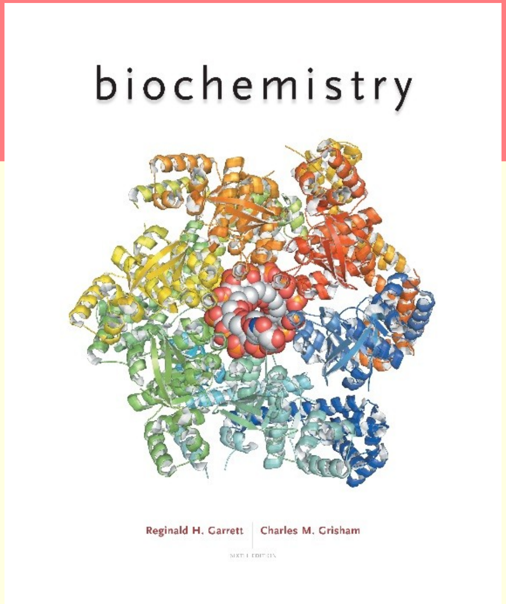

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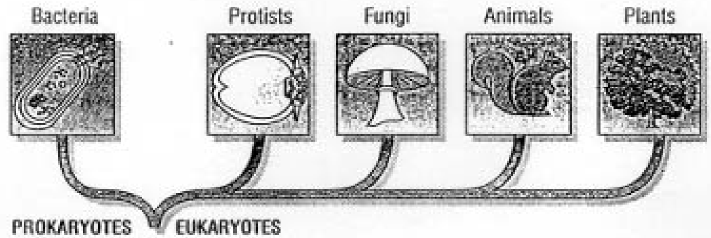
Chapter 1
The Facts of Life: Chemistry is the Logic of Biological Phenomena

From the Science Section of the Dallas Morning News

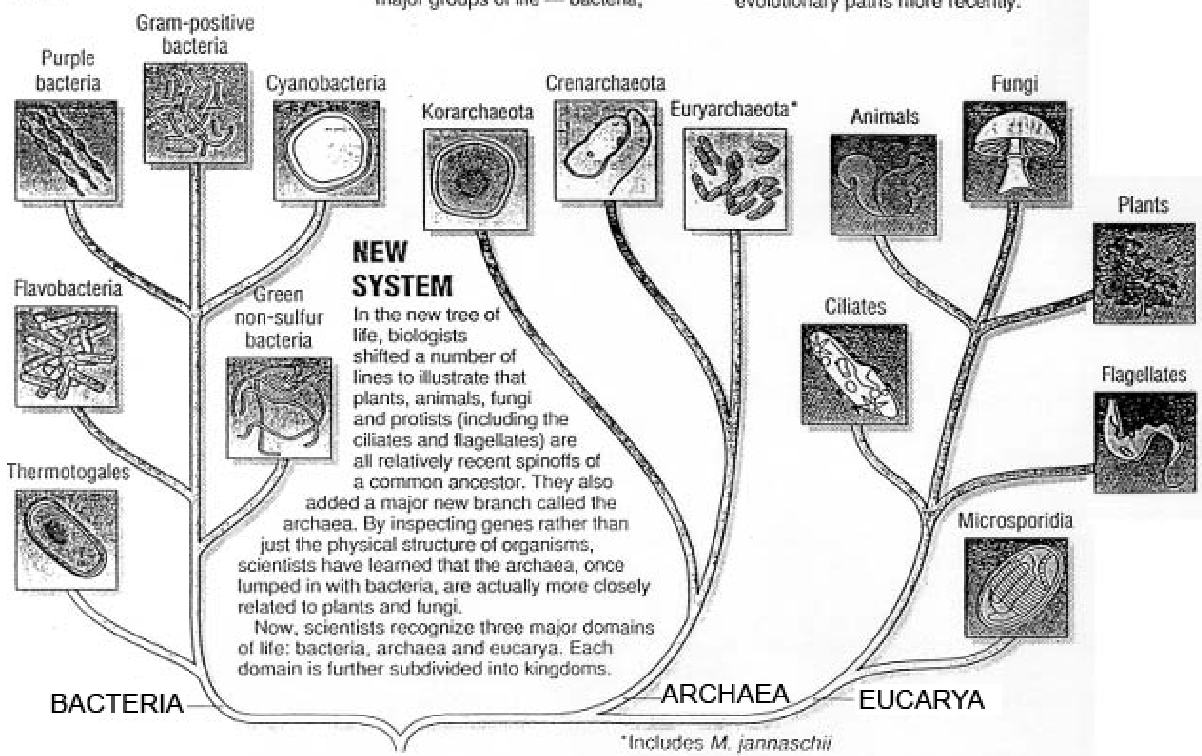
BRANCHING

Last month, biologists announced that they had completely sequenced the DNA — the cellular blueprints — of an organism called *Methanococcus jannaschii.* The domain of organisms to which this one belonged — the archaea — has been recognized by biologists as a distinct group for several years. New genetic evidence, however, indicates that the archaea are far more diverse than previously believed. Moreover, knowing the gene sequence of an archaea is helping biologists get a clearer picture of the evolution of life on Earth.



OLD SYSTEM

The outdated five-kingdom tree of life illustrated traditional ideas about how living species were believed to be related to one another. Until new research techniques revolutionized the field, biologists described five major groups of life — bacteria, plants, fungi, protists (such as the amoeba) and animals. While the bacterial kingdom diverged from the other four kingdoms almost 3 billion years ago, the fungal and animal kingdoms began on their separate evolutionary paths more recently.



NEW SYSTEM

In the new tree of life, biologists shifted a number of lines to illustrate that plants, animals, fungi and protists (including the ciliates and flagellates) are all relatively recent spinoffs of a common ancestor. They also added a major new branch called the archaea. By inspecting genes rather than just the physical structure of organisms, scientists have learned that the archaea, once lumped in with bacteria, are actually more closely related to plants and fungi.

Now, scientists recognize three major domains of life: bacteria, archaea and eucarya. Each domain is further subdivided into kingdoms.

*Includes *M. jannaschii*

How Many Genes Does a Cell Need?

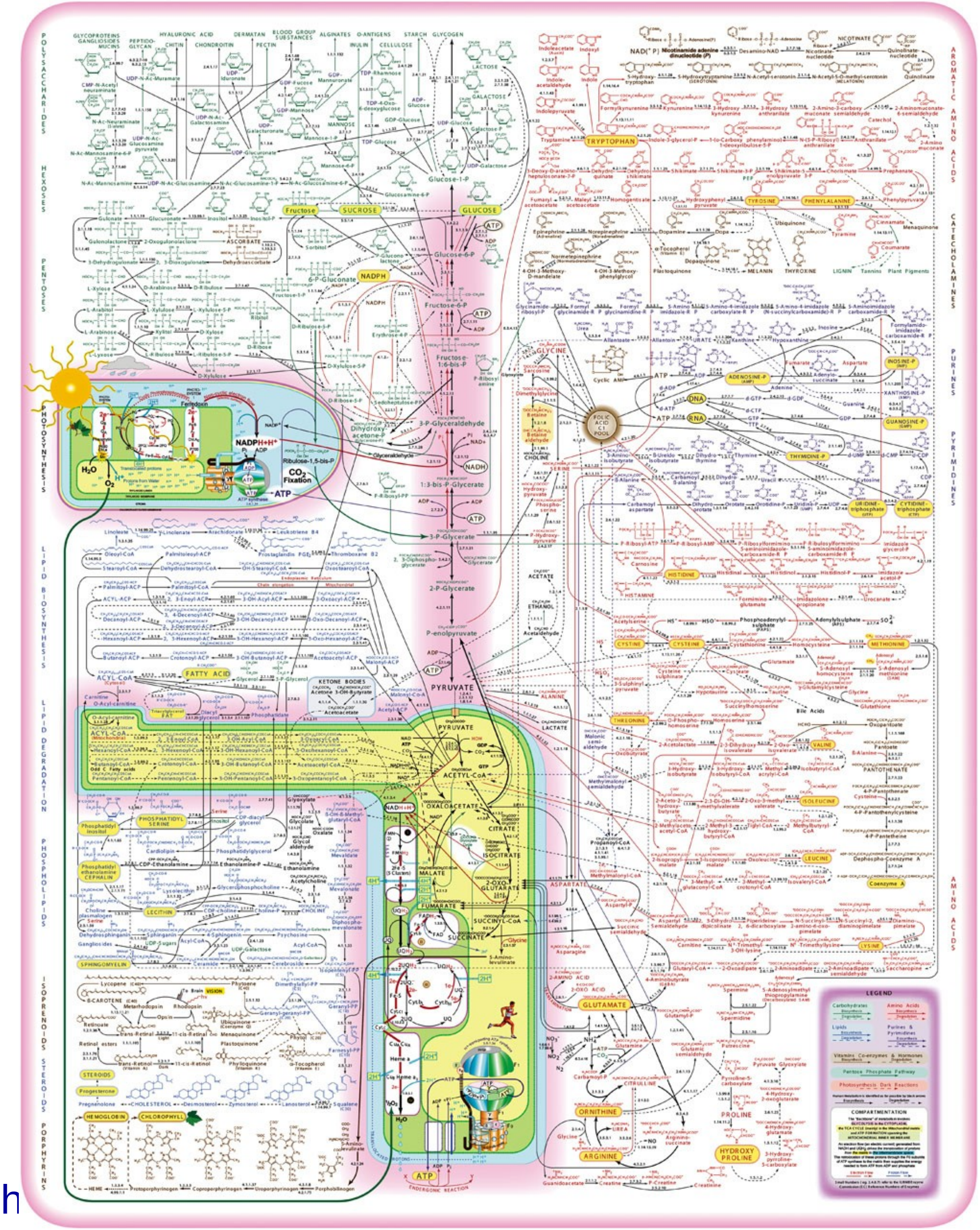
TABLE 1.6 How Many Genes Does It Take To Make An Organism?

Organism	Number of Cells in Adult*	Number of Genes
~~*Mycobacterium*~~ *genitalium* (*Mycoplasma genitalium*) Pathogenic bacterium	1	523
Methanococcus jannaschii Archaeal methanogen	1	1,800
Escherichia coli K12 Intestinal bacterium	1	4,400
Saccharomyces cereviseae Baker's yeast (eukaryote)	1	6,000
Caenorhabditis elegans Nematode worm	959	19,000
Drosophila melanogaster Fruit fly	10^4	13,500
Arabidopsis thaliana Flowering plant	10^7	27,000
Fugu rubripes Pufferfish	10^{12}	26,700 (est.)
Homo sapiens Human	10^{14}	20,500 (est.)

Figure 17.2 A metabolic map, indicating the reactions of intermediary metabolism and the enzymes that catalyze them. More than 500 different chemical intermediates, or metabolites, and a greater number of enzymes are represented here.

For a detailed look go to:

http://www.sigmaaldrich.com/etc/medialib/docs/Sigma-Aldrich/General_Information/metabolicpathways_updated_02_07.Par.0001.File.tmp/metabolic_pathways_poster.pdf



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Garrett and Grish

Outline

- Three Domains of Life – Biochemistry in Common
- Chemical Elements of Life
- Functional Groups of Biomolecules
- Biopolymers
- Weak Forces
- Bond Energies

1.2 What Kinds of Molecules are Biomolecules?

- H, O, C and N make up 99+% of atoms in the human body

ELEMENT	PERCENTAGE
Hydrogen	63
Oxygen	25.5
Carbon	9.5
Nitrogen	1.4

Elements highlighted in red comprise 99.9% of human body

Elements highlighted in green are essential trace elements in human body

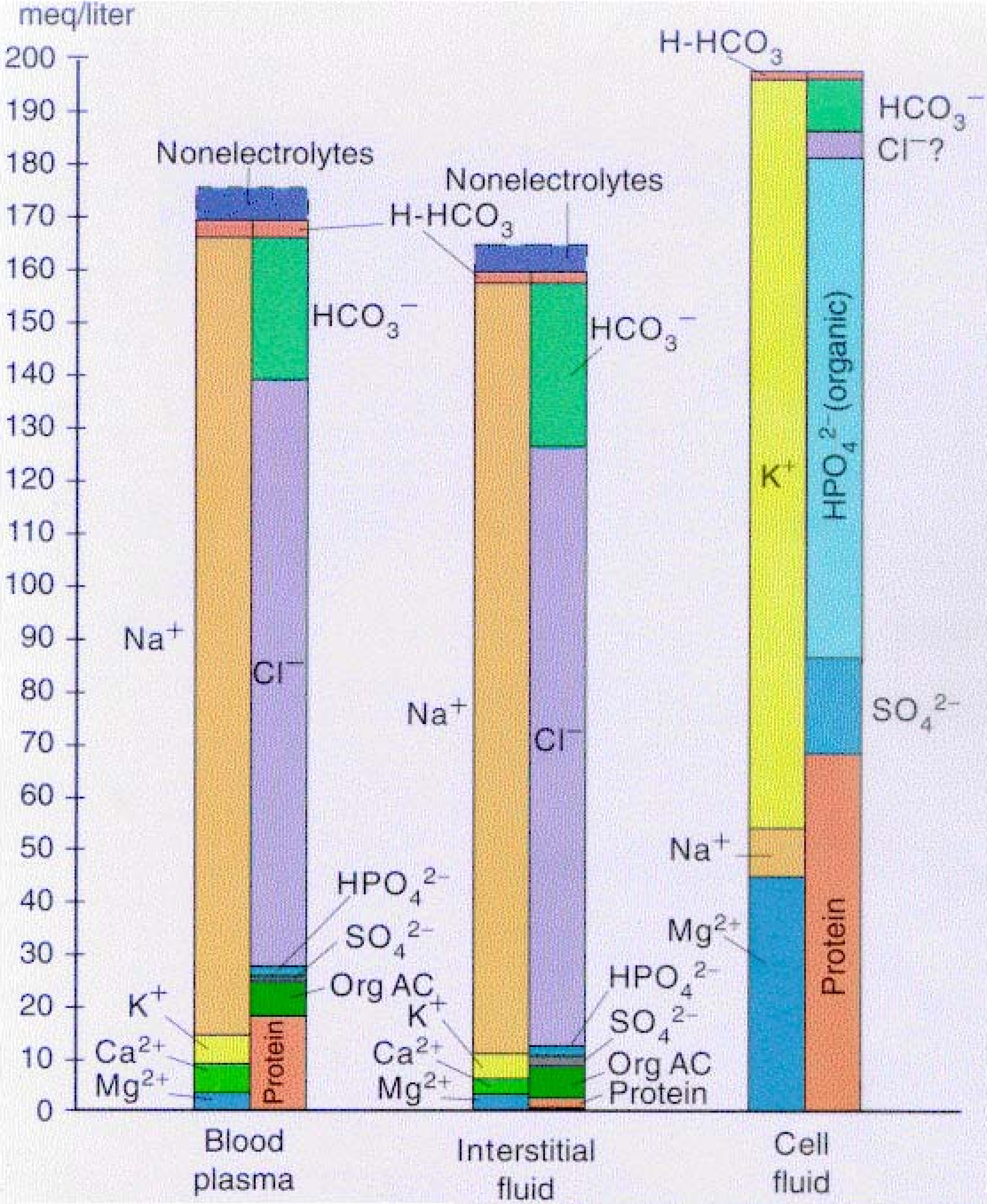
Elements highlighted in blue are trace elements found in some organisms

Periodic Table of the Elements

Period	Group Ia	Group IIa	Group IIIa	Group IVa	Group Va	Group VIa	Group VIIa	Group VIII			Group Ib	Group IIb	Group IIIb	Group IVb	Group Vb	Group VIb	Group VIIb	Group O
1 1s	1 H																1 H	2 He
2 2s2p	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3 3s3p	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4 4s3d 4p	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
5 5s4d 5p	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
6 6s (4f) 5d 6p	55 Cs	56 Ba	57* La	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
7 7s (5f) 6d	87 Fr	88 Ra	89** Ac															

*Lanthanide series 4f	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
**Actinide series 5f	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No(?)	103 Lw

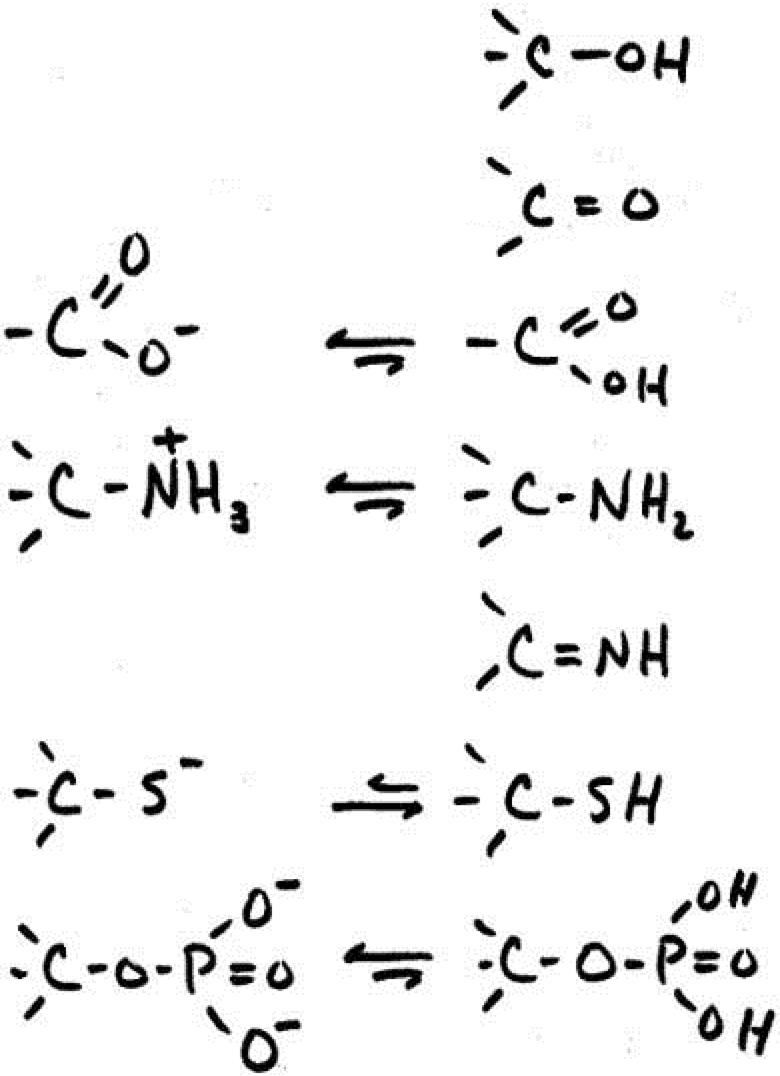
What are the major ions of life?



Electrolyte Composition of Body Fluids

Major Functional Groups in Biomolecules

Ionized Form	Structure	Name



HYDROXYL

CARBONYL

CARBOXYL

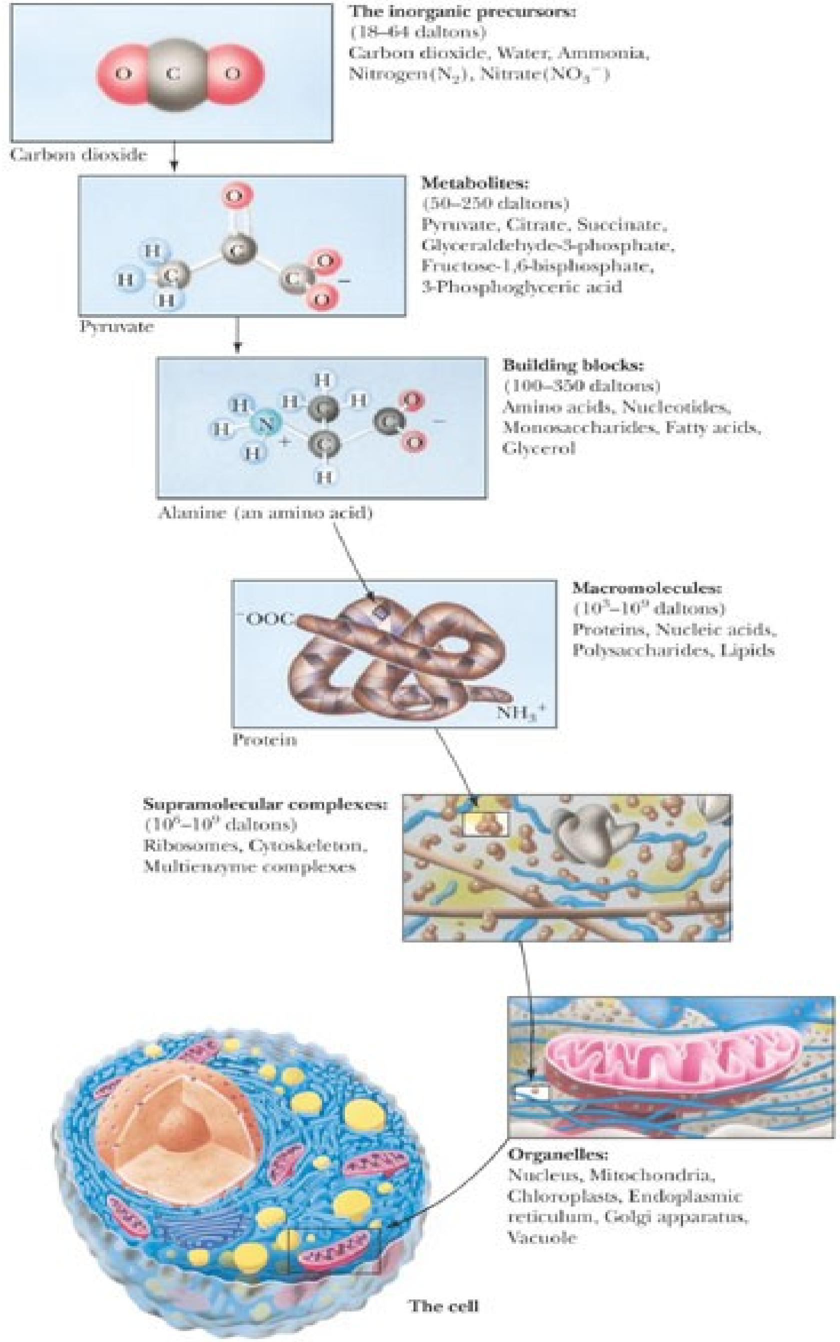
AMINO

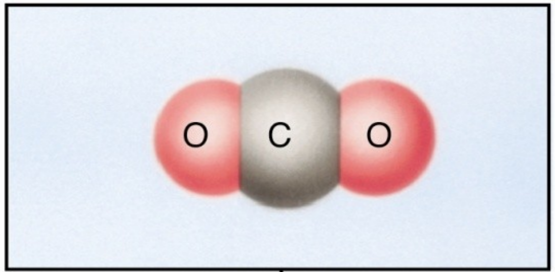
IMINO

THIOL

PHOSPHATE

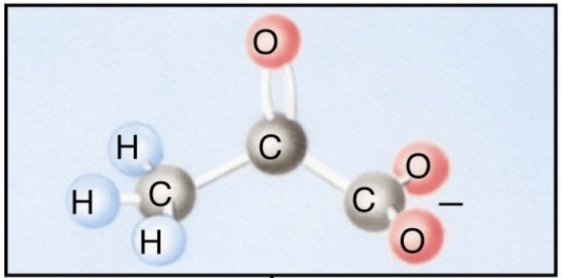
Figure 1.8
Molecular organization
in the cell is a hierarchy.





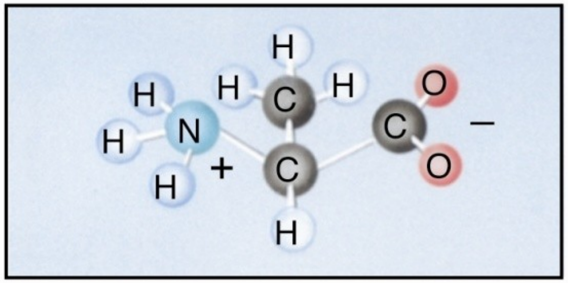
Carbon dioxide

The inorganic precursors:
(18–64 daltons)
Carbon dioxide, Water, Ammonia, Nitrogen(N_2), Nitrate(NO_3^-)



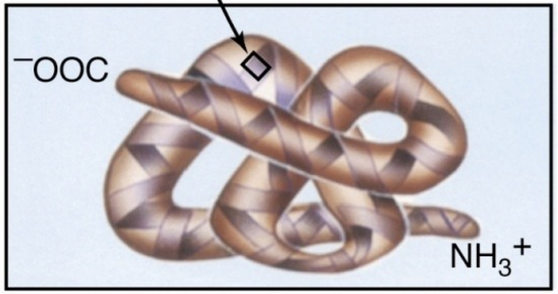
Pyruvate

Metabolites:
(50–250 daltons)
Pyruvate, Citrate, Succinate, Glyceraldehyde-3-phosphate, Fructose-1,6-bisphosphate, 3-Phosphoglyceric acid



Alanine (an amino acid)

Building blocks:
(100–350 daltons)
Amino acids, Nucleotides, Monosaccharides, Fatty acids, Glycerol



Protein

Macromolecules:
(10^3–10^9 daltons)
Proteins, Nucleic acids, Polysaccharides, Lipids

Fig.1.9 Biopolymers (aka. macromolecules)

Amino acids build proteins

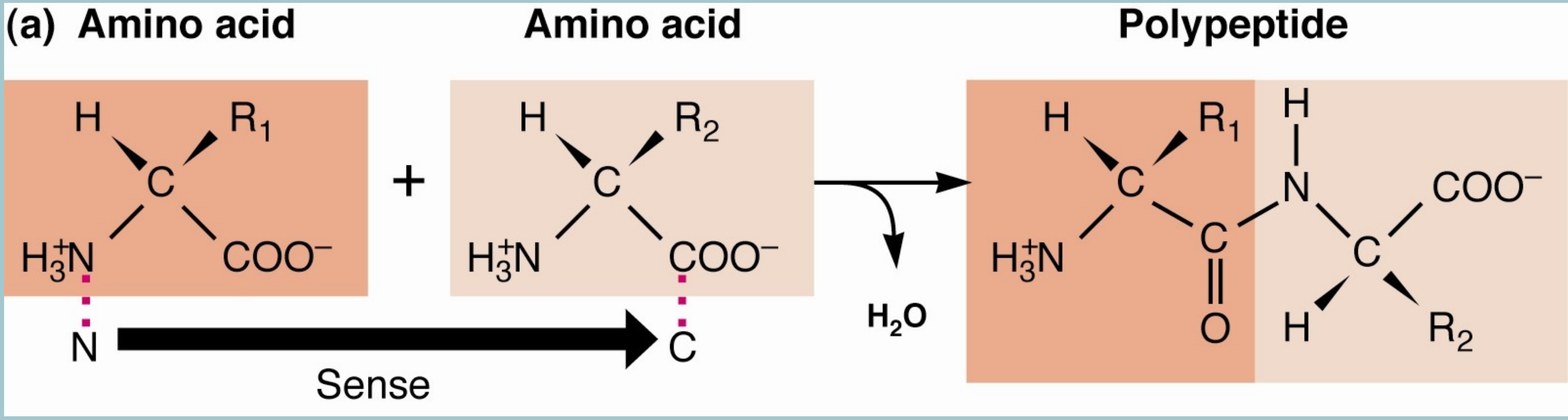


Fig.1.9 Biopolymers (aka. macromolecules)

Polysaccharides are built by joining sugars together

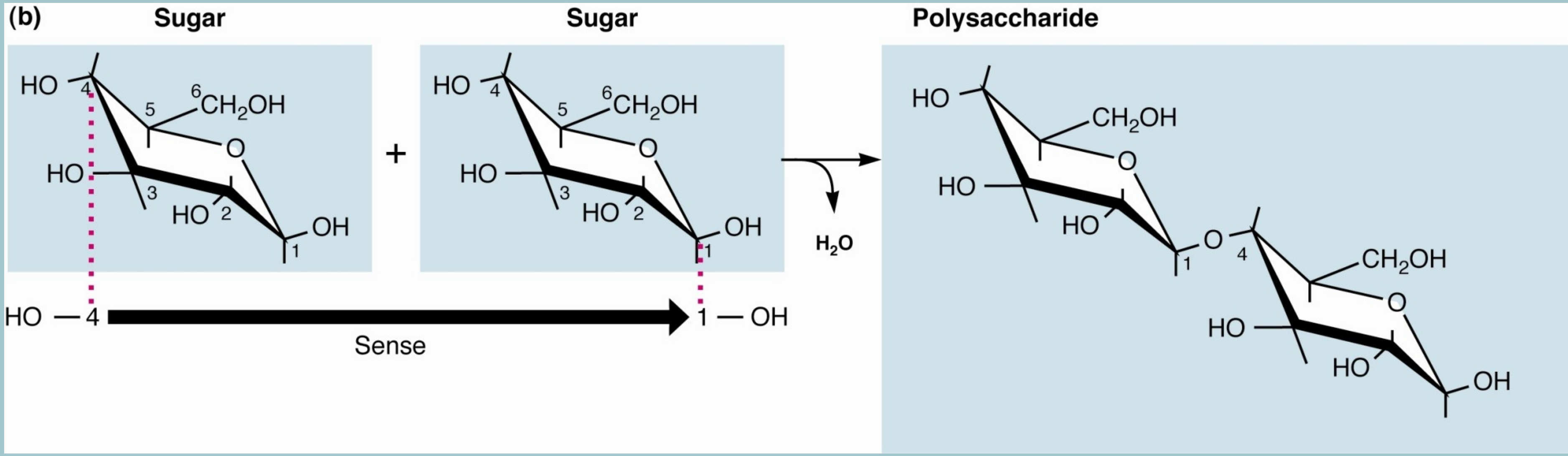
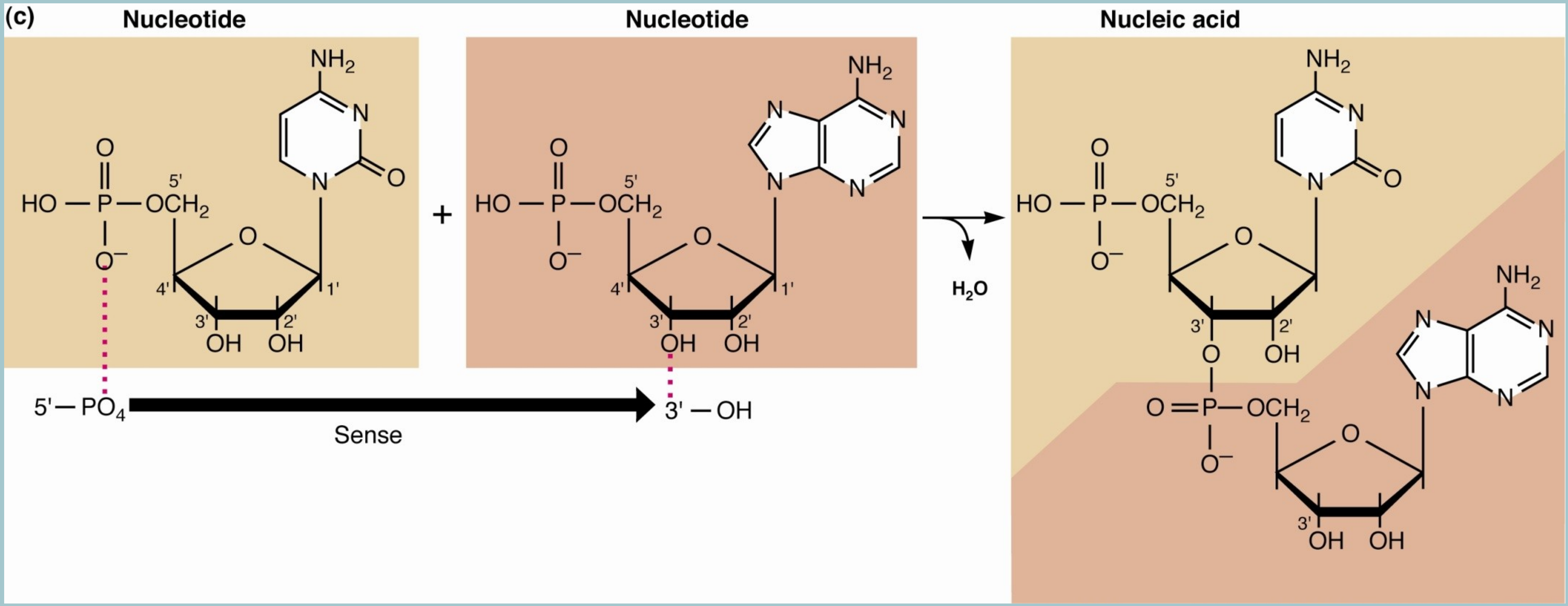
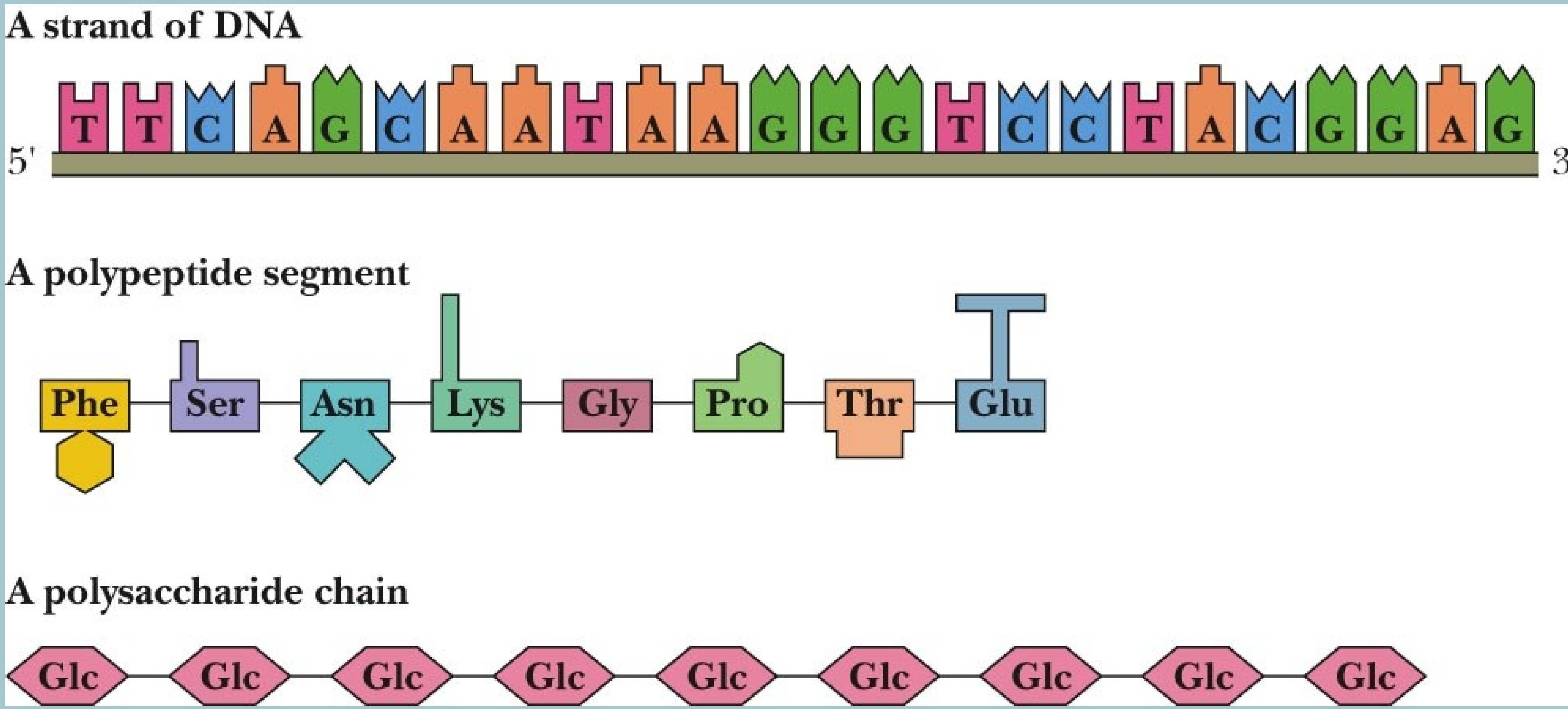


Fig.1.9 Biopolymers (aka. macromolecules)

Nucleic acids are polymers of nucleotides



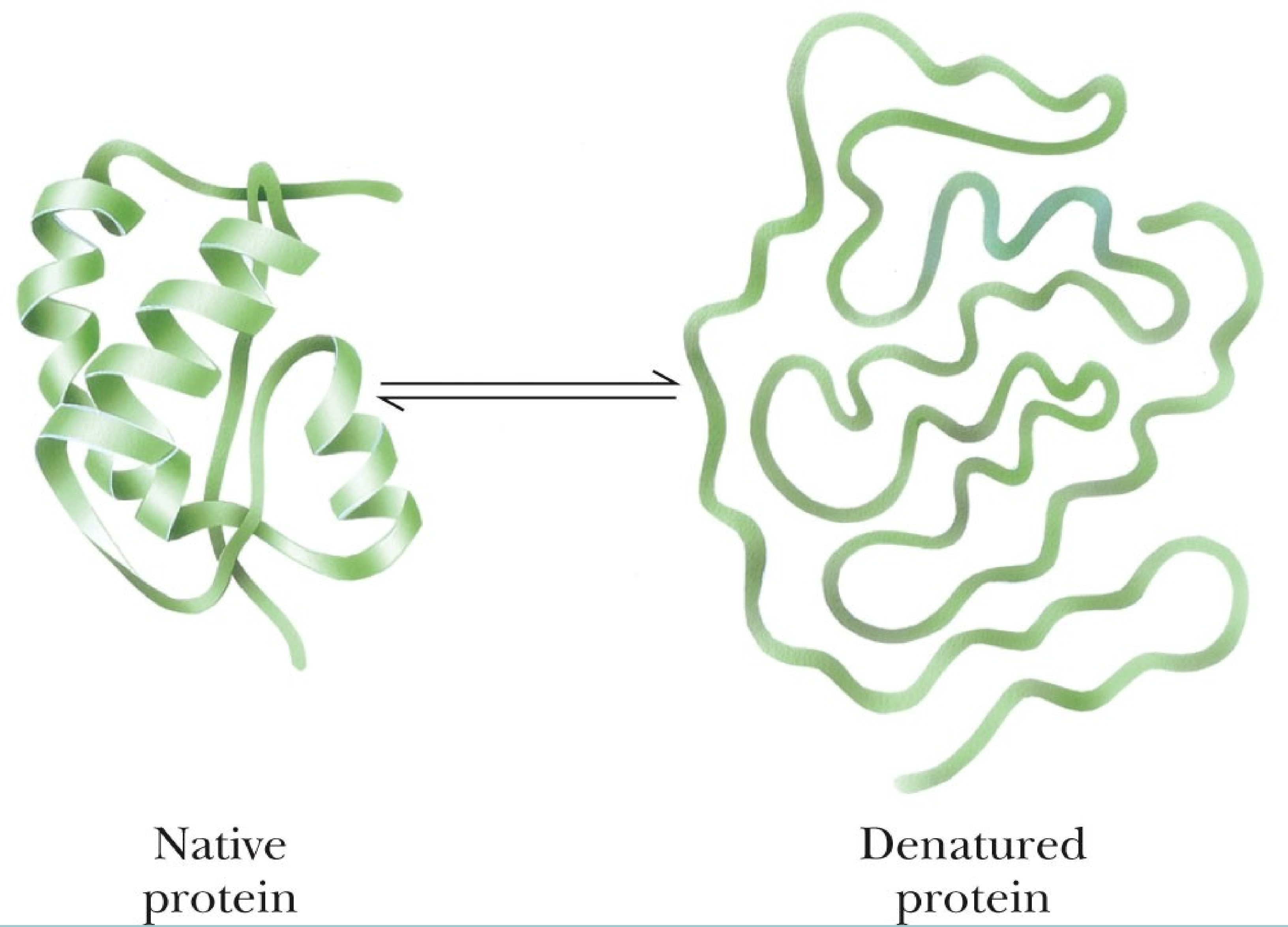
The Major Biopolymers

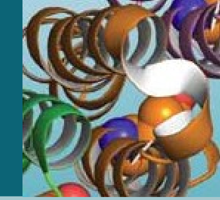


Sec. 1.4 Properties of Biomolecules Reflect Their Fitness to the Living Condition

- Macromolecules and their building blocks have a “sense” or directionality
- Macromolecules are informational
- Biomolecules have characteristic three-dimensional architecture

Figure 1.17 Denaturation and renaturation of the intricate structure of a protein.

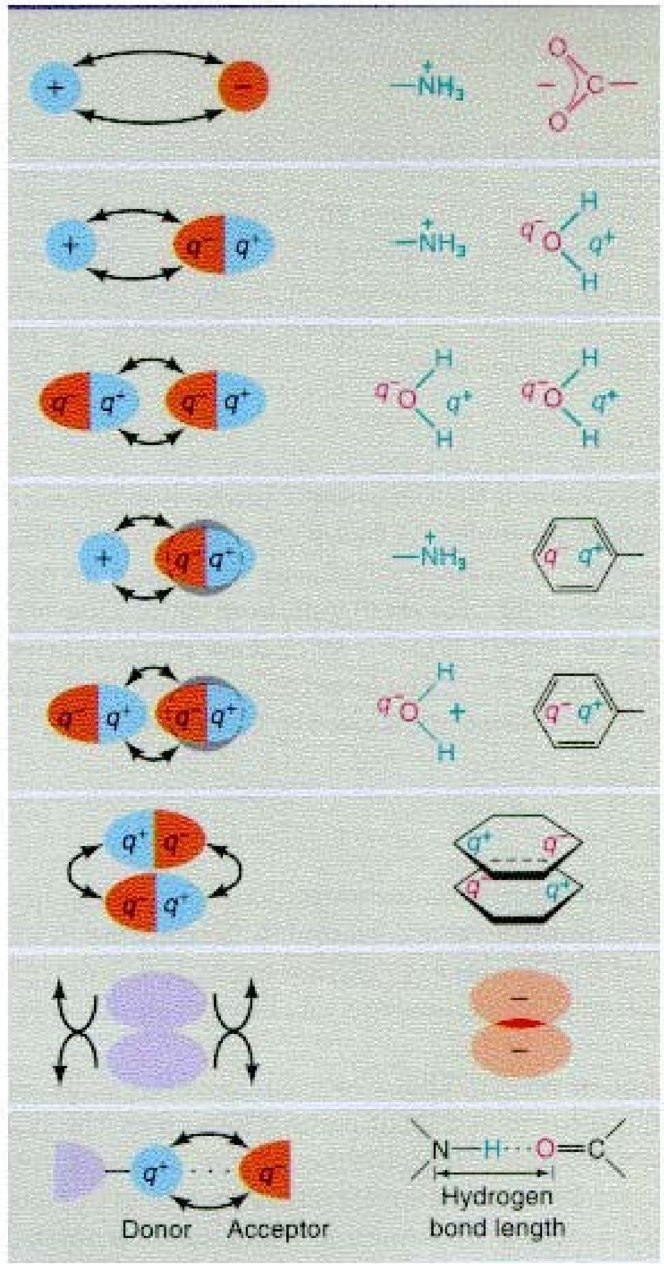




Weak Forces

- Maintain Biological Structure
- Determine Biomolecular Interactions

Weak Interaction	Electrostatic Model	Example	E(r)
charge - charge			r^{-1}
charge - dipole			r^{-2}
dipole - dipole			r^{-3}
charge - induced dipole			r^{-4}
dipole - induced dipole			r^{-5}
dispersion			r^{-6}
van der waals repulsion			r^{-12}
hydrogen bond			Fixed bond length



Coulomb's Law
for electrostatic interactions

$$F = \frac{k\, q_1 q_2}{\epsilon\, r^2}$$

where q = charge
ϵ = dielectric const
$\epsilon_{H_2O} = 80$

Energy of interaction = work needed to completely separate charges

$$E = \frac{k\, q_1 q_2}{\epsilon} \int_r^{\infty} \frac{1}{r^2}\, dr$$

$$= \frac{k\, q_1 q_2}{\epsilon\, r}$$

Terms for energy:

1 cal = 4.184 joules

Van der Waals Interactions
E(distance of separation, r)

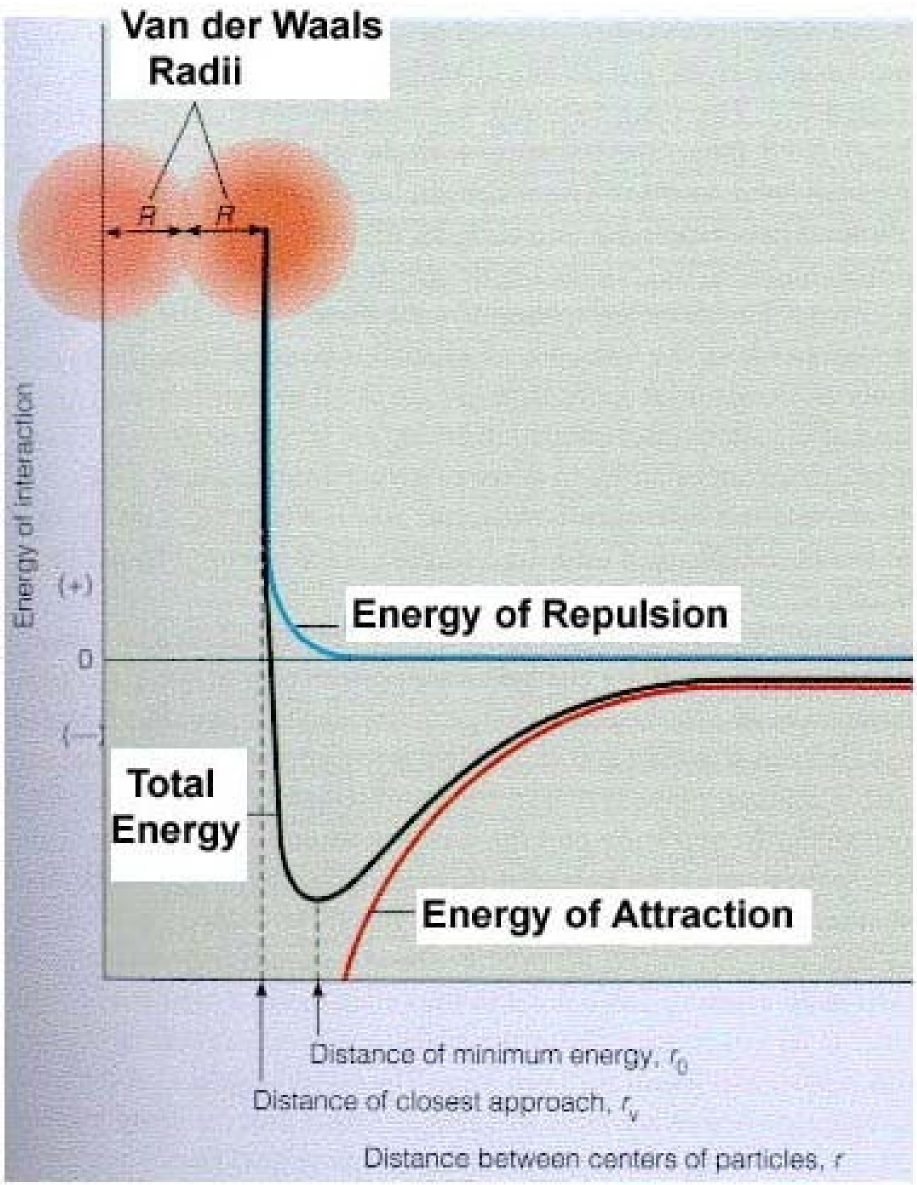


Fig. 1.12 Van der Waals Forces Are Important to Biomolecular Interactions

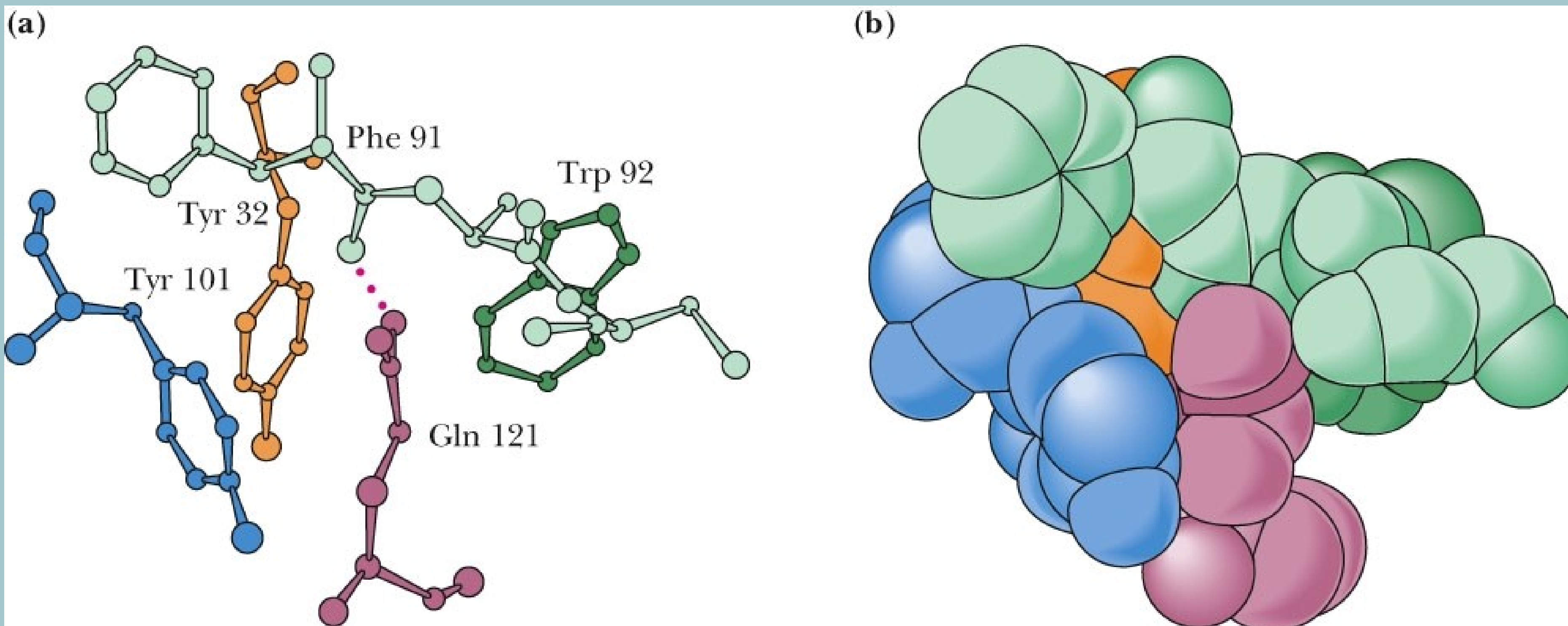


Figure 1.12
Van der Waals packing is enhanced in molecules that are structurally complementary. Gln^{121} represents a surface protuberance on the protein lysozyme. This protuberance fits nicely within a pocket (formed by Tyr^{101}, Tyr^{32}, Phe^{91}, and Trp^{92}) in the antigen-binding domain of an antibody raised against lysozyme. (See also Figure 1.16.) (a) A ball-and-stick model. (b) A space-filling representation. (*From* Science ***233****:751 (1986), figure 5*.)

Fig. 1.14 Some biologically important H bonds

H bonds Bonded atoms	Approximate bond length*
O—H---O	0.27 nm
O—H---O^-	0.26 nm
O—H---N	0.29 nm
N—H---O	0.30 nm
^+N—H---O	0.29 nm
N—H---N	0.31 nm

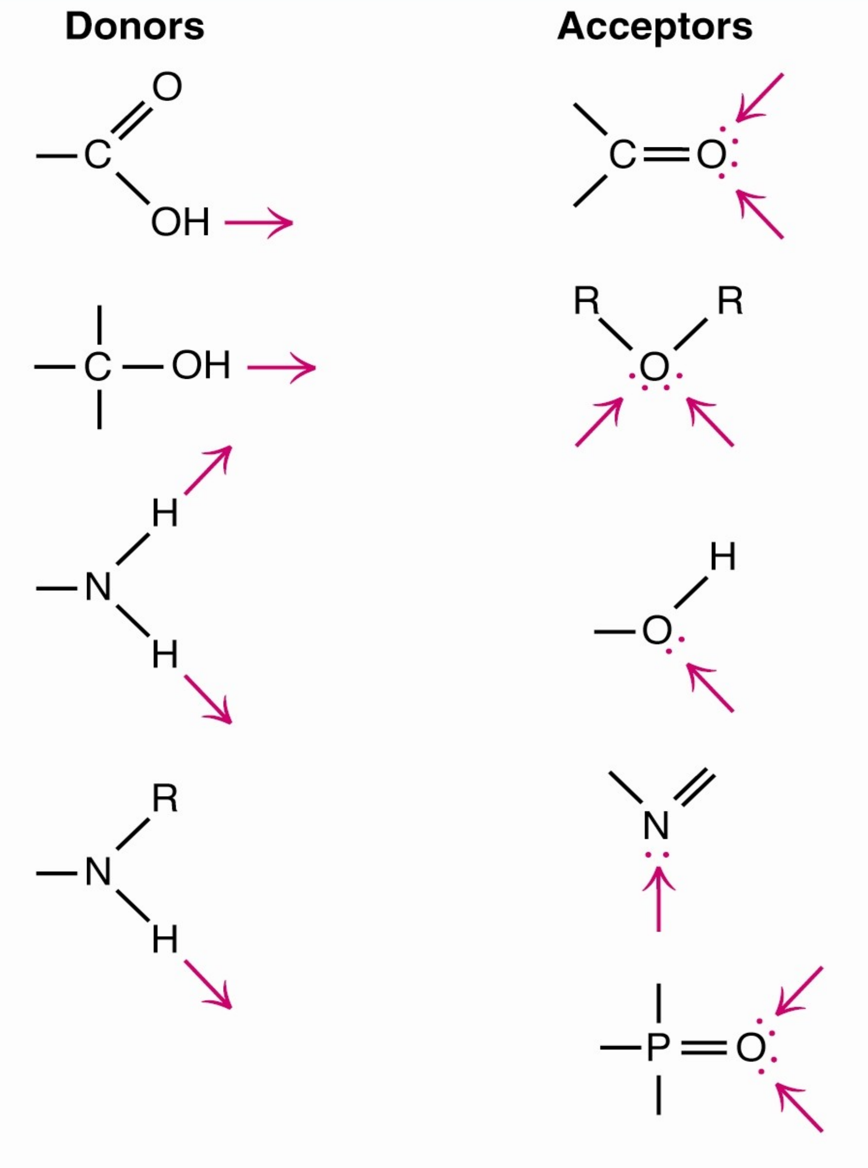
*Lengths given are distances from the atom covalently linked to the H to the atom H bonded to the hydrogen:

O—H---O

|←0.27 nm→|

Figure 1.14
Some of the biologically important functional groups that serve as H bond donors and acceptors.

Functional groups that are important H-bond donors and acceptors:



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N—H---N	0.31 nm

*Lengths given are distances from the atom covalently linked to the H to the atom H bonded to the hydrogen:

O—H---O

|←0.27 nm→|

Covalent and Noncovalent Bond Energies

Bond	Strength (kJ/mol)
C – H	414
C – OH	351
C – C	343
C – NH	292
Van der Waals and dipole interactions	0.4 - 4.0
H-bonds	12 - 30
Ionic (aka. Charge - Charge)	20
Hydrophobic Interactions (not a specific bond, but energy derived from changes in H-bonding in the solvent H_2O)	<40

Two Important Points About Weak Forces

- Biomolecular Recognition is Mediated by Weak Chemical Forces

- Weak Forces Restrict Organisms to a Narrow Range of Environmental Conditions