Origin of life and universal features of cells

BASIC THEMES OF LIFE

Key Concepts

1. Basic themes of biology include evolution, interactions of biological systems, inter-relationships of structure and function, information transfer, and energy transfer.

2 Characteristics of life include cellular structure, growth and development, self-regulated metabolism, response to stimuli, and reproduction.

3 Biological organization is hierarchical and includes chemical, cell, tissue, organ, organ system, and organism levels; ecological organization includes population, community, ecosystem, and biosphere levels.

4 Information transfer includes DNA transfer of information from one generation to the next, chemical and electrical signals within and among the cells of every organism, and sensory receptors and response systems that allow organisms to communicate with one another and interact with their environment.

5 Individual organisms and entire ecosystems depend on a continuous input of energy. Energy is transferred within cells and from one organism to another.

6 Evolution is the process by which populations of organisms change over time, adapting to changes in their environment; the tree of life includes three major branches, or domains.

7 Biologists ask questions, develop hypotheses, make predictions, and collect data by careful observation and by performing experiments; based on their results, they come to conclusions and then share their work with other scientists and with the public.

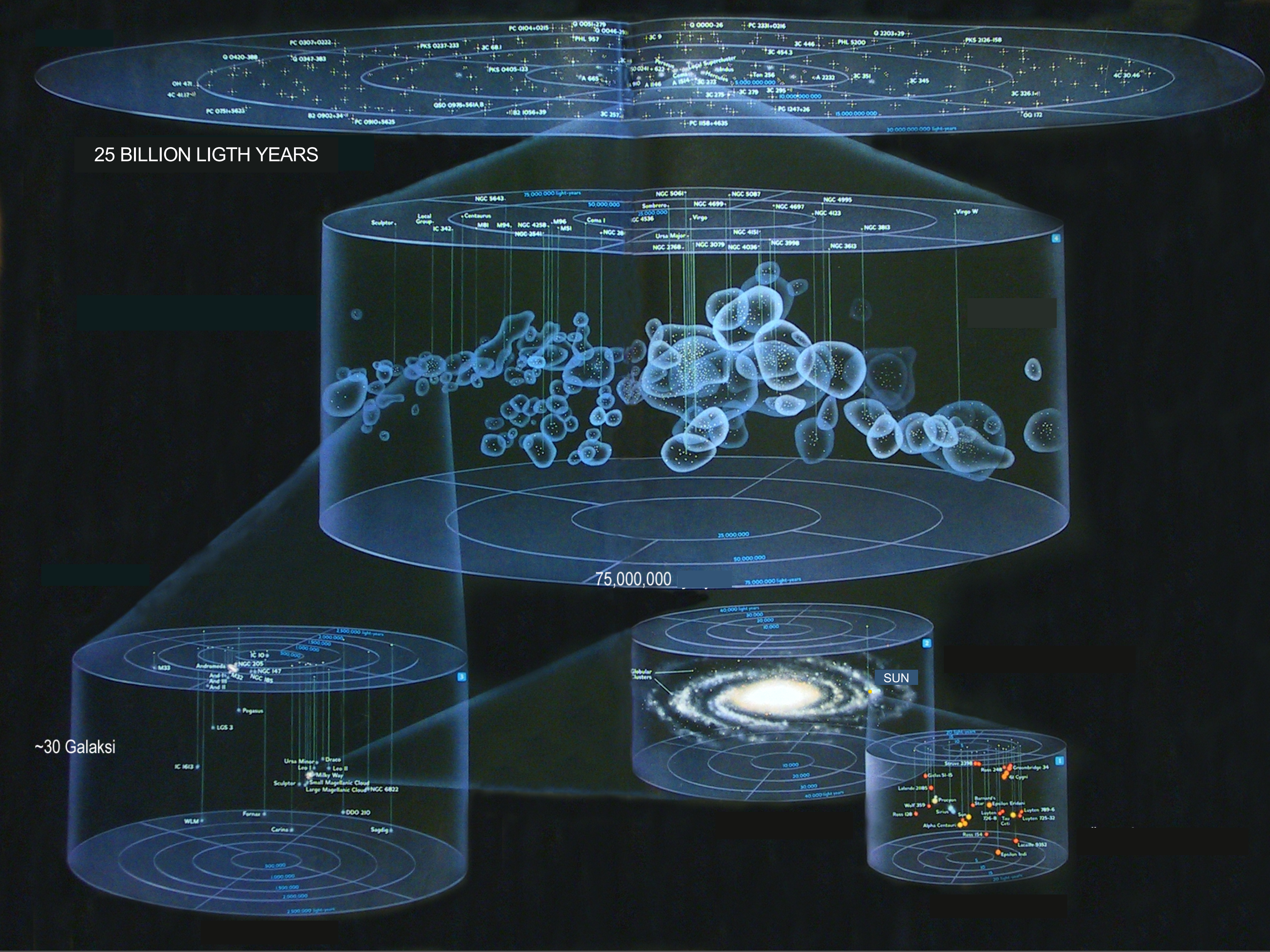
LEARNING OBJECTIVES

Describe the differences between living and non-living things

Describe the term “life form”

Describe five basic universal features of cells

ORIGIN OF LIFE


25 BILLION LIGTH YEARS
75,000,000
~30 Galaksi
SUN
Globular Clusters

UNIVERSAL FEATURES OF CELLS

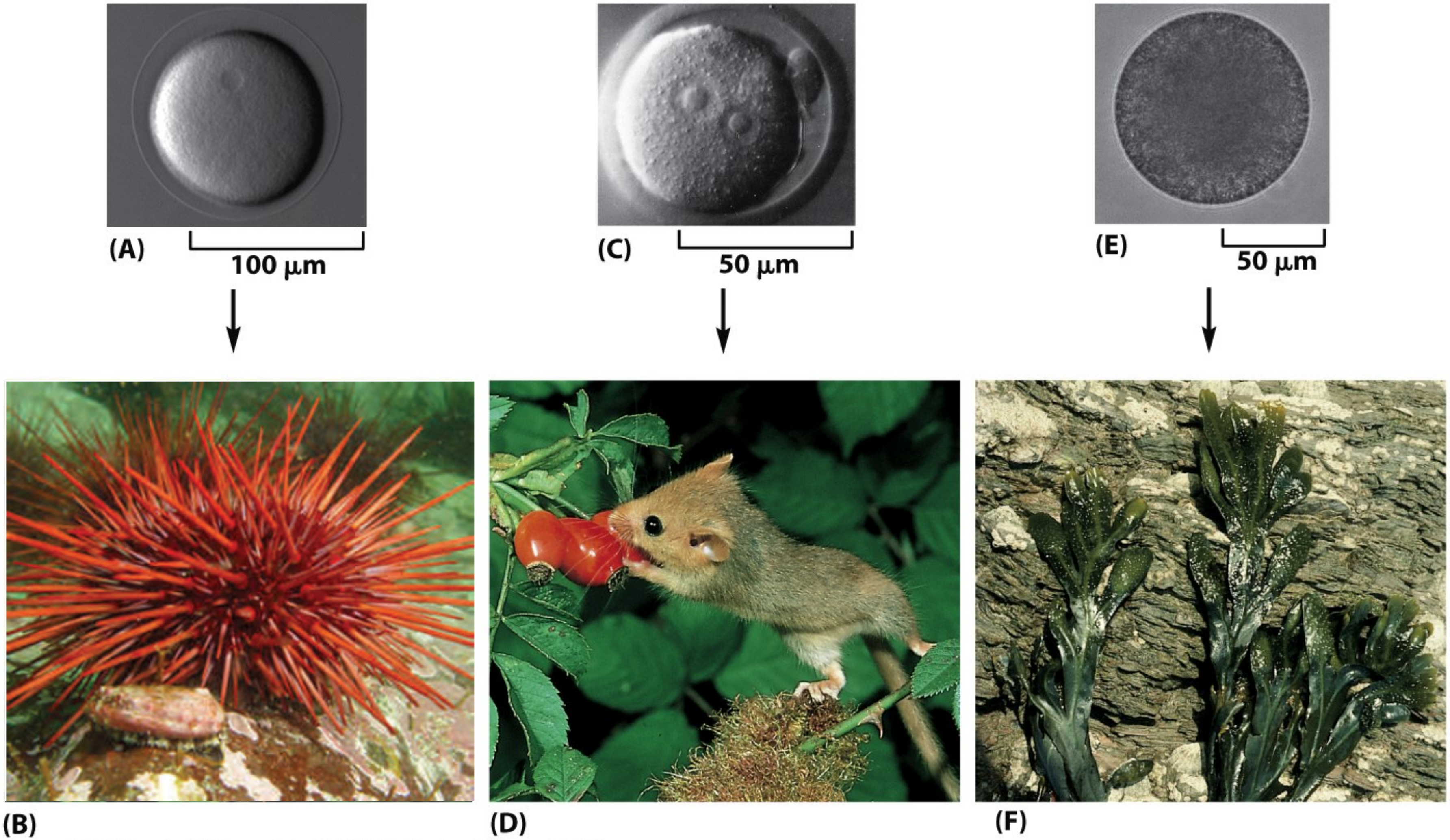
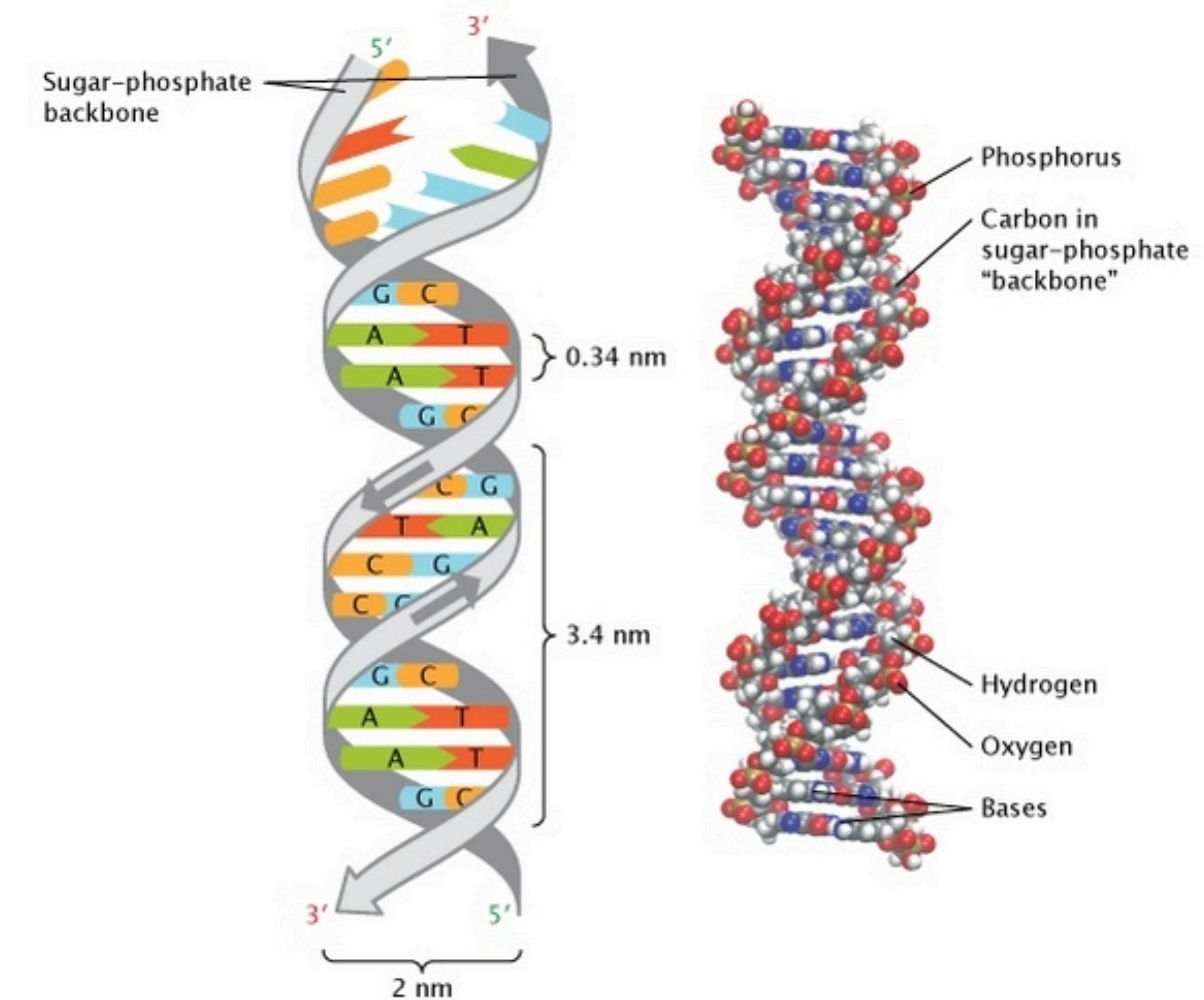


Figure 1-1 Molecular Biology of the Cell 5/e (© Garland Science 2008)

1. All Cells Store Their Hereditary Information in the Same Linear Chemical Code: DNA



5′
3′
Sugar-phosphate backbone
G C
A T
0.34 nm
A T
G C
C G
T A
C G
C G
3.4 nm
G C
A T
A T
G C
3′
5′
2 nm
Phosphorus
Carbon in sugar-phosphate "backbone"
Hydrogen
Oxygen
Bases

equipment, and to Dr. G. E. R. Deacon and the captain and officers of R.R.S. *Discovery II* for their part in making the observations.

[1] Young, F. B., Gerrard, H., and Jevons, W., *Phil. Mag.*, **40**, 149 (1920).
[2] Longuet-Higgins, M. S., *Mon. Not. Roy. Astro. Soc., Geophys. Supp.*, **5**, 285 (1949).
[3] Von Arx, W. S., Woods Hole Papers in Phys. Oceanog. Meteor., **11** (3) (1950).
[4] Ekman, V. W., *Arkiv. Mat. Astron. Fysik. (Stockholm)*, **2** (11) (1905).

MOLECULAR STRUCTURE OF NUCLEIC ACIDS

A Structure for Deoxyribose Nucleic Acid

WE wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable biological interest.

A structure for nucleic acid has already been proposed by Pauling and Corey[1]. They kindly made their manuscript available to us in advance of publication. Their model consists of three intertwined chains, with the phosphates near the fibre axis, and the bases on the outside. In our opinion, this structure is unsatisfactory for two reasons: (1) We believe that the material which gives the X-ray diagrams is the salt, not the free acid. Without the acidic hydrogen atoms it is not clear what forces would hold the structure together, especially as the negatively charged phosphates near the axis will repel each other. (2) Some of the van der Waals distances appear to be too small.

Another three-chain structure has also been suggested by Fraser (in the press). In his model the phosphates are on the outside and the bases on the inside, linked together by hydrogen bonds. This structure as described is rather ill-defined, and for this reason we shall not comment on it.

This figure is purely diagrammatic. The two ribbons symbolize the two phosphate—sugar chains, and the horizontal rods the pairs of bases holding the chains together. The vertical line marks the fibre axis

We wish to put forward a radically different structure for the salt of deoxyribose nucleic acid. This structure has two helical chains each coiled round the same axis (see diagram). We have made the usual chemical assumptions, namely, that each chain consists of phosphate di-ester groups joining β-D-deoxyribofuranose residues with 3′,5′ linkages. The two chains (but not their bases) are related by a dyad perpendicular to the fibre axis. Both chains follow right-handed helices, but owing to the dyad the sequences of the atoms in the two chains run in opposite directions. Each chain loosely resembles Furberg's[2] model No. 1; that is, the bases are on the inside of the helix and the phosphates on the outside. The configuration of the sugar and the atoms near it is close to Furberg's 'standard configuration', the sugar being roughly perpendicular to the attached base. There is a residue on each chain every 3·4 A. in the z-direction. We have assumed an angle of 36° between adjacent residues in the same chain, so that the structure repeats after 10 residues on each chain, that is, after 34 A. The distance of a phosphorus atom from the fibre axis is 10 A. As the phosphates are on the outside, cations have easy access to them.

The structure is an open one, and its water content is rather high. At lower water contents we would expect the bases to tilt so that the structure could become more compact.

The novel feature of the structure is the manner in which the two chains are held together by the purine and pyrimidine bases. The planes of the bases are perpendicular to the fibre axis. They are joined together in pairs, a single base from one chain being hydrogen-bonded to a single base from the other chain, so that the two lie side by side with identical z-co-ordinates. One of the pair must be a purine and the other a pyrimidine for bonding to occur. The hydrogen bonds are made as follows: purine position 1 to pyrimidine position 1; purine position 6 to pyrimidine position 6.

If it is assumed that the bases only occur in the structure in the most plausible tautomeric forms (that is, with the keto rather than the enol configurations) it is found that only specific pairs of bases can bond together. These pairs are: adenine (purine) with thymine (pyrimidine), and guanine (purine) with cytosine (pyrimidine).

In other words, if an adenine forms one member of a pair, on either chain, then on these assumptions the other member must be thymine; similarly for guanine and cytosine. The sequence of bases on a single chain does not appear to be restricted in any way. However, if only specific pairs of bases can be formed, it follows that if the sequence of bases on one chain is given, then the sequence on the other chain is automatically determined.

It has been found experimentally[3,4] that the ratio of the amounts of adenine to thymine, and the ratio of guanine to cytosine, are always very close to unity for deoxyribose nucleic acid.

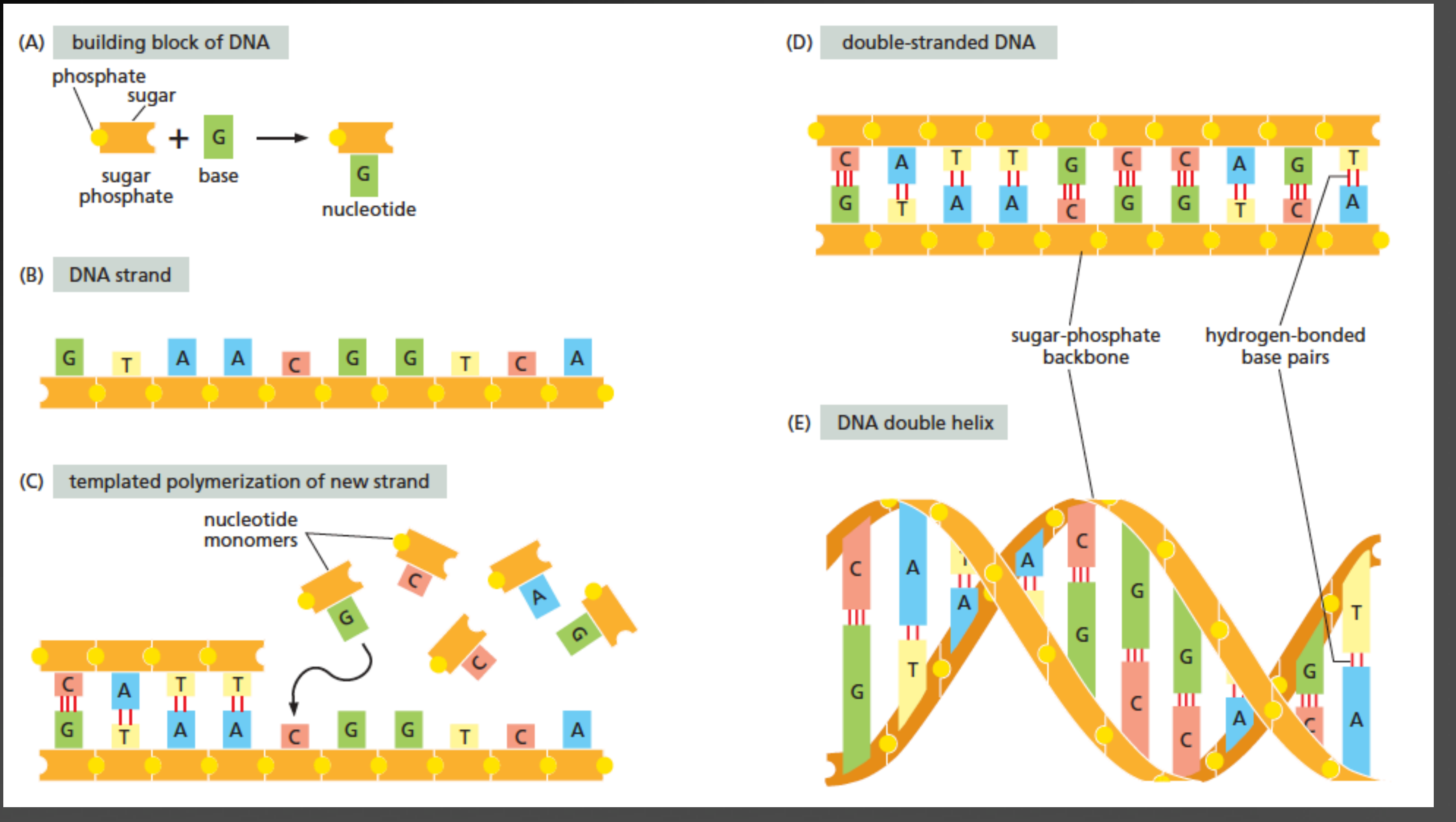
It is probably impossible to build this structure with a ribose sugar in place of the deoxyribose, as the extra oxygen atom would make too close a van der Waals contact.

The previously published X-ray data[5,6] on deoxyribose nucleic acid are insufficient for a rigorous test of our structure. So far as we can tell, it is roughly compatible with the experimental data, but it must be regarded as unproved until it has been checked against more exact results. Some of these are given in the following communications. We were not aware of the details of the results presented there when we devised our structure, which rests mainly though not entirely on published experimental data and stereochemical arguments.

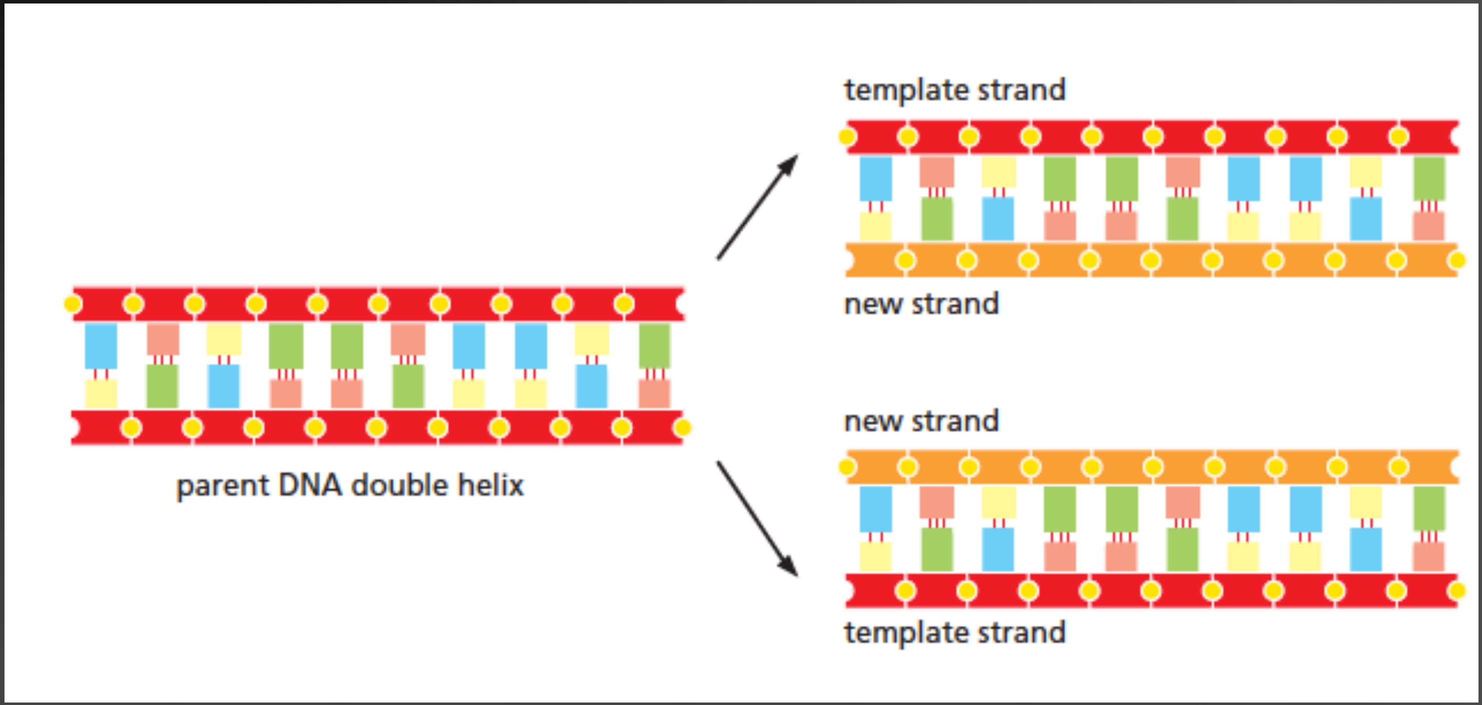
It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.

Full details of the structure, including the conditions assumed in building it, together with a set of co-ordinates for the atoms, will be published elsewhere.

We are much indebted to Dr. Jerry Donohue for constant advice and criticism, especially on inter-atomic distances. We have also been stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M. H. F. Wilkins, Dr. R. E. Franklin and their co-workers at


(A) building block of DNA
phosphate
sugar
sugar phosphate
base
nucleotide
(B) DNA strand
(C) templated polymerization of new strand
nucleotide monomers
(D) double-stranded DNA
sugar-phosphate backbone
hydrogen-bonded base pairs
(E) DNA double helix

2. All Cells Replicate Their Hereditary Information by Templated Polymerization


template strand
new strand
parent DNA double helix
new strand
template strand

3. All Cells Transcribe Portions of Their Hereditary Information into the Same Intermediary Form: RNA

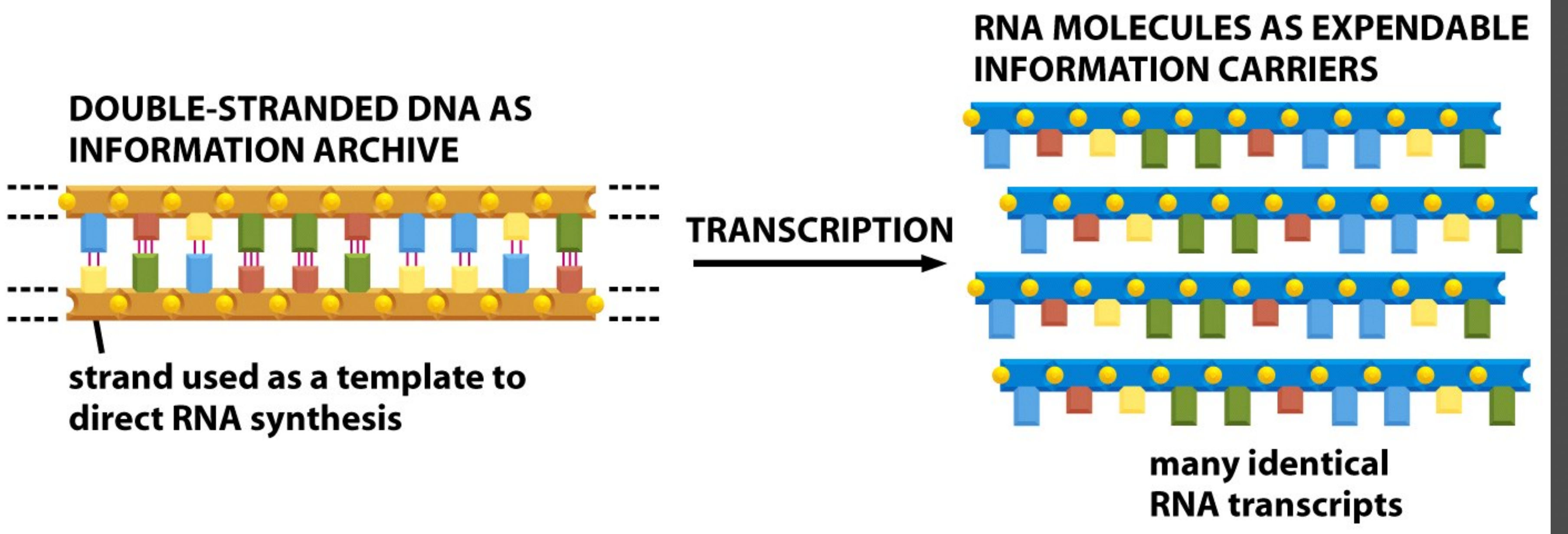


Figure 1-5 Molecular Biology of the Cell 5/e (© Garland Science 2008)

4. All Cells Translate RNA into Protein in the Same Way

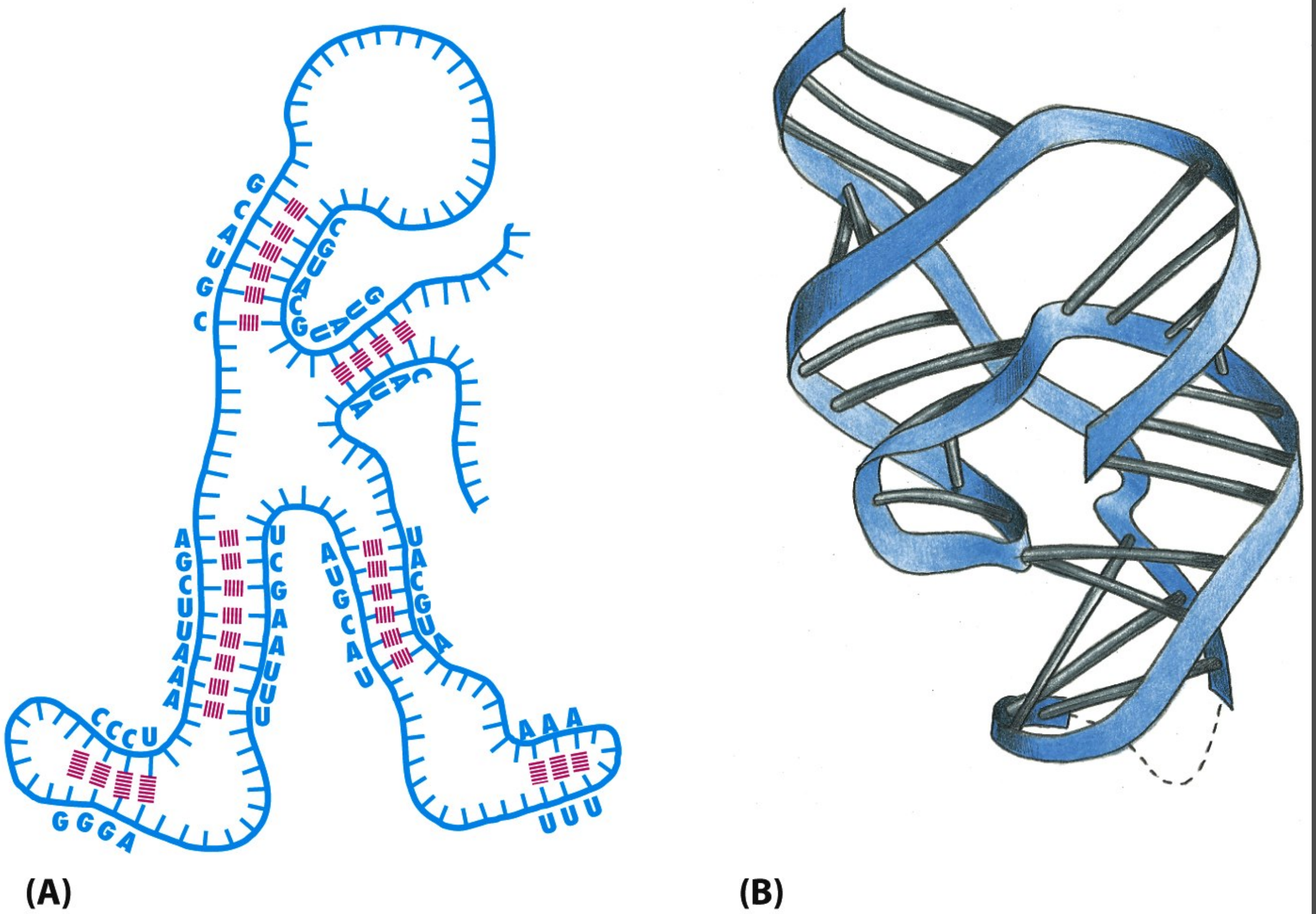


Figure 1-6 Molecular Biology of the Cell 5/e (© Garland Science 2008)

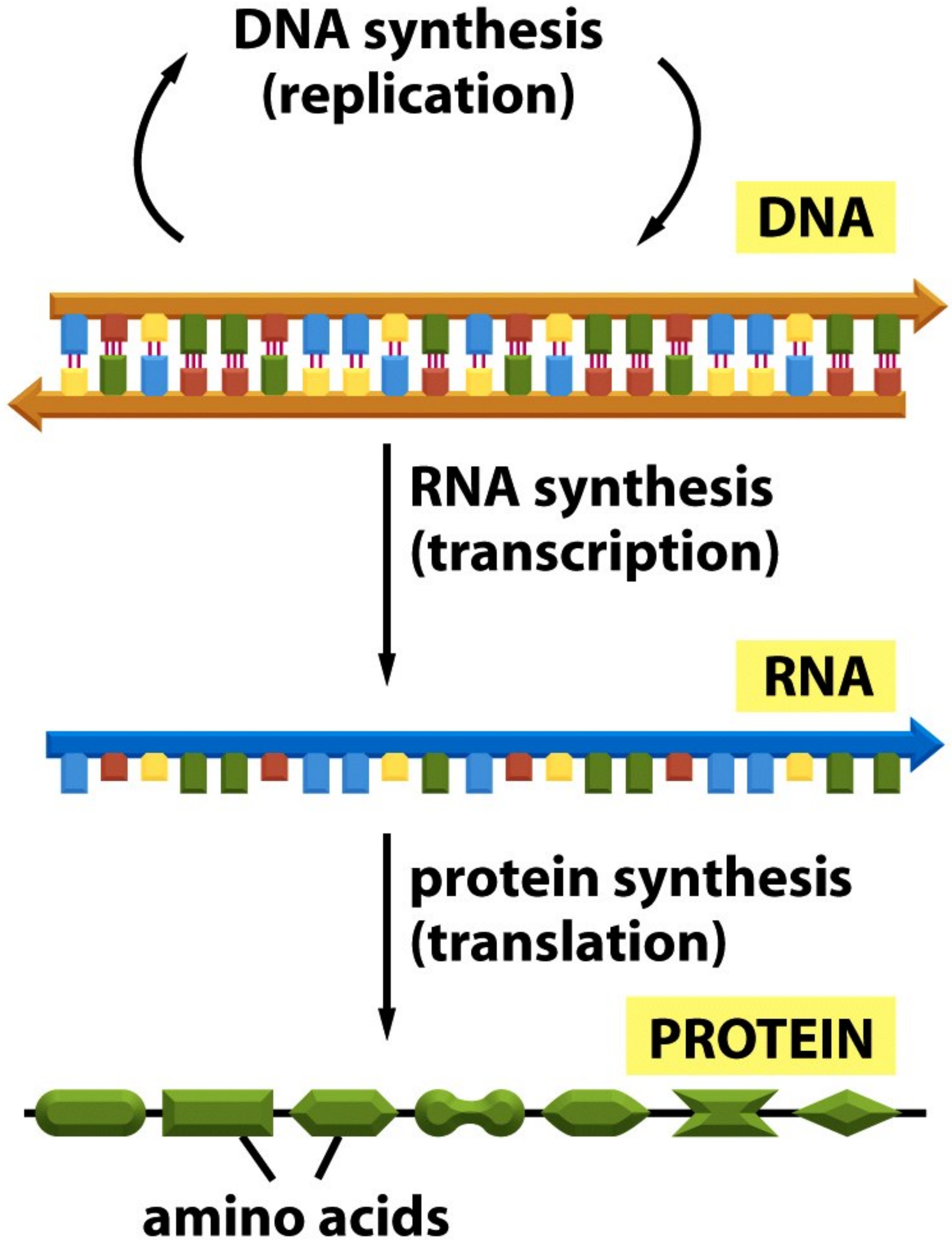
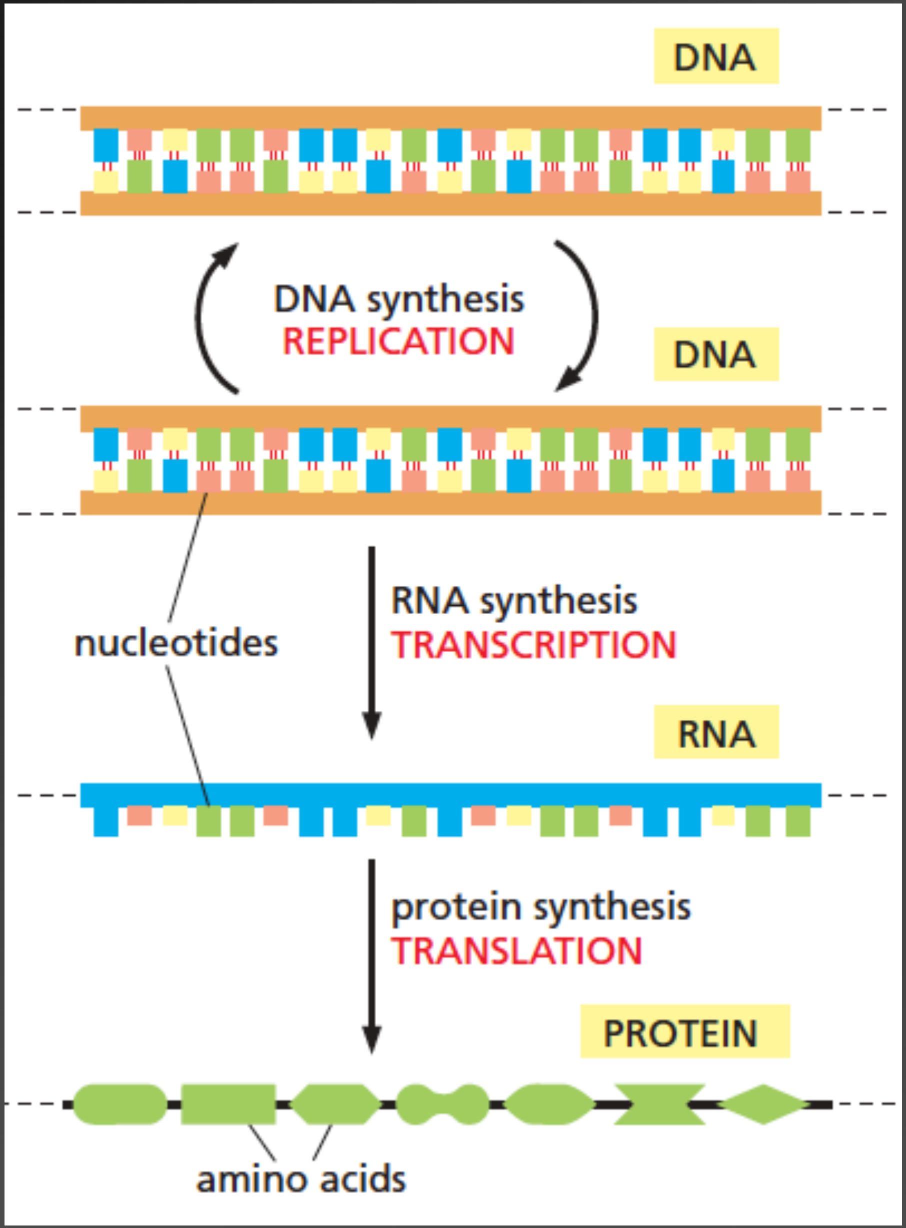


Figure 1-4 Molecular Biology of the Cell 5/e (© Garland Science 2008)


DNA
DNA synthesis
REPLICATION
DNA
nucleotides
RNA synthesis
TRANSCRIPTION
RNA
protein synthesis
TRANSLATION
PROTEIN
amino acids

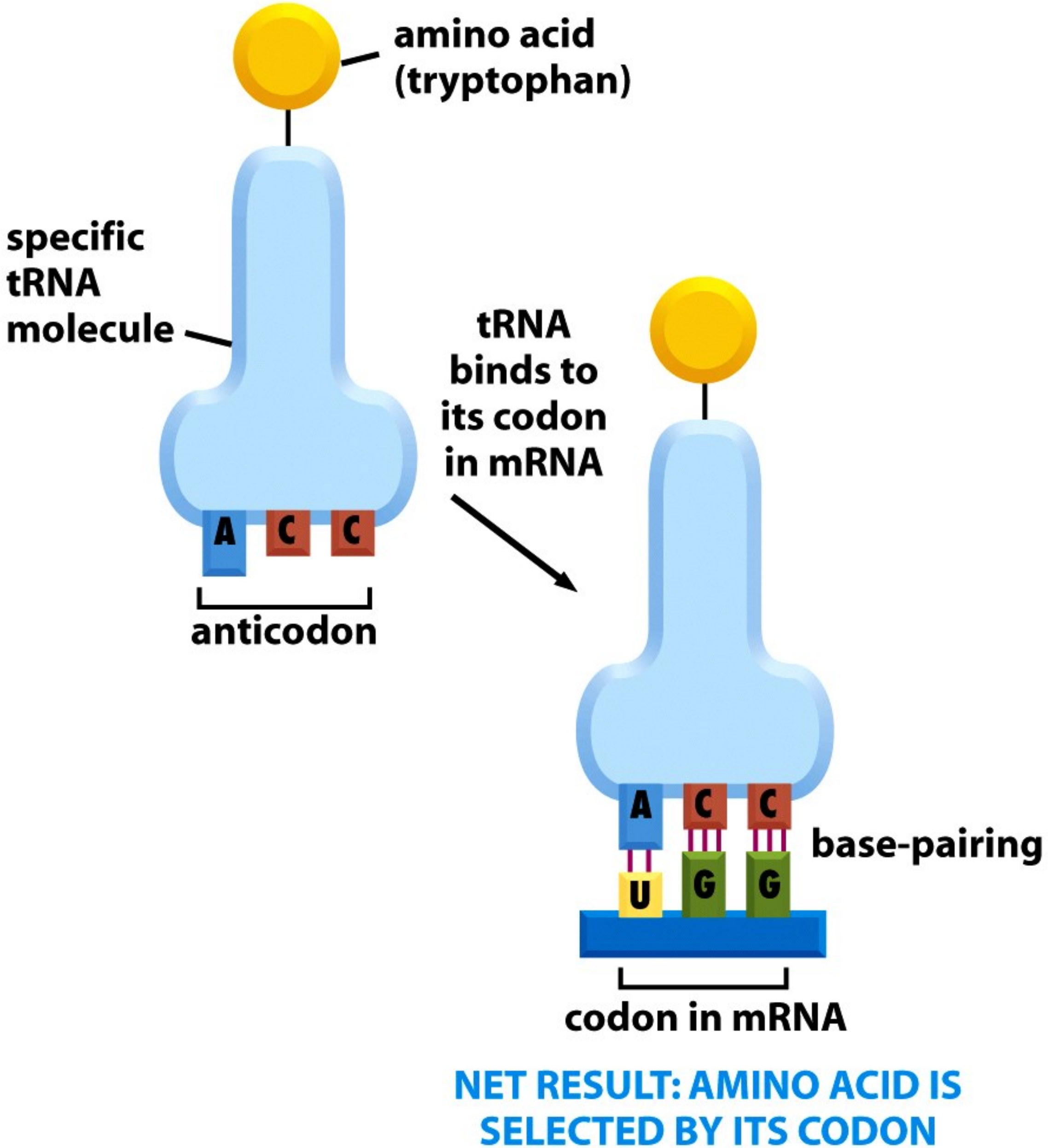


Figure 1-9a Molecular Biology of the Cell 5/e (© Garland Science 2008)

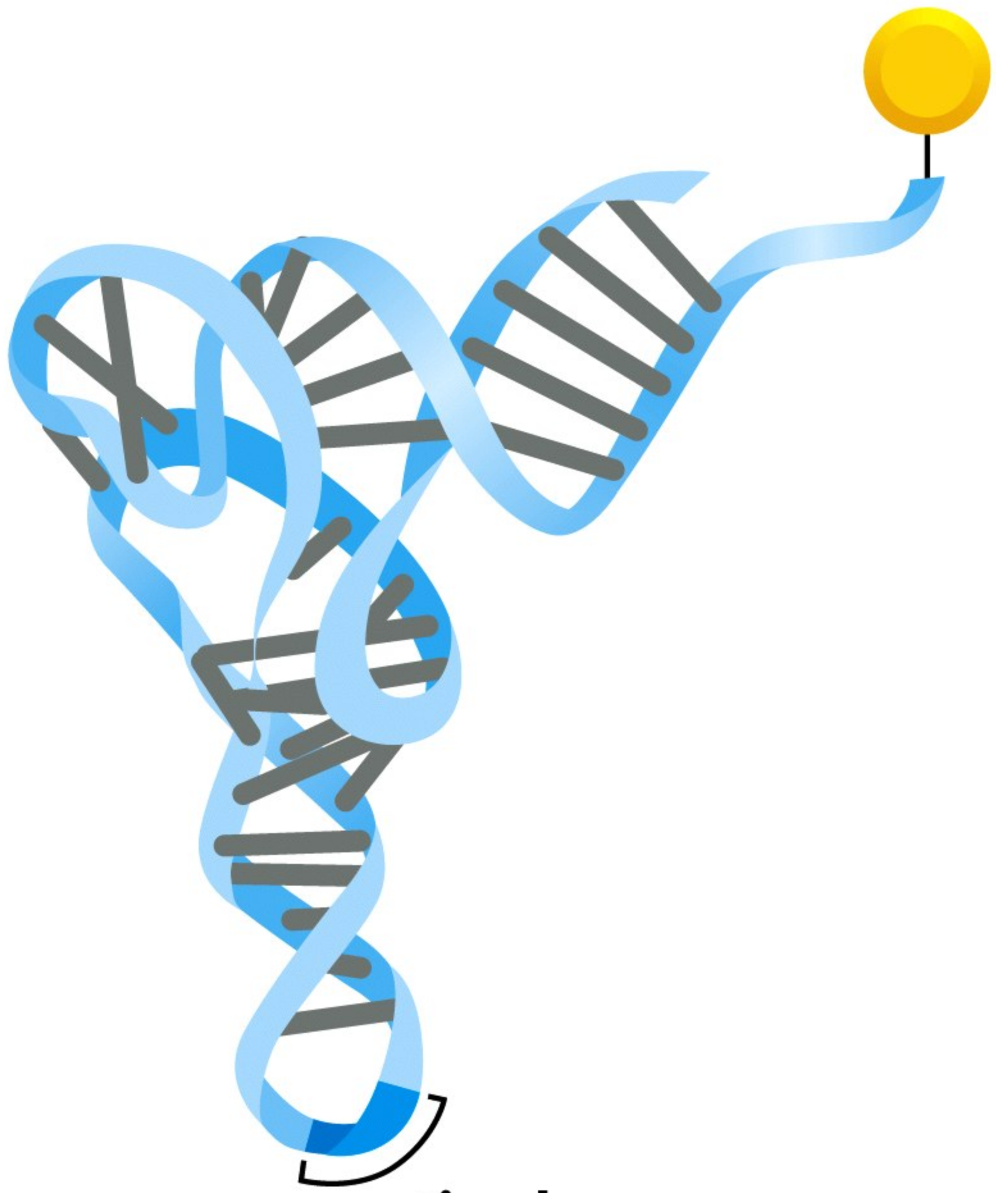


Figure 1-9b Molecular Biology of the Cell 5/e (© Garland Science 2008)

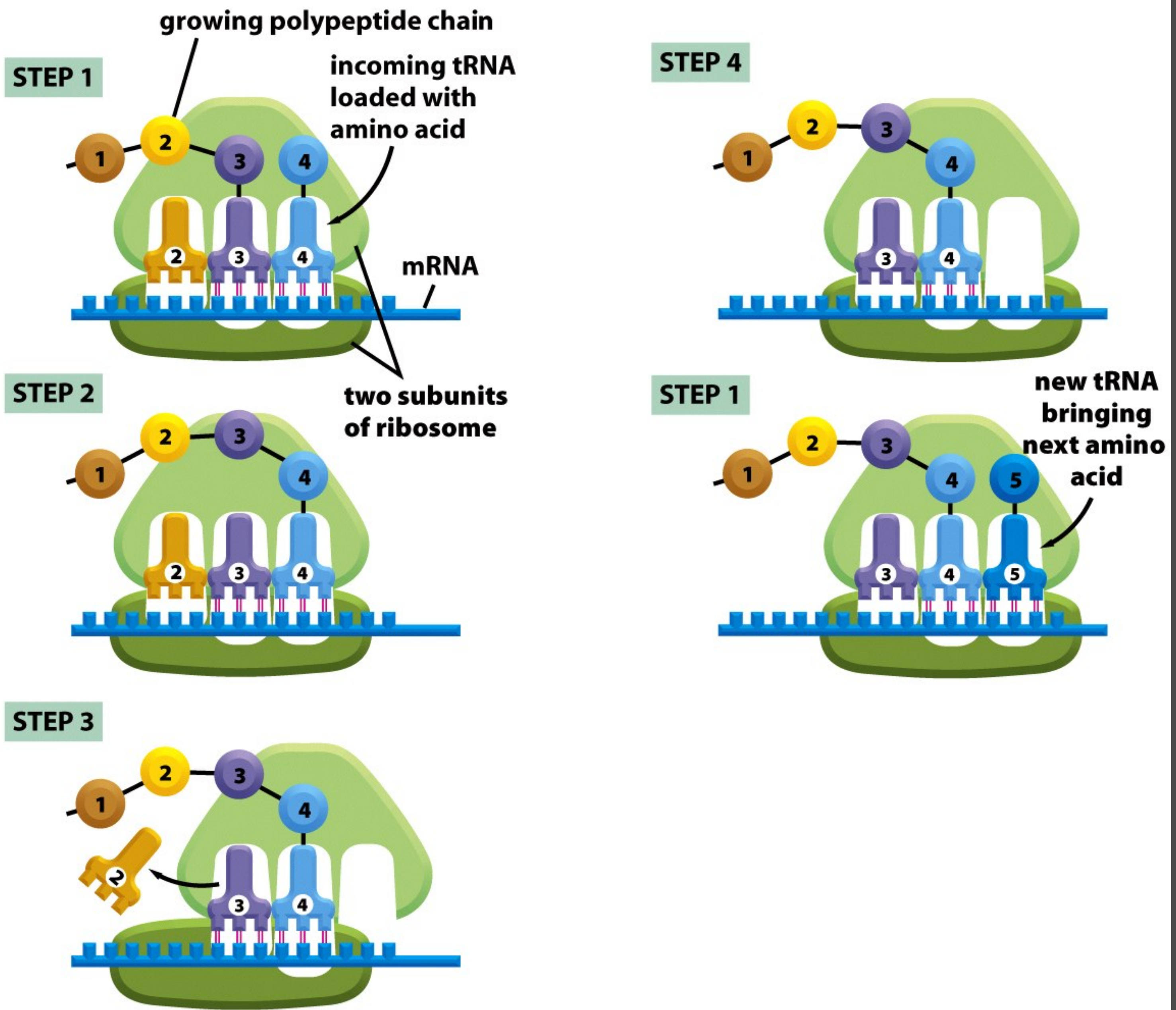


Figure 1-10a Molecular Biology of the Cell 5/e (© Garland Science 2008)

5. All Cells Use Proteins as Catalysts

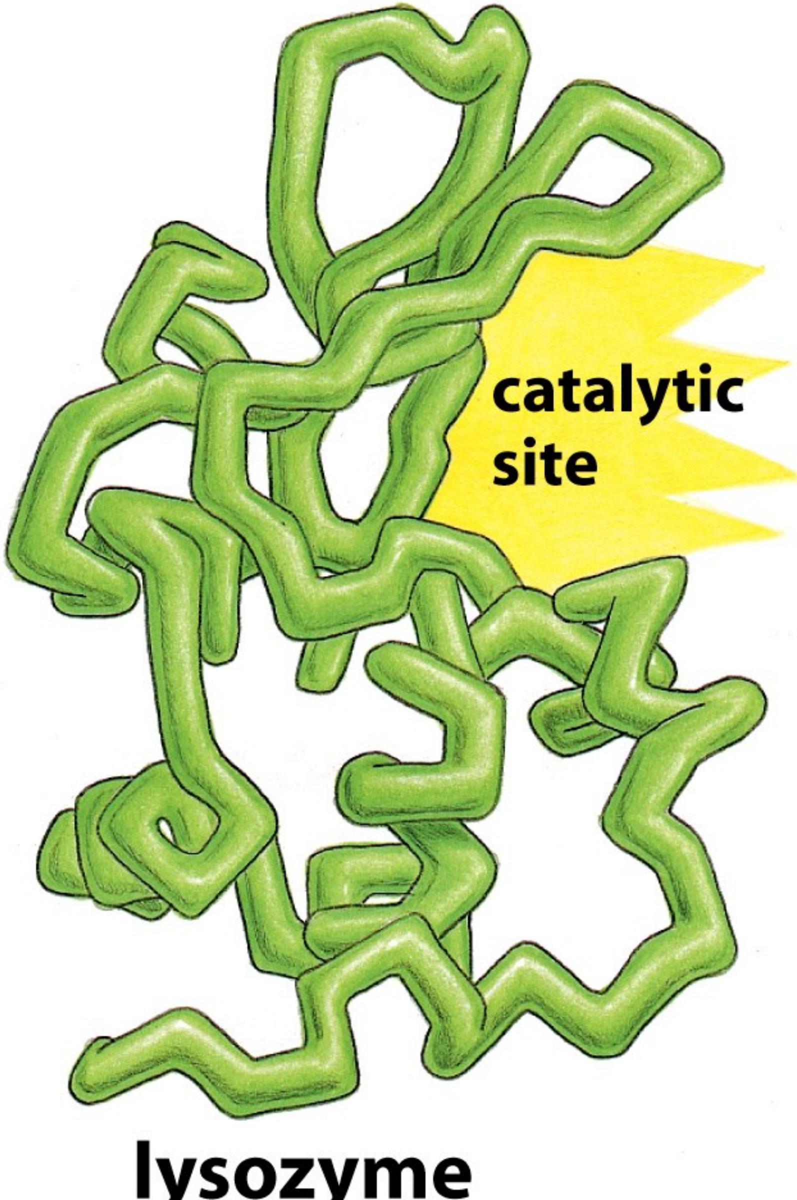


Figure 1-7a Molecular Biology of the Cell 5/e (© Garland Science 2008)

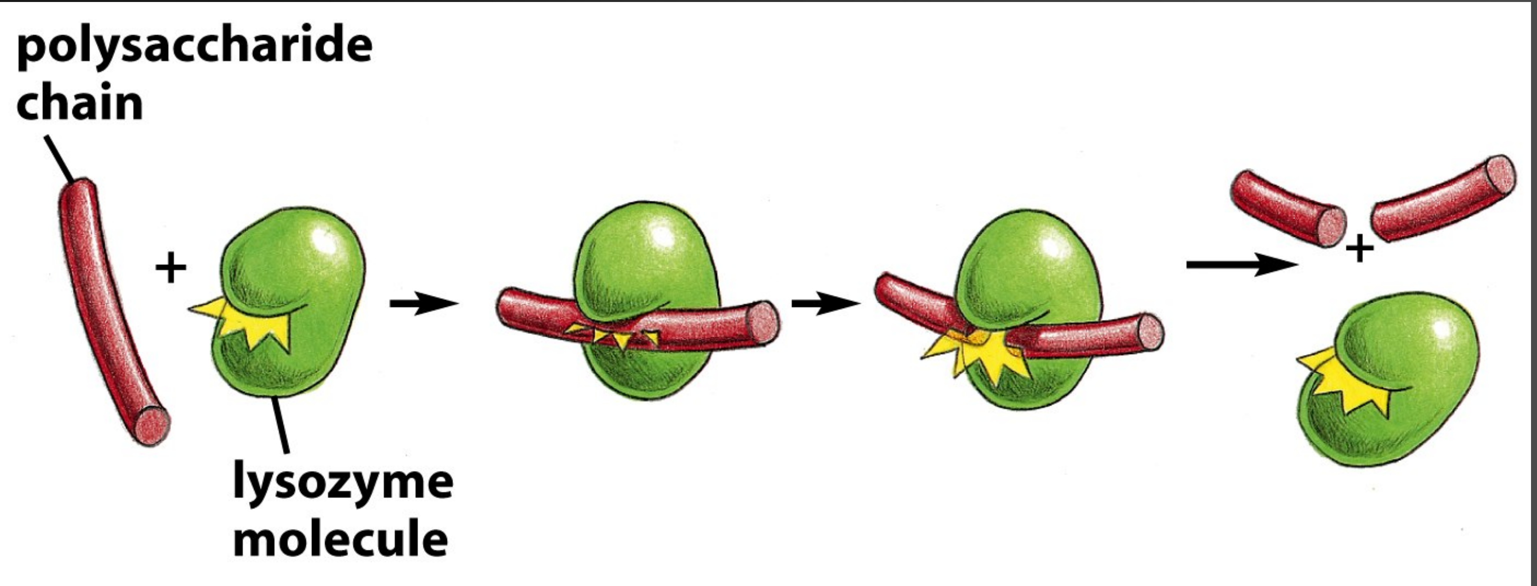


Figure 1-7b Molecular Biology of the Cell 5/e (© Garland Science 2008)

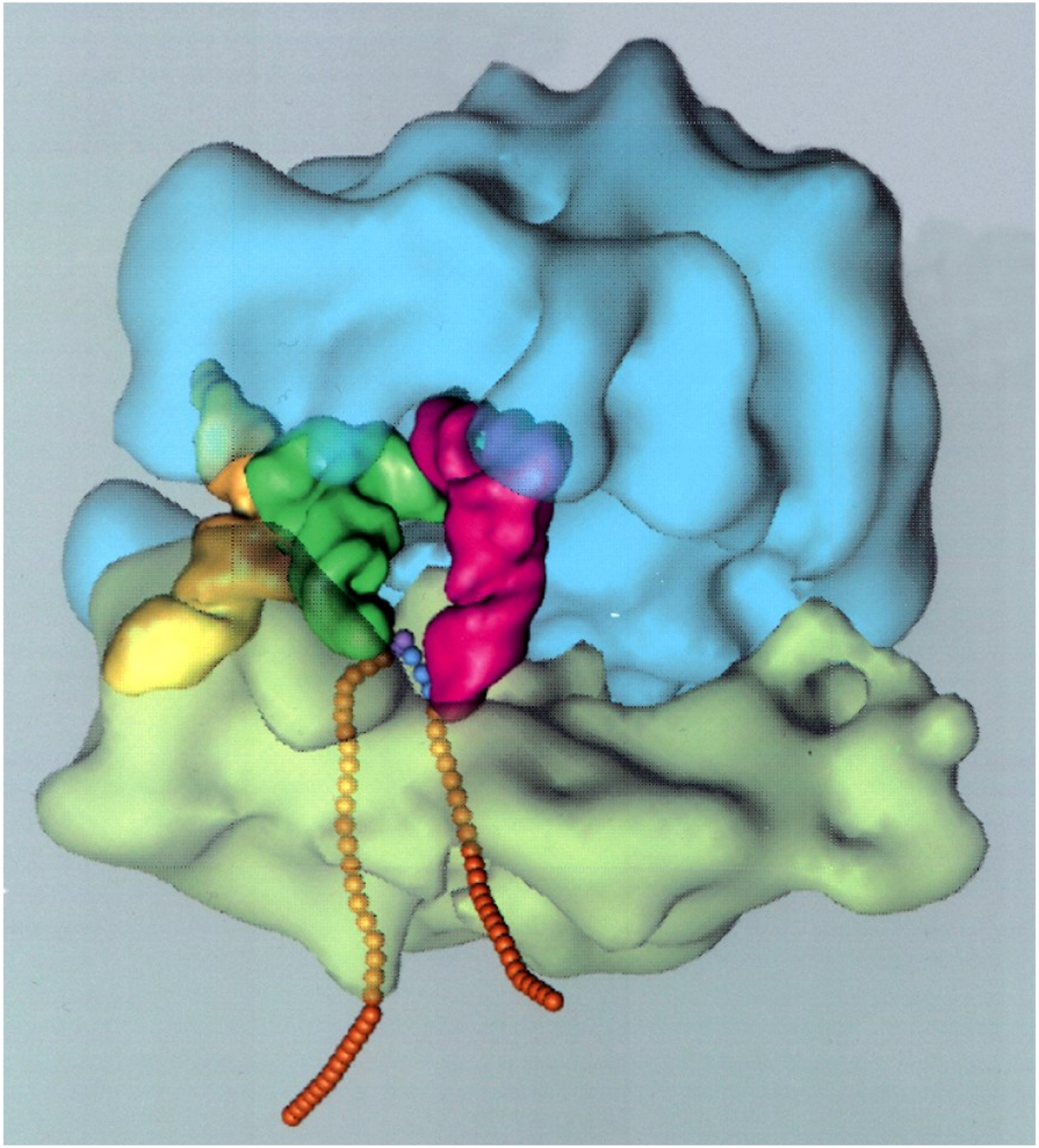
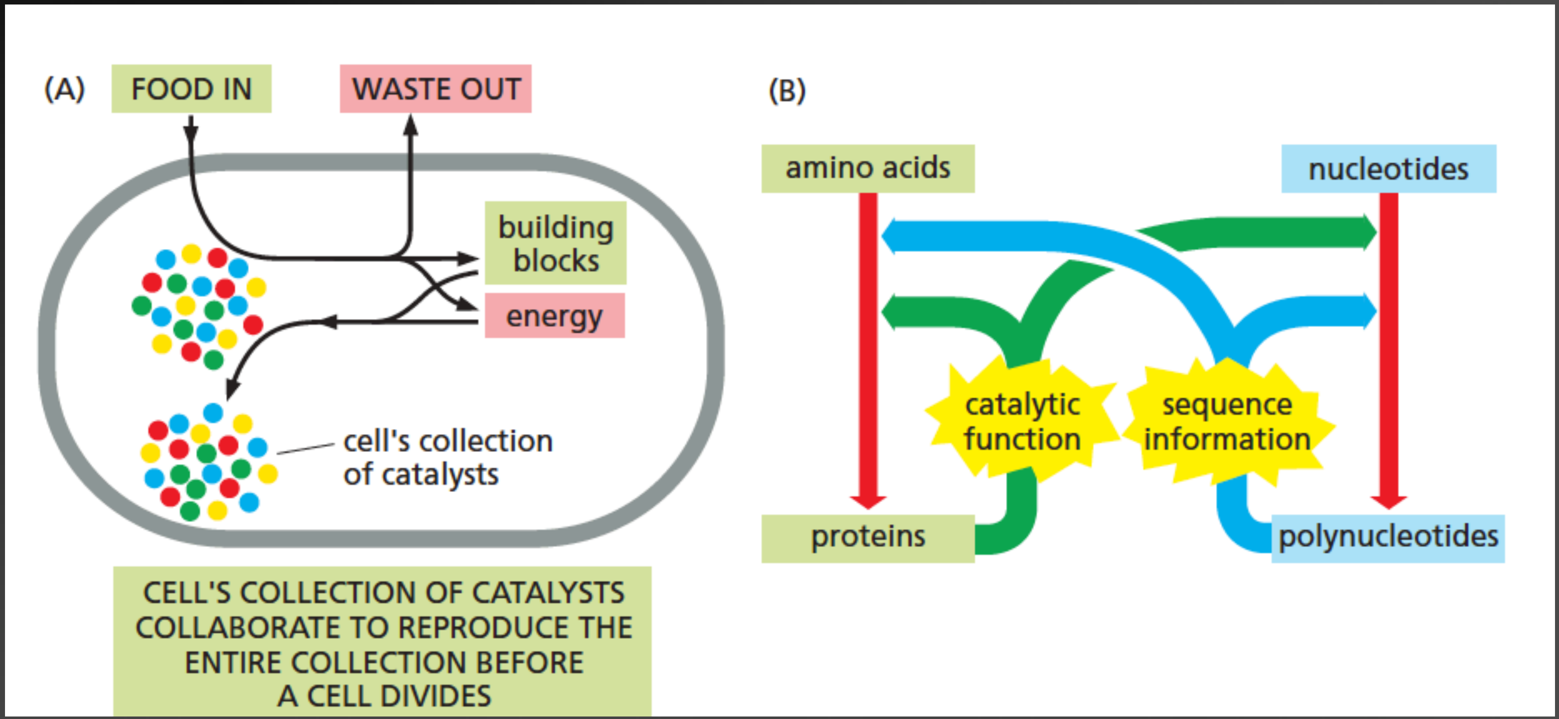


Figure 1-10b Molecular Biology of the Cell 5/e (© Garland Science 2008)

6. Life Requires Free Energy

7. All Cells Function as Biochemical Factories Dealing with the Same Basic Molecular Building Blocks


(A)
FOOD IN
WASTE OUT
building blocks
energy
cell's collection of catalysts
CELL'S COLLECTION OF CATALYSTS COLLABORATE TO REPRODUCE THE ENTIRE COLLECTION BEFORE A CELL DIVIDES
(B)
amino acids
nucleotides
catalytic function
sequence information
proteins
polynucleotides

8. All Cells Are Enclosed in a Plasma Membrane Across Which Nutrients and Waste Materials Must Pass

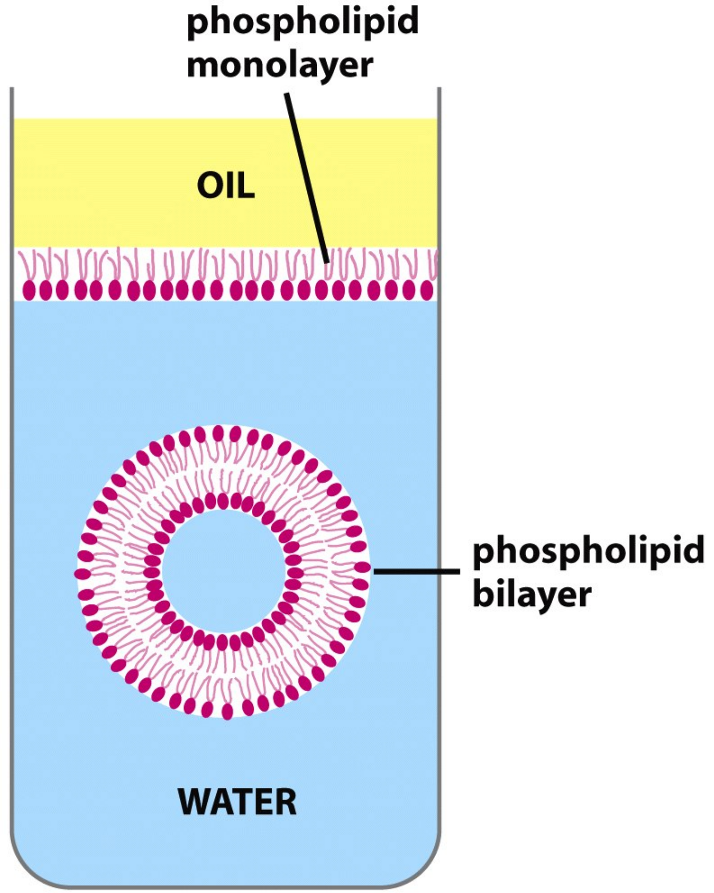


Figure 1-12 Molecular Biology of the Cell 5/e (© Garland Science 2008)

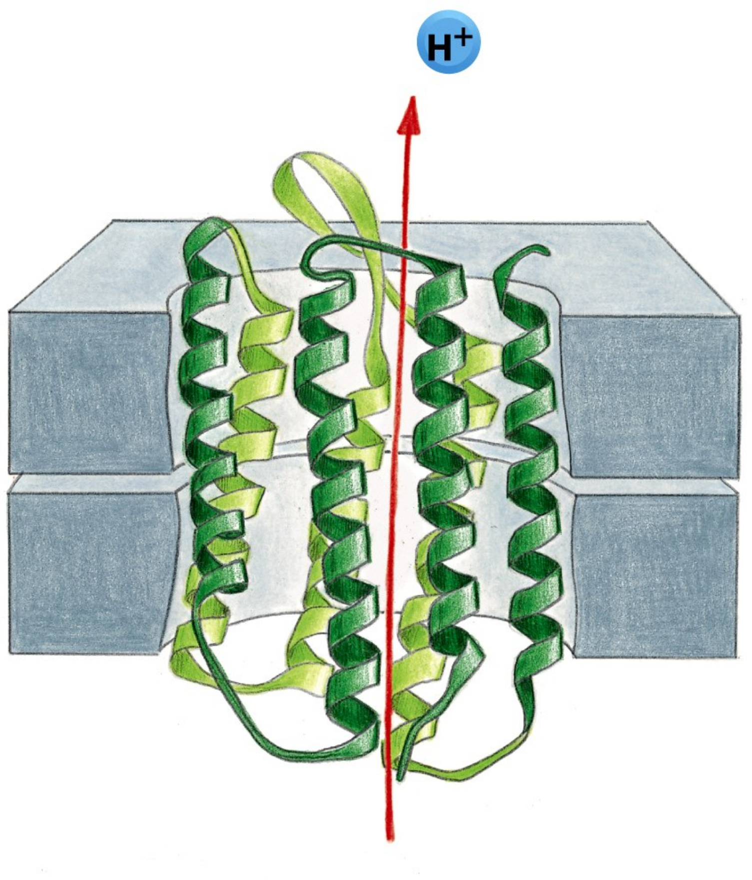


Figure 1-13a Molecular Biology of the Cell 5/e (© Garland Science 2008)

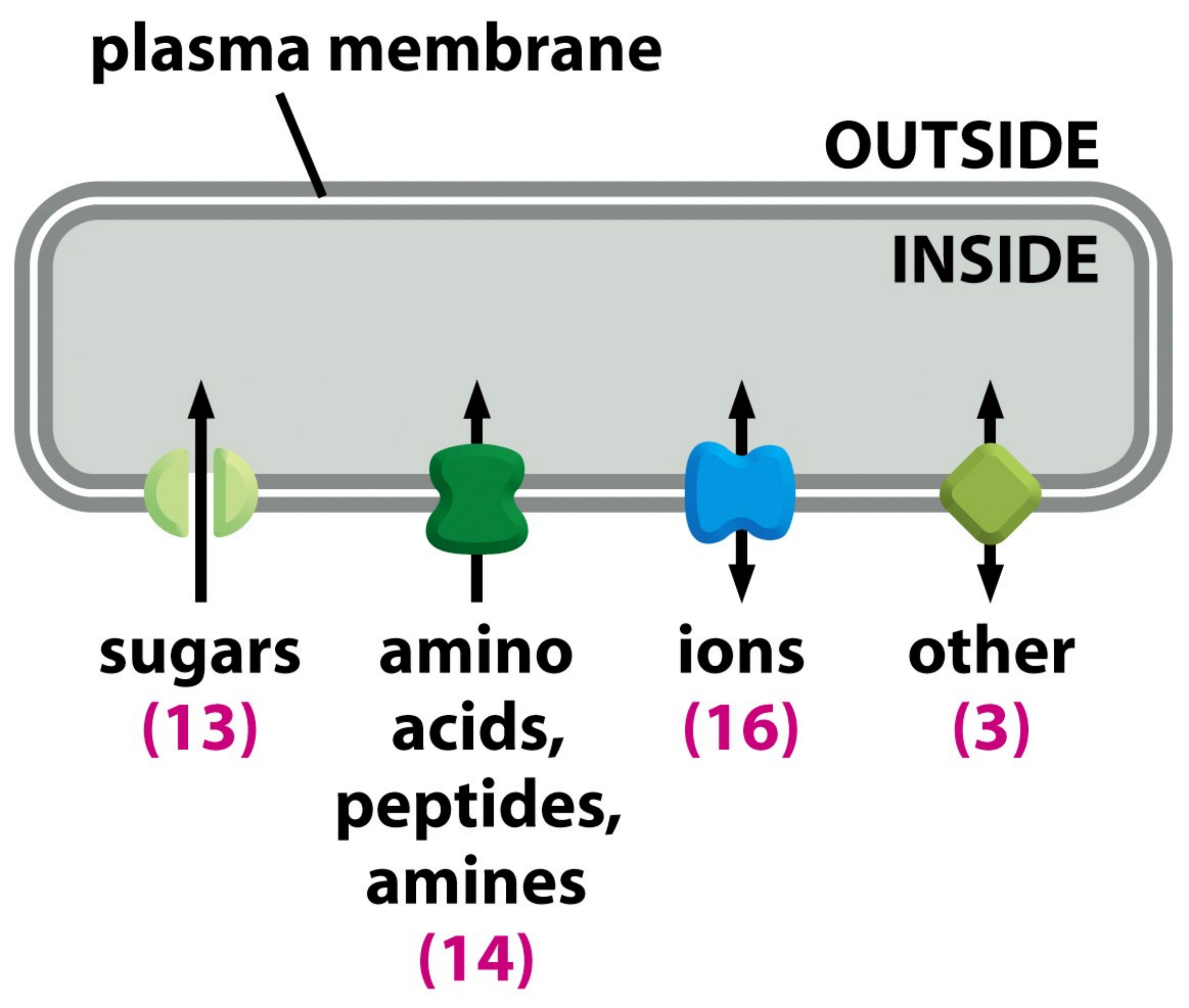
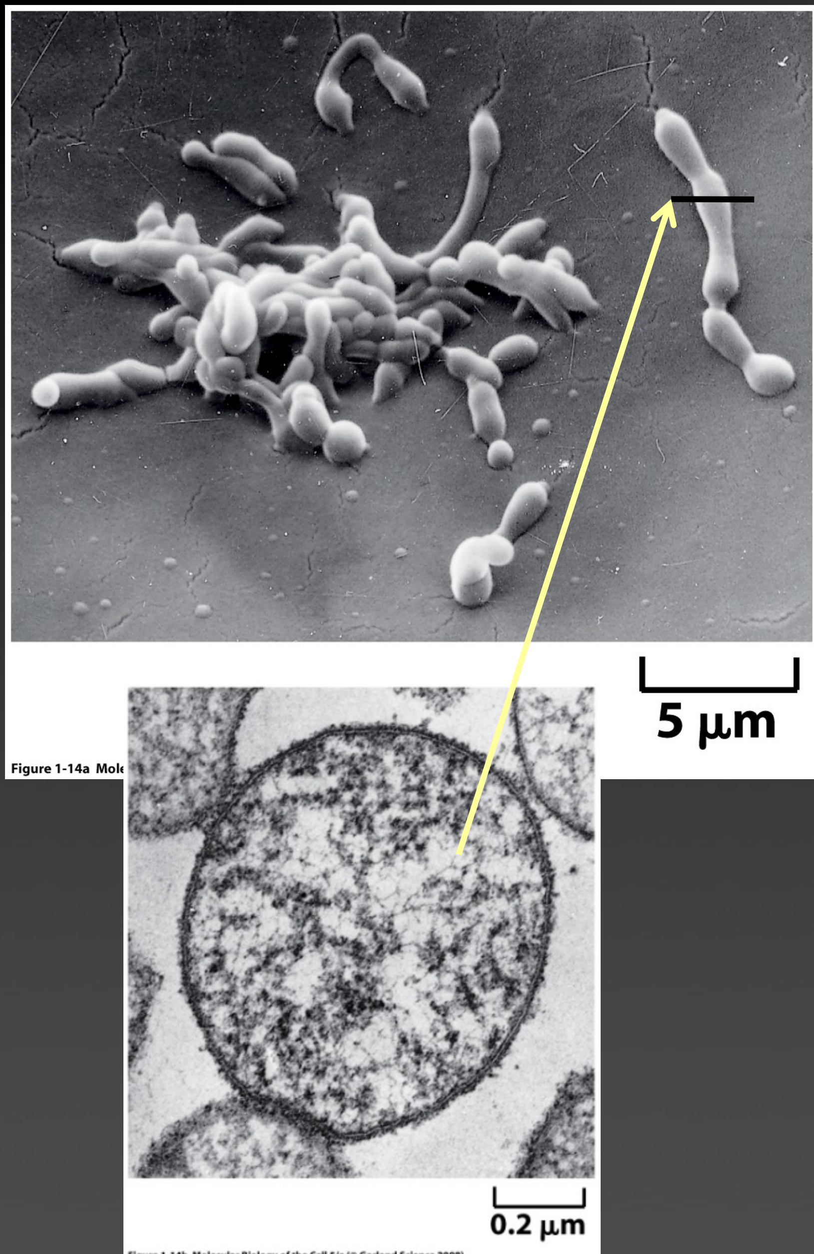


Figure 1-13b Molecular Biology of the Cell 5/e (© Garland Science 2008)

Genetic Information that Encodes Proteins and RNAs are Called Genes

A Living Cell Can Exist with Fewer Than 500 Genes



Mycoplasma genitalium

580.000 bps
530 genes

<u>Specialty genes</u>

RNA	37
DNA/RNA/Protein synthesis	153
Cell membrane proteins	29
Transport	33
Energy transformation and metabolism	71