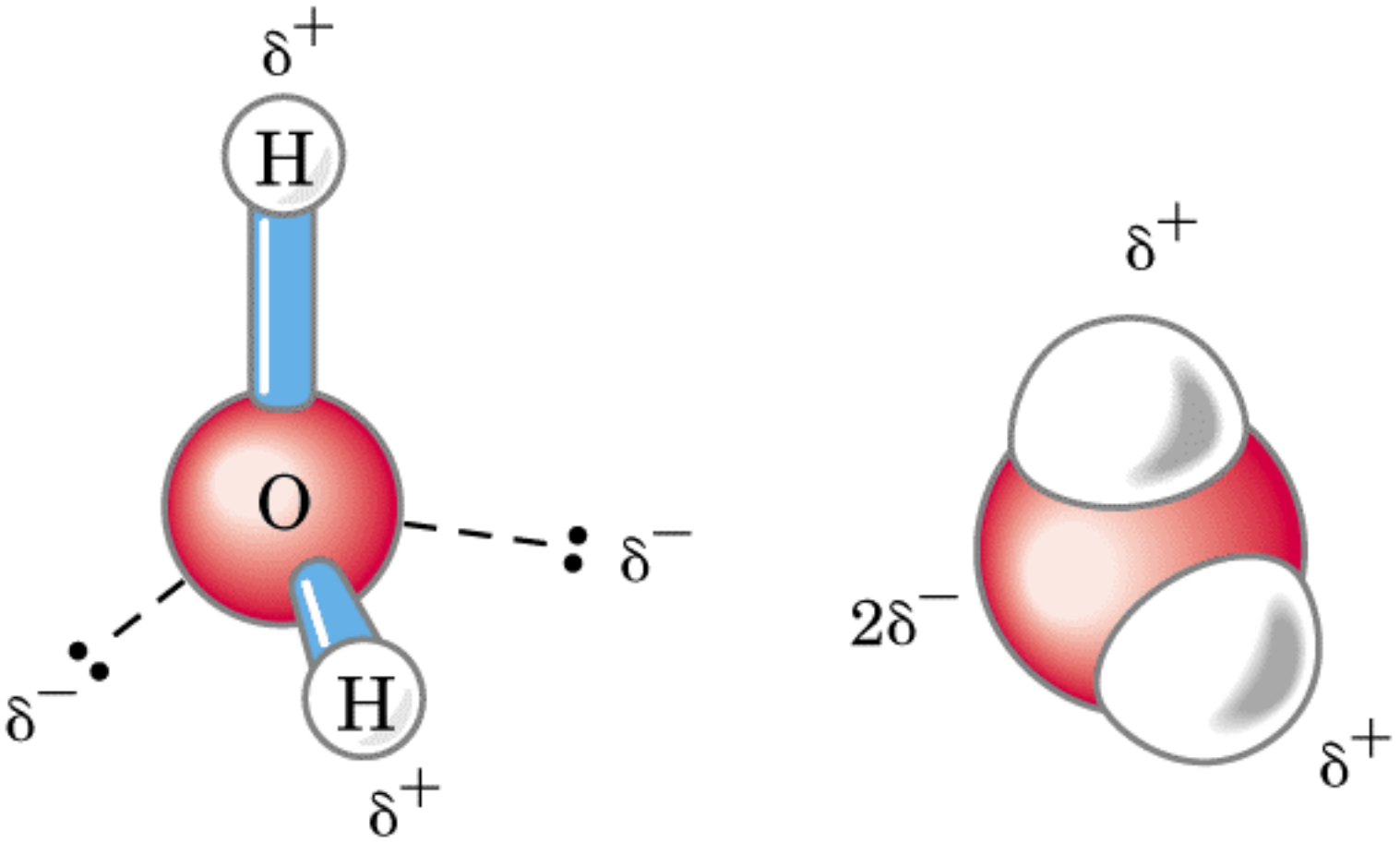
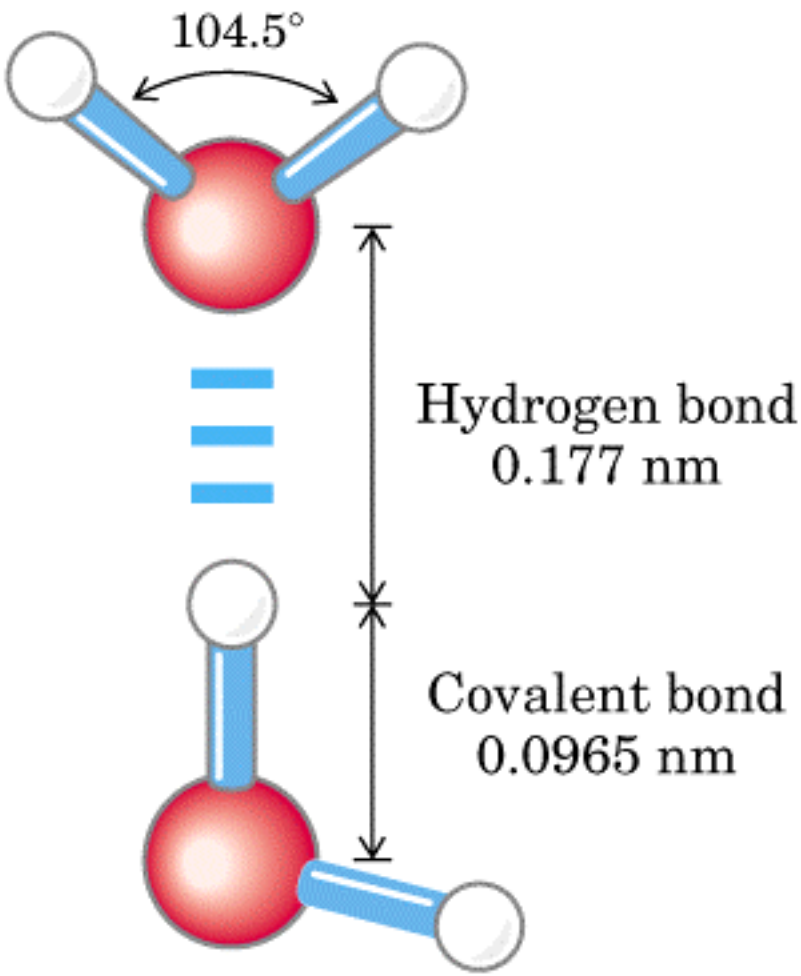


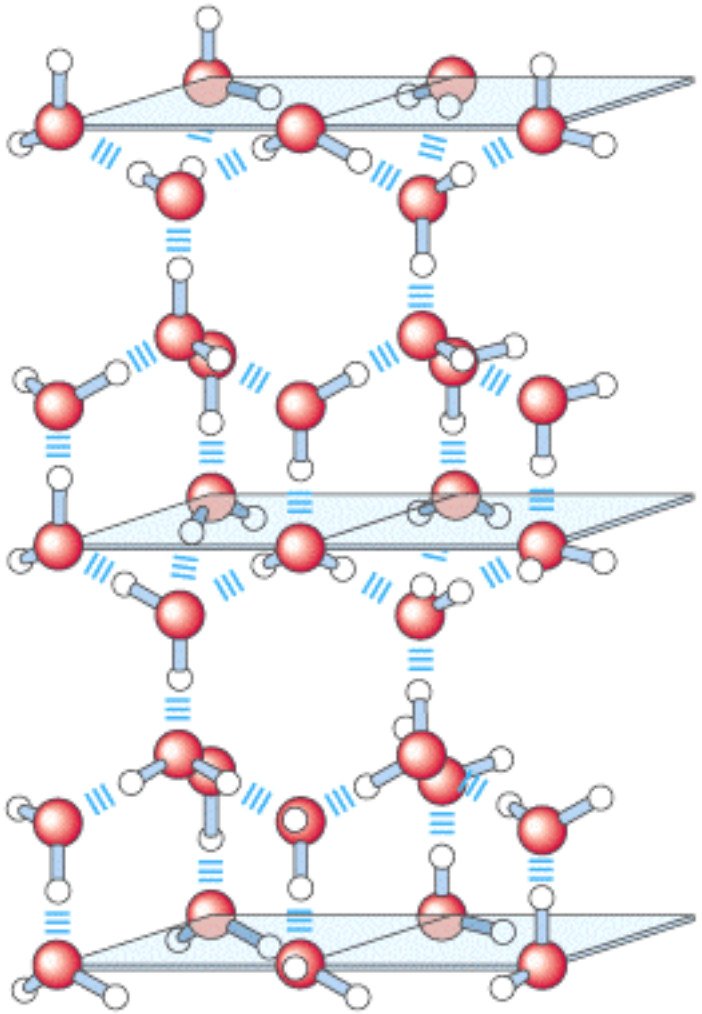
Figure 14-38 *Molecular Biology of the Cell* (© Garland Science 2008)

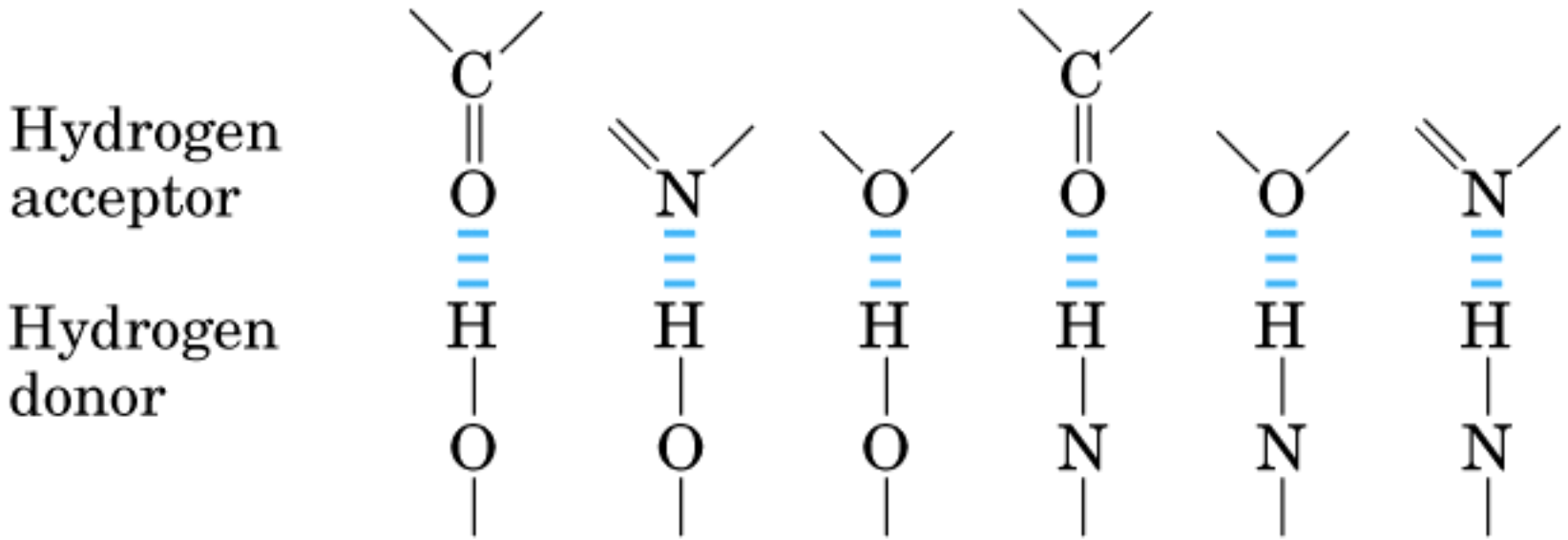

Anaerobic metabolism is inefficient because fuel is not completely oxidized.
Bacterium is engulfed by ancestral eukaryote, and multiplies within it.
Symbiotic system can now carry out aerobic catabolism. Some bacterial genes move to the nucleus, and the bacterial endosymbionts become mitochondria.
Nucleus
Ancestral anaerobic eukaryote
Bacterial genome
Aerobic bacterium
Aerobic eukaryote
Nonphotosynthetic eukaryote
Mitochondrion
Cyanobacterial genome
Photosynthetic cyanobacterium
Chloroplast
Photosynthetic eukaryote
Aerobic metabolism is efficient because fuel is oxidized to CO_2.
Light energy is used to synthesize biomolecules from CO_2.
Engulfed cyanobacterium becomes an endosymbiont and multiplies; new cell can make ATP using energy from sunlight.
In time, some cyanobacterial genes move to the nucleus, and endosymbionts become plastids (chloroplasts).


δ+
H
O
δ−
δ−
H
δ+
(a)
δ+
2δ−
δ+
(b)



(c)




Hydrogen acceptor
Hydrogen donor
C
O
H
O
N
H
O
O
H
O
C
O
H
N
O
H
N
N
H
N

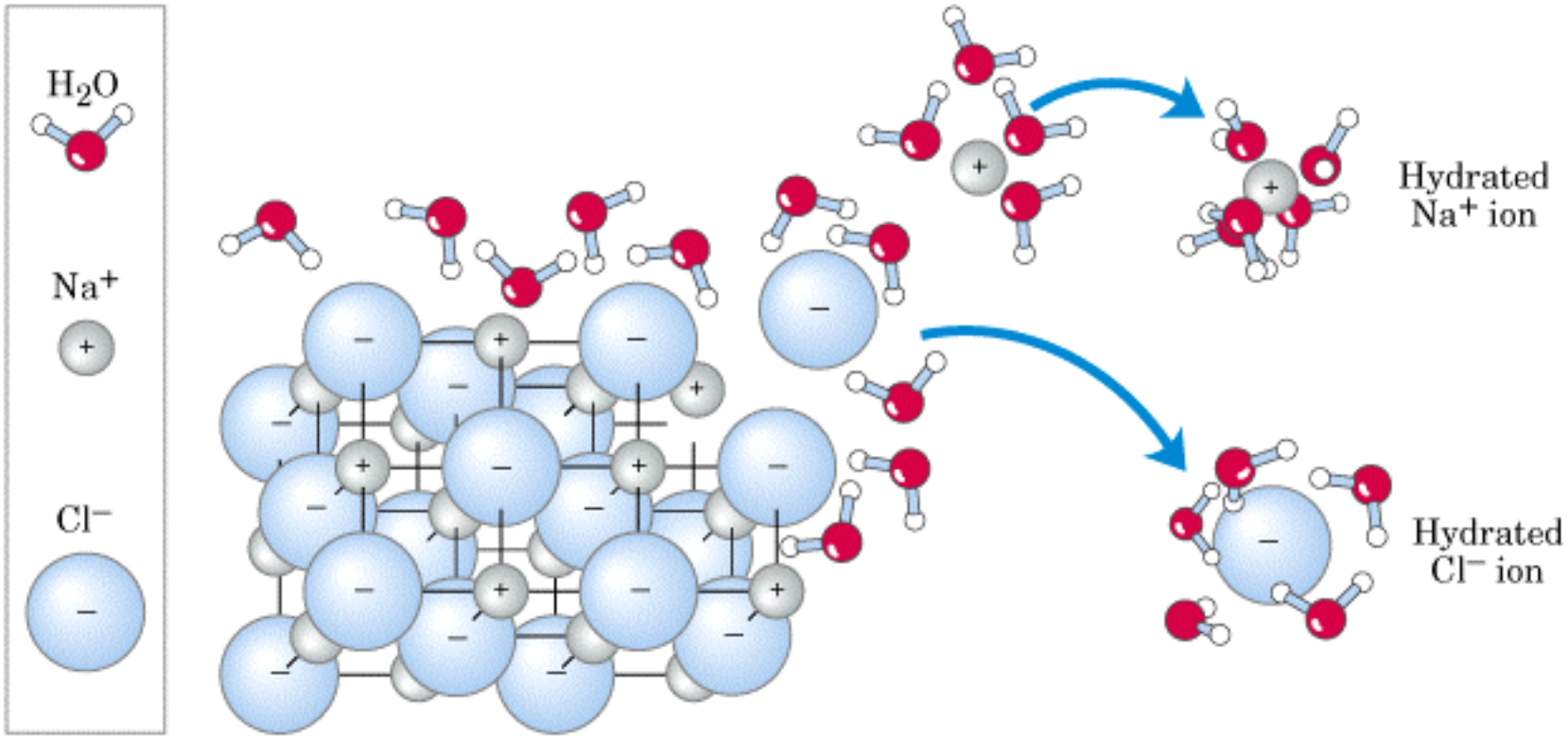
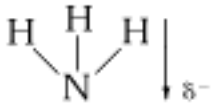
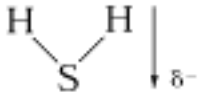

H_2O
Na^+
Cl^-
Hydrated Na^+ ion
Hydrated Cl^- ion

table 4–3

Solubilities of Some Gases in Water

Gas	Structure*	Polarity	Solubility in water (g/L)†
Nitrogen	$N \equiv N$	Nonpolar	0.018 (40 °C)
Oxygen	$O=O$	Nonpolar	0.035 (50 °C)
Carbon dioxide	$\overset{\delta^-}{\leftarrow} \quad \overset{\delta^-}{\rightarrow}$ $O=C=O$	Nonpolar	0.97 (45 °C)
Ammonia		Polar	900 (10 °C)
Hydrogen sulfide		Polar	1,860 (40 °C)

*The arrows represent electric dipoles; there is a partial negative charge (δ^-) at the head of the arrow, a partial positive charge (δ^+; not shown here) at the tail.

†Note that polar molecules dissolve far better even at low temperatures than do nonpolar molecules at relatively high temperatures.

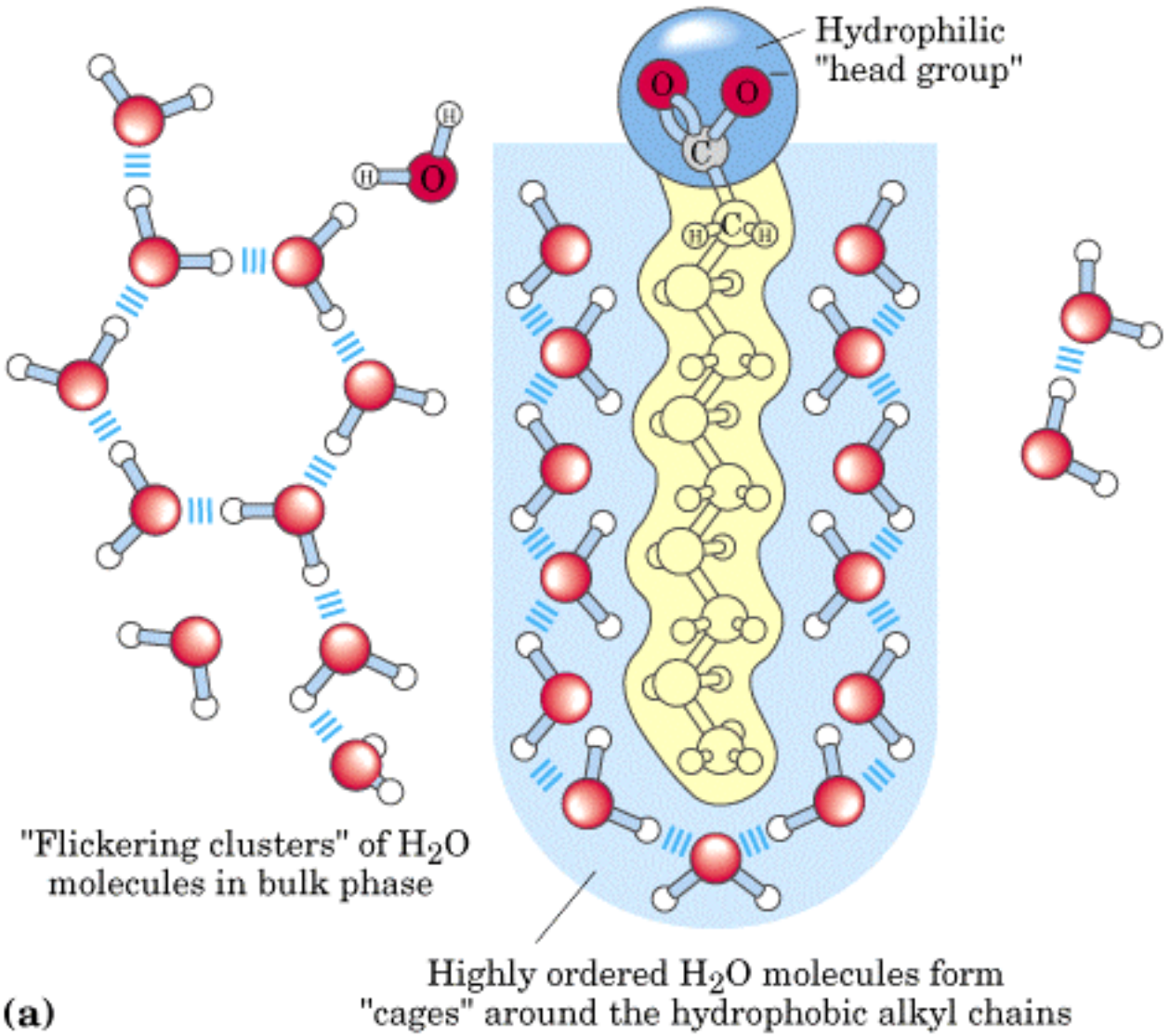

Hydrophilic
"head group"
"Flickering clusters" of H_2O
molecules in bulk phase
Highly ordered H_2O molecules form
"cages" around the hydrophobic alkyl chains
(a)

table 4–4

Four Types of Noncovalent ("Weak") Interactions among Biomolecules in Aqueous Solvent

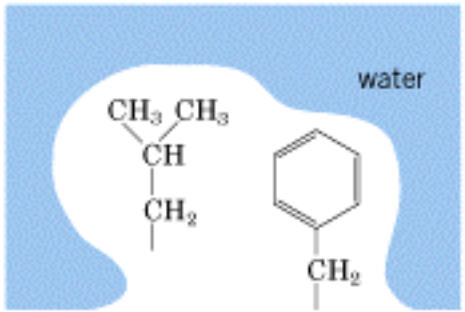
Hydrogen bonds	
Between neutral groups	
Between peptide bonds	
Ionic interactions	
Attraction	
Repulsion	
Hydrophobic interactions	
Van der Waals interactions	Any two atoms in close proximity

Table 2–1 Covalent and Noncovalent Chemical Bonds

BOND TYPE	LENGTH (nm)	STRENGTH (kcal/mole) IN VACUUM	IN WATER
Covalent	0.15	90	90
Noncovalent: ionic*	0.25	80	3
hydrogen	0.30	4	1
van der Waals attraction (per atom)	0.35	0.1	0.1

*An ionic bond is an electrostatic attraction between two fully charged atoms.

Table 2-1 *Molecular Biology of the Cell* (© Garland Science 2008)