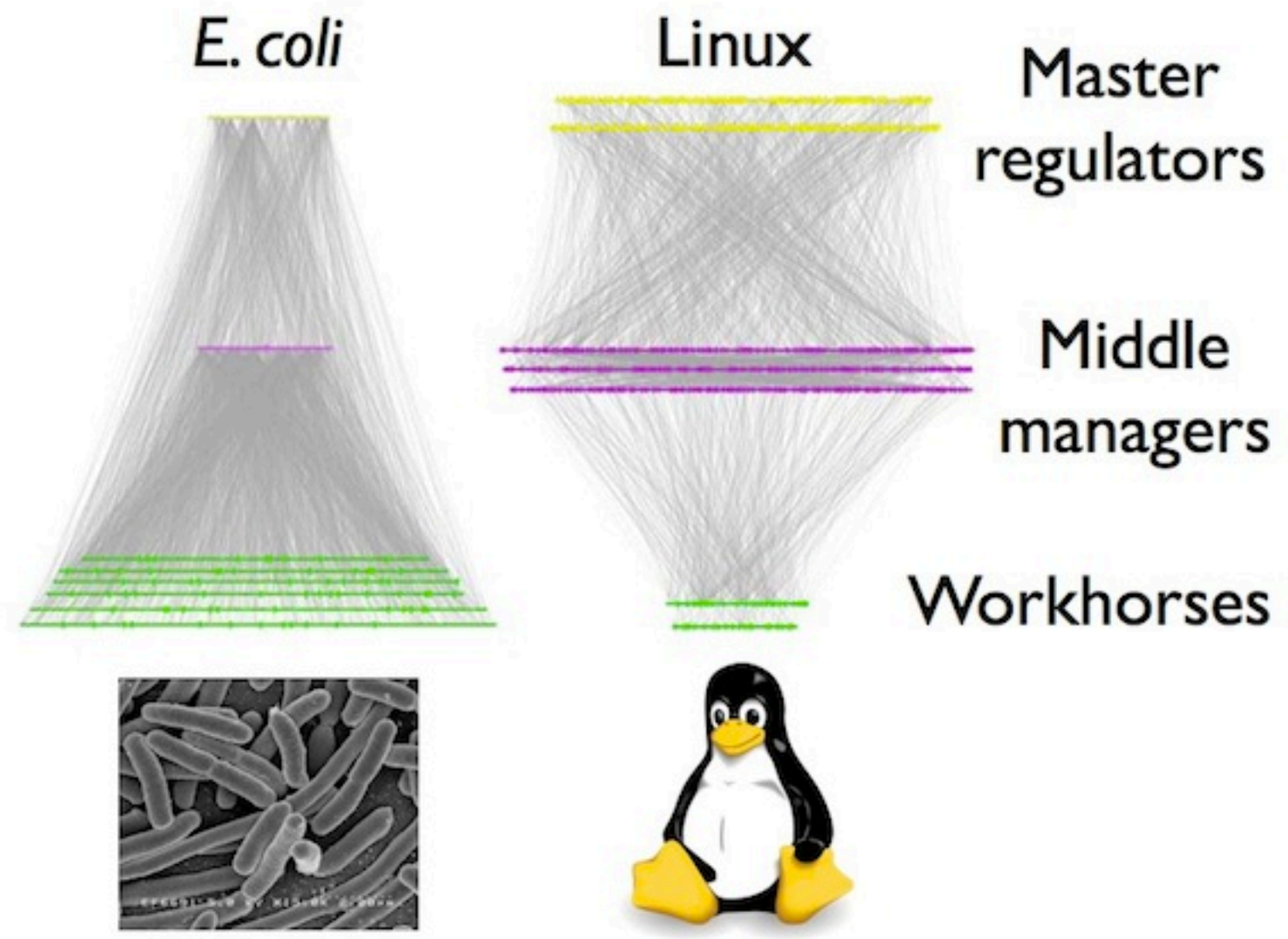
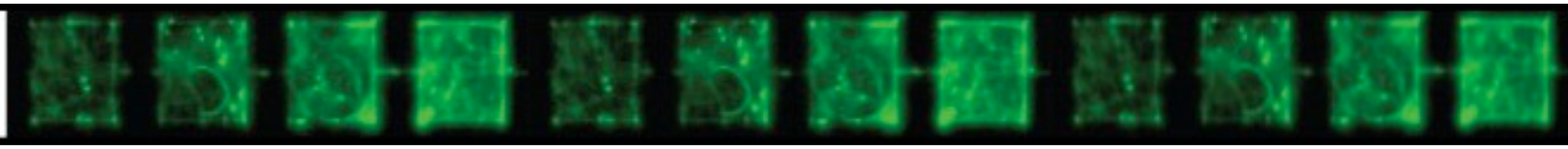
linux-versus-e-coli



Made by one (itself)

Made by many (humans)



AP-3511-TU Biophysics (2011-2012)

Credits: 6 (ECTS)
Examination:
Written examination (70%)
3 homework assignments (30%)

- Juan E. Keymer (Assistant Professor @ Kavli Institute of Nanoscience:BioNano)
- Felix Hol (Graduate Student @ Kavli Institute of Nanoscience:BioNano)
- Fabai Wu (Graduate Student @ Kavli Institute of Nanoscience:BioNano)

Physical Biology of the Cell

Rob Phillips, Jane Kondev, Julie Theriot

November 2008

Paperback: 978-0-8153-4163-5

Schedule: @TN - Classroom F104

Jaarindeling TU Delft, studiejaar 2011/2012

1E SEMESTER

weeknr.	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5
weektype	C	C	C	C	C	C	C	CW	CWT	T	C	C	C	C	C	C	V	V	C	CW	CWT	T
onderwijsweek	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	2.1	2.2	2.3	2.4	2.5	2.6	Kerst week1	Kerst week2	2.7	2.8	2.9	2.10
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dinsdag	6	13	20	27	4	11	18	25	1	8	15	22	29	6	13	20	27	3	10	17	24	31
woensdag	7	14	21	28	5	12	19	26	2	9	16	23	30	7	14	21	28	4	11	18	25	1
donderdag	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	2
vrijdag	9	16	23	30	7	14	21	28	4	11	18	25	2	9	16	23	30	6	13	20	27	3
zaterdag	10/09	17/09	24/09	1/10	8/10	15/10	22/10	29/10	5/11	12/11	19/11	26/11	3/12	10/12	17/12	24/12	31/12	7/01	14/01	21/01	28/01	4/02
zondag	11/09	18/09	25/09	2/10	9/10	16/10	23/10	30/10	6/11	13/11	20/11	27/11	4/12	11/12	18/12	25/12	1/01	8/01	15/01	22/01	29/01	5/02

1 2 3 4 5 6 7 8 9 10 11 12 13

14

Ex-I

I	1,2,3,4.	Facts of life
II	5,6,7,8,9,10,11	Life at rest
III	12,13,14,15,16,17	Life in motion
IV	18,19,20	Meaning of life

Today's Lecture:

Chapter 1
The Facts of Life: (why? biology by the numbers)

Chapter 2
What and Where: Construction Plans for Cells and Organisms

“Organisms are constructed from: <u>4 Macro-molecular classes</u>”

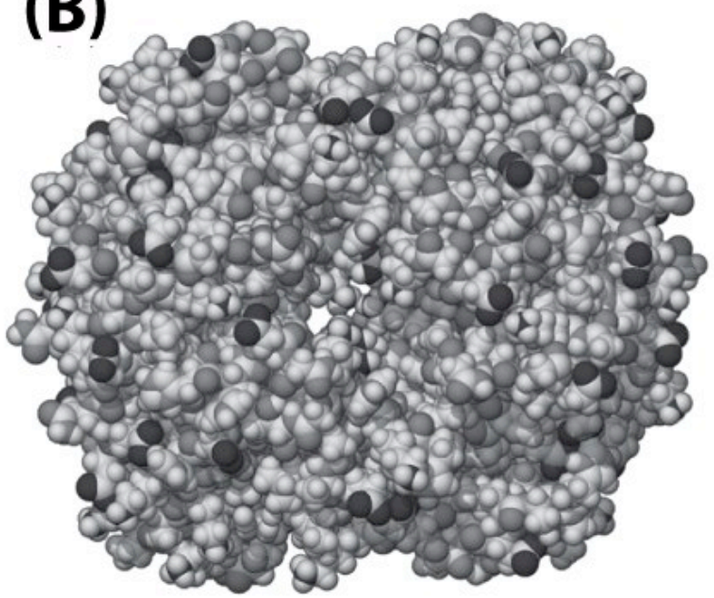
DNA

(A)

2 nm

Hemoglobin

(B)



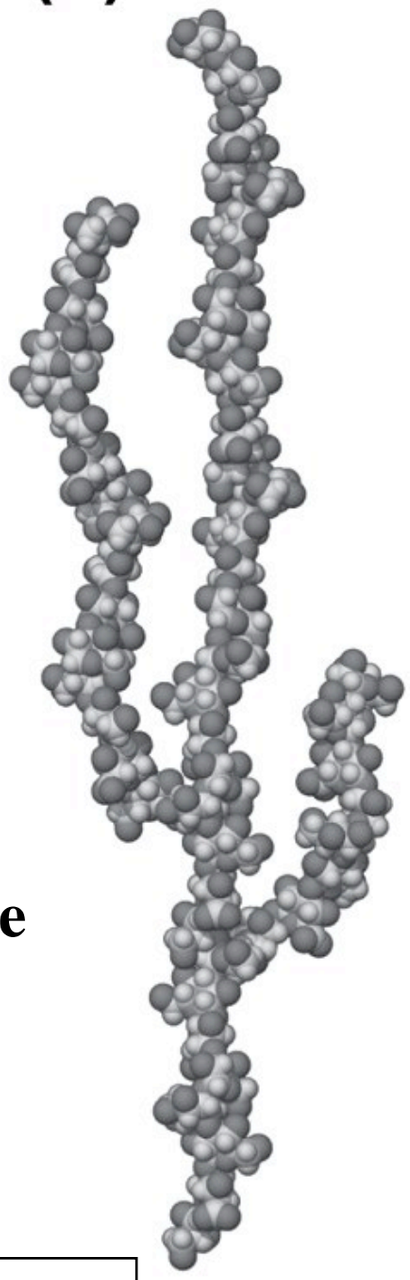
Phosphatidylcholine

(C)

polymer languages,
memory,
operating instructions.

M41 Capsular polysaccharide

(D)



1. Proteins
2. Carbohydrates
3. Lipids
4. Nucleic Acids.

1. Carbon
2. Hydrogen
3. Oxygen
4. Nitrogen
5. Sulfur*
6. Phosphorus*

polymer languages

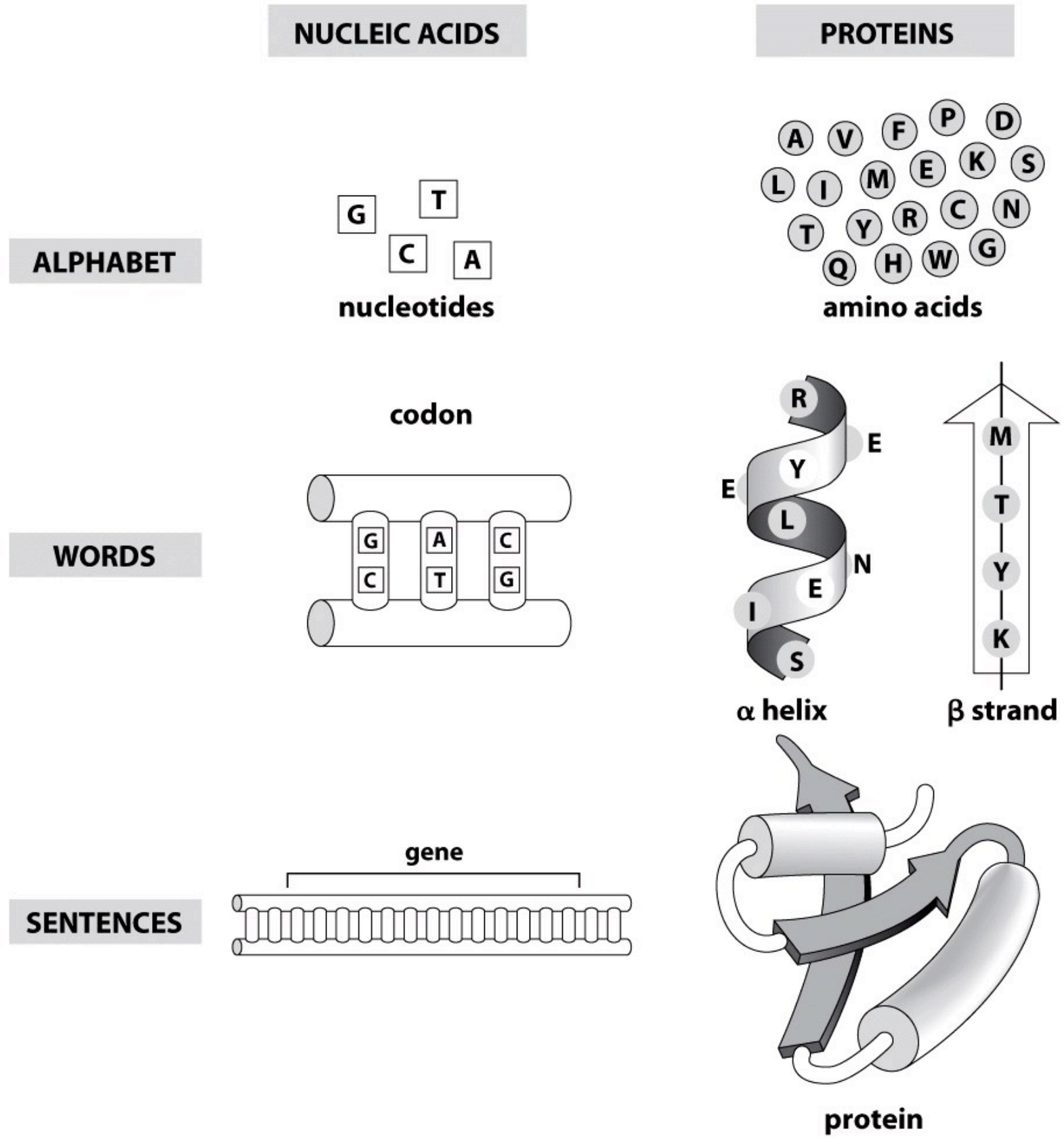


Figure 1.2 Physical Biology of the Cell (© Garland Science 2009)

DNA:

operating instructions?
memory?

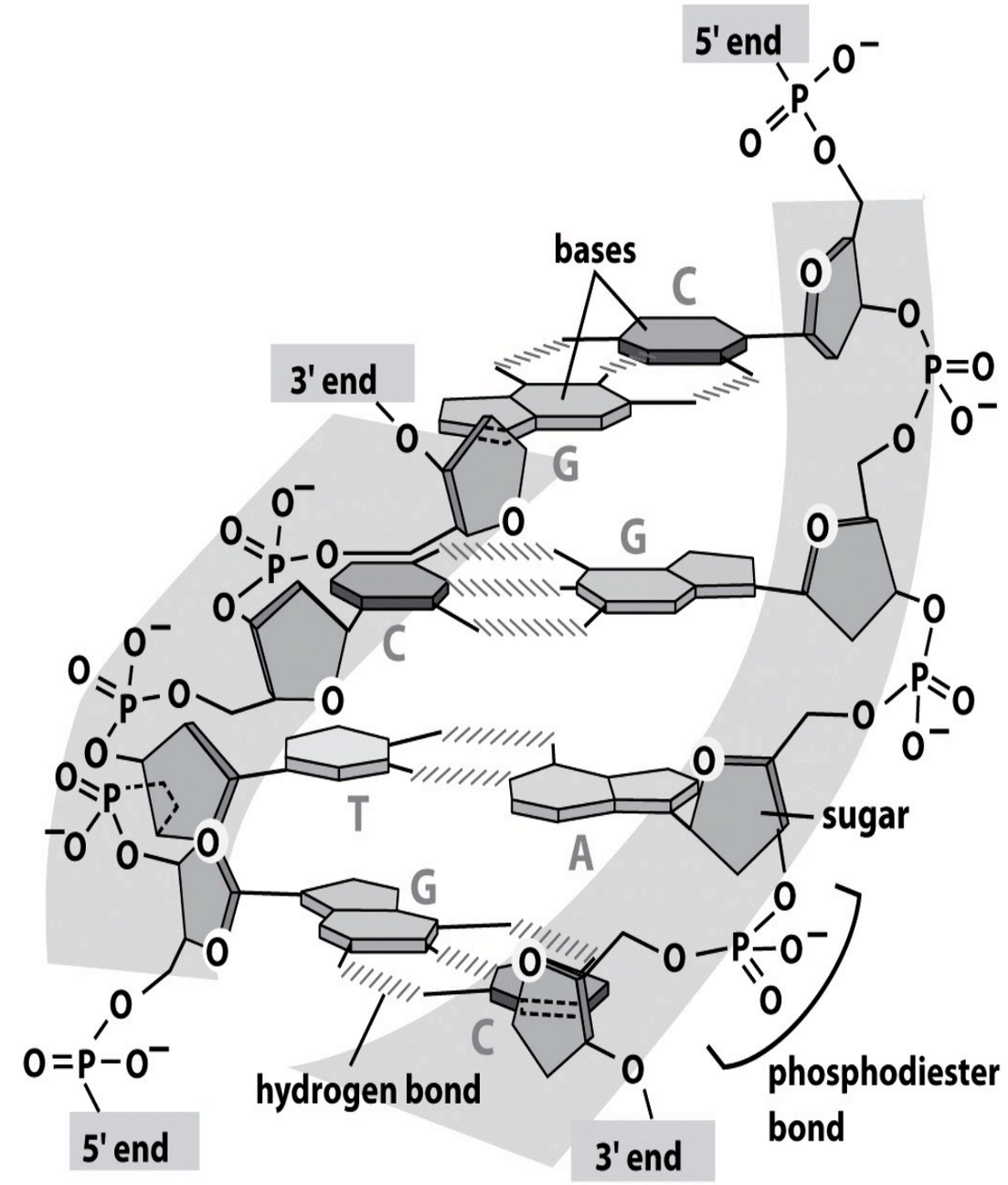
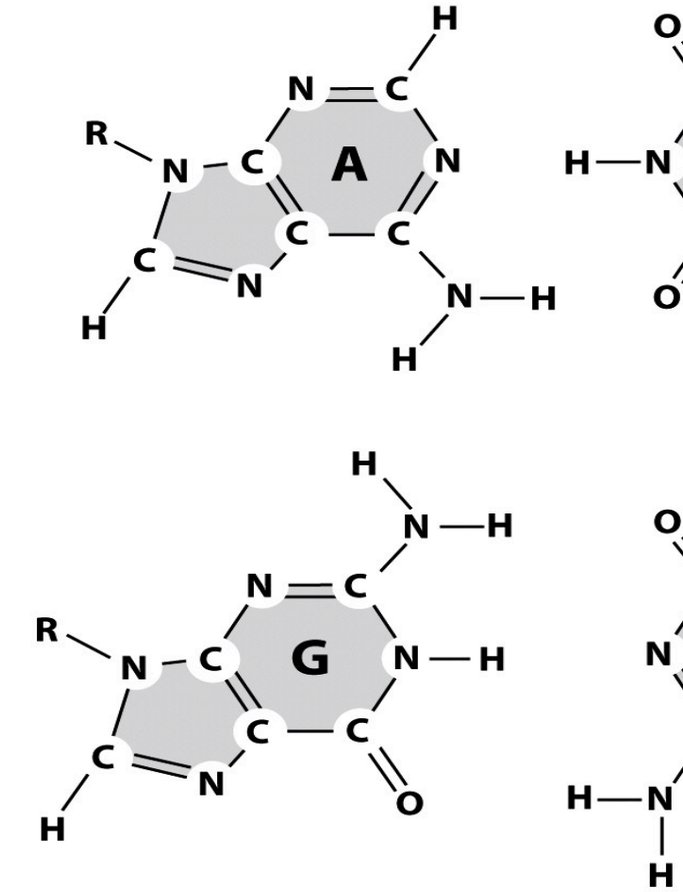


Figure 1.3b Physical Biology of the Cell (© Garland Science 2009)



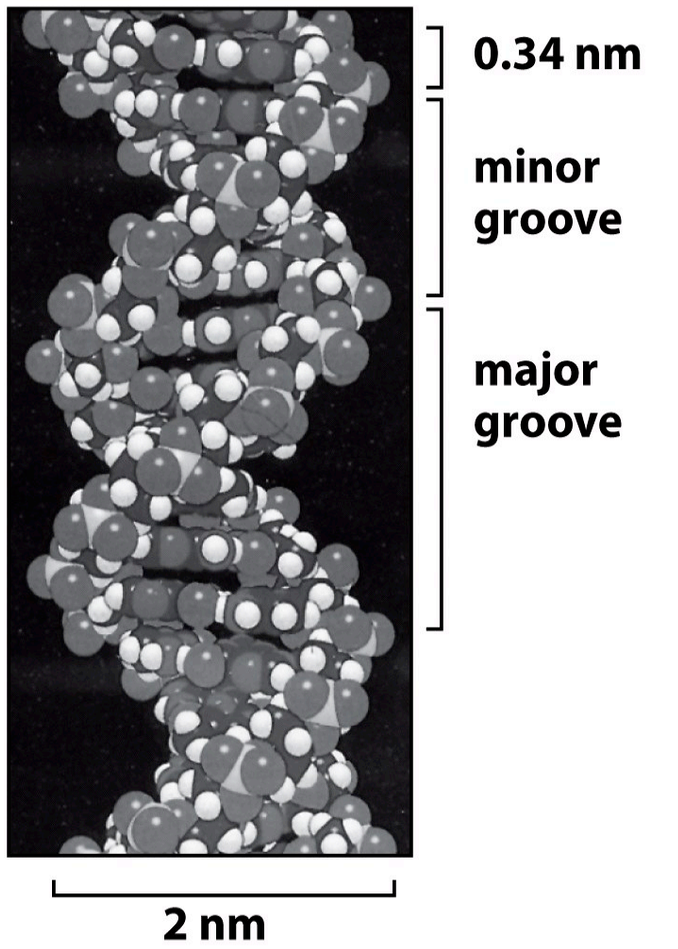


Figure 1.3c Physical Biology of the Cell (© Garland Science 2009)

The genetic code:

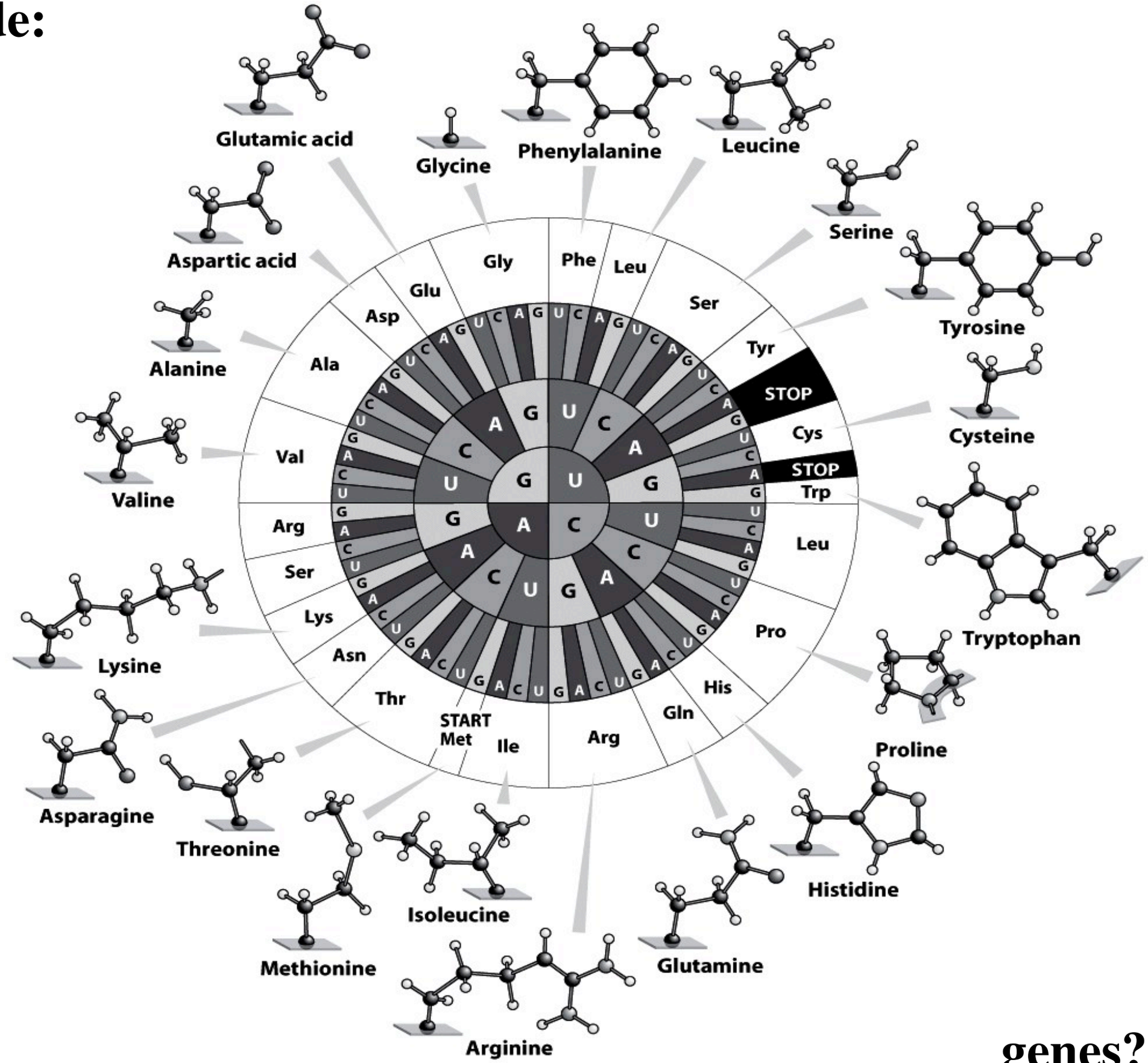


Figure 1.4 Physical Biology of the Cell (© Garland Science 2009)

genes?

Models are Idealizations: Bio-physics mapping

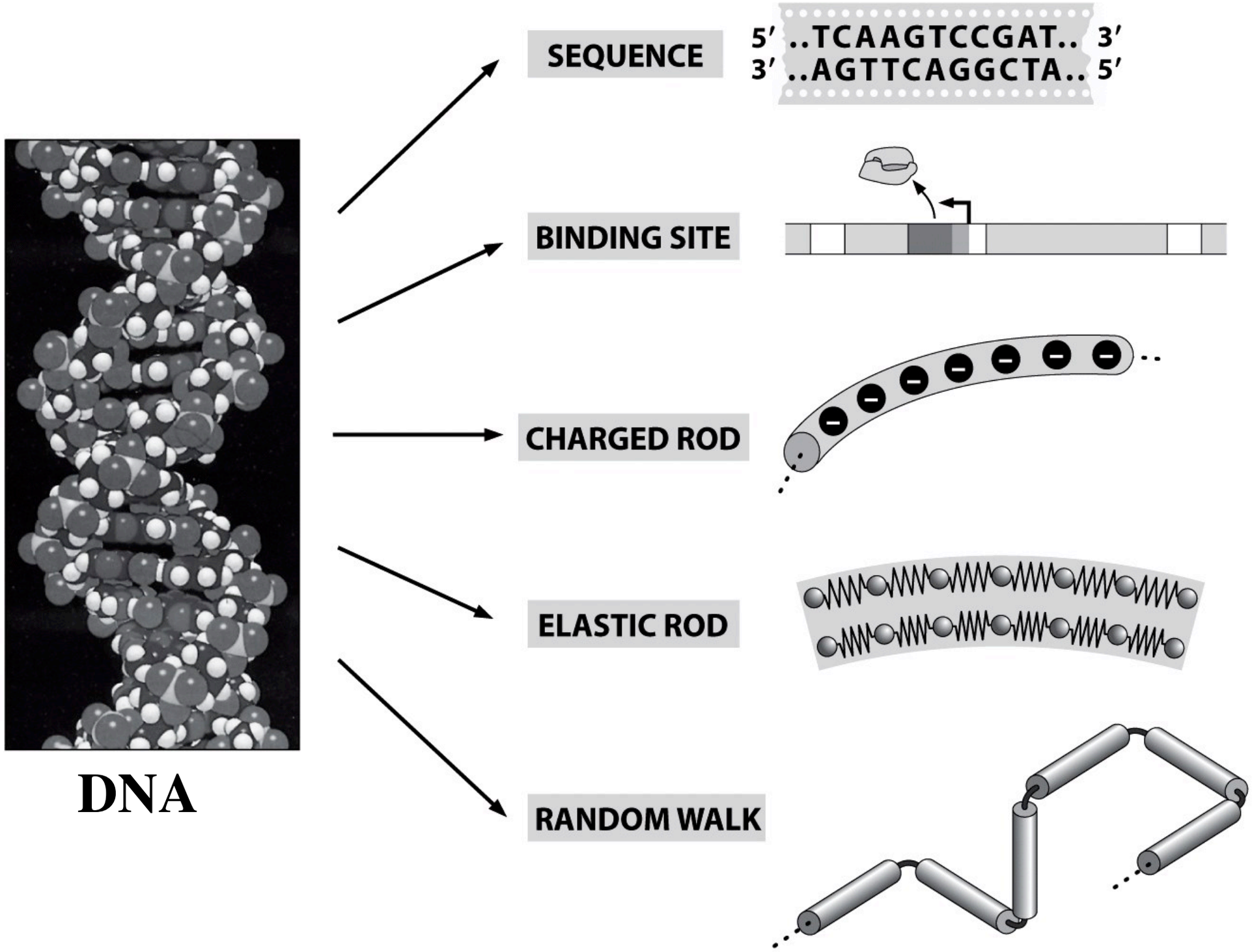


Figure 1.5 Physical Biology of the Cell (© Garland Science 2009)

Models are Idealizations: Bio-physics mapping

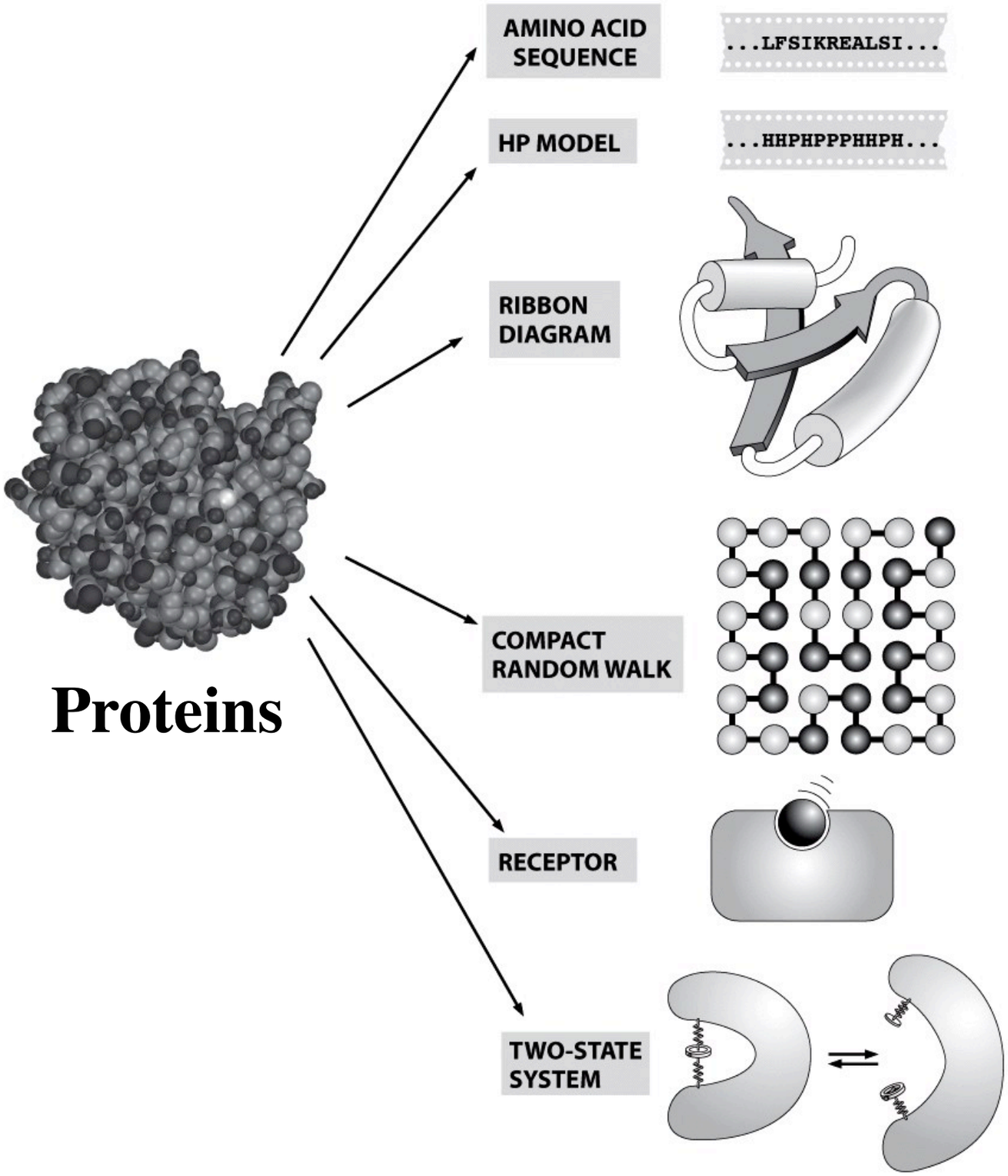


Figure 1.6 Physical Biology of the Cell (© Garland Science 2009)

Models are Idealizations: Bio-physics mapping

Membranes
Lipids

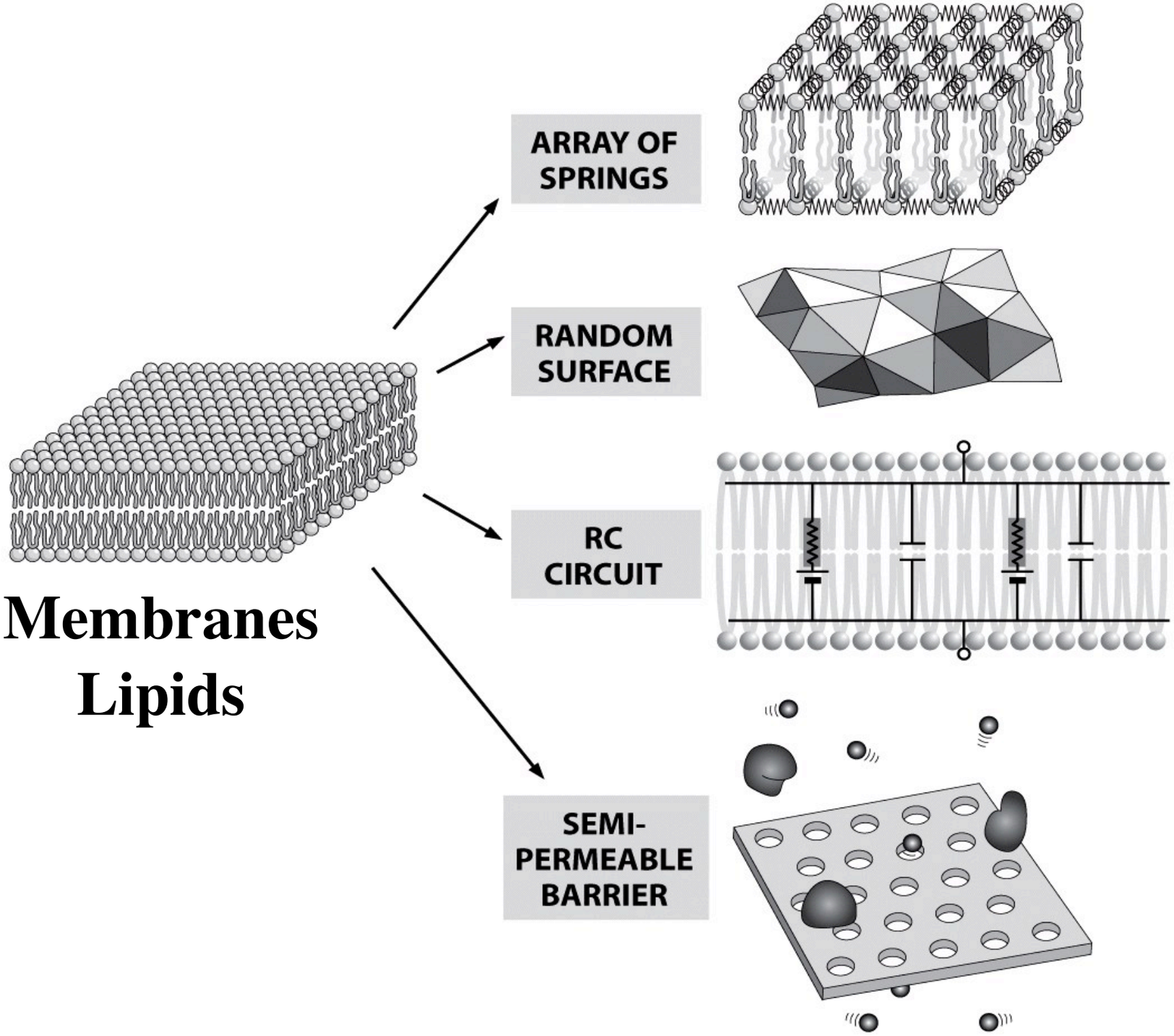


Figure 1.7 Physical Biology of the Cell (© Garland Science 2009)

Models are Idealizations: Bio-physics mapping

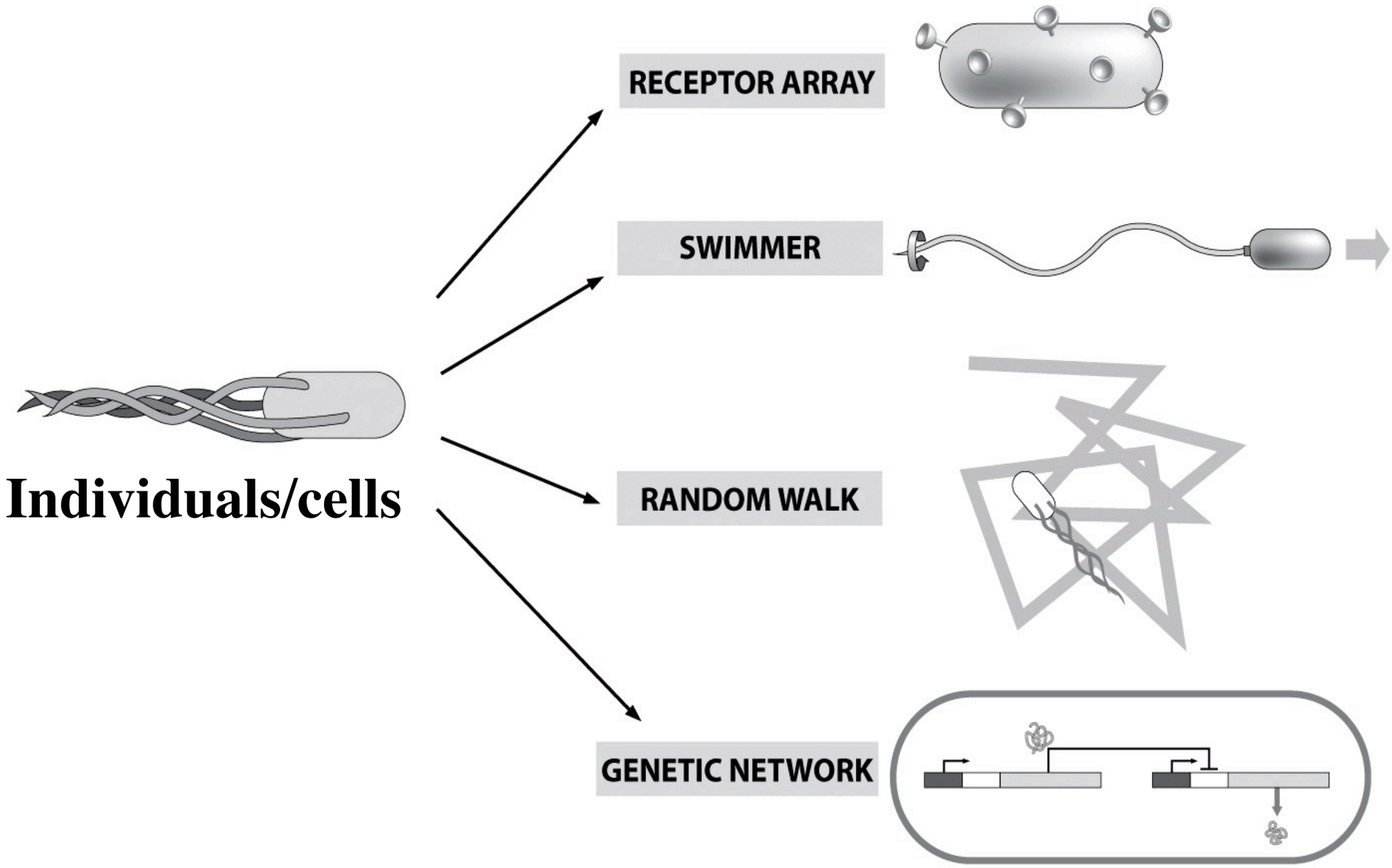


Figure 1.8 Physical Biology of the Cell (© Garland Science 2009)

Models are Idealizations: Bio-physics mapping

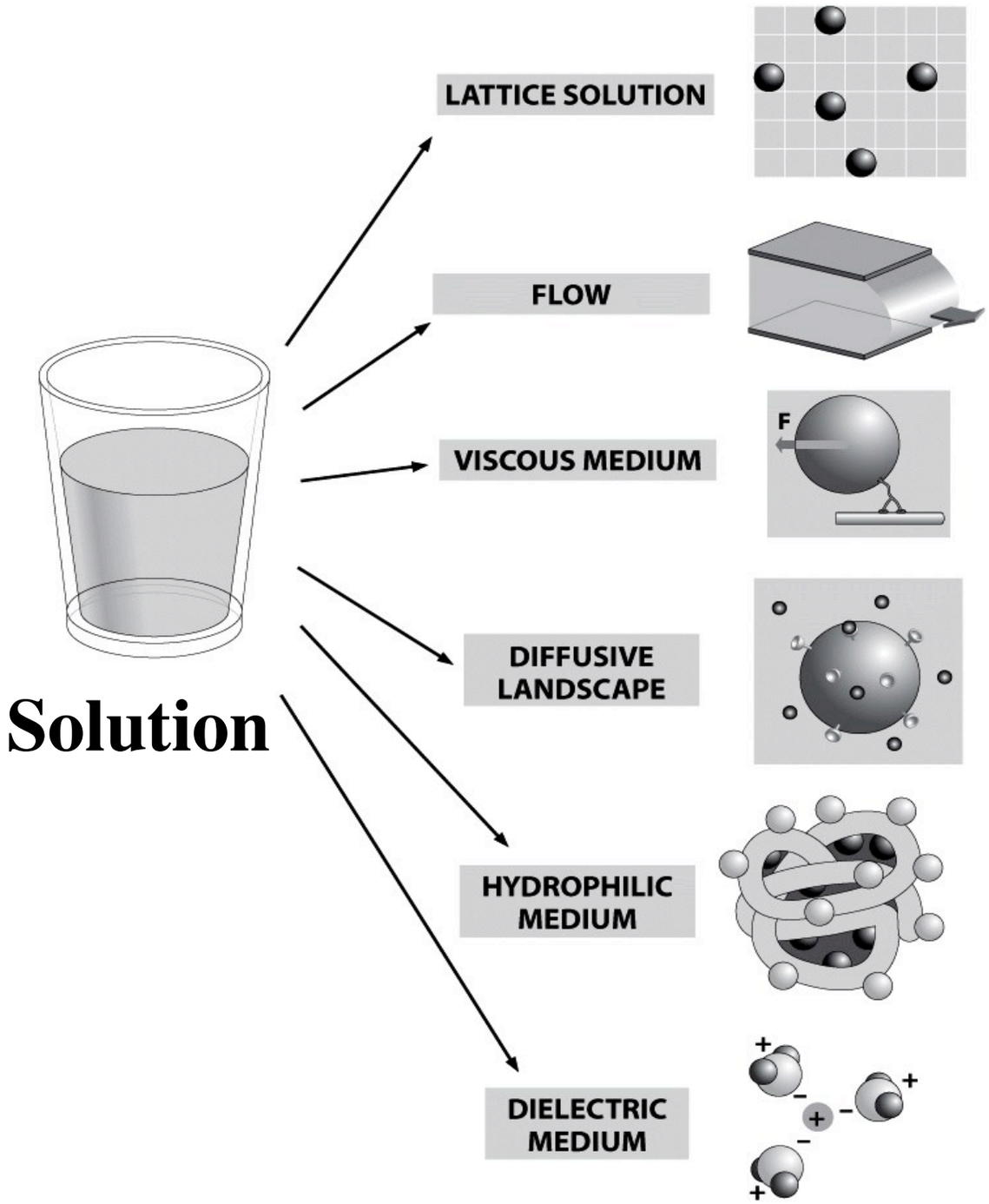


Figure 1.9 Physical Biology of the Cell (© Garland Science 2009)

Mitocondria

0.5 μm

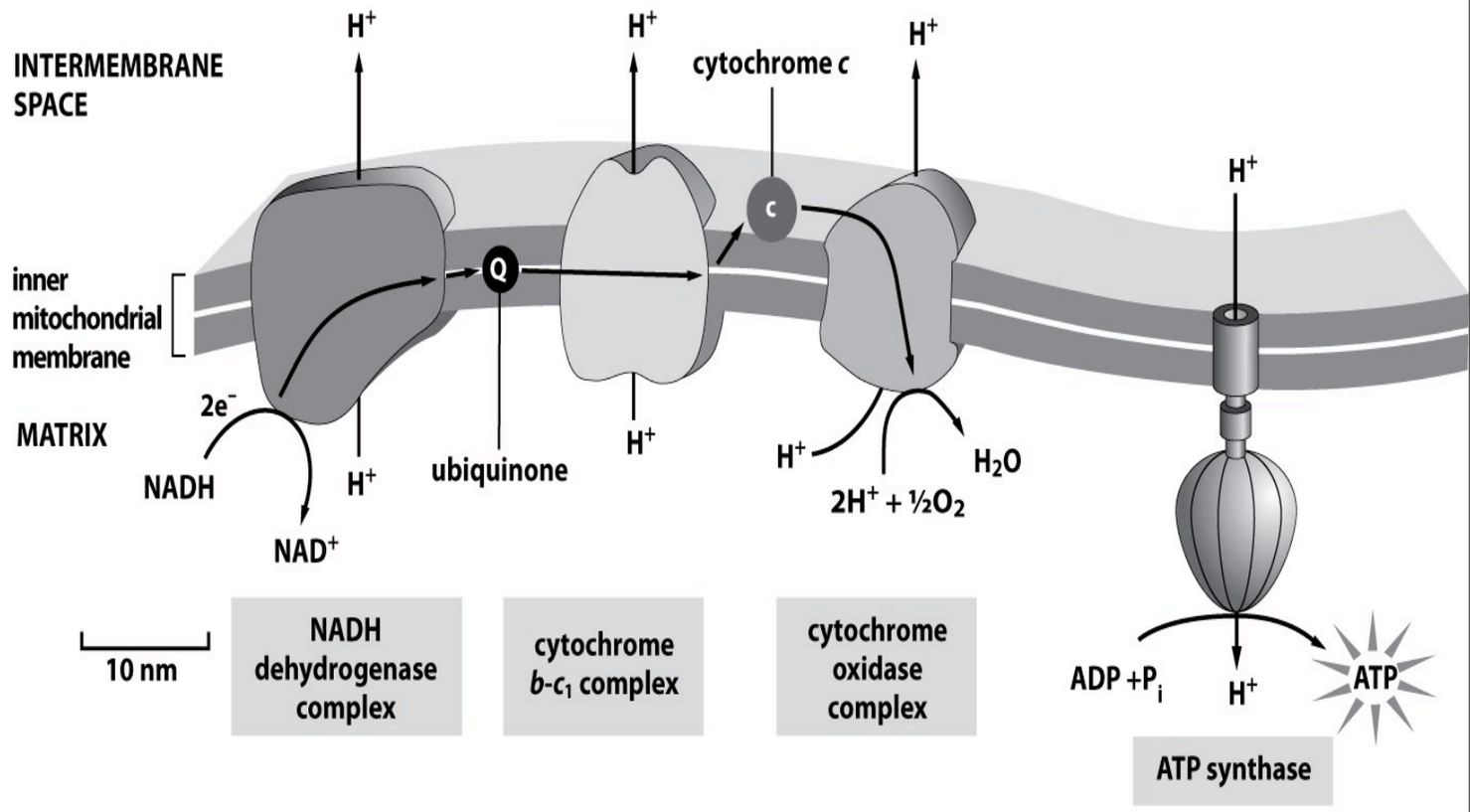
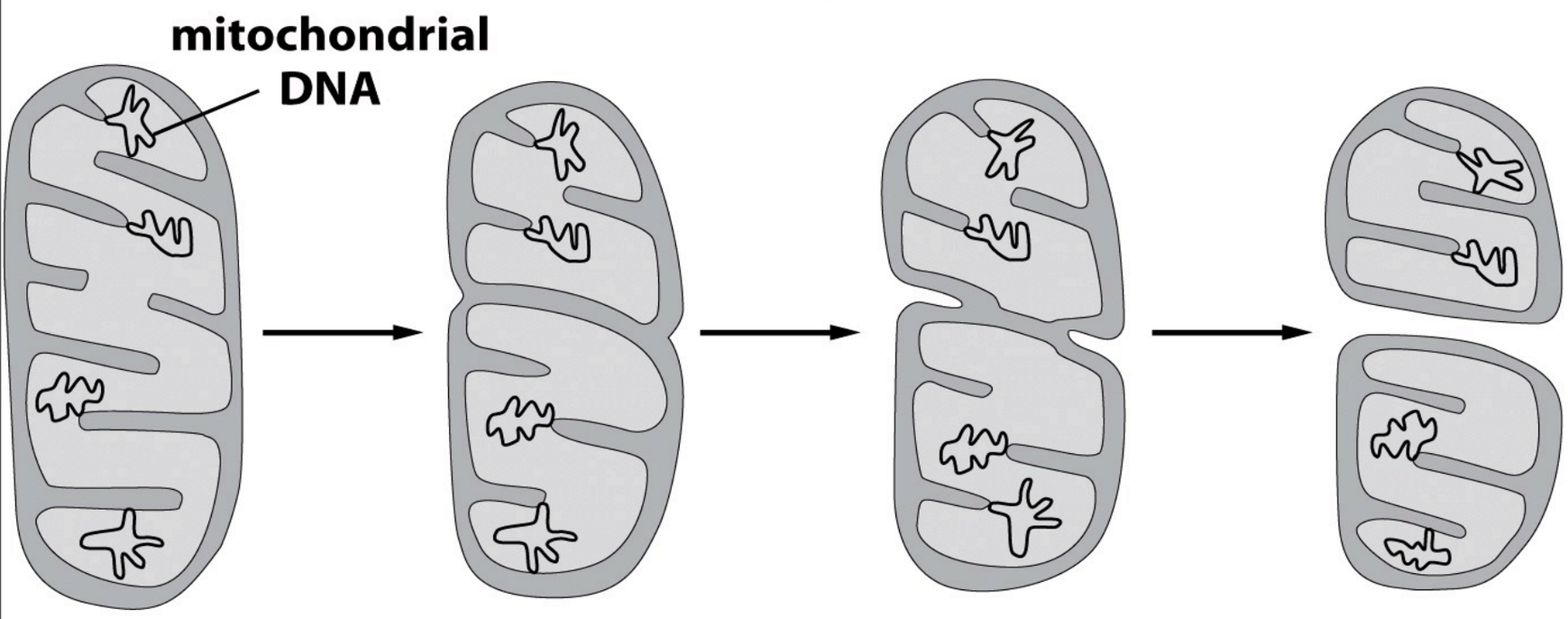
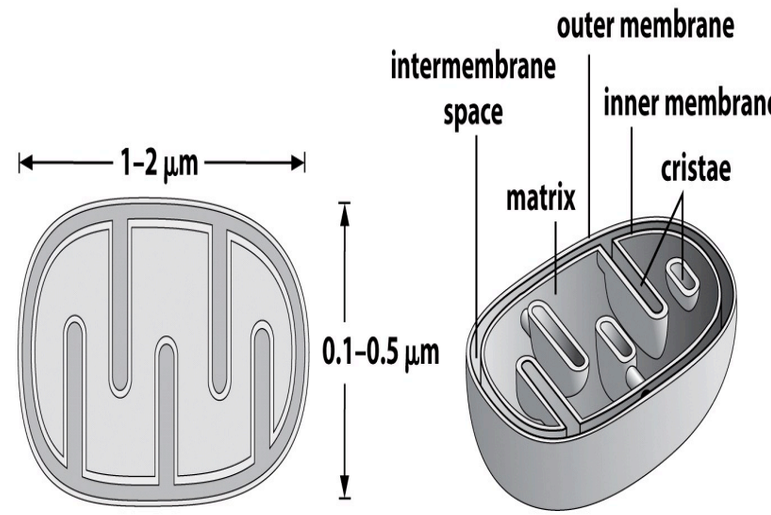


Figure 1.10c Physical Biology of the Cell (© Garland Science 2009)



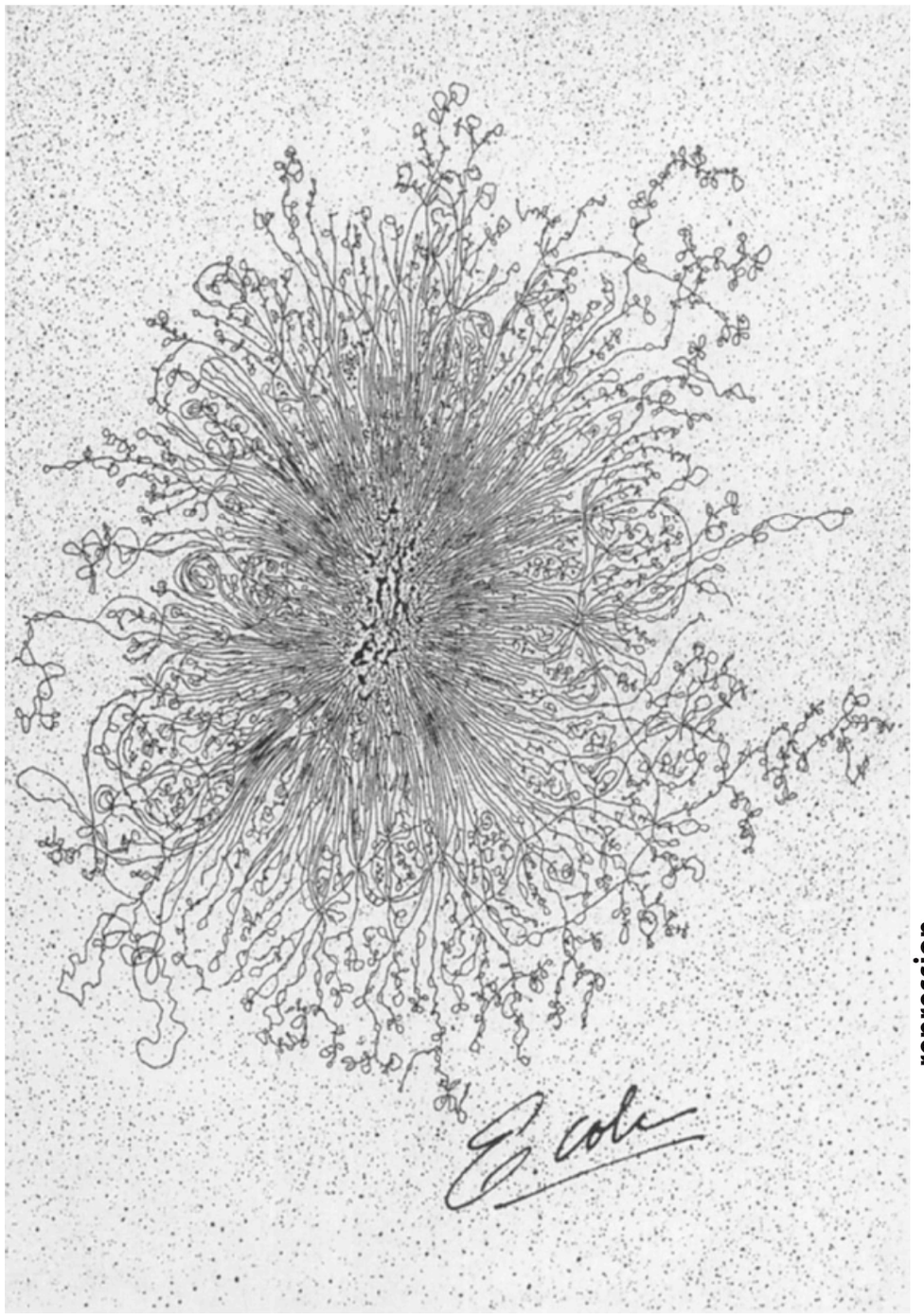
Make idealizations



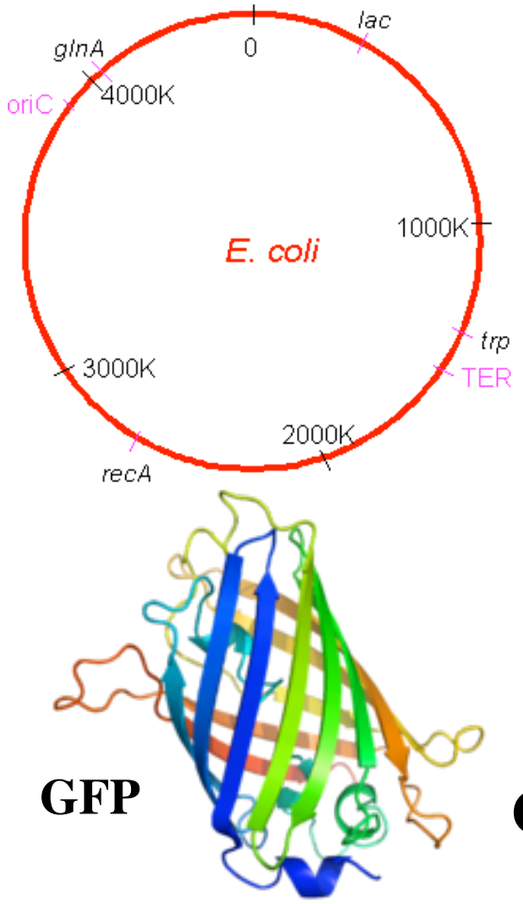
organelles vs organisms..

Quantitative models can be build by mathematizing cartoons

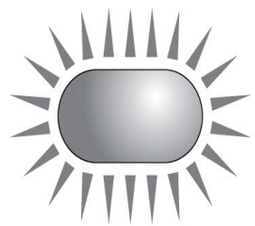
Book's approach (p.18)



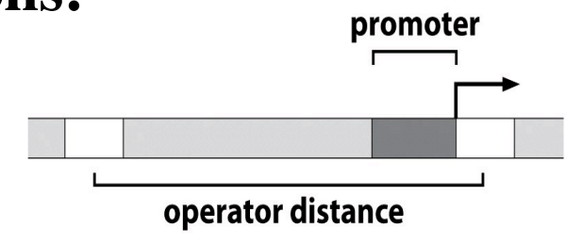
Biological Cartoons.



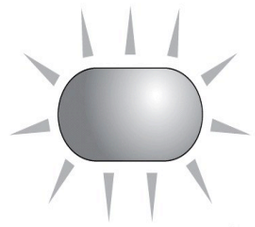
GFP



gene expressed



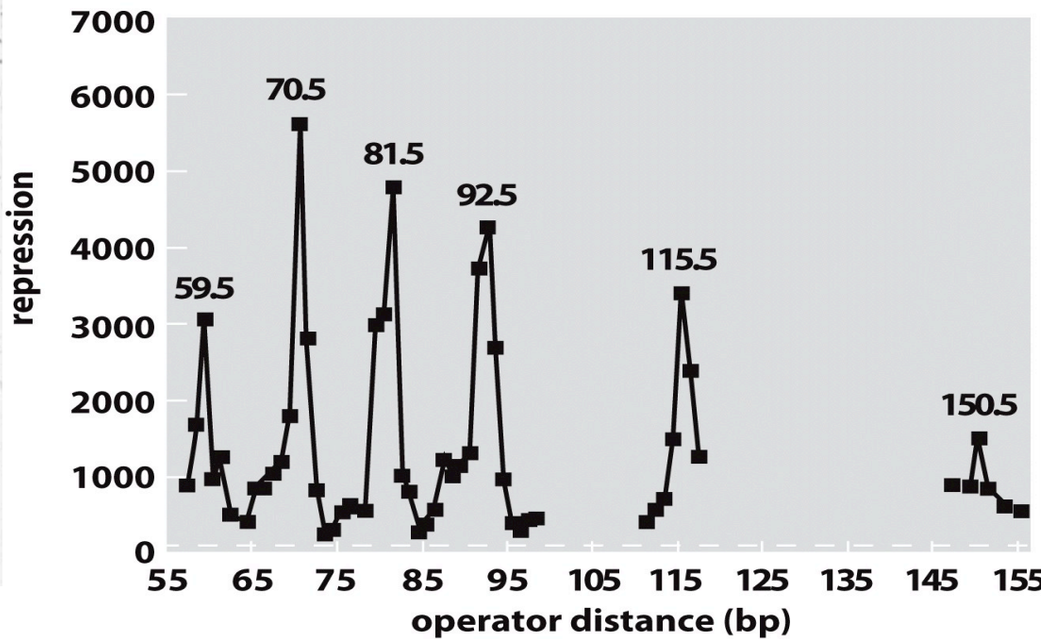
mRNA made (gene expressed)

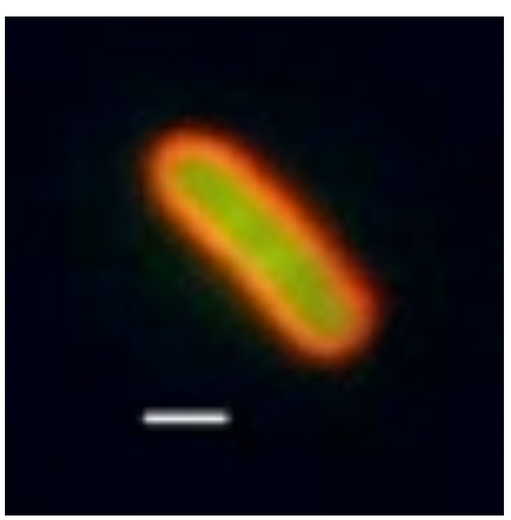


gene repressed

no mRNA made (gene repressed)

Quantitative data.





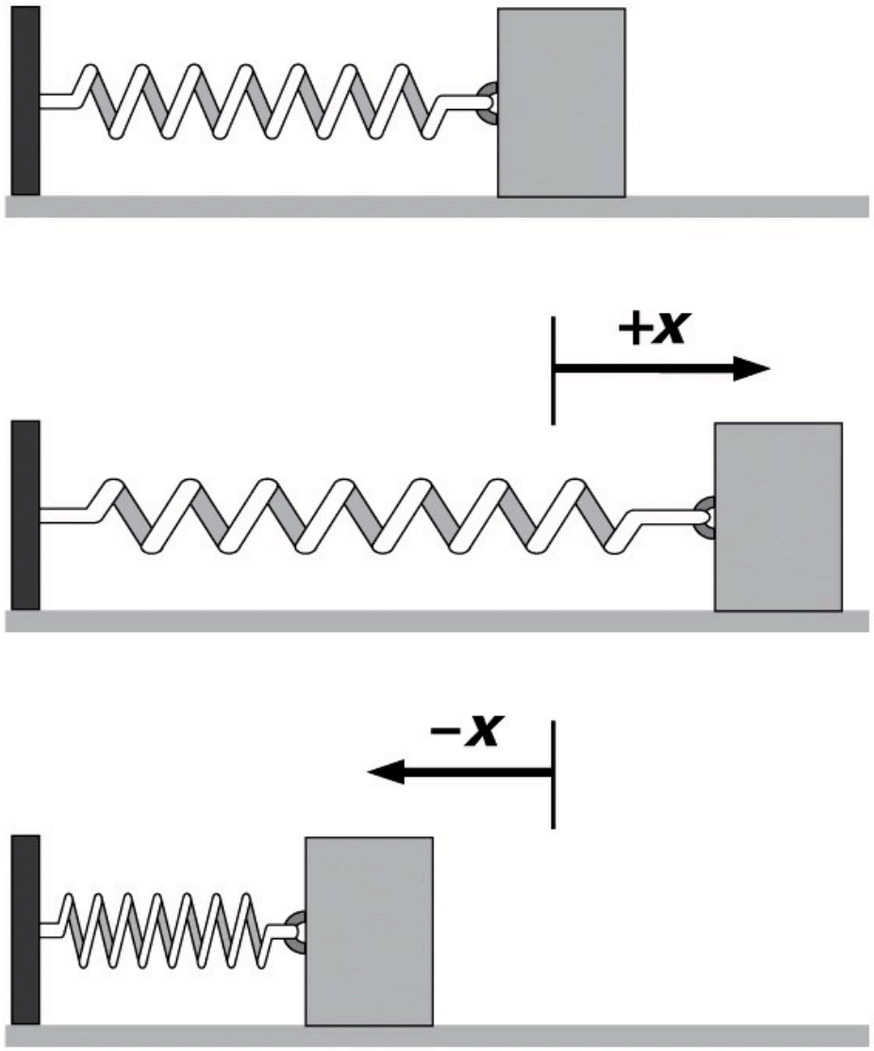
O1 wt lacYZ::GFP

Figure 1.11c Physical Biology of the Cell (© Garland Science 2009)

Biological “springs”

$$F = -kx$$

$$E = \frac{1}{2}kx^2$$



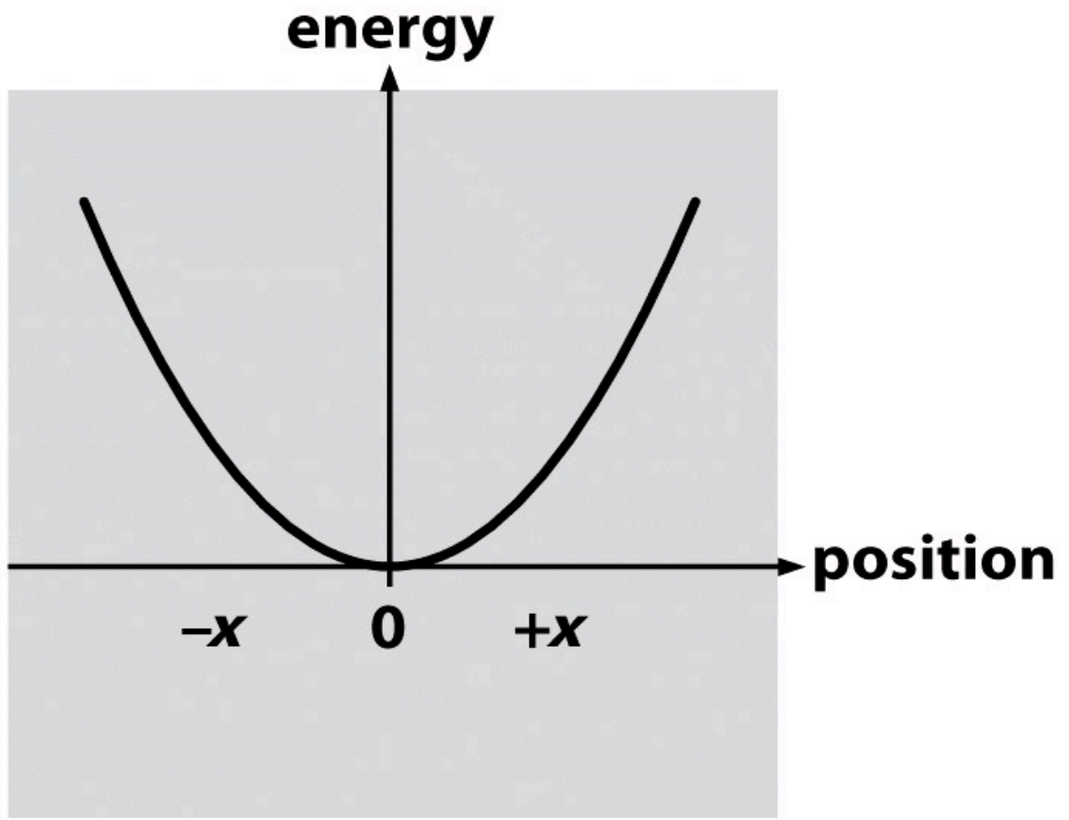
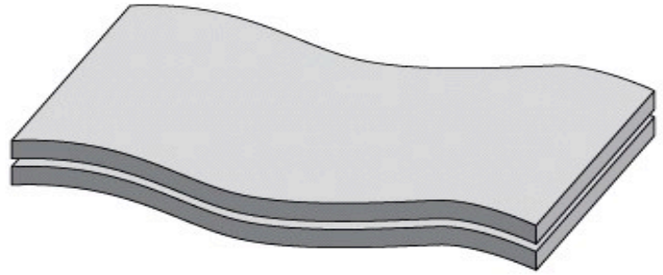


Figure 1.12a Physical Biology of the Cell (© Garland Science 2009)

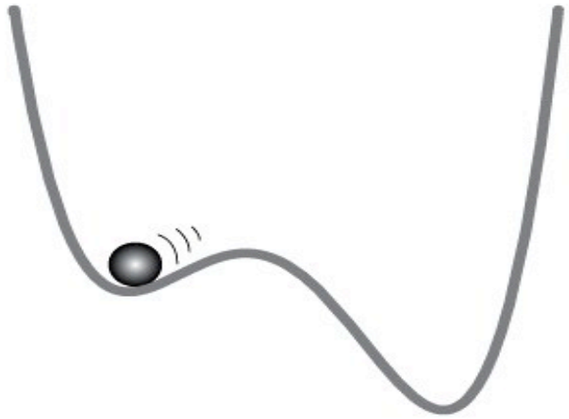
Biological “springs”

beam bending
(e.g., AFM cantilever)

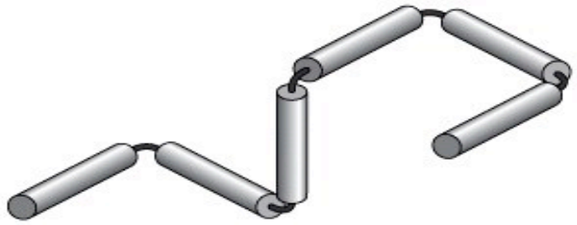


cell membrane fluctuating

bead pulled to center
of an optical trap

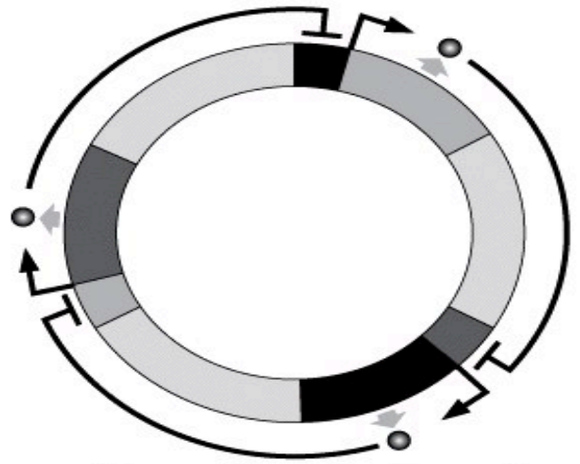


molecules in an
energy landscape



DNA polymer wriggling
in solution

flagellum beating on
a swimming sperm



genetic network changing
expression levels over time

Figure 1.12b Physical Biology of the Cell (© Garland Science 2009)

Key "physical foundation" models p.22:

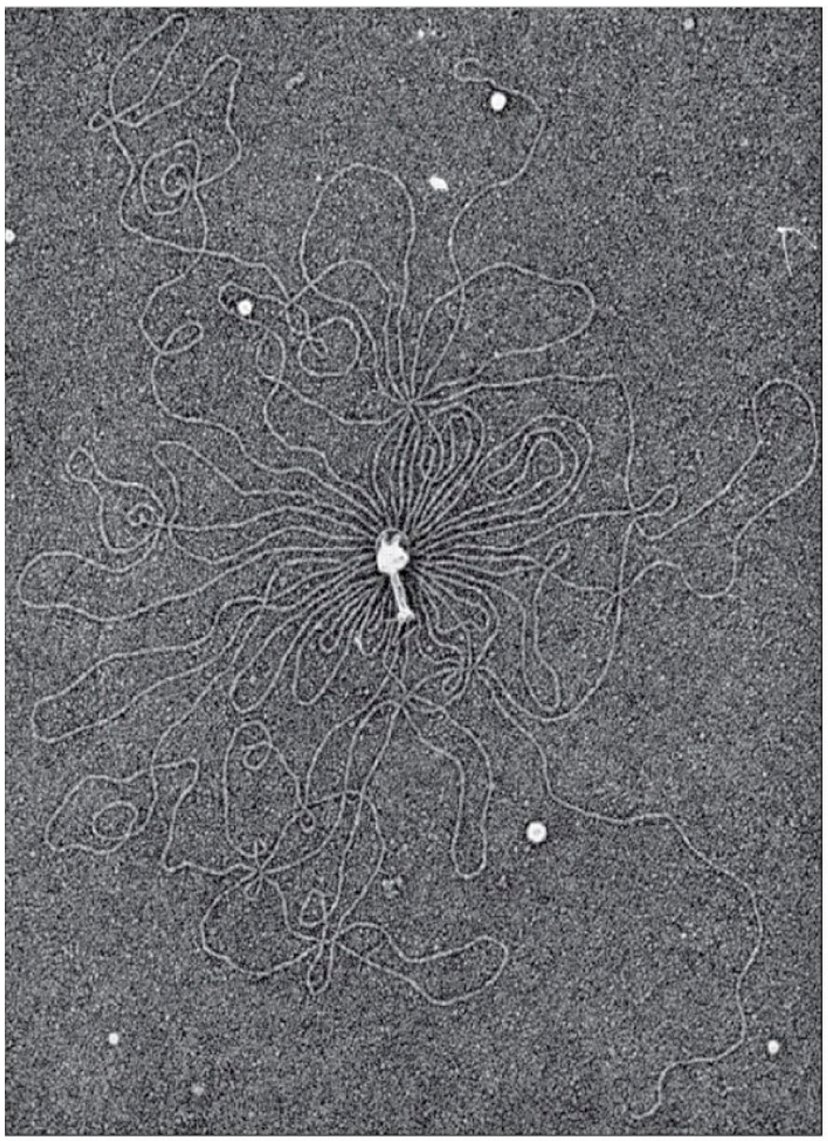


Figure 1.13 Physical Biology of the Cell (© Garland Science 2009)

1.simple harmonic oscillator (ch.5)
2.ideal gas & ideal solution models (ch.6)
3.two-state systems & the Ising model (ch.7)
4.random walks, entropy, & macromolecular structure(ch.8*)
5.Poisson-Boltzmann model of charges solution (ch.9)
6.elastic theory of 1D rods and 2D sheeds (ch.10, ch.11)
7.Newtonian Fluid model & Navier-stokes eqs. (ch. 12)
8.diffusion & random walks (ch.13)
9.rate equation models of chemical kinetics (ch.15)

The role of estimates:

-structure & process into numbers

-reality check

Rules of Thumb: biology by the numbers

$$k_B T_R \approx 4[\mathrm{pN} \cdot \mathrm{nm}]$$

Table 1.1 Rules of thumb for biological estimates

	Quantity of interest	Symbol	Rule of thumb
E. coli	Cell volume	$V_{E.\ coli}$	$\approx 1\,\mu m^3$
	Cell mass	$m_{E.\ coli}$	≈ 1 pg
	Cell cycle time	$t_{E.\ coli}$	≈ 3000 s
	Cell surface area	$A_{E.\ coli}$	$\approx 6\,\mu m^2$
	Genome length	$N_{bp}^{E.\ coli}$	$\approx 5 \times 10^6$ bp
	Swimming speed	$v_{E.\ coli}$	$\approx 20\,\mu$m/s
Yeast	Volume of cell	V_{yeast}	$\approx 60\,\mu m^3$
	Mass of cell	m_{yeast}	≈ 60 pg
	Diameter of cell	d_{yeast}	$\approx 5\,\mu$m
	Cell cycle time	t_{yeast}	≈ 200 min
	Genome length	N_{bp}^{yeast}	$\approx 10^7$ bp
Organelles	Diameter of nucleus	$d_{nucleus}$	$\approx 5\,\mu$m
	Length of mitochondrion	l_{mito}	$\approx 2\,\mu$m
	Diameter of transport vesicles	$d_{vesicle}$	≈ 50 nm
Water	Volume of molecule	V_{H_2O}	$\approx 10^{-2}$ nm^3
	Density of water	ρ	1 g/cm^3
	Viscosity of water	η	$\approx$1 centipoise (10^{-2} g/(cm s))
	Hydrophobic embedding energy	$\approx E_{hydr}$	25 cal/(mol Å^2)
DNA	Length per base pair	l_{bp}	$\approx 1/3$ nm
	Volume per base pair	V_{bp}	≈ 1 nm^3
	Charge density	λ_{DNA}	2 e/0.34 nm
	Persistence length	ξ_P	50 nm
Amino acids and proteins	Radius of "average" protein	$r_{protein}$	≈ 2 nm
	Volume of "average" protein	$V_{protein}$	≈ 25 nm^3
	Mass of "average" amino acid	M_{aa}	≈ 100 Da
	Mass of "average" protein	$M_{protein}$	$\approx 30{,}000$ Da
	Protein concentration in cytoplasm	$c_{protein}$	≈ 300 mg/mL
	Characteristic force of protein motor	F_{motor}	≈ 5 pN
	Characteristic speed of protein motor	v_{motor}	≈ 200 nm/s
	Diffusion constant of "average" protein	$D_{protein}$	$\approx 100\,\mu m^2/s$
Lipid bilayers	Thickness of lipid bilayer	d	≈ 5 nm
	Area per molecule	A_{lipid}	$\approx \frac{1}{2}$ nm^2
	Mass of lipid molecule	m_{lipid}	≈ 800 Da

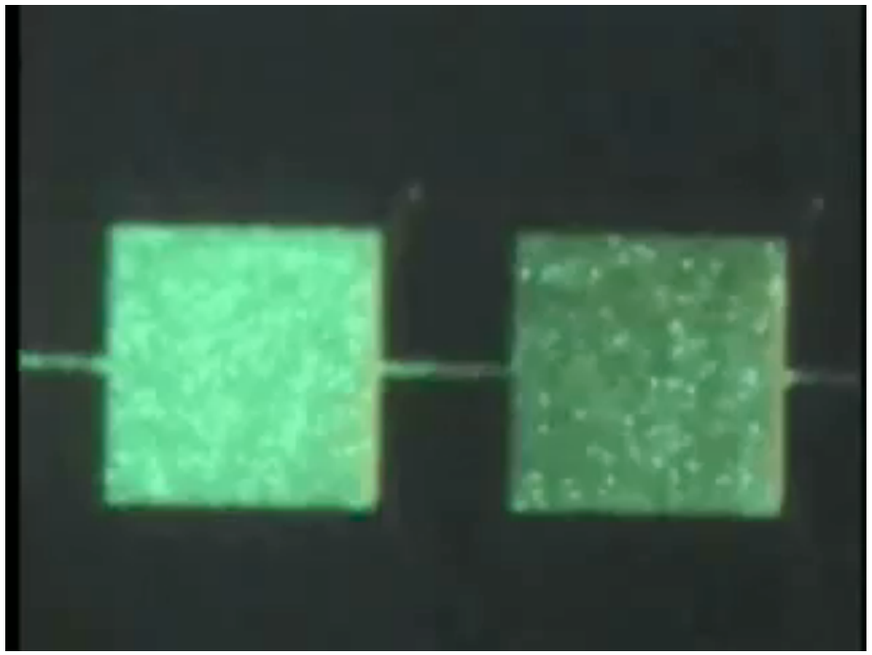
Table 1.1 Physical Biology of the Cell (© Garland Science 2009)

2 skills:

1.describe the biological system in terms of the key fundamental physical models (physical model).
2.quantitative estimated to make order-of-magnitude predictions of sizes, numbers, timescales, energy scales involved (reality check).

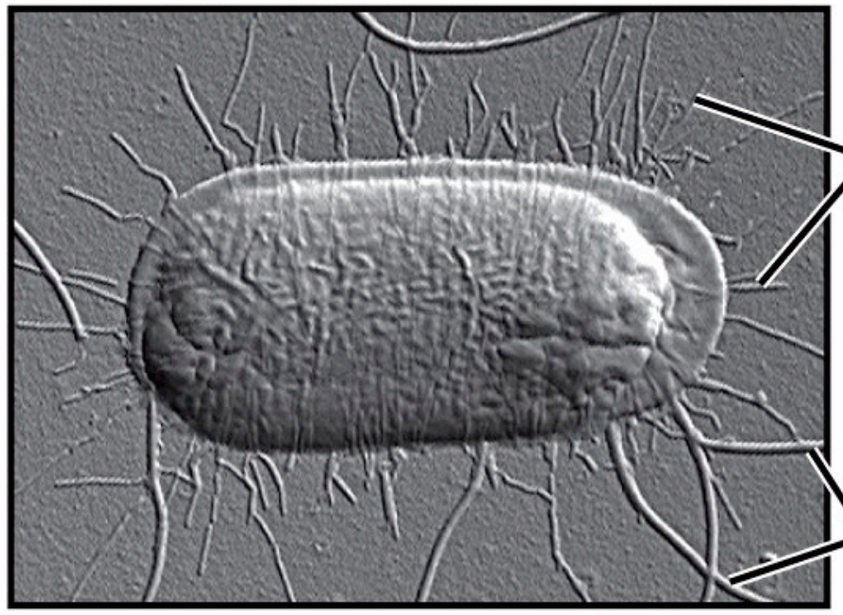
Chapter 2

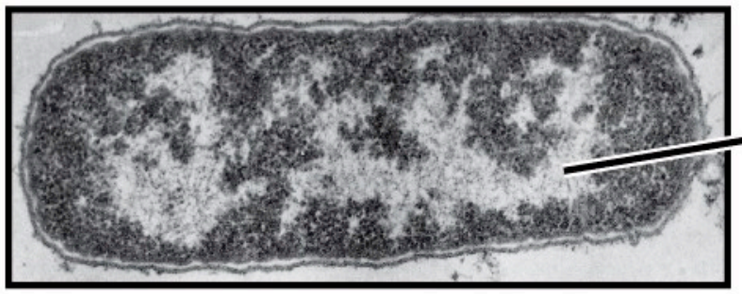
What and Where: Construction Plans for Cells and Organisms

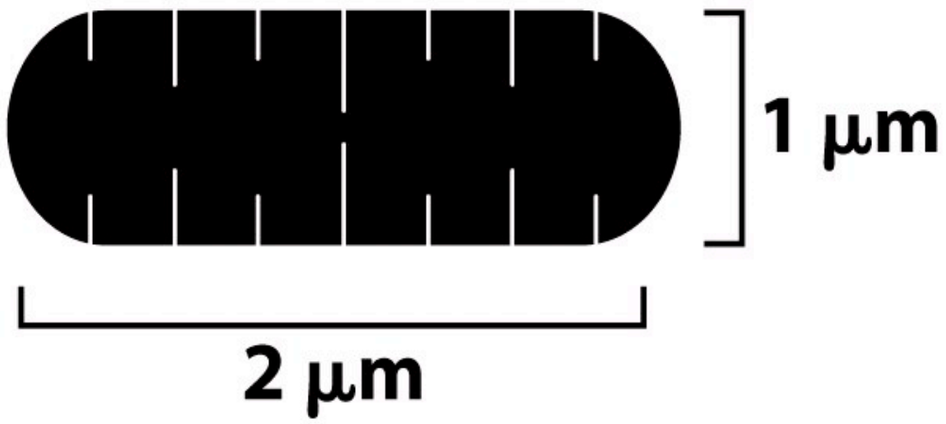


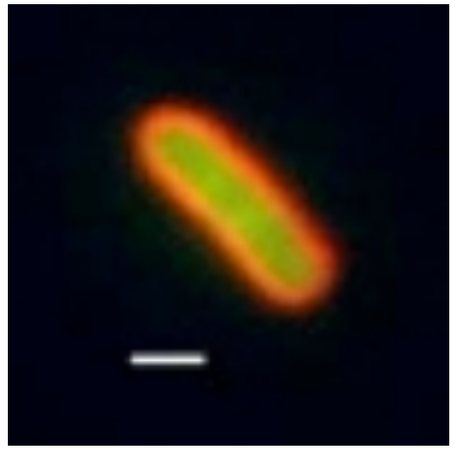
“What is **true** for E. **coli** is **true** for the **elephant**.”
J. Monod.

An ode to *E. coli*



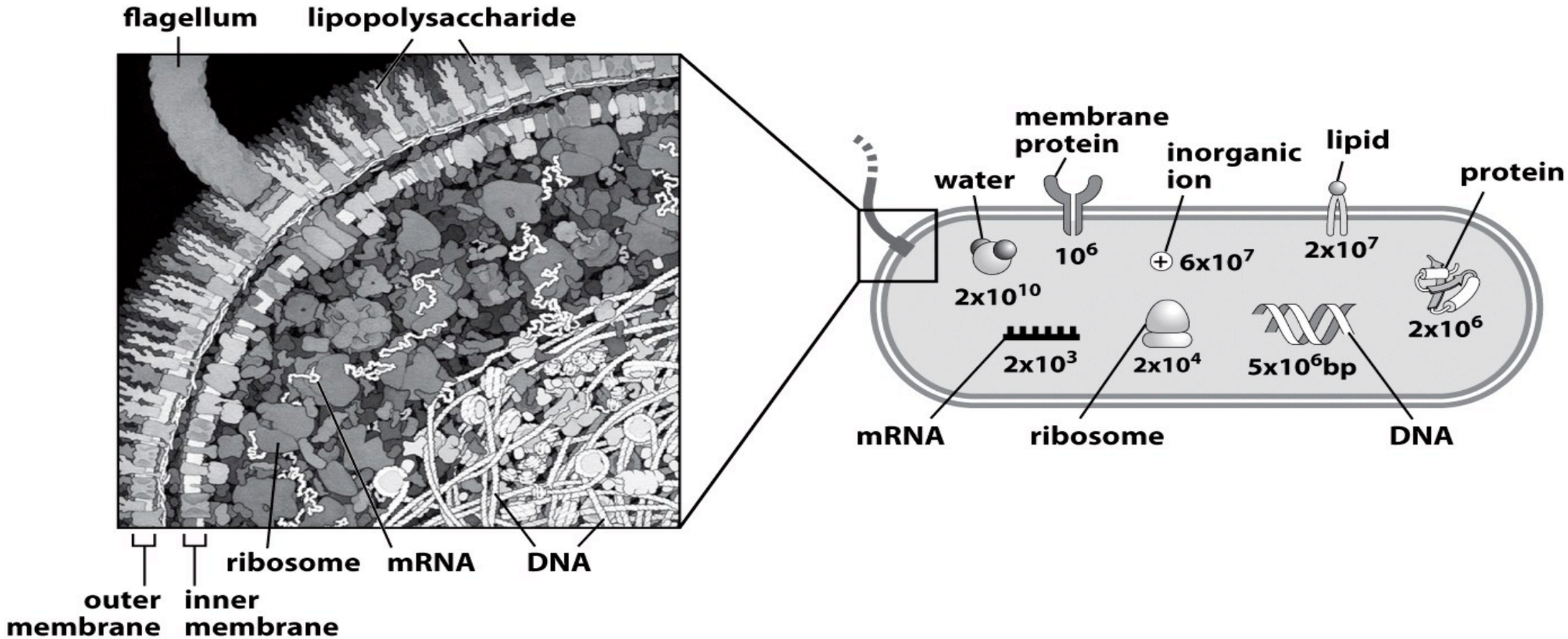


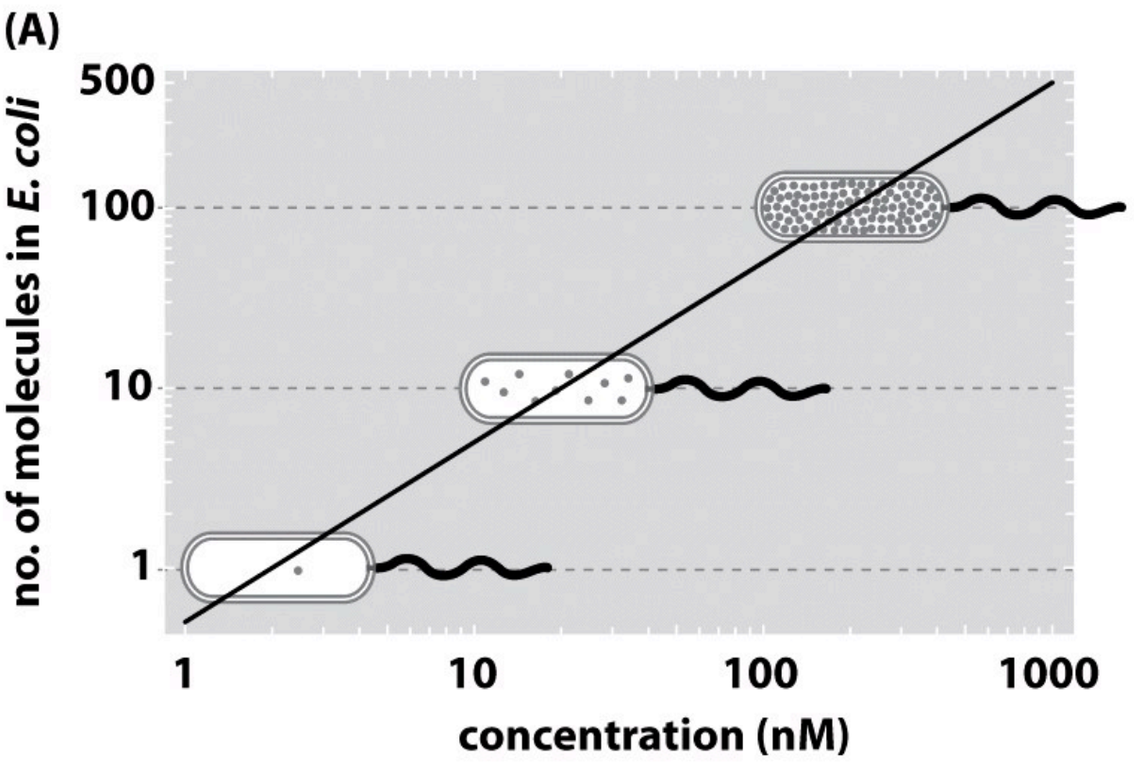




wt lacYZ::GFP

Molecular contents of bacterium *E. coli*





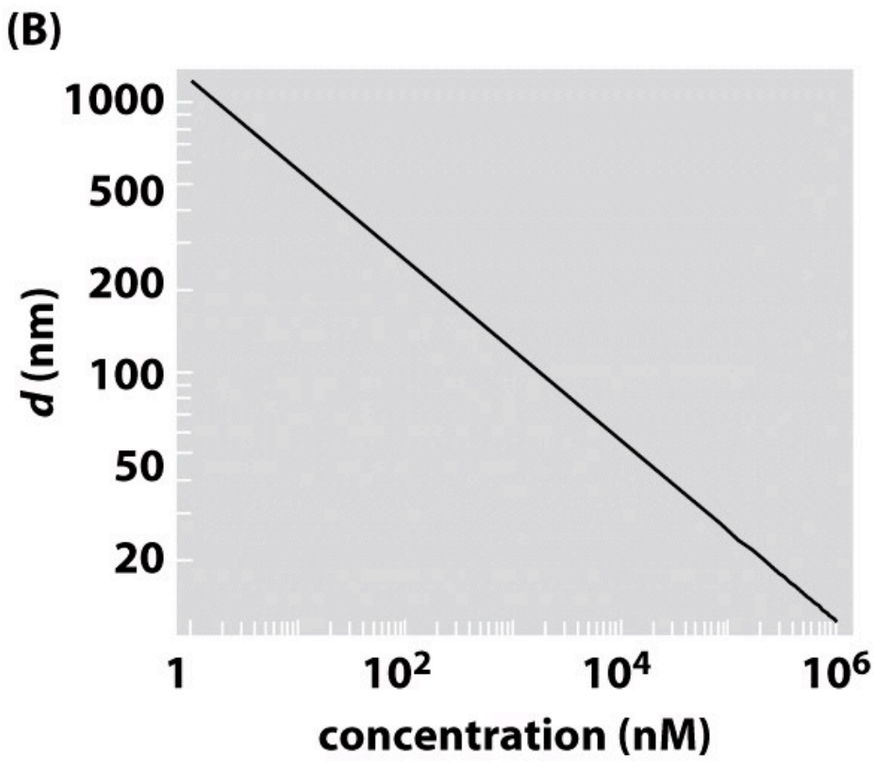


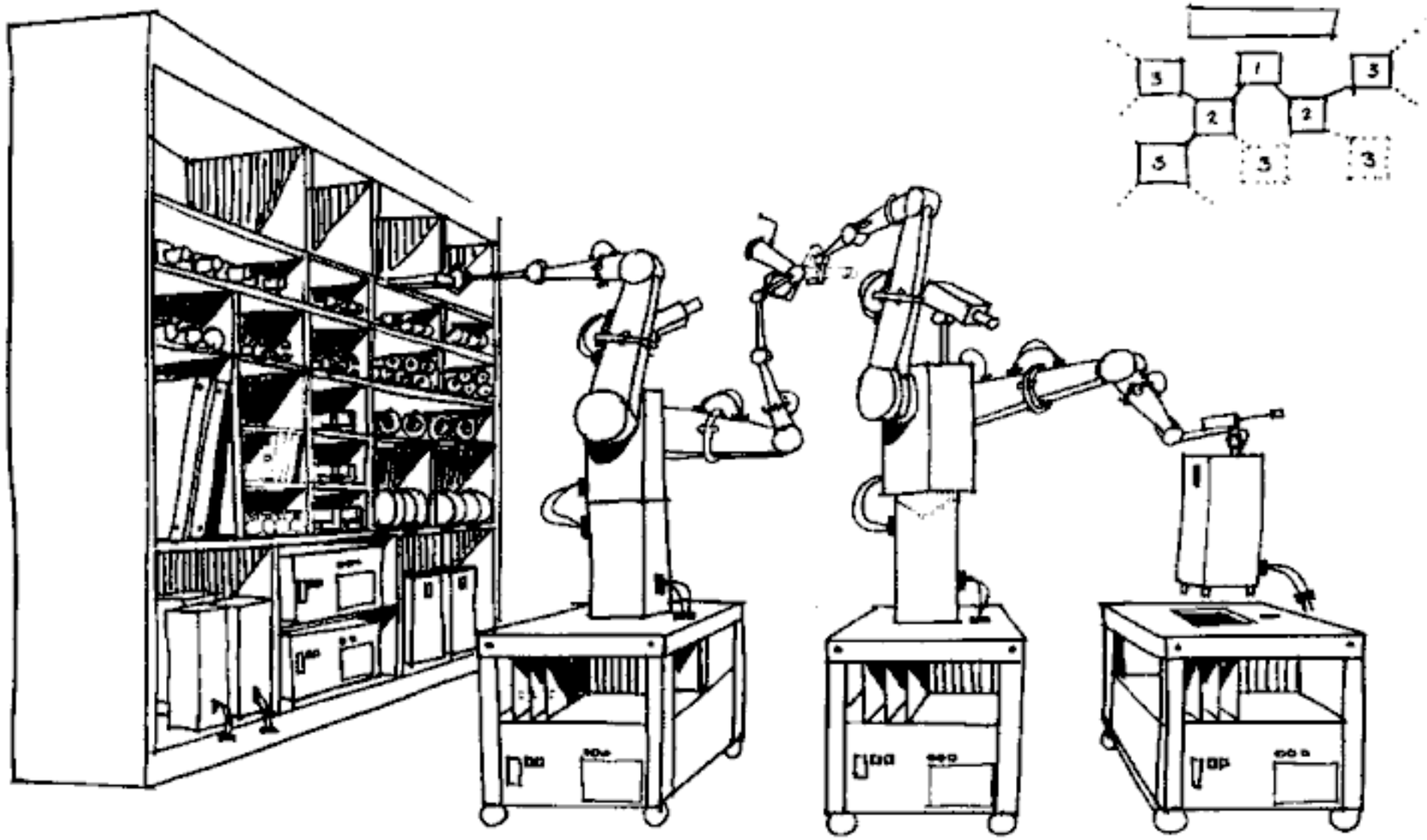
Figure 2.4 Physical Biology of the Cell (© Garland Science 2009)

Molecular contents of bacterium *E. coli*

Substance	% of total dry weight	Number of molecules
Macromolecule		
Protein	55.0	2.4×10^6
RNA	20.4	
23S RNA	10.6	19,000
16S RNA	5.5	19,000
5S RNA	0.4	19,000
Transfer RNA (4S)	2.9	200,000
Messenger RNA	0.8	1,400
Phospholipid	9.1	22×10^6
Lipopolysaccharide	3.4	1.2×10^6
DNA	3.1	2
Murein	2.5	1
Glycogen	2.5	4,360
Total macromolecules	**96.1**	
Small molecules		
Metabolites, building blocks, etc.	2.9	
Inorganic ions	1.0	
Total small molecules	**3.9**	

Table 2.1 Observed macromolecular census of an *E. coli* cell. (Data from F. C. Neidhardt et al., Physiology of the Bacterial Cell, Sunderland, Sinauer Associates Inc., 1990 and M. Schaechter et al., Microbe, Washington DC, ASM Press, 2006.)

Table 2.1 Physical Biology of the Cell (© Garland Science 2009)



murein : 1 molecule many life-times!

E. coli has age!

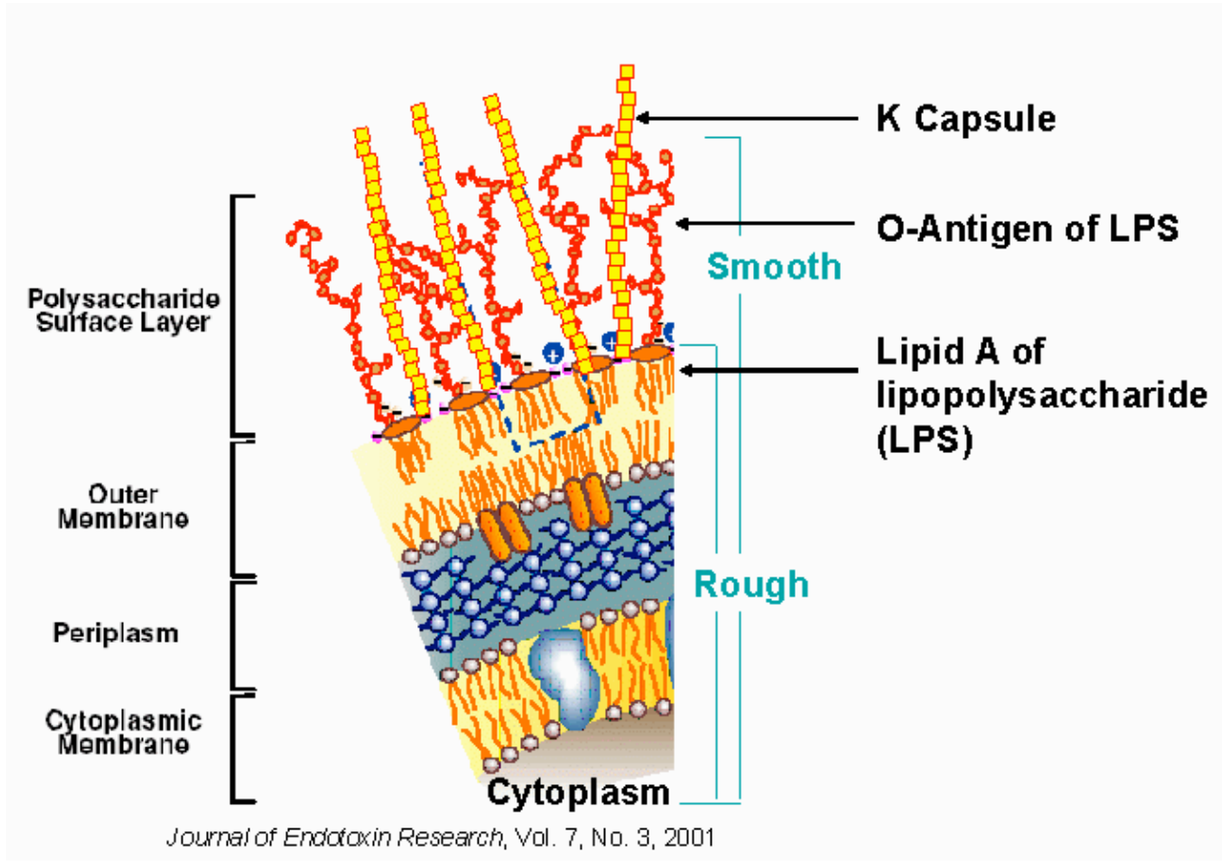
Von Neumann: a universal constructor?

The Fluid Mosaic Model of the Structure of Cell Membranes

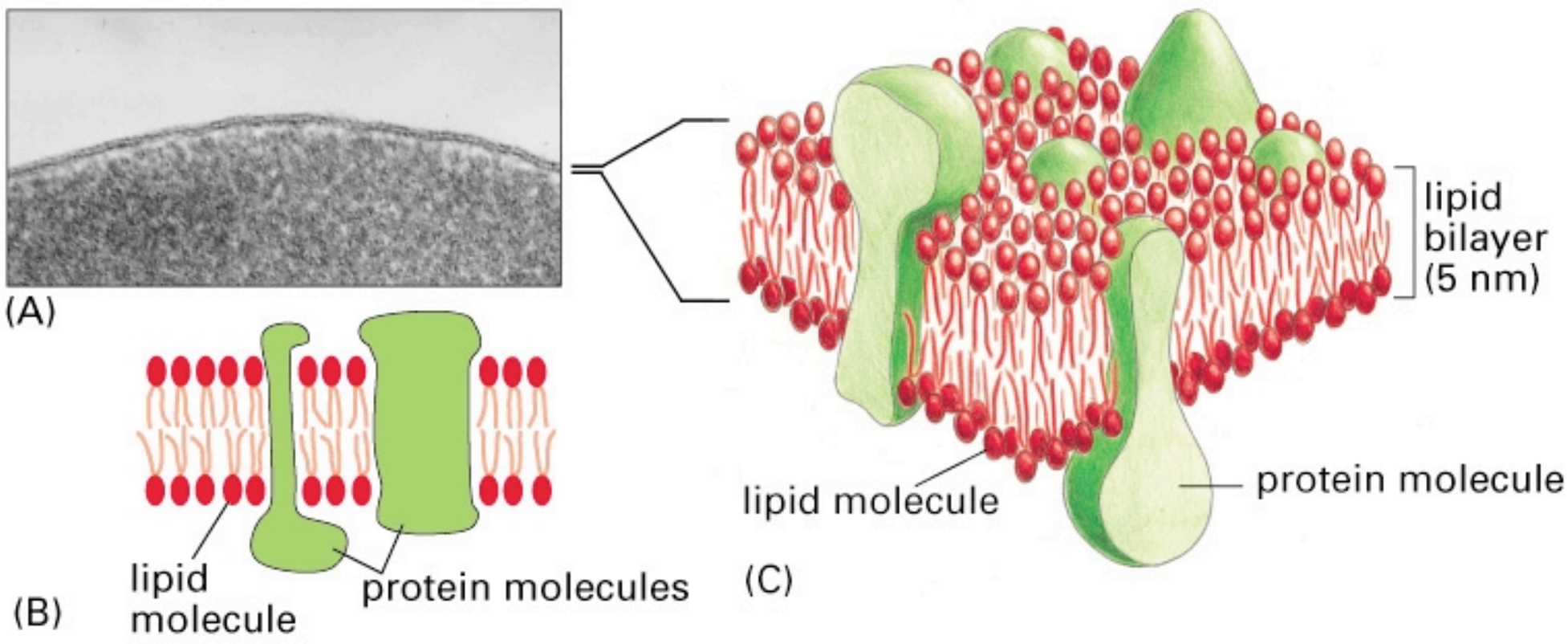
Cell membranes are viewed as two-dimensional solutions of oriented globular proteins and lipids.

S. J. Singer and Garth L. Nicolson

1972

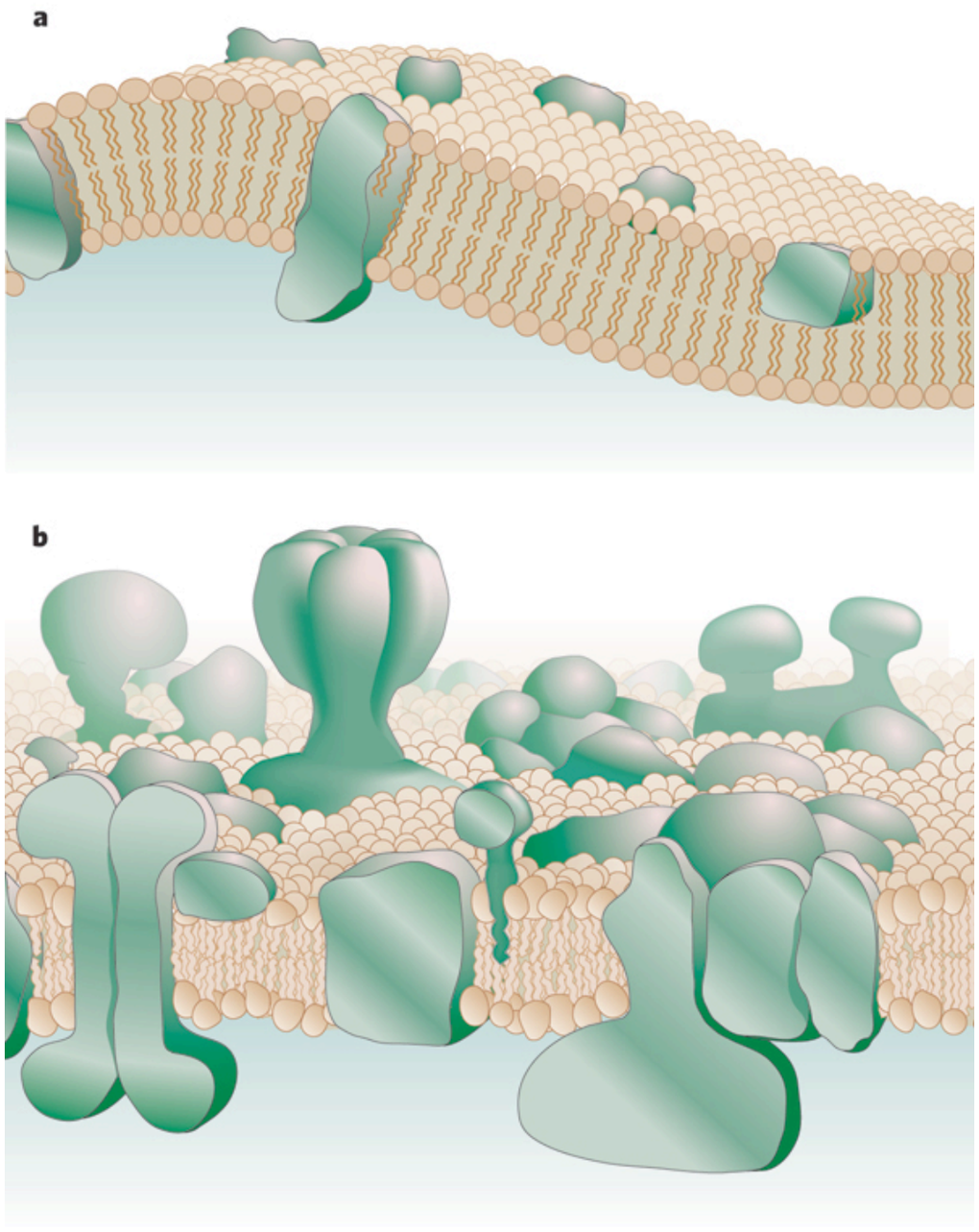


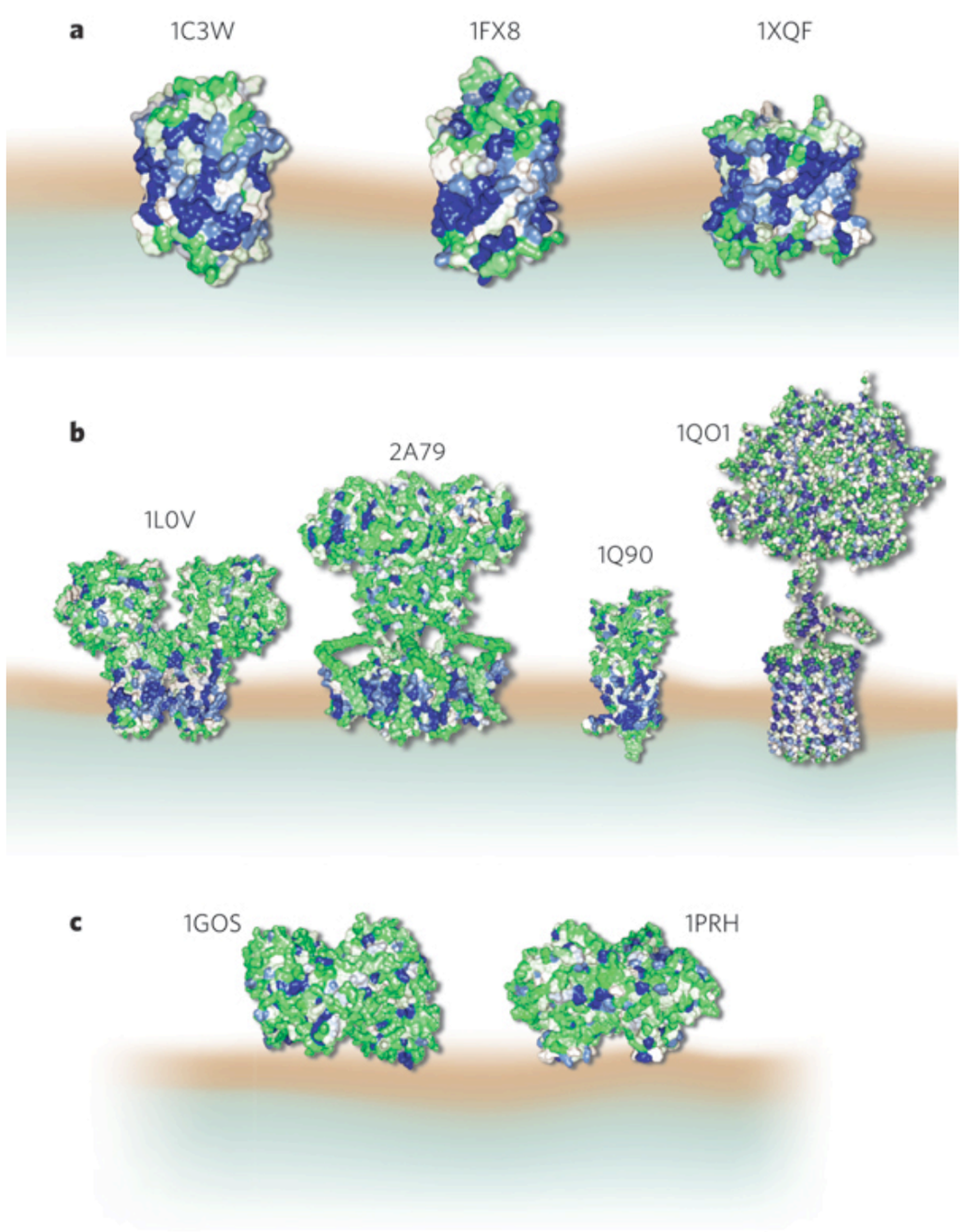
Journal of Endotoxin Research, Vol. 7, No. 3, 2001



Scienc

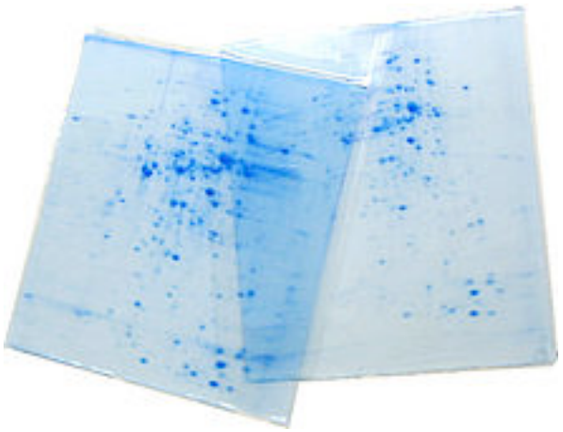
Membrane (boundary): the self and origin of individuality?





Membranes are more mosaic than fluid!!

Protein contents of bacterium *E. coli?*



Two-dimensional gel electrophoresis

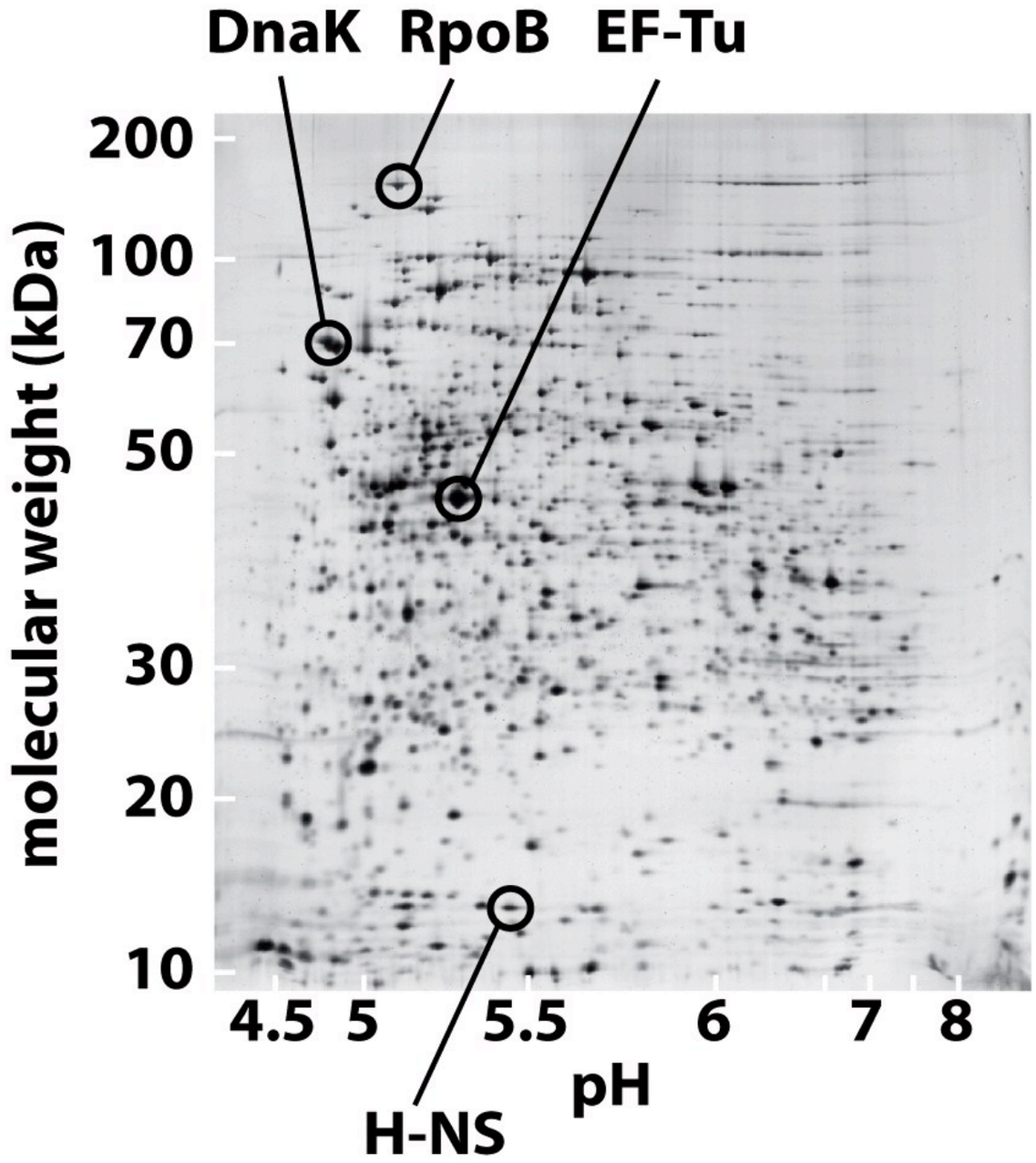
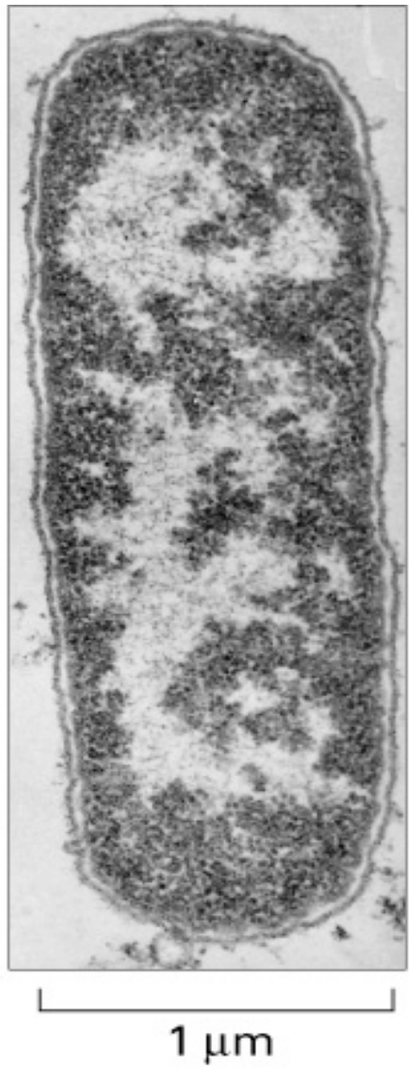
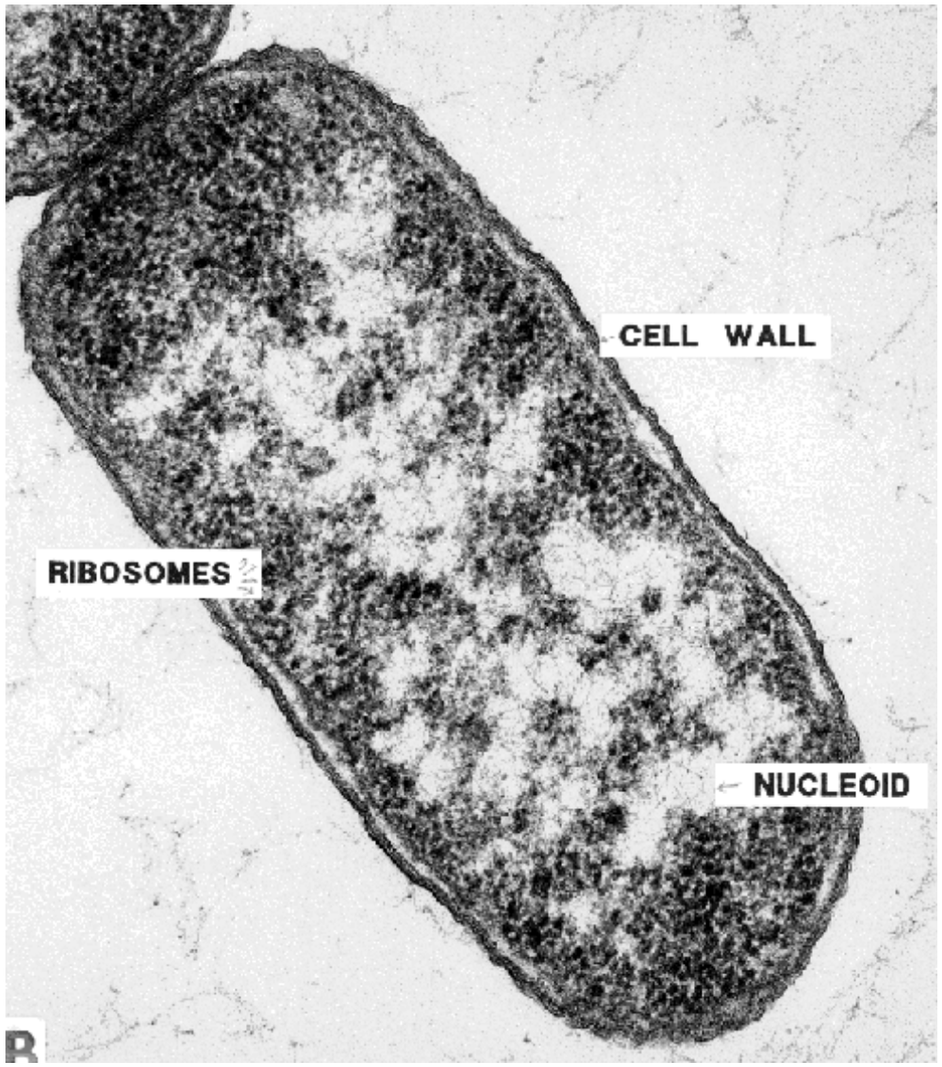
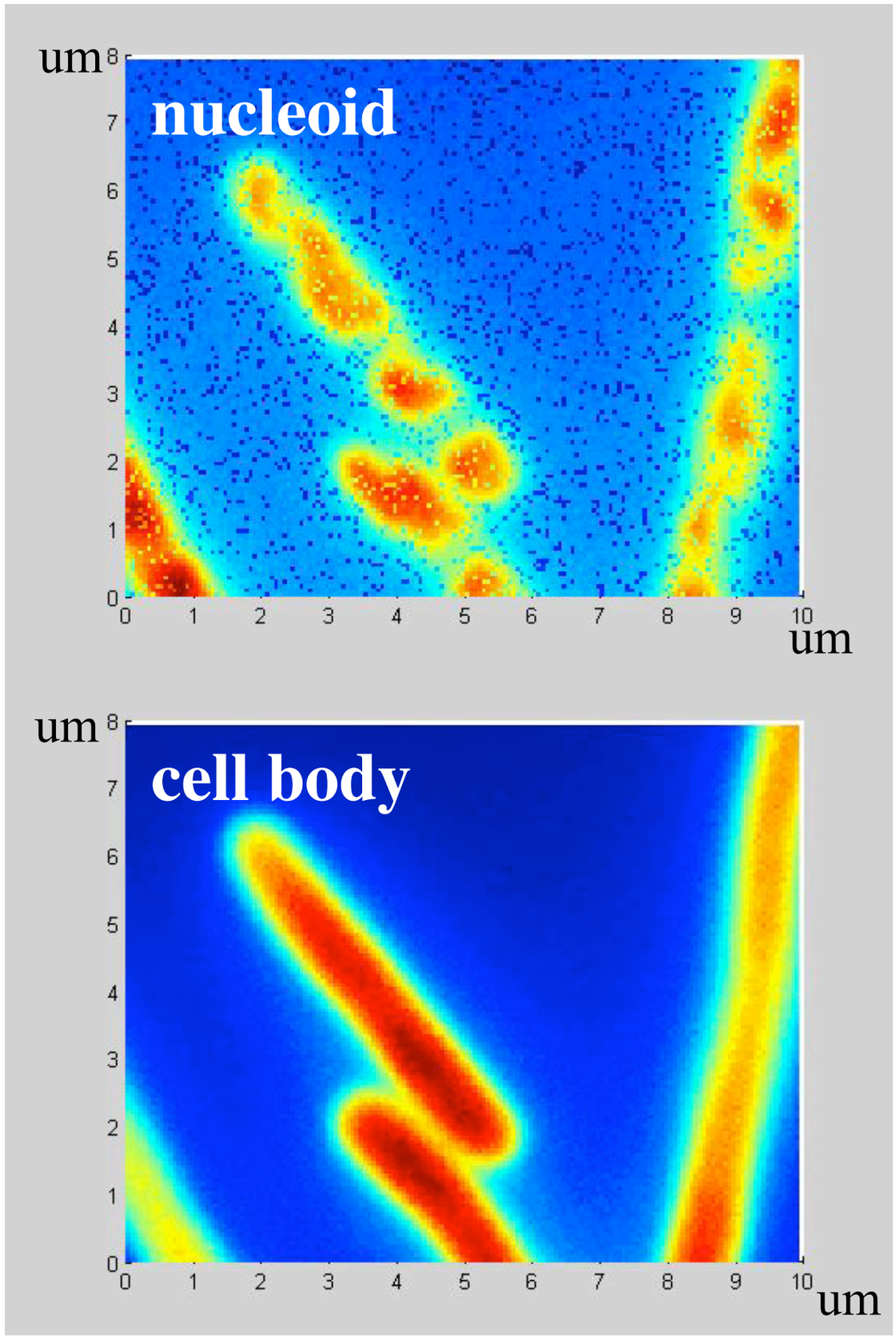


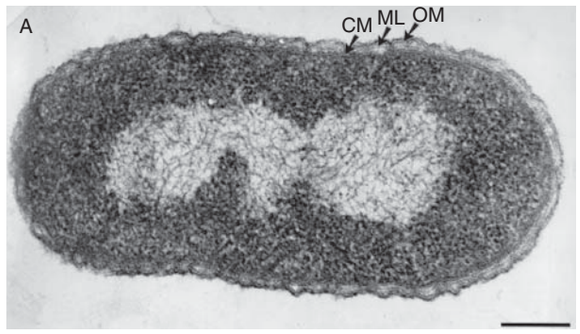
Figure 2.3 Physical Biology of the Cell (© Garland Science 2009)



E. coli growing in “standard” conditions


CELL WALL
RIBOSOMES
NUCLEOID
B


um
nucleoid
0 1 2 3 4 5 6 7 8 9 10
um
um
cell body
0 1 2 3 4 5 6 7 8 9 10
um


A
CM
ML
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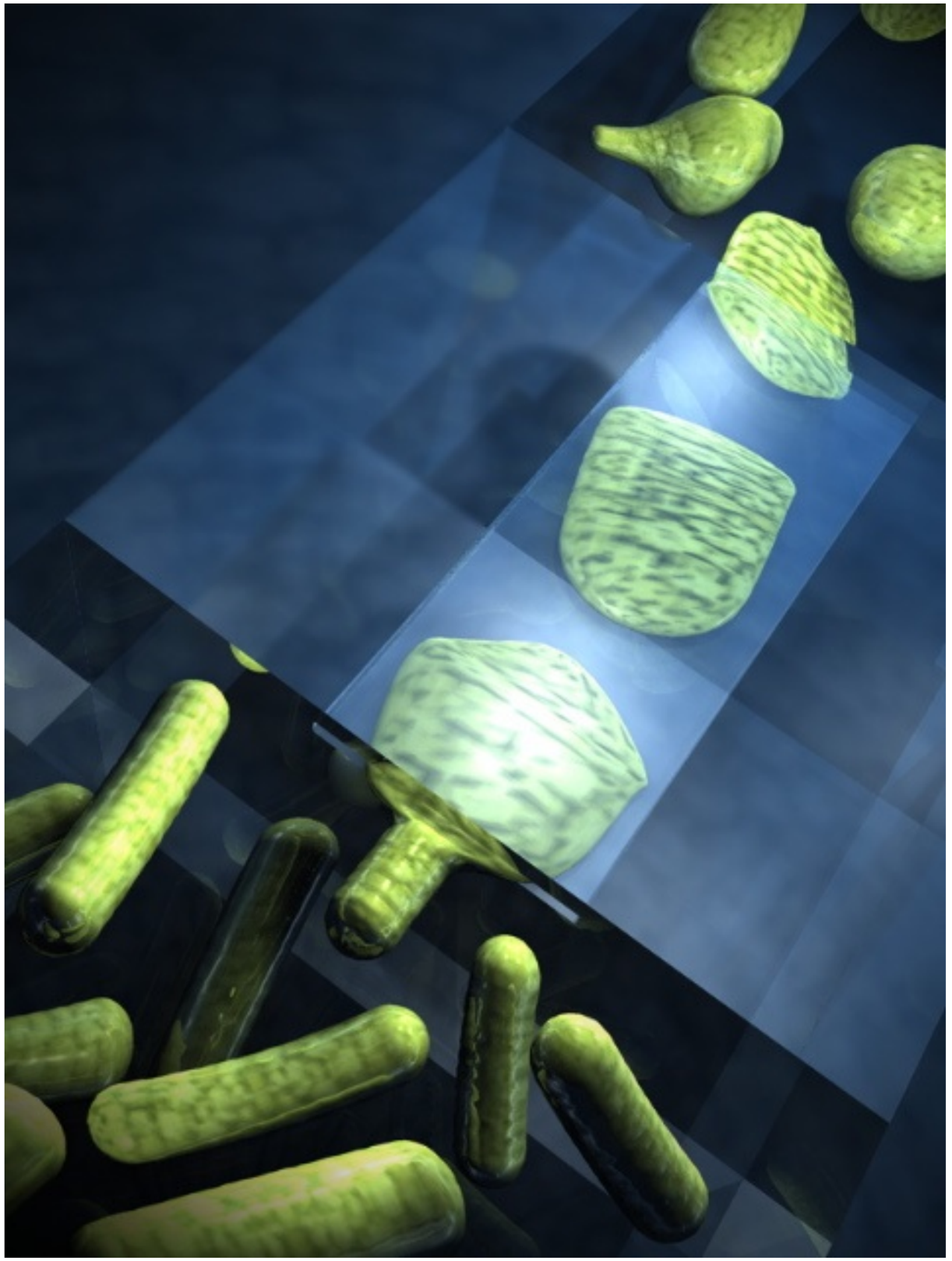
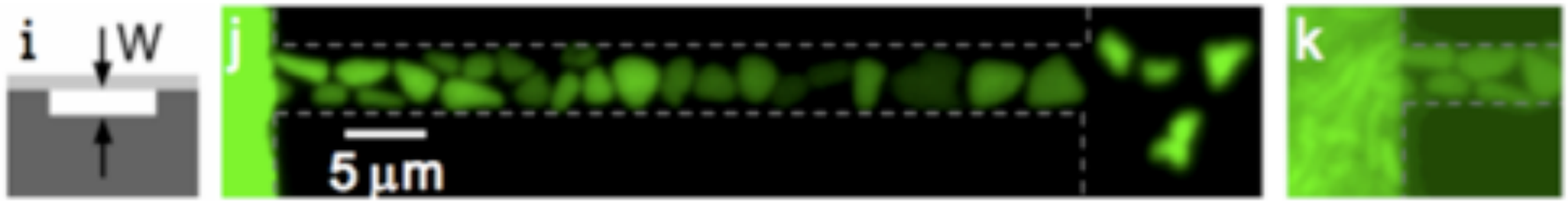
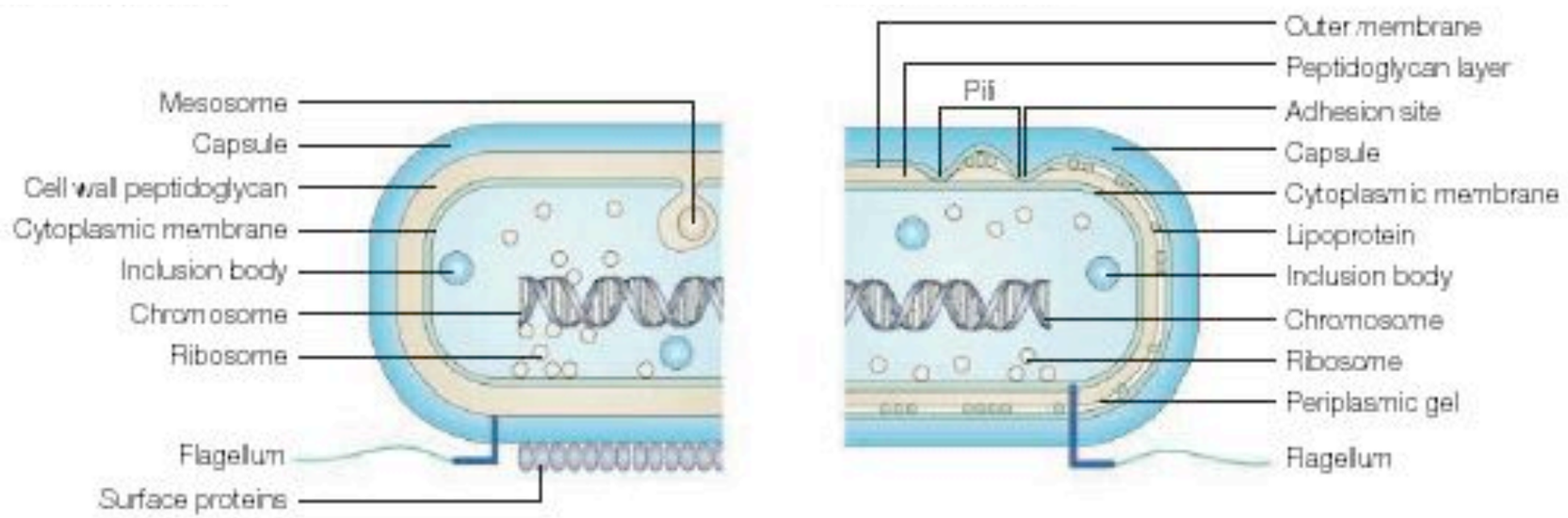
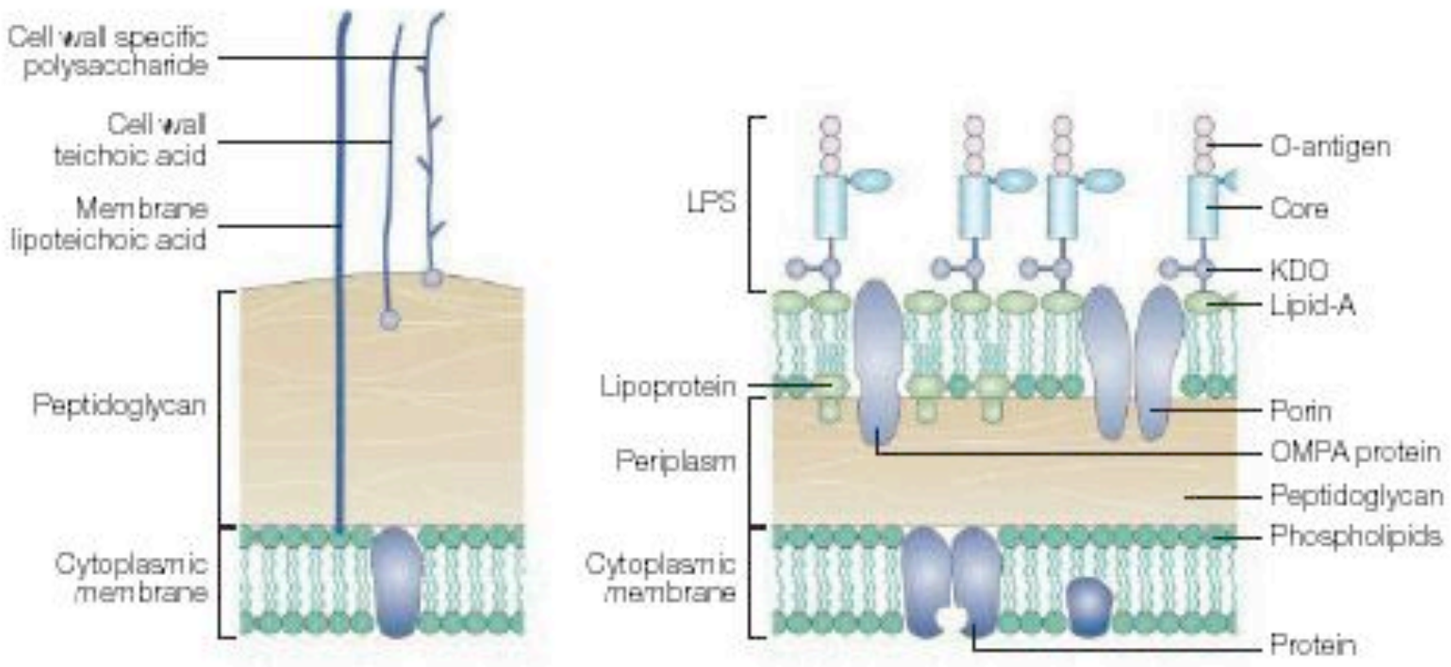


“standard” v.s. “non-standard”

Cell shapes are adaptive and have plasticity.

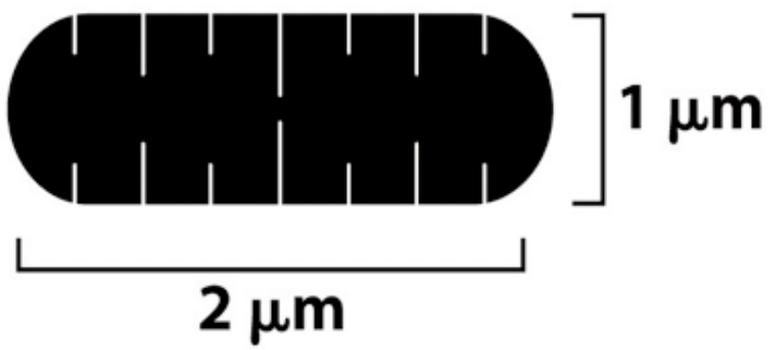






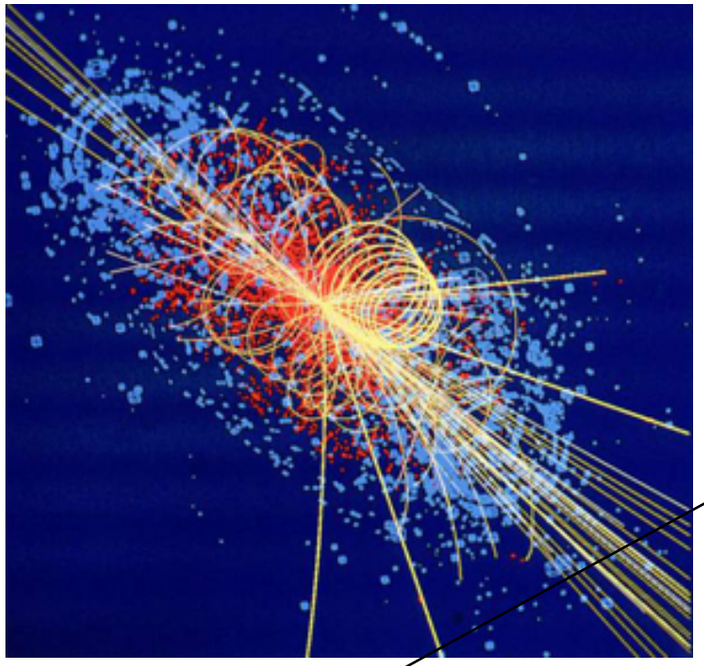
Membranes are complex machines on their own right.

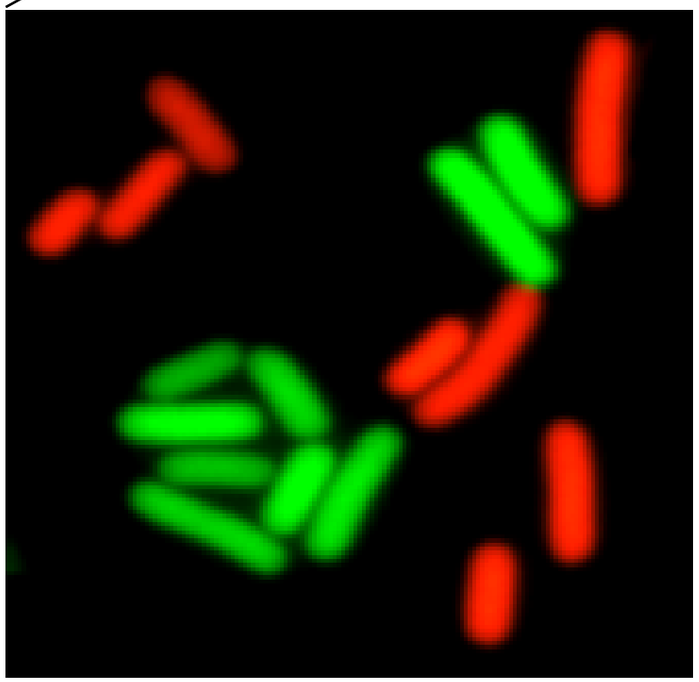
Zoom out

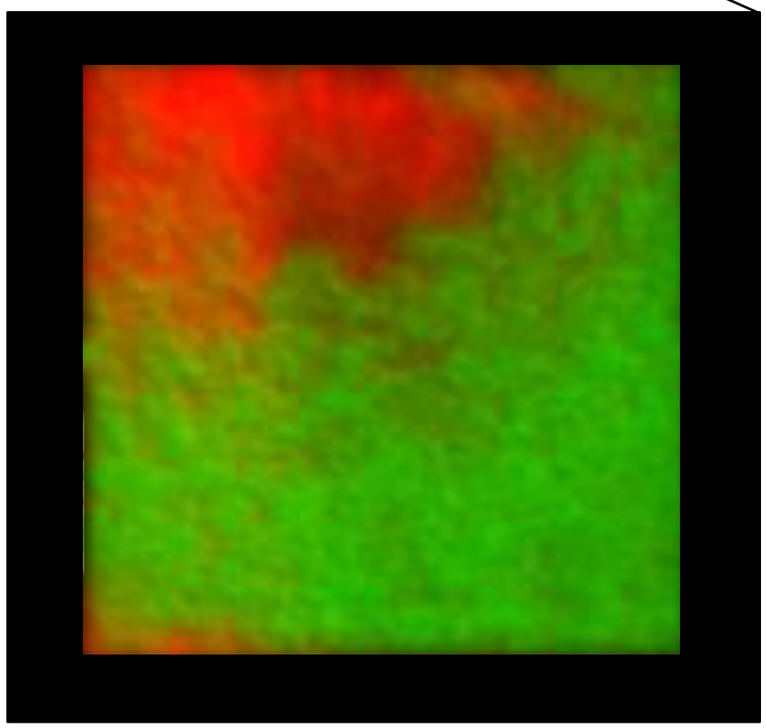


Zoom in

complexity: scale and hierarchy







“More is different”

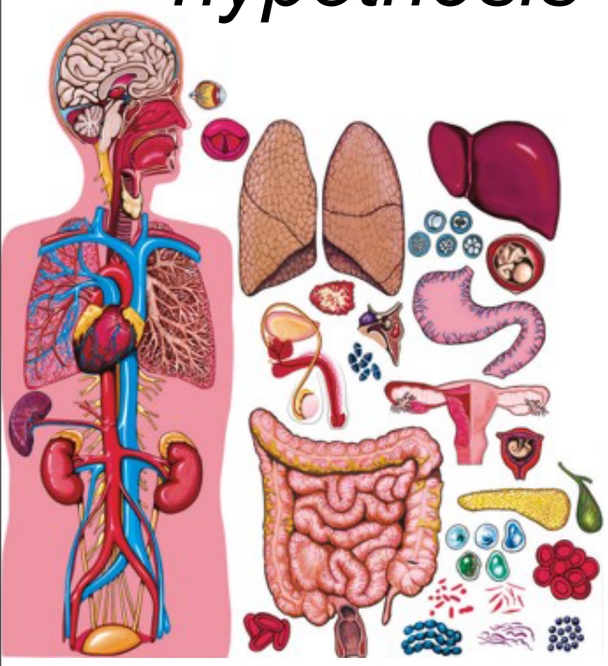
P. W. Anderson Science (1972) 177 p393

Observed world *(broken symmetries)*

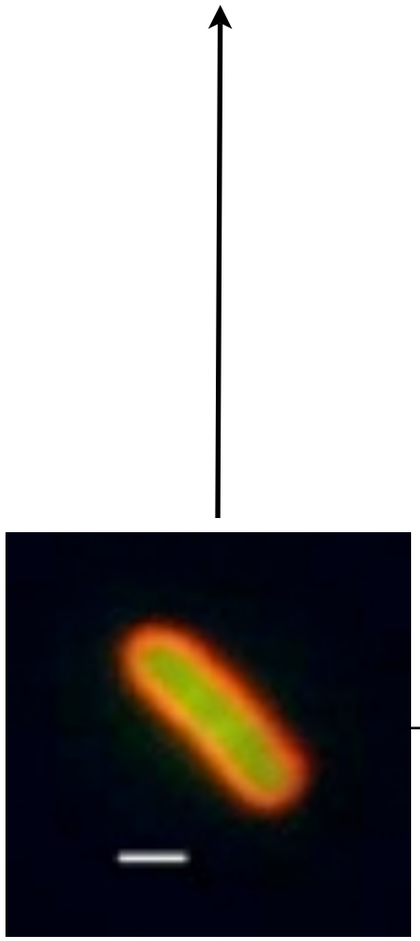
reductionist hypothesis

constructionist hypothesis

scale, complexity



Fundamental laws *(symmetries)*



wt lacYZ::GFP

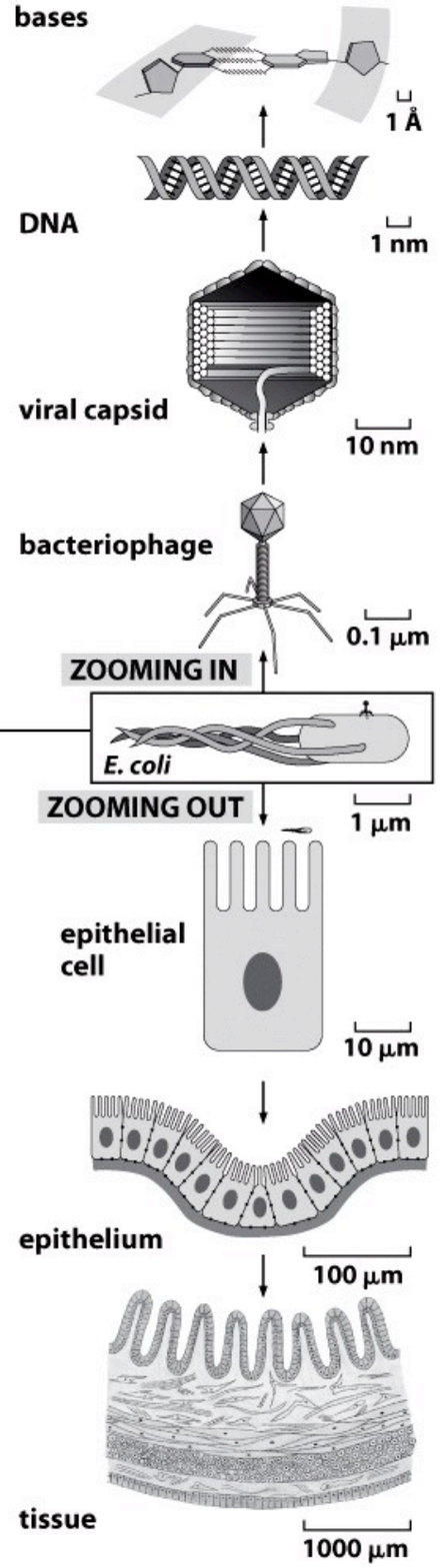


Figure 2.7 Physical Biology of the Cell (© Garland Science 2009)

Zooming IN

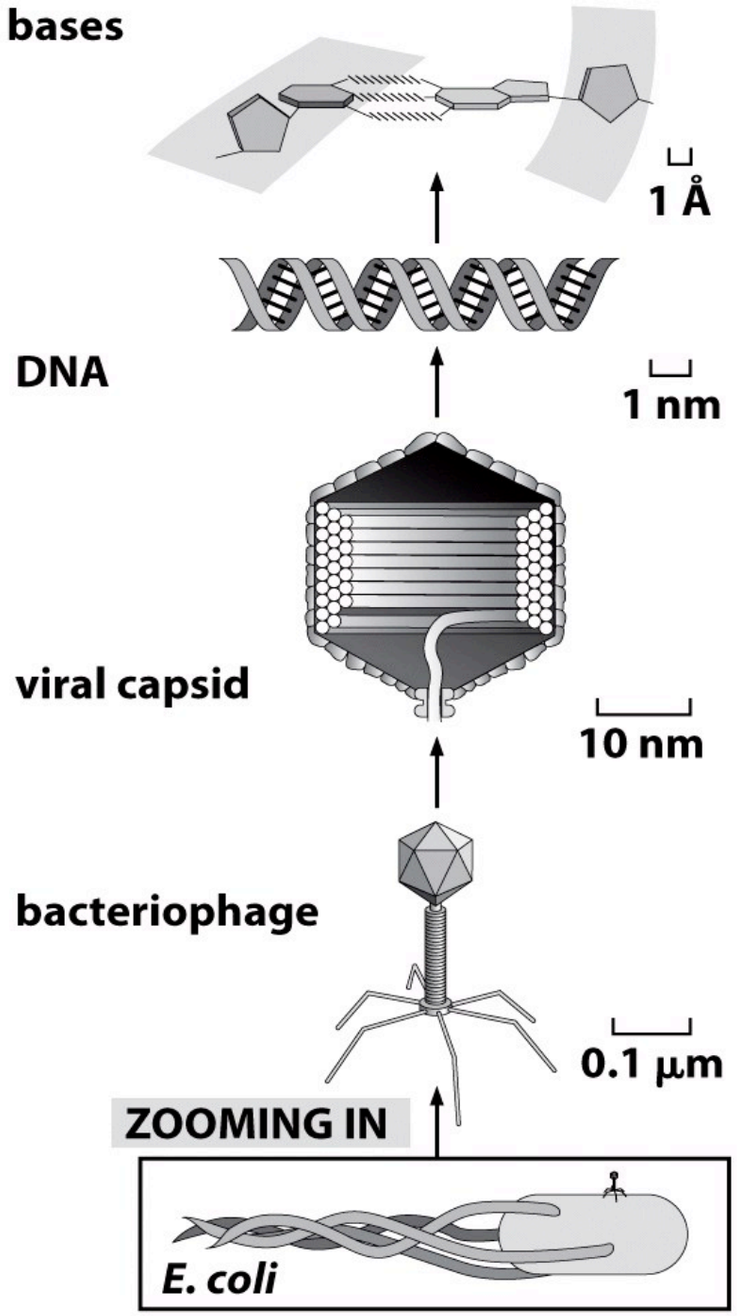


Figure 2.7 (part 1) Physical Biology of the Cell (© Garland Science 2009)

Cells and structures within them (zoom in): biodiversity

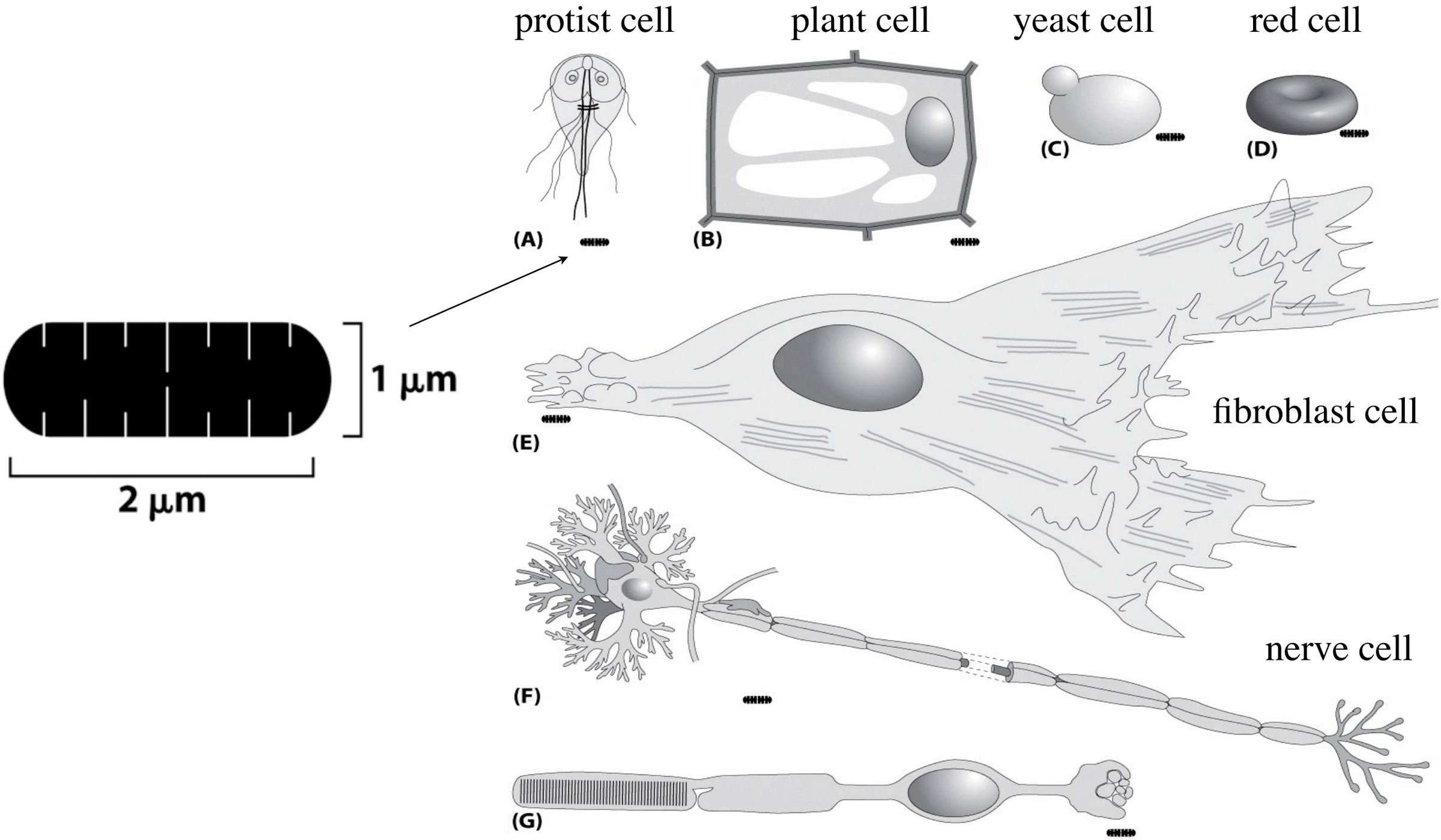
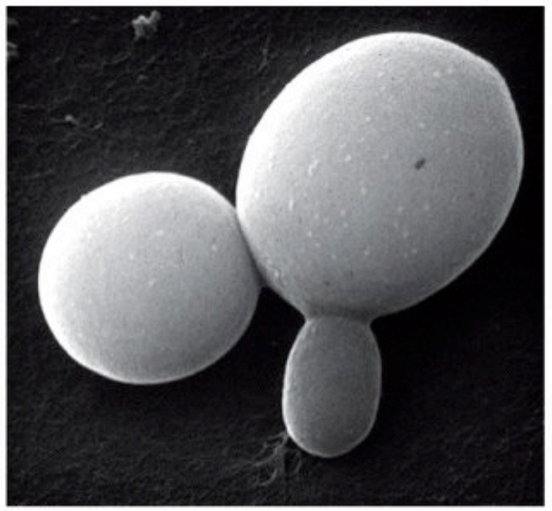


Figure 2.8 Physical Biology of the Cell (© Garland Science 2009)

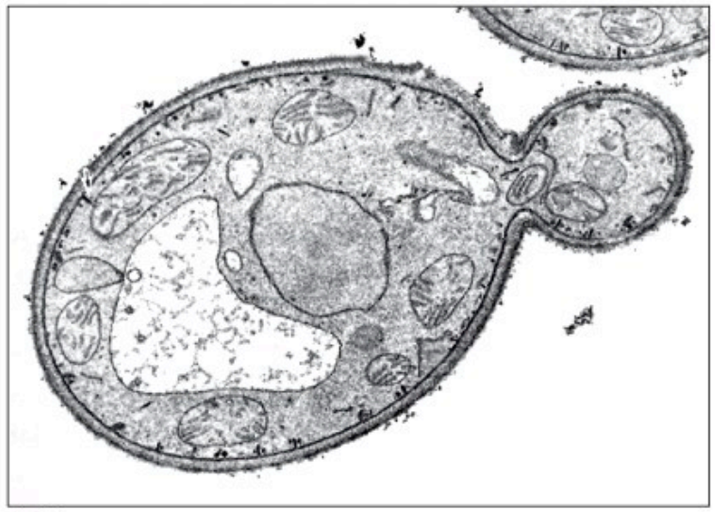
Cells and structures within them (zoom in): organelles

yeast: Candida albicans

SEM



EM



mitocondria: S. cerevisiae

confocal

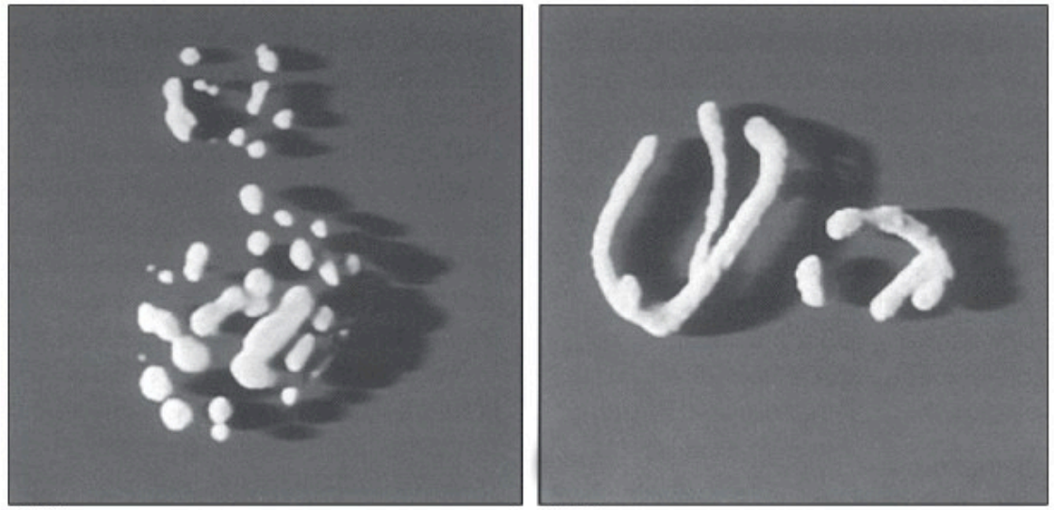
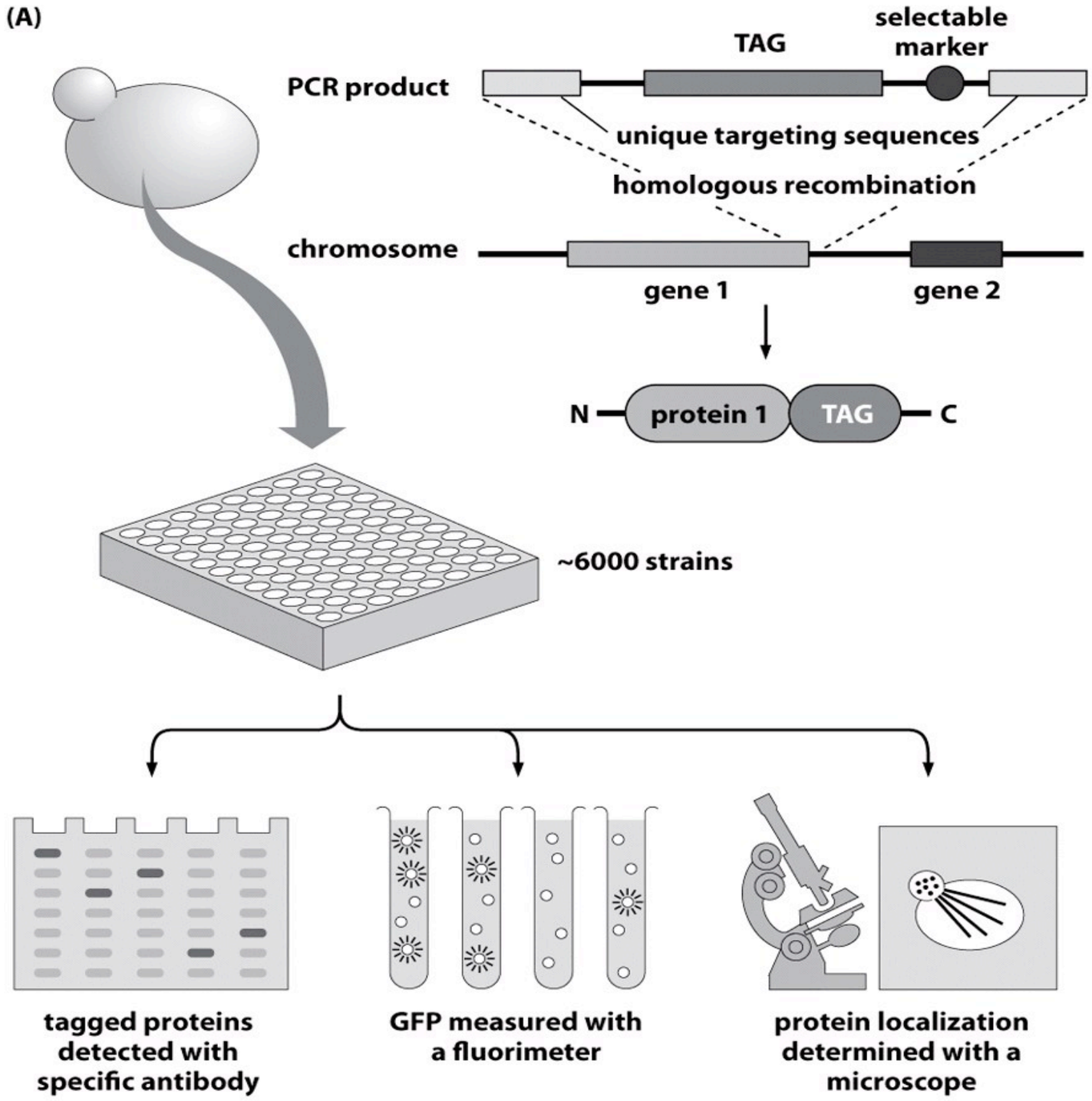
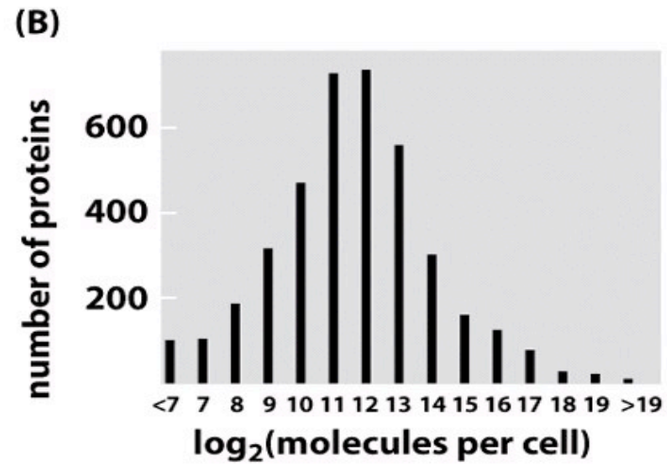


Figure 2.9 Physical Biology of the Cell (© Garland Science 2009)

Cells and structures within them (zoom in): proteins





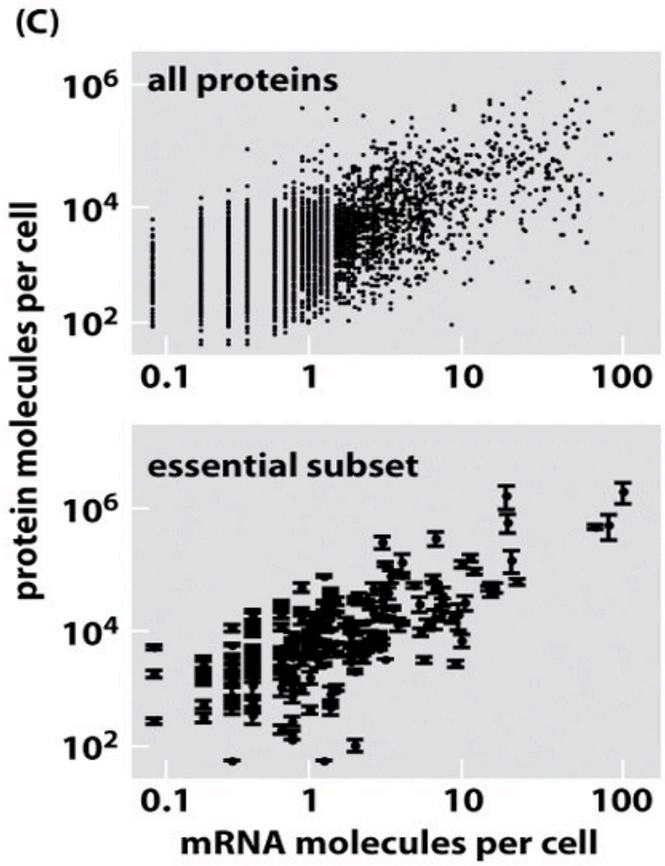
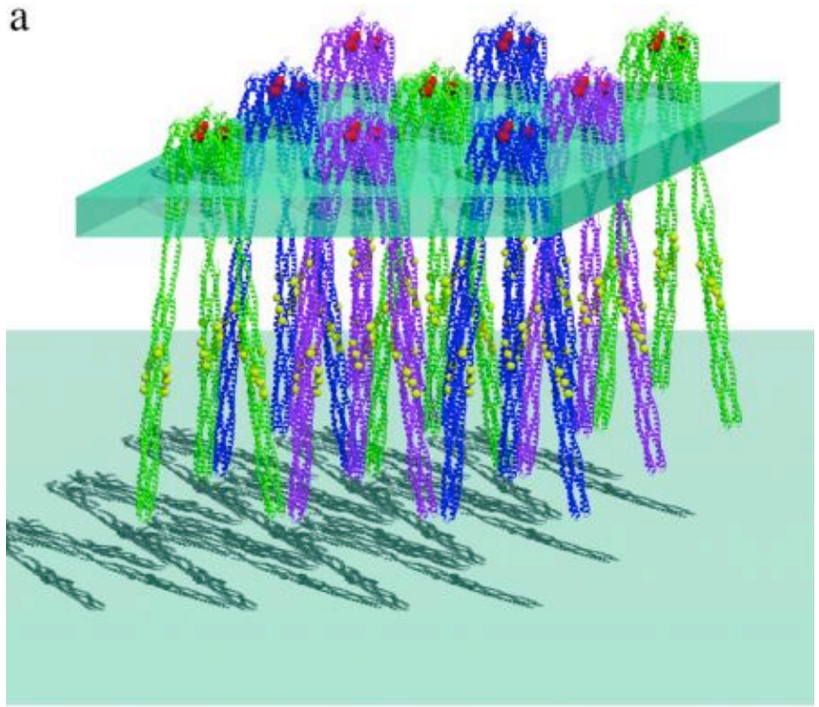
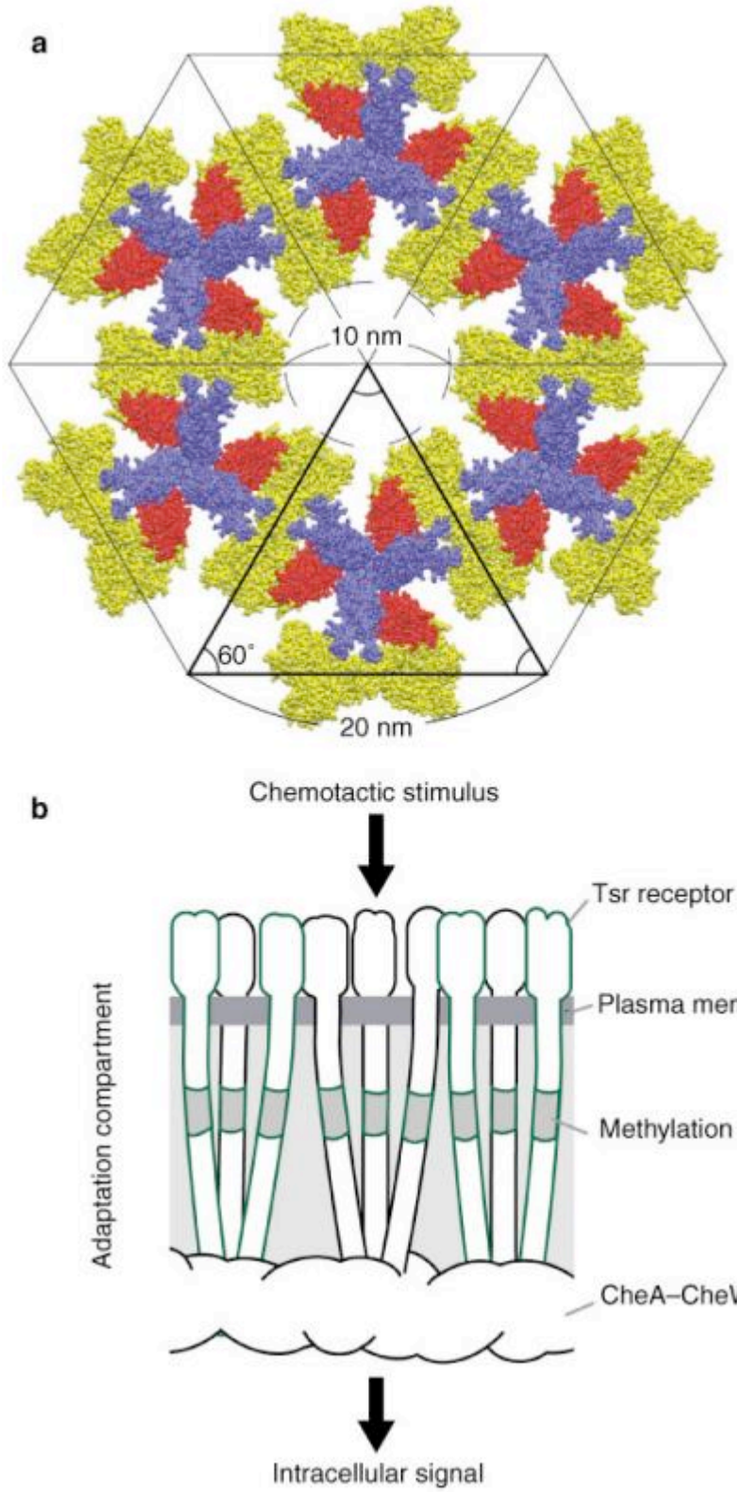
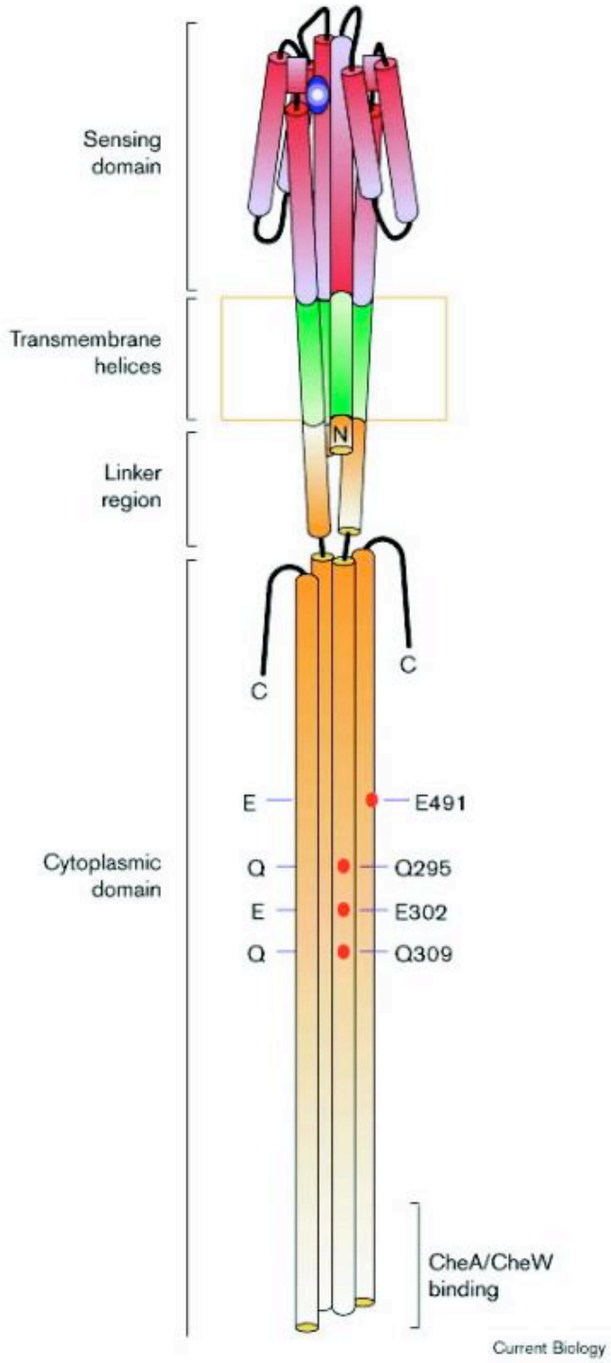


Figure 2.10 Physical Biology of the Cell (© Garland Science 2009)

Cells and structures within them (zoom in): protein-machines







Cells and structures within them (zoom in): protein-machines

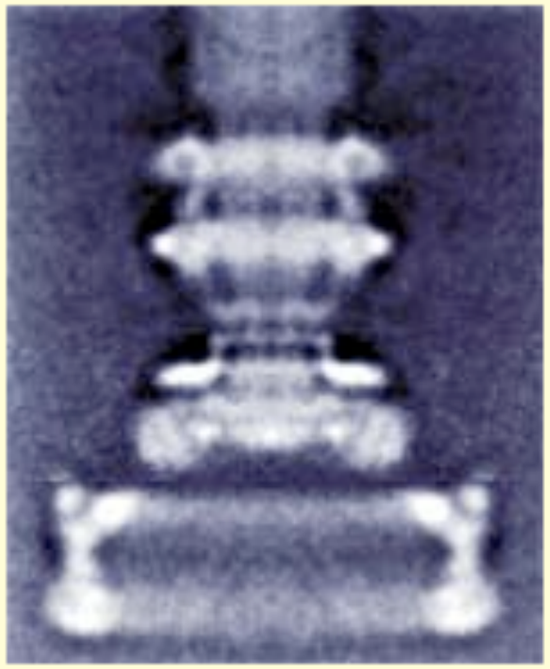
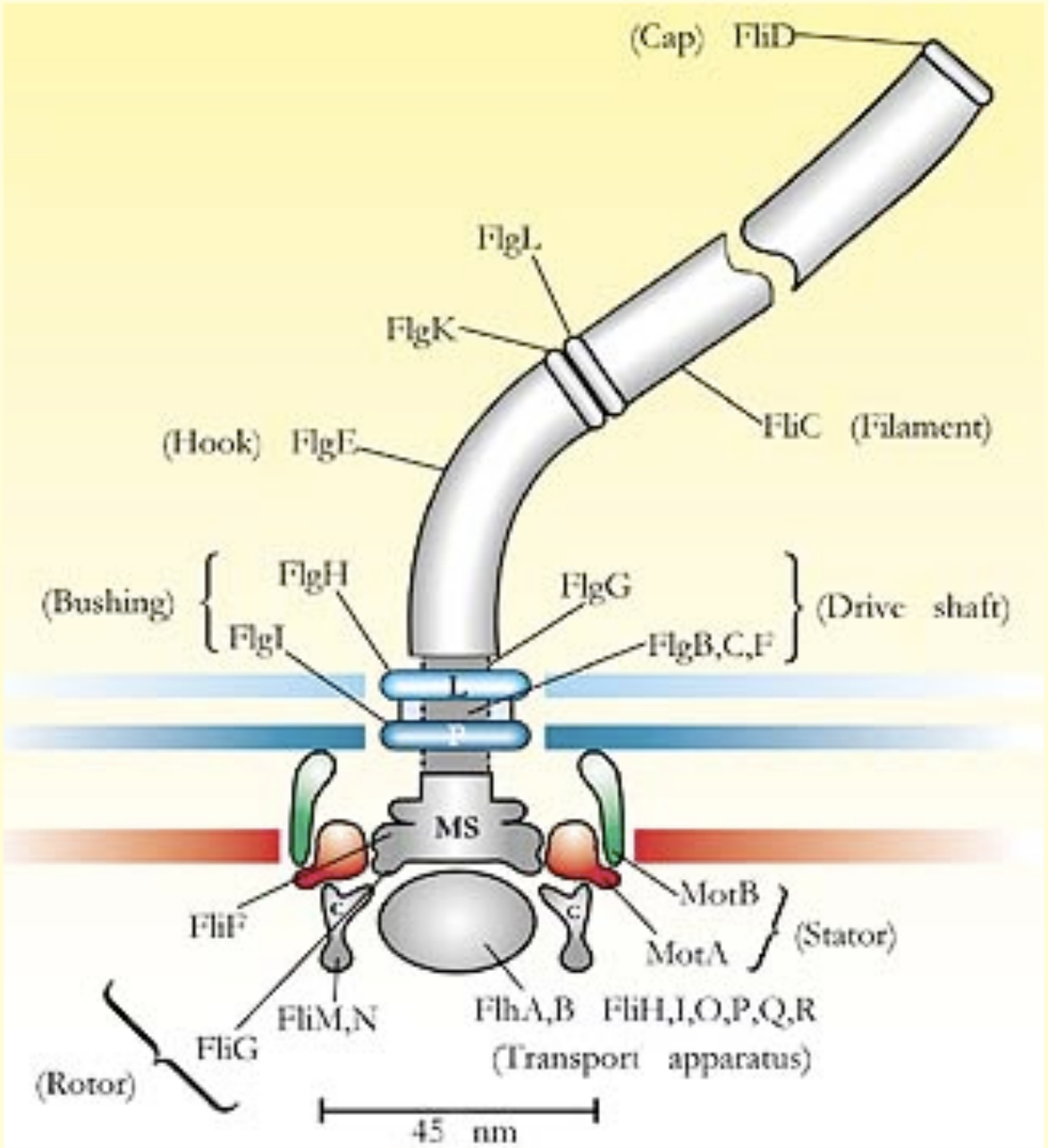
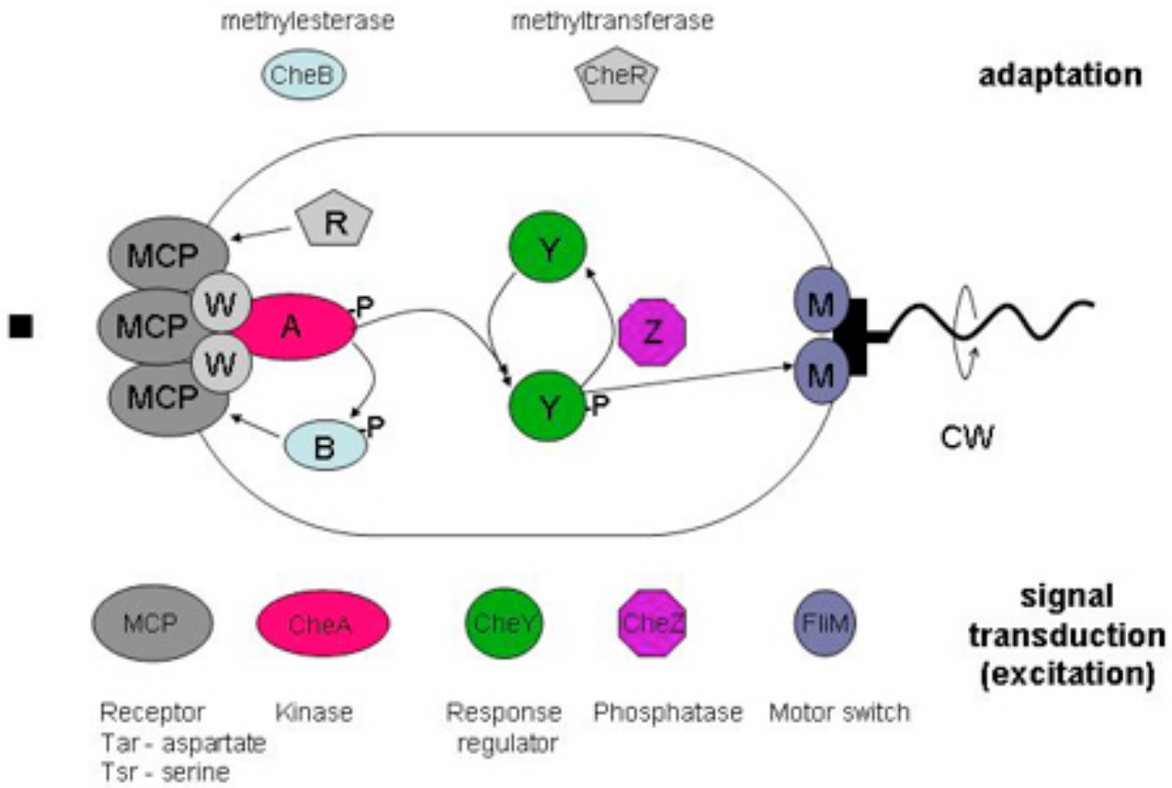


Figure 2. Bacterial motor and drive train.

Above: Rotationally averaged reconstruction of electron micrographs of purified hook-basal bodies. The rings seen in the image and labeled in the schematic diagram **(right)** are the L ring, P ring, MS ring, and C ring. *(Digital print courtesy of David DeRosier, Brandeis University.)*



Cells and structures within them (zoom in): protein-machines



E. coli “cognition” and its intracellular networks

Cells and structures within them (zoom in):
cell functions = adaptations = computations.

Red cells deforming to pass-through

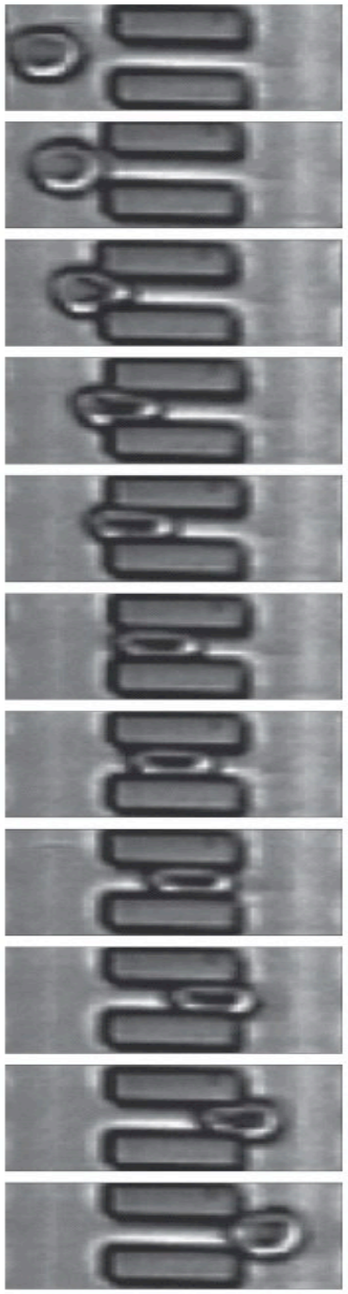
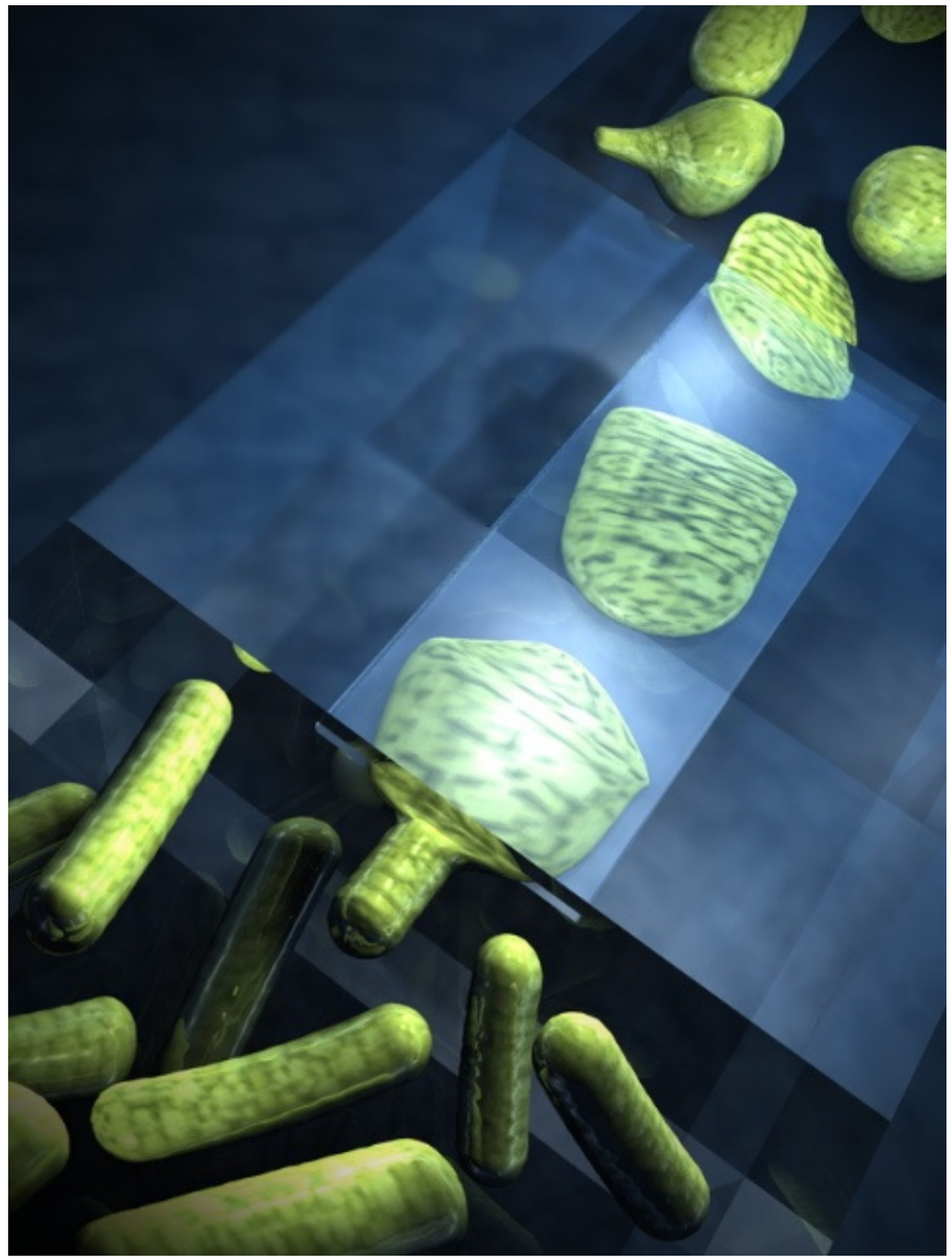


Figure 2.11 Physical Biology of the Cell (© Garland Science 2009)

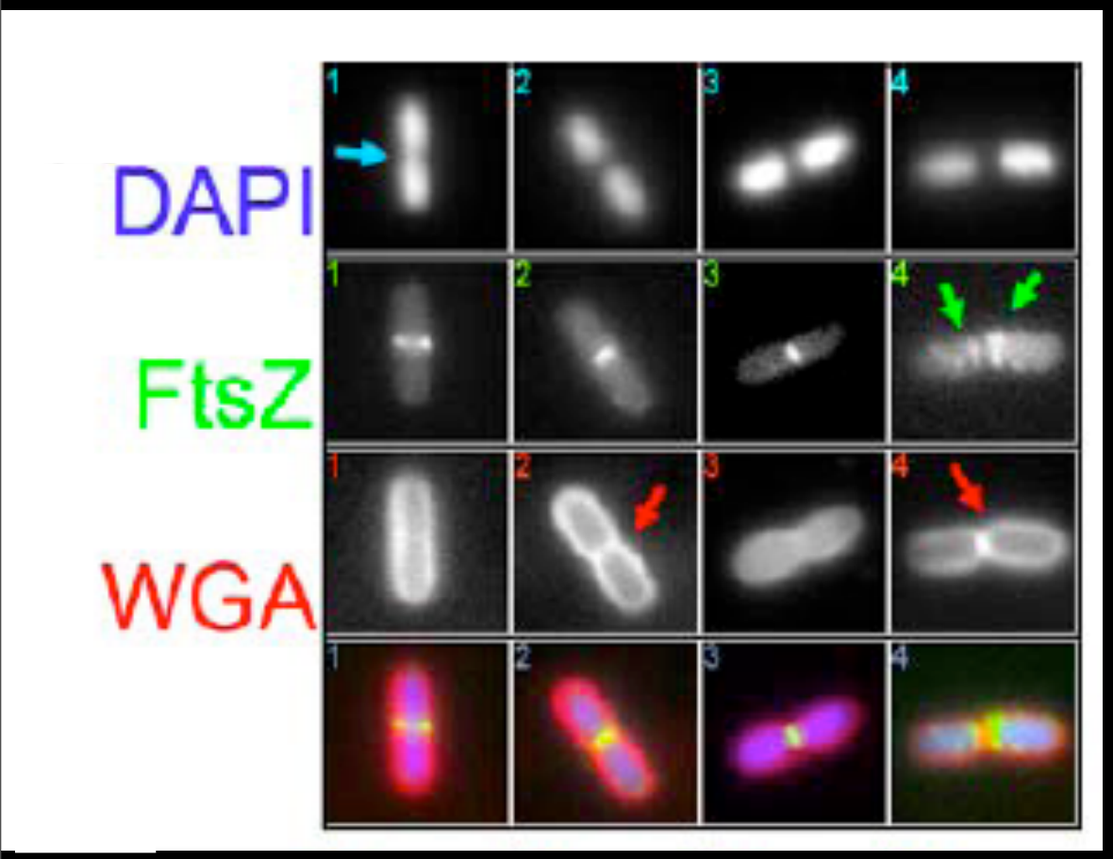
E. coli cells deforming to pass-through



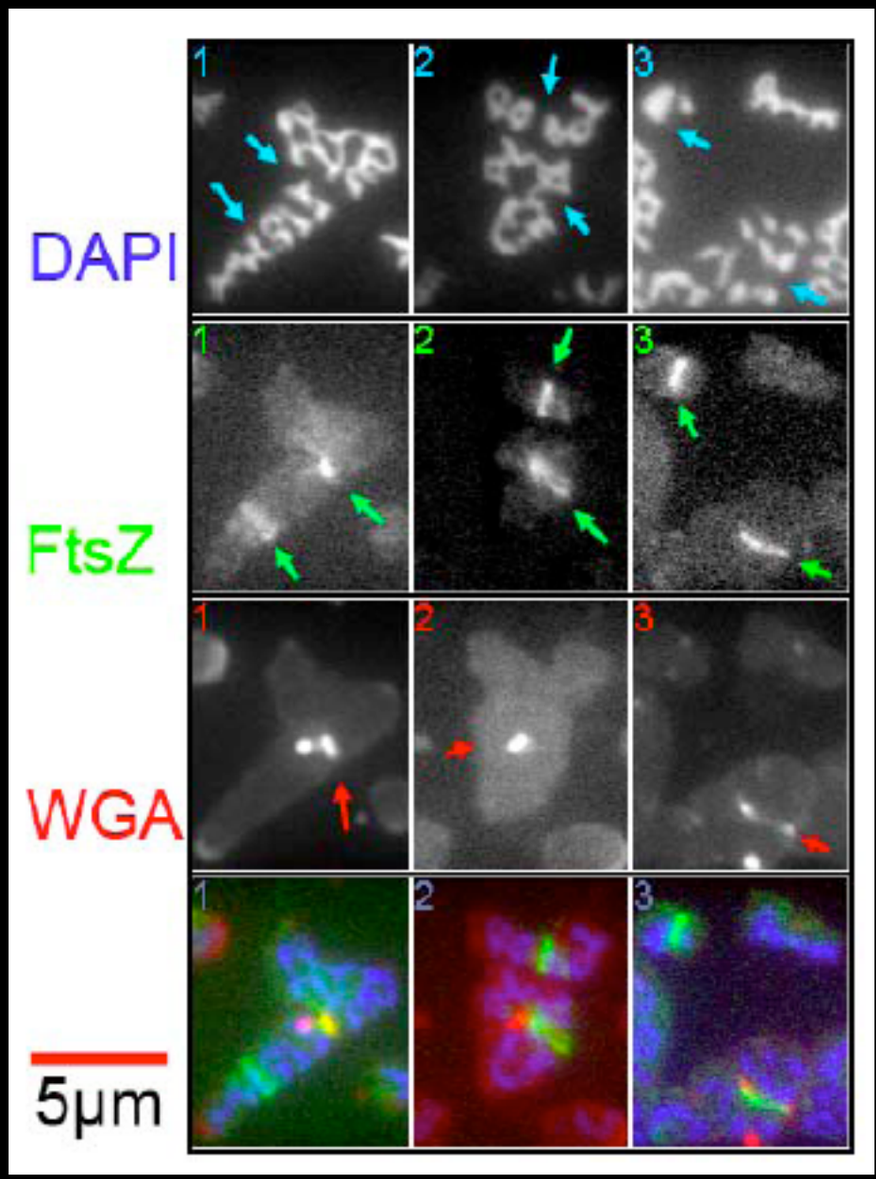
0.25 hr

E. coli

Normal form



L-*ish* form



Cells and structures within them (zoom in):
reticulum

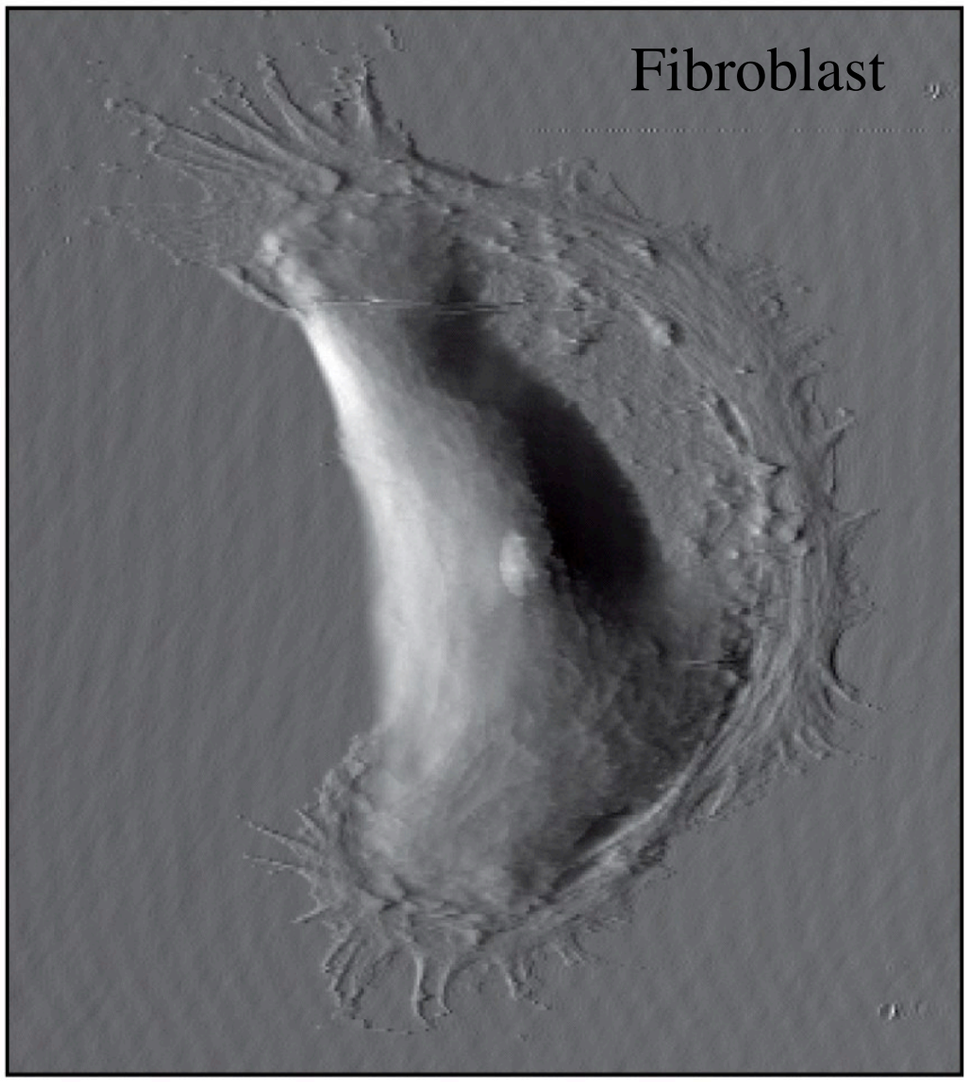


Figure 2.12a Physical Biology of the Cell (© Garland Science 2009)

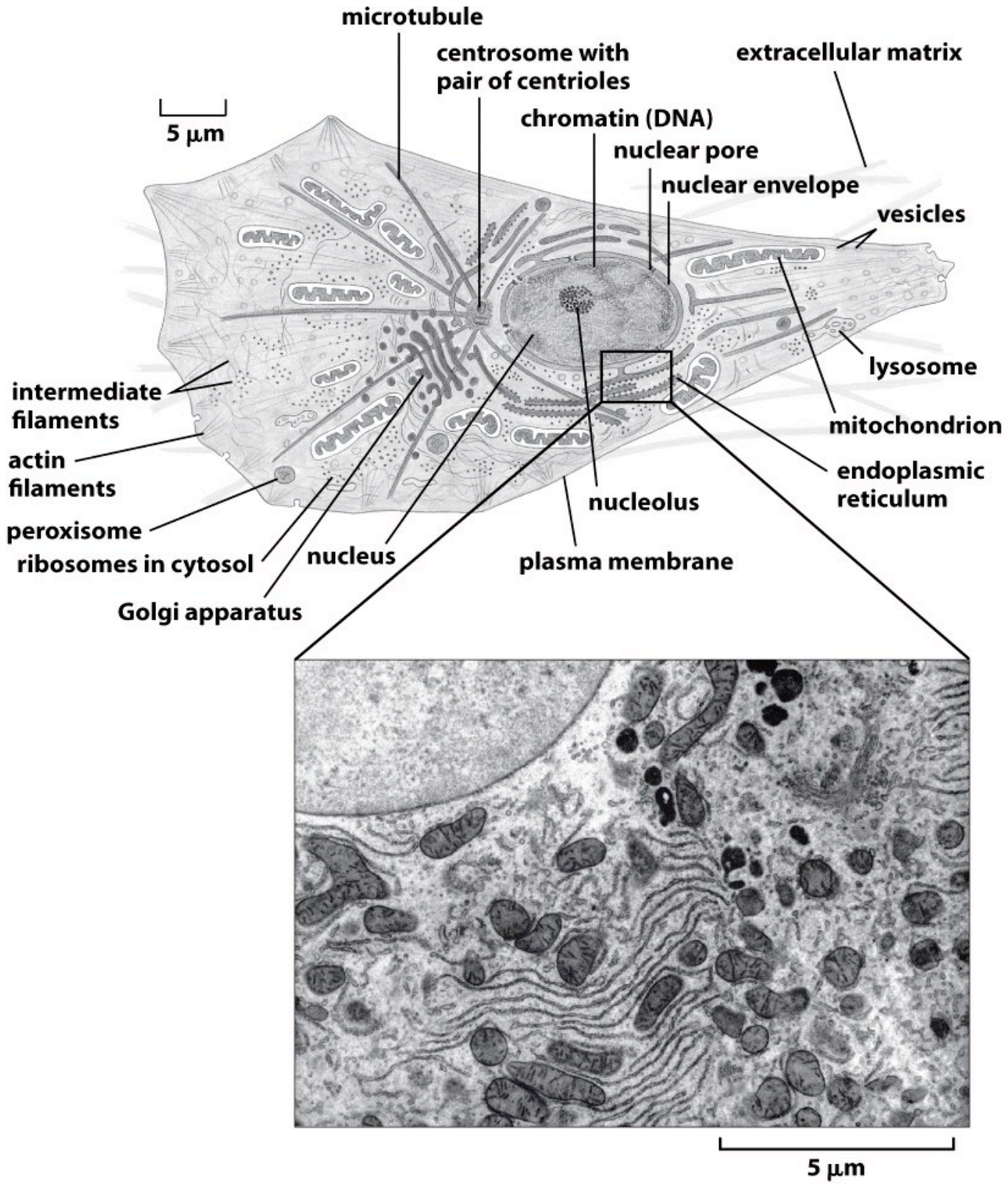


Figure 2.13 Physical Biology of the Cell (© Garland Science 2009)

Cells and structures within them (zoom in):

reticulum

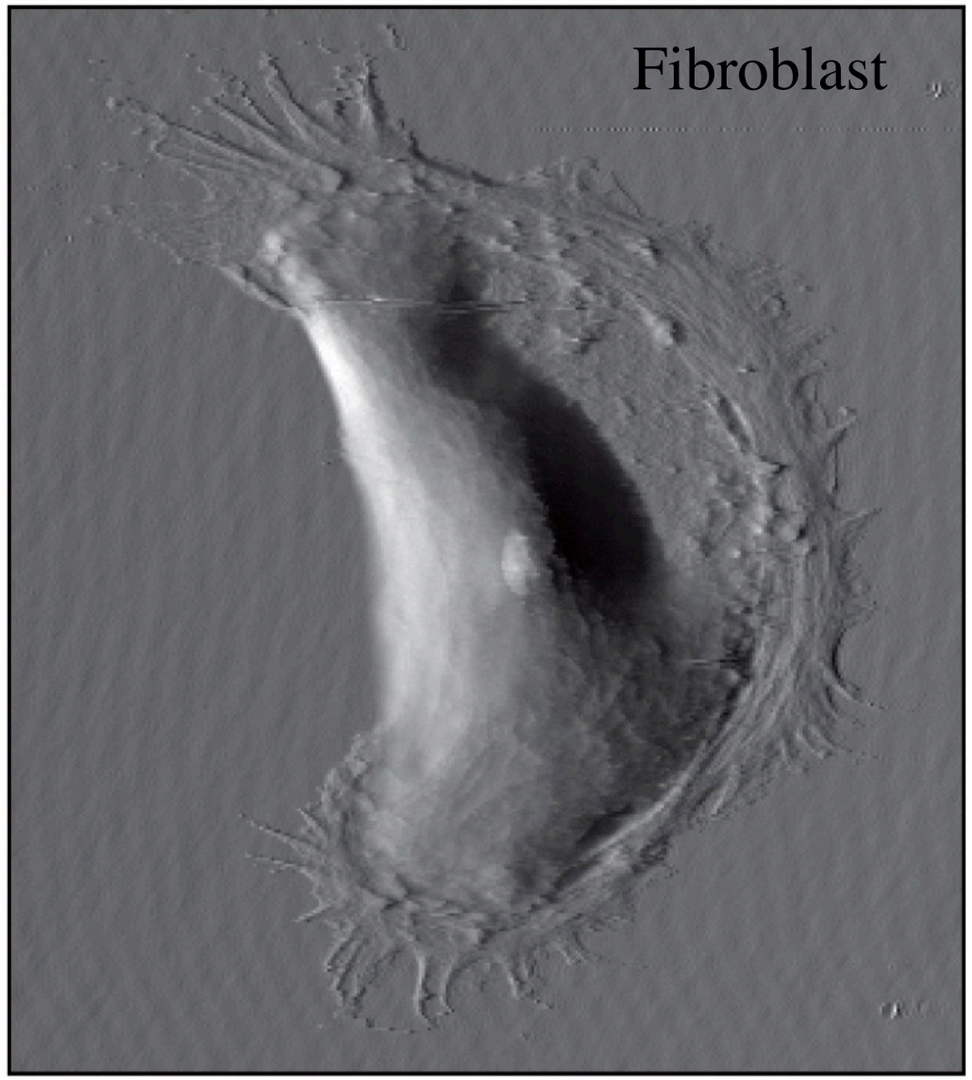
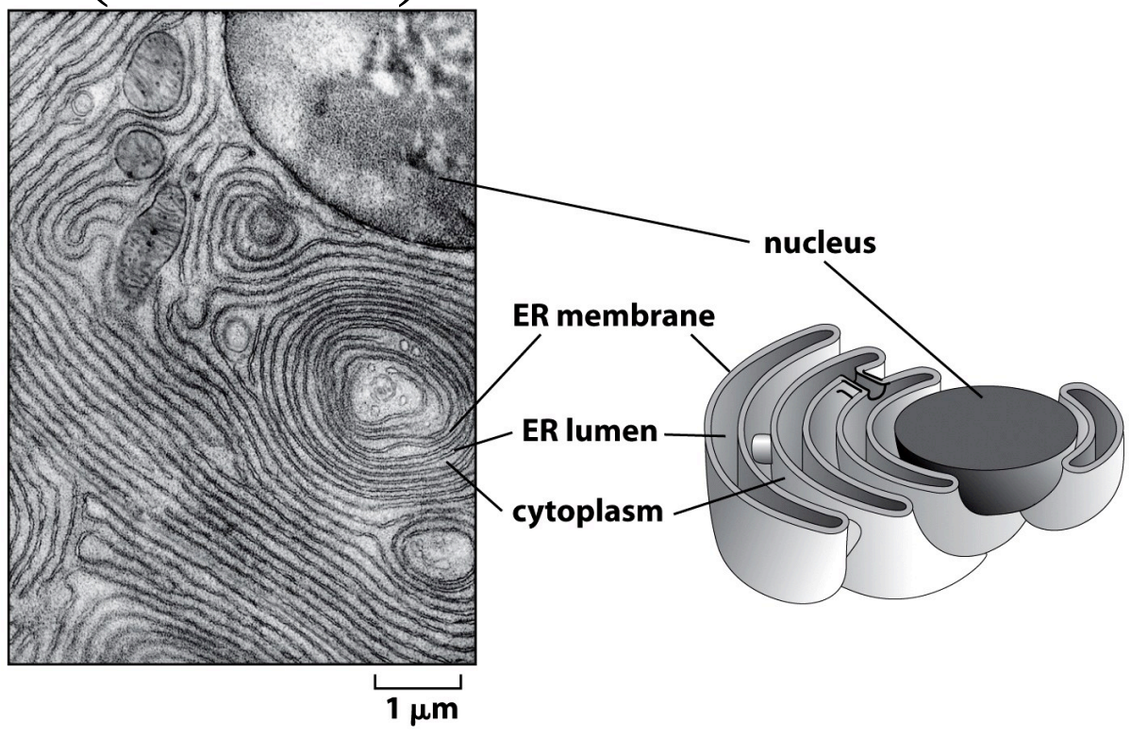
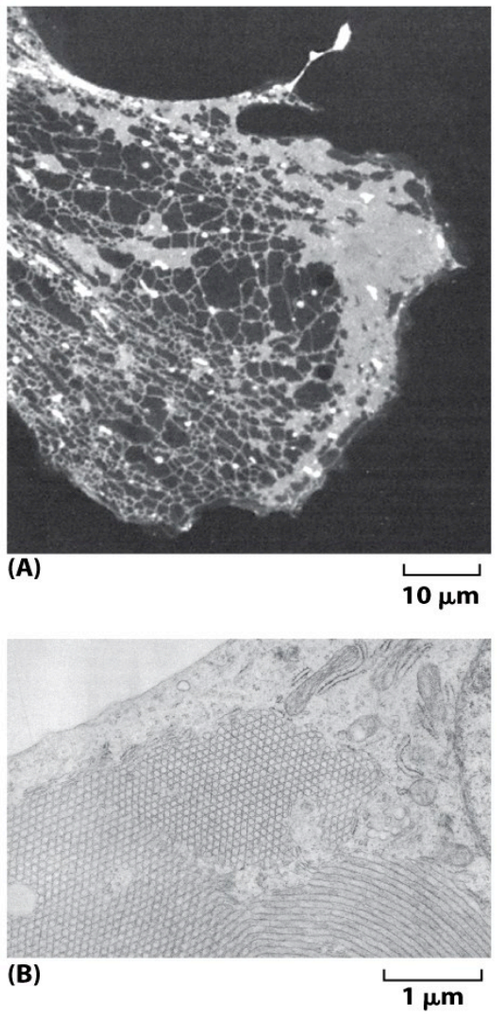


Figure 2.12a Physical Biology of the Cell (© Garland Science 2009)





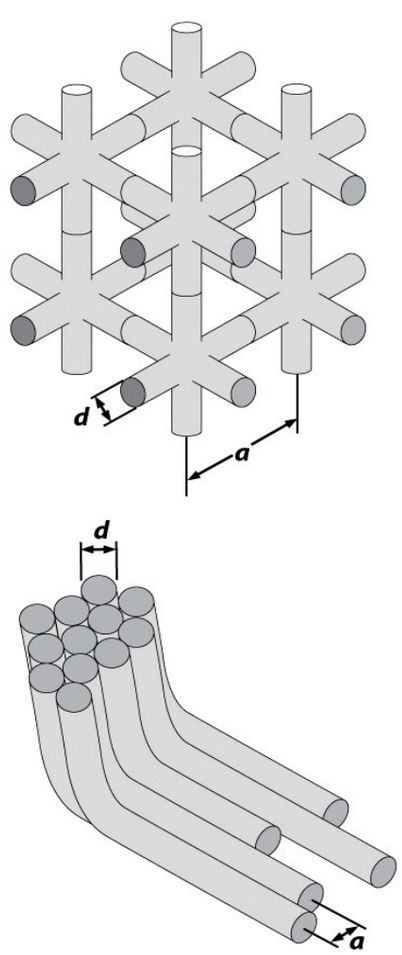


Figure 2.15 Physical Biology of the Cell (© Garland Science 2009)

Cells and structures within them (zoom in): macro-molecular machines (cell assembly?)

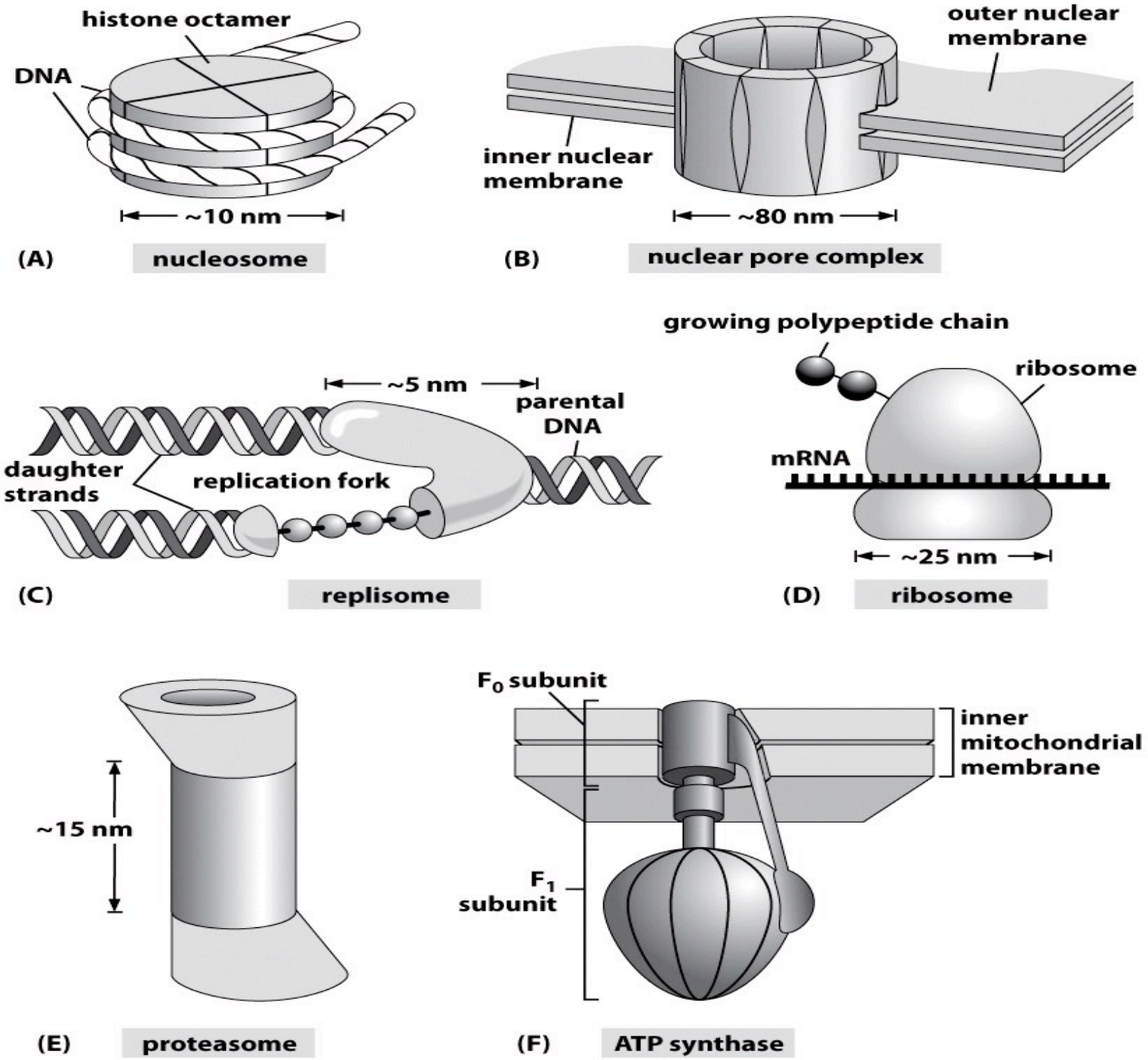


Figure 2.16 Physical Biology of the Cell (© Garland Science 2009)

Cells and structures within them (zoom in): macro-molecular helical motifs

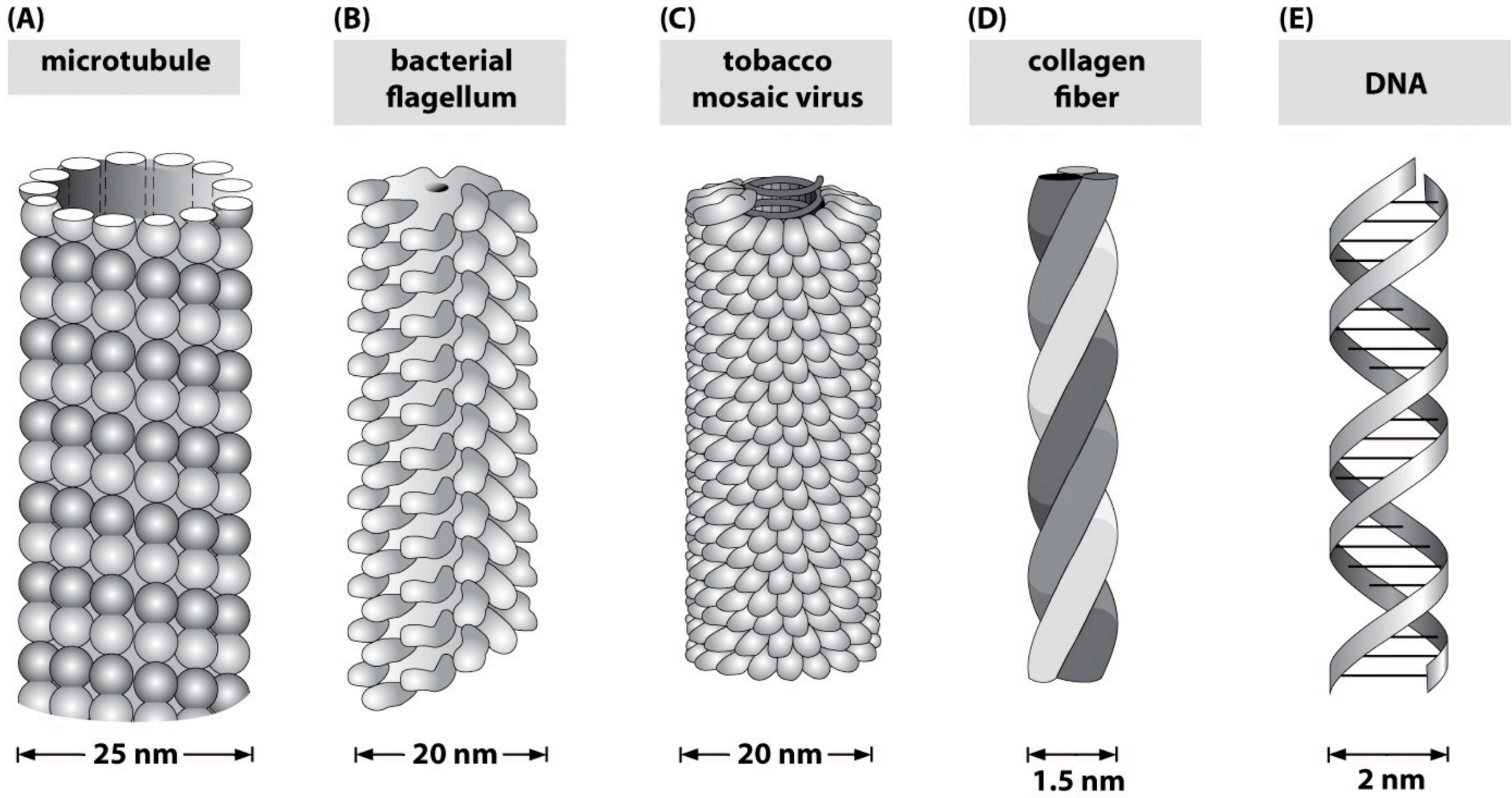


Figure 2.17 Physical Biology of the Cell (© Garland Science 2009)

Cells and structures within them (zoom in): macro-molecular super-structures

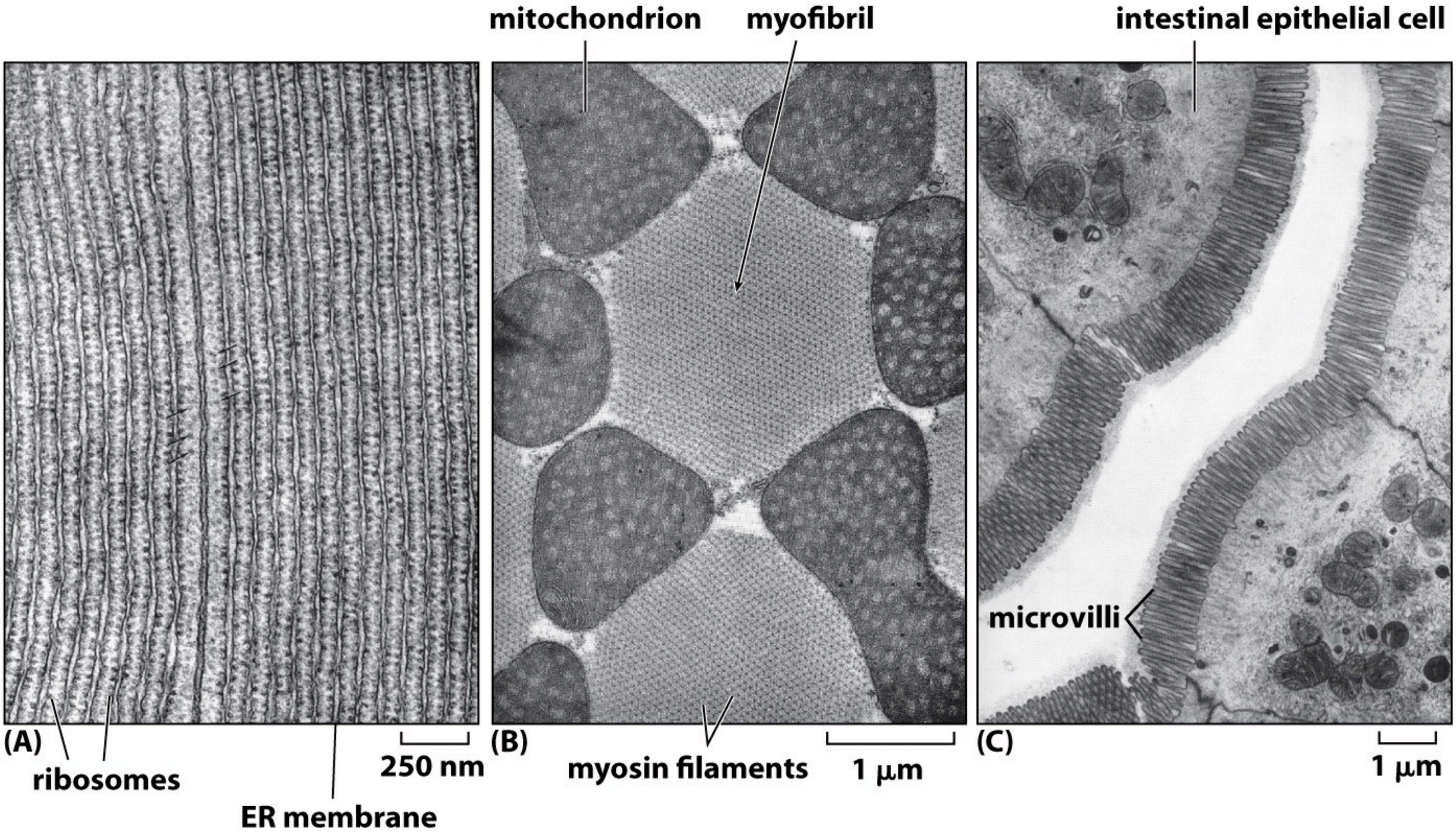


Figure 2.18 Physical Biology of the Cell (© Garland Science 2009)

Cells and structures within them (zoom in): macro-molecular parcels (viruses & phages)

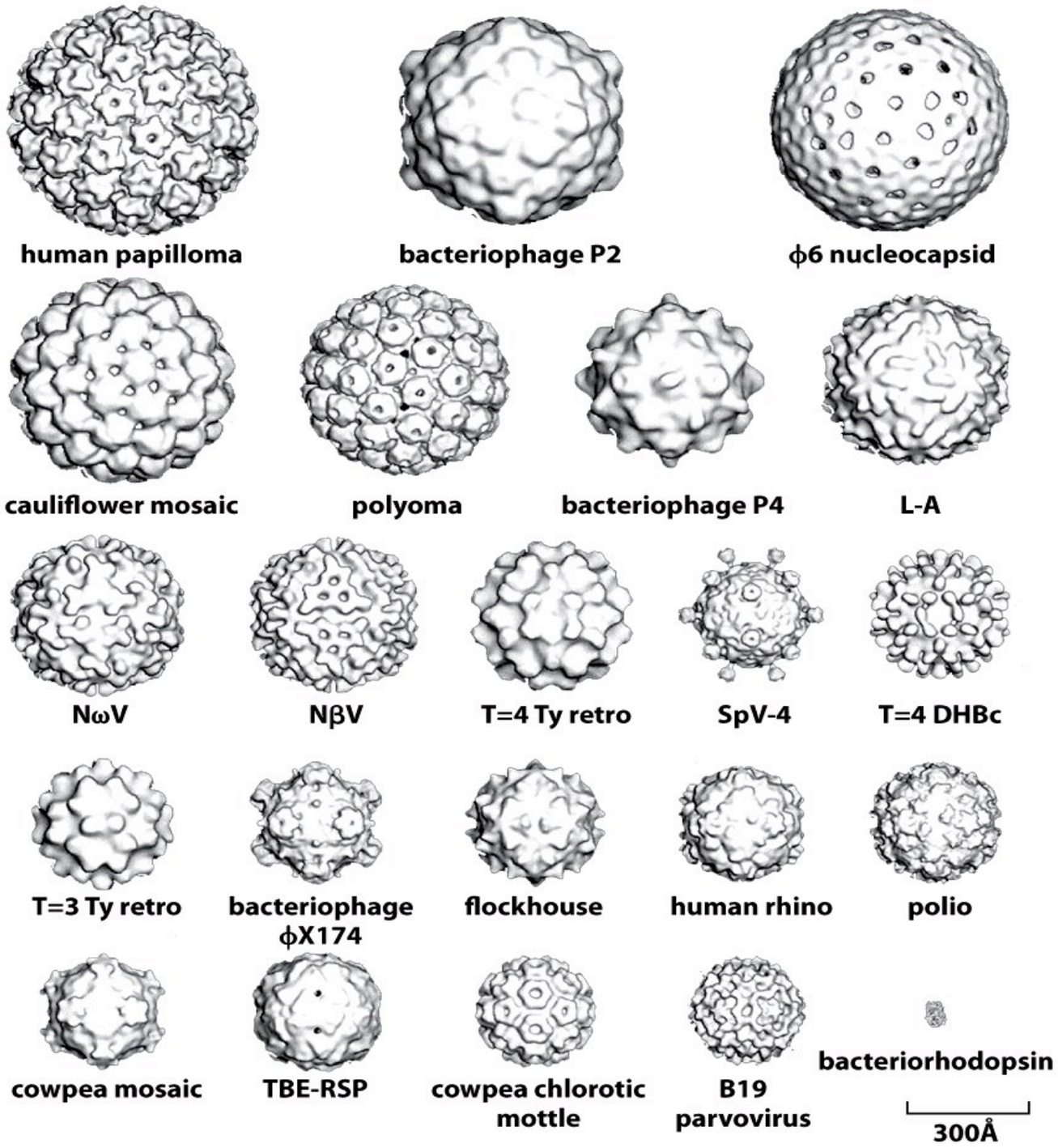


Figure 2.19 Physical Biology of the Cell (© Garland Science 2009)

Cells and structures within them (zoom in): proteins (databases)

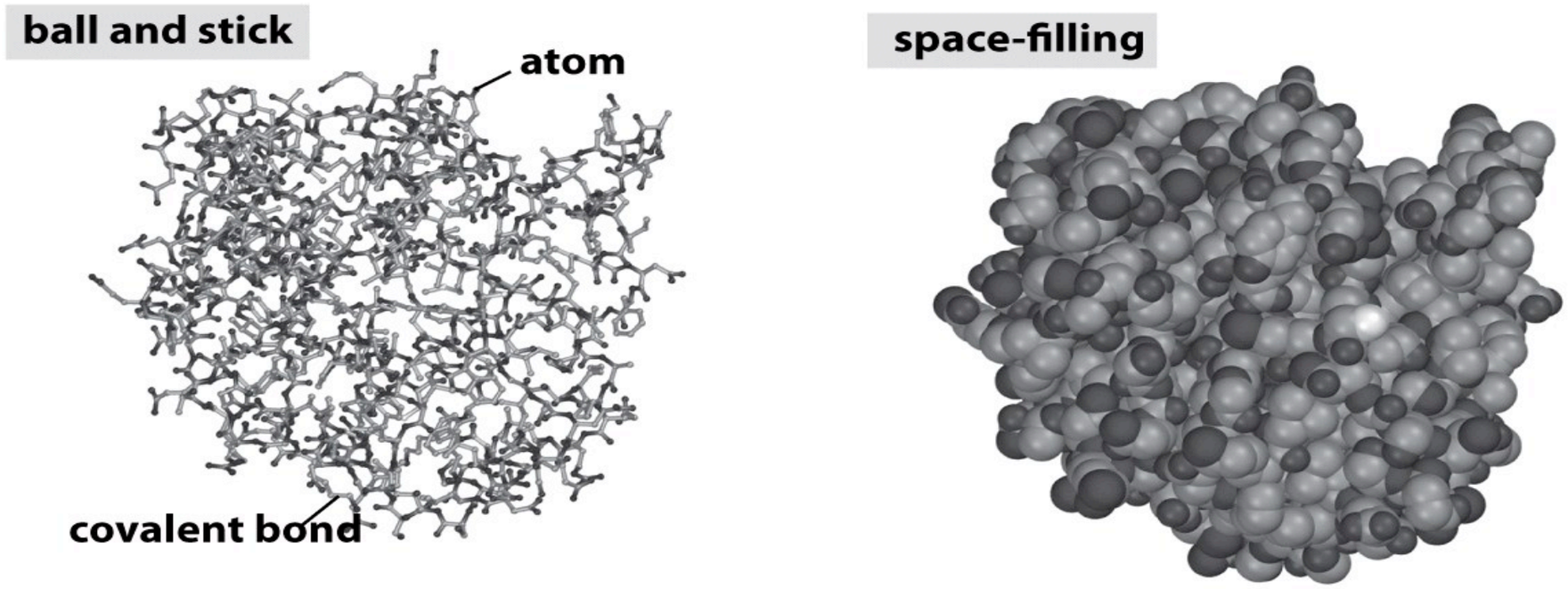


Figure 2.22 Physical Biology of the Cell (© Garland Science 2009)

Cells and structures within them (zoom in): amino acid & chemical groups

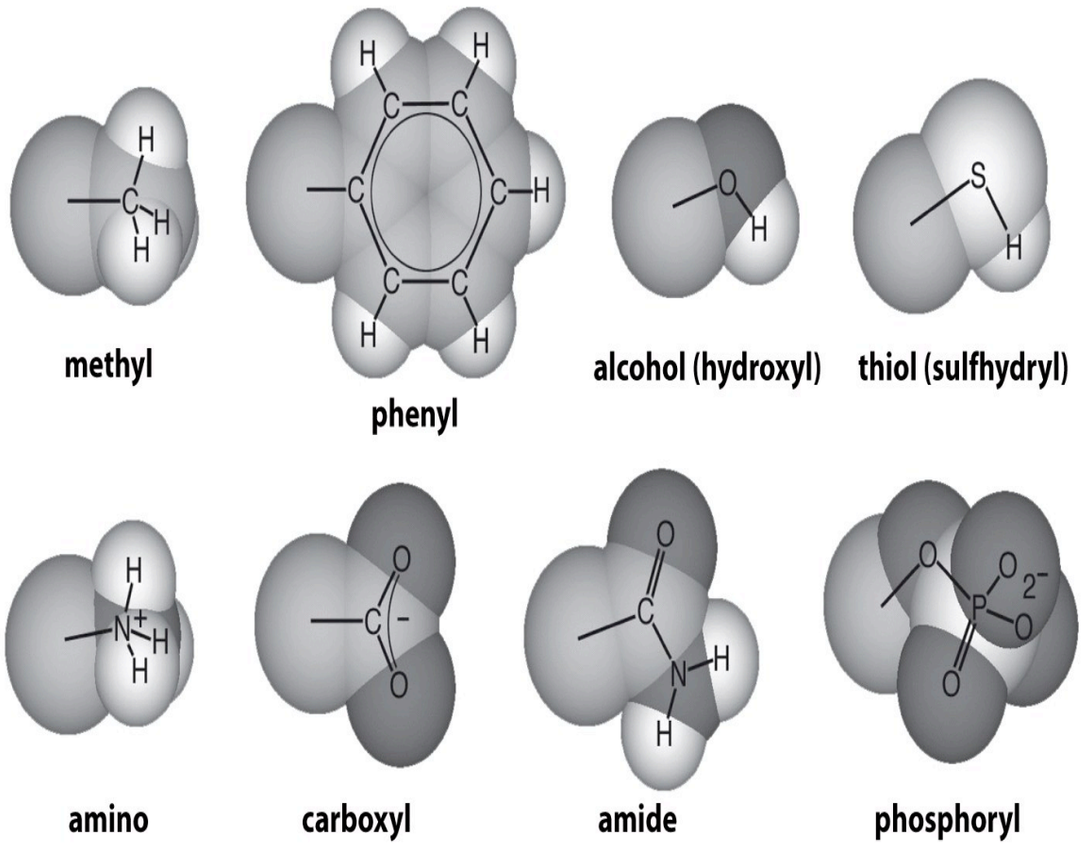


Figure 2.24 Physical Biology of the Cell (© Garland Science 2009)

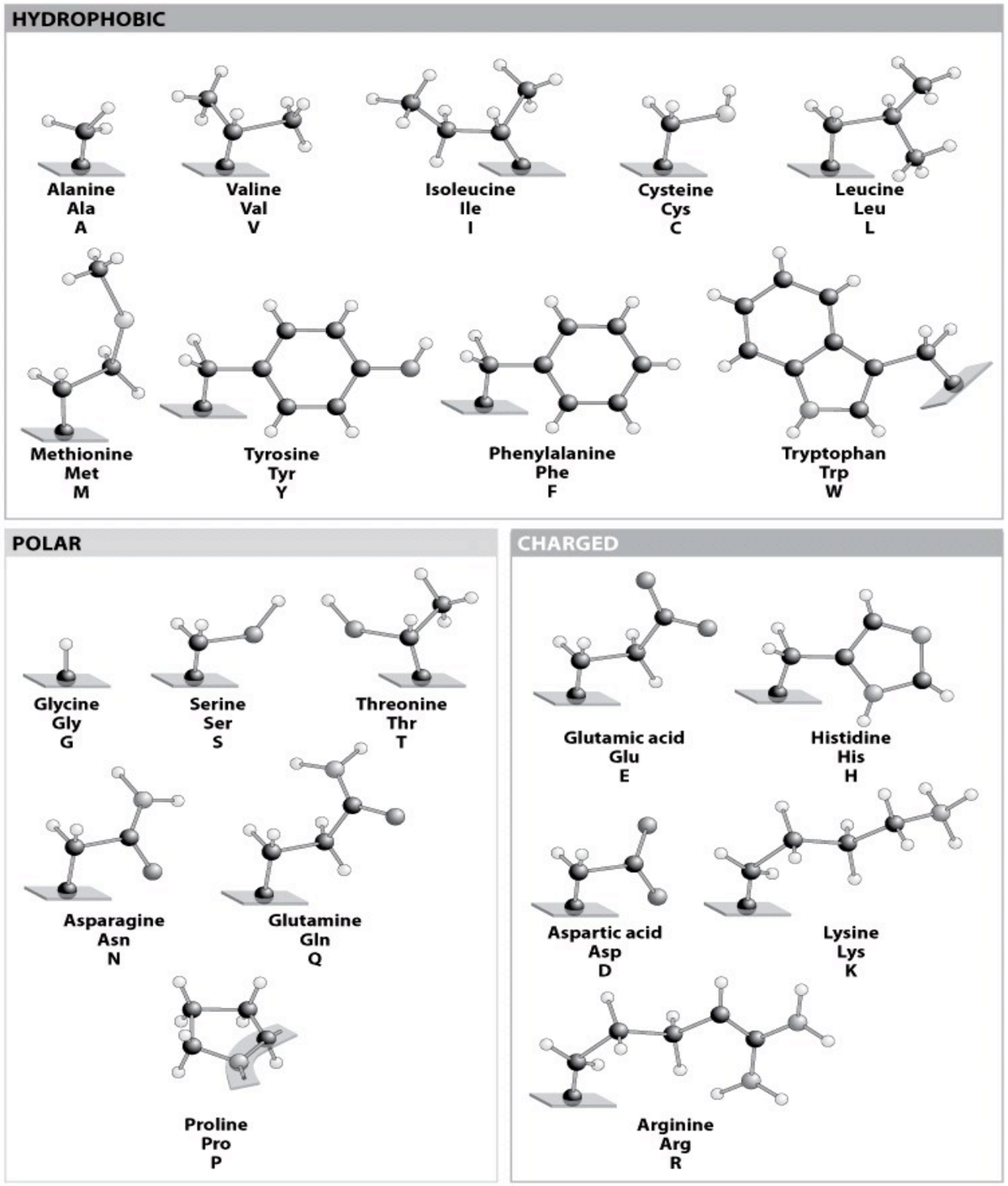
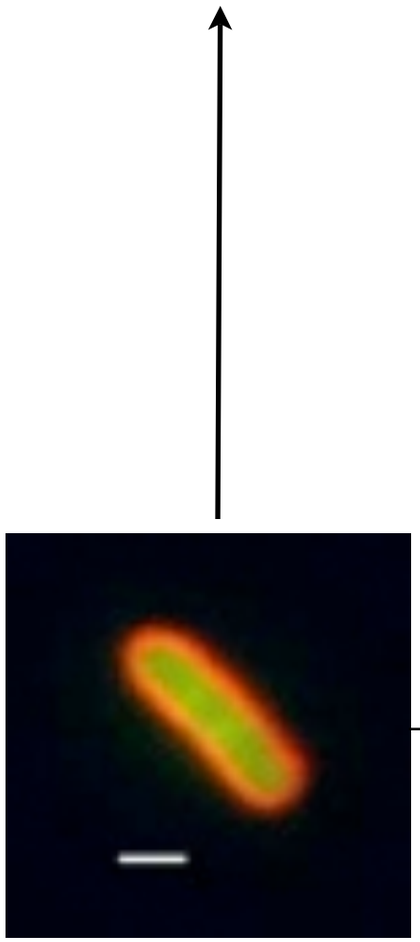


Figure 2.23 Physical Biology of the Cell (© Garland Science 2009)



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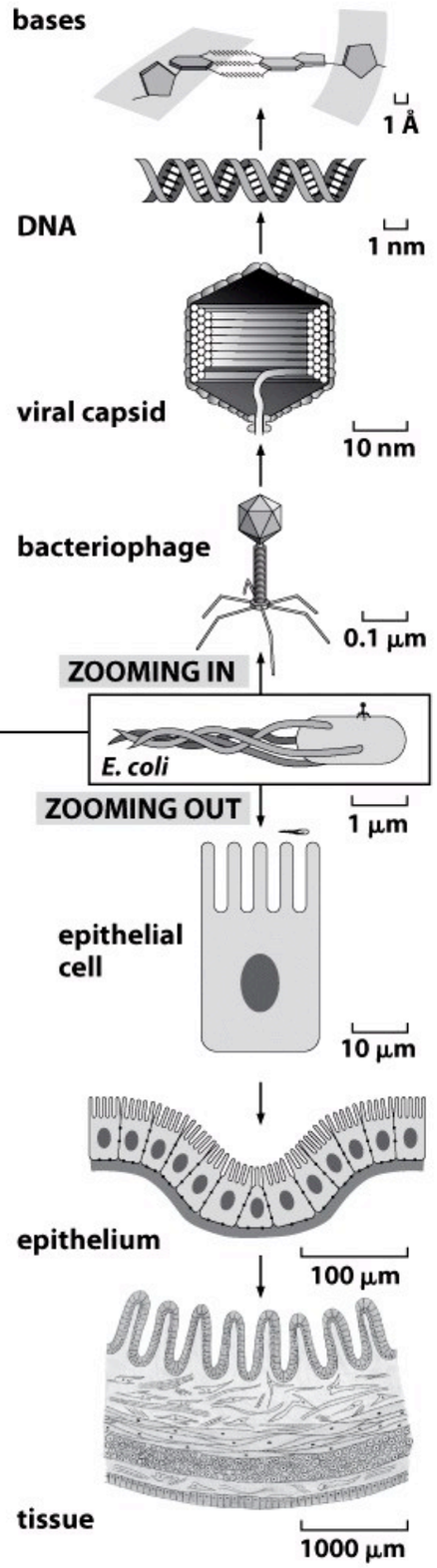


Figure 2.7 Physical Biology of the Cell (© Garland Science 2009)

Zooming OUT

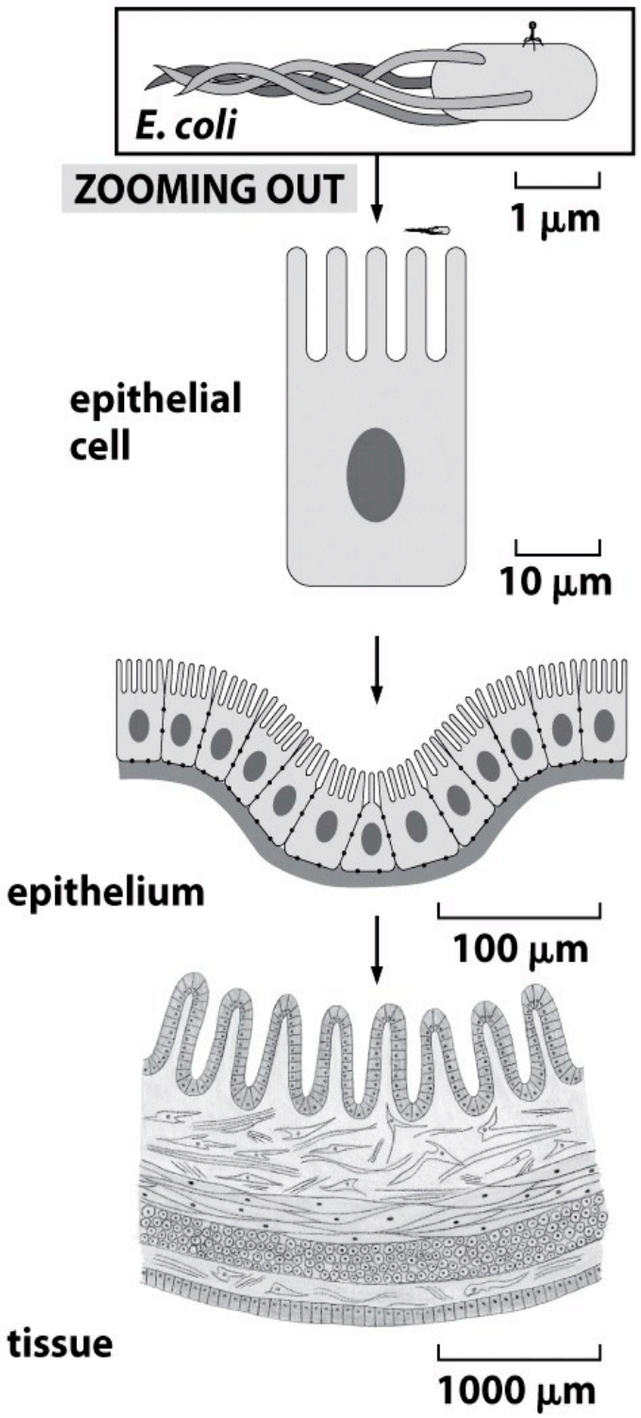


Figure 2.7 (part 2) Physical Biology of the Cell (© Garland Science 2009)

Cells do not go it alone (telescoping out): cellular communities (ecologies of cooperation)

Stromatolites | Bacterial biofilms | Social ameba | Drosophila eye

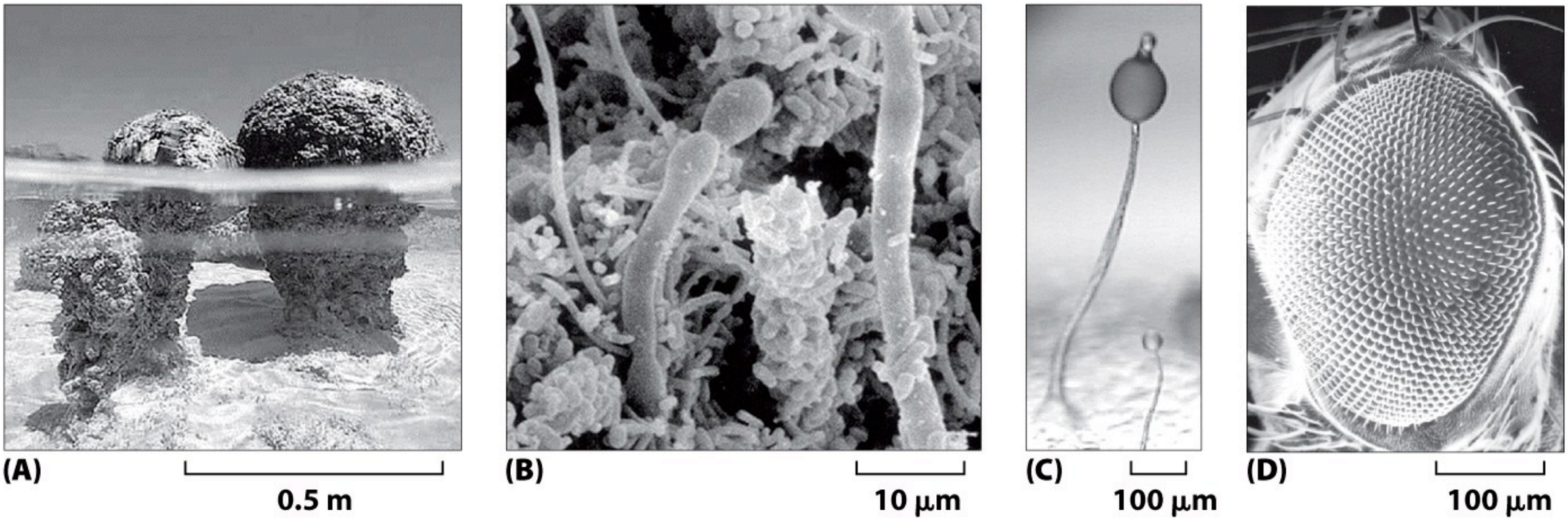


Figure 2.25 Physical Biology of the Cell (© Garland Science 2009)

Multi-cellularity is one of evolution's greatest inventions (cell communication and cooperation).

Cell communication and cooperation

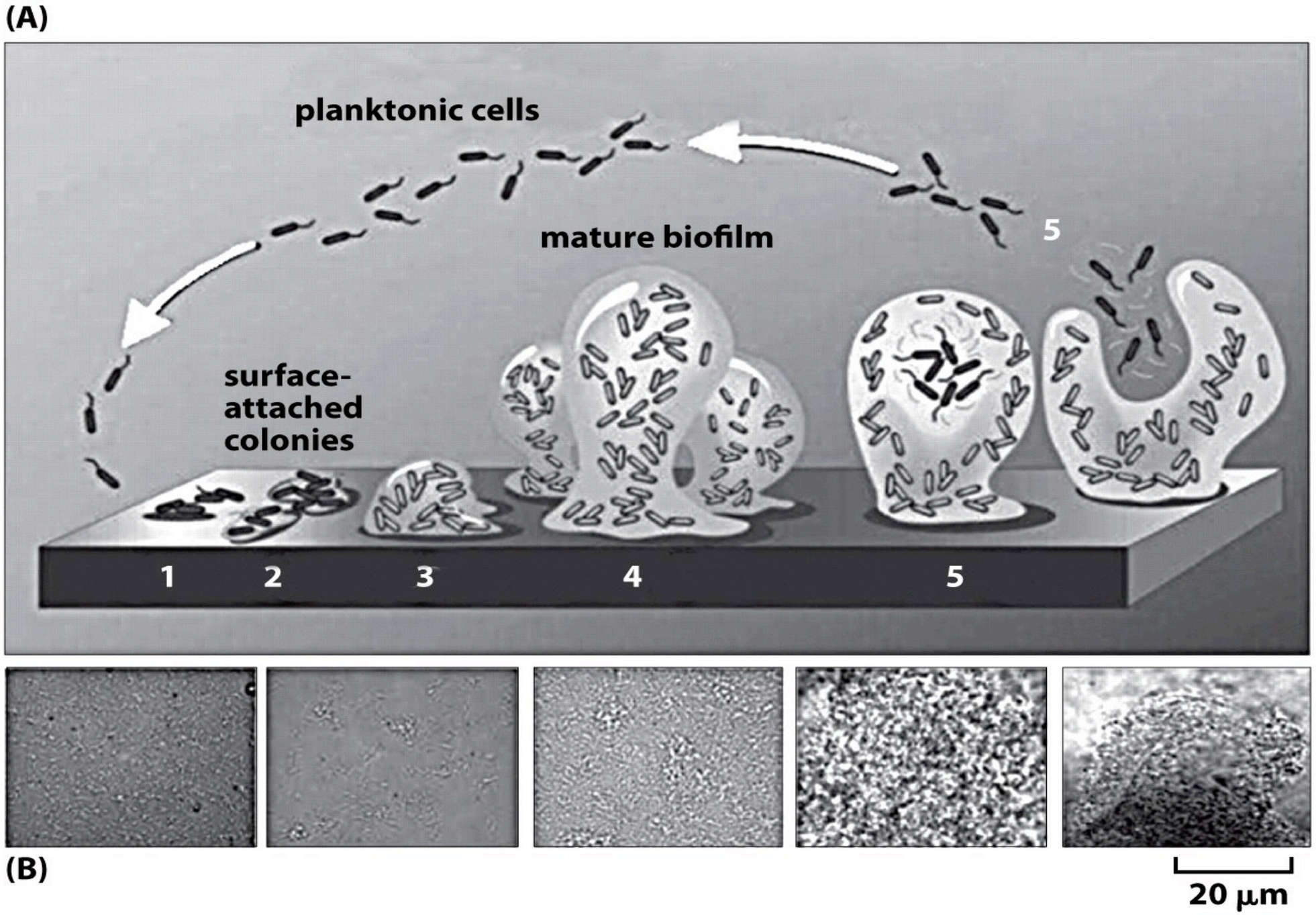


Figure 2.26 Physical Biology of the Cell (© Garland Science 2009)

Tissues are collections of cells and extracellular matter

Dynamic E. coli biofilms (meta populations)

Snapshots every 10’ to MHP array of 85 habitat islands (patches)

Cell communication and cooperation

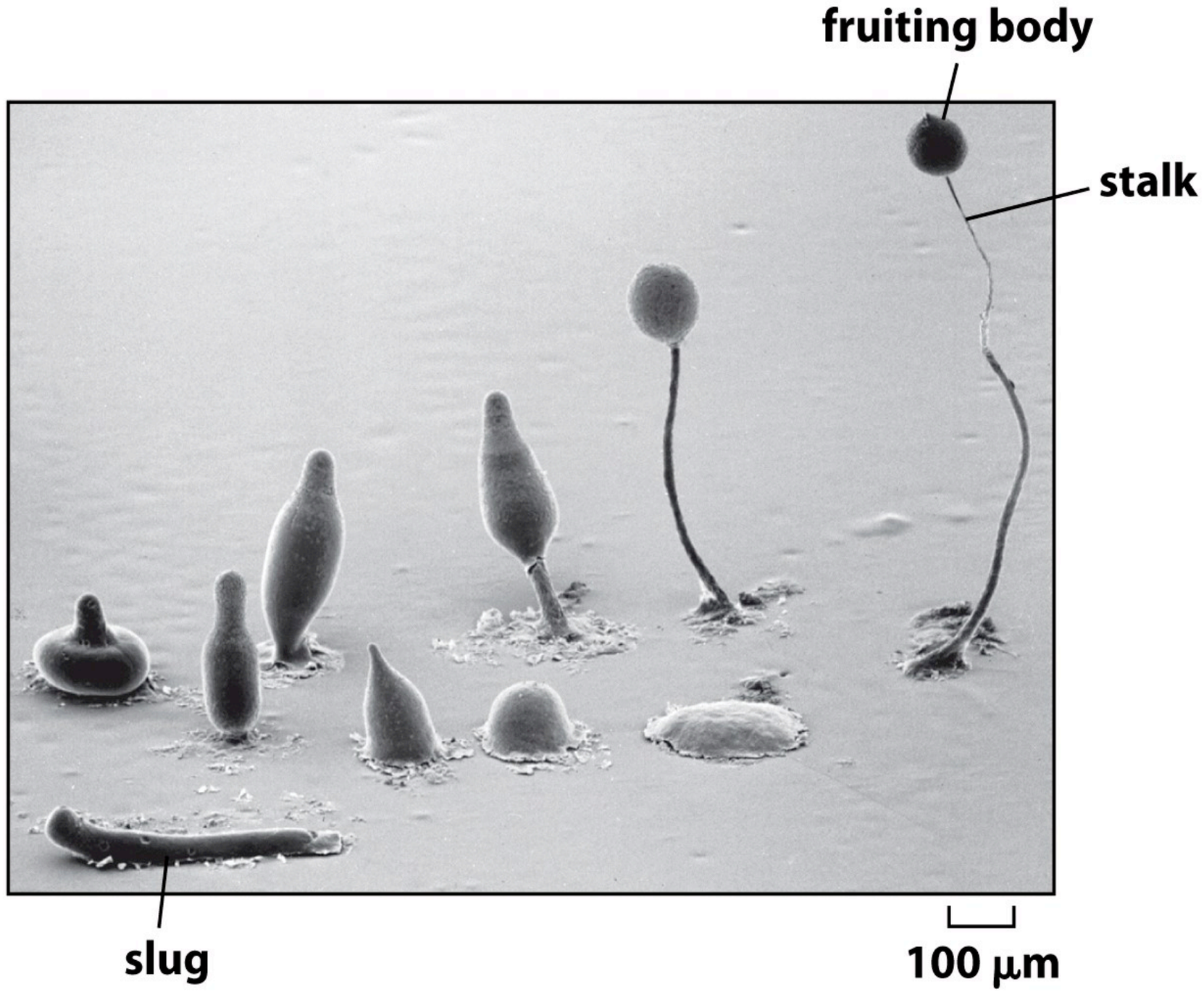


Figure 2.27 Physical Biology of the Cell (© Garland Science 2009)

From cellular to multicellular and back...

Cell communication and cooperation's best?:
traditional "multicellular organisms"

cellular-machines

epithelial sheets

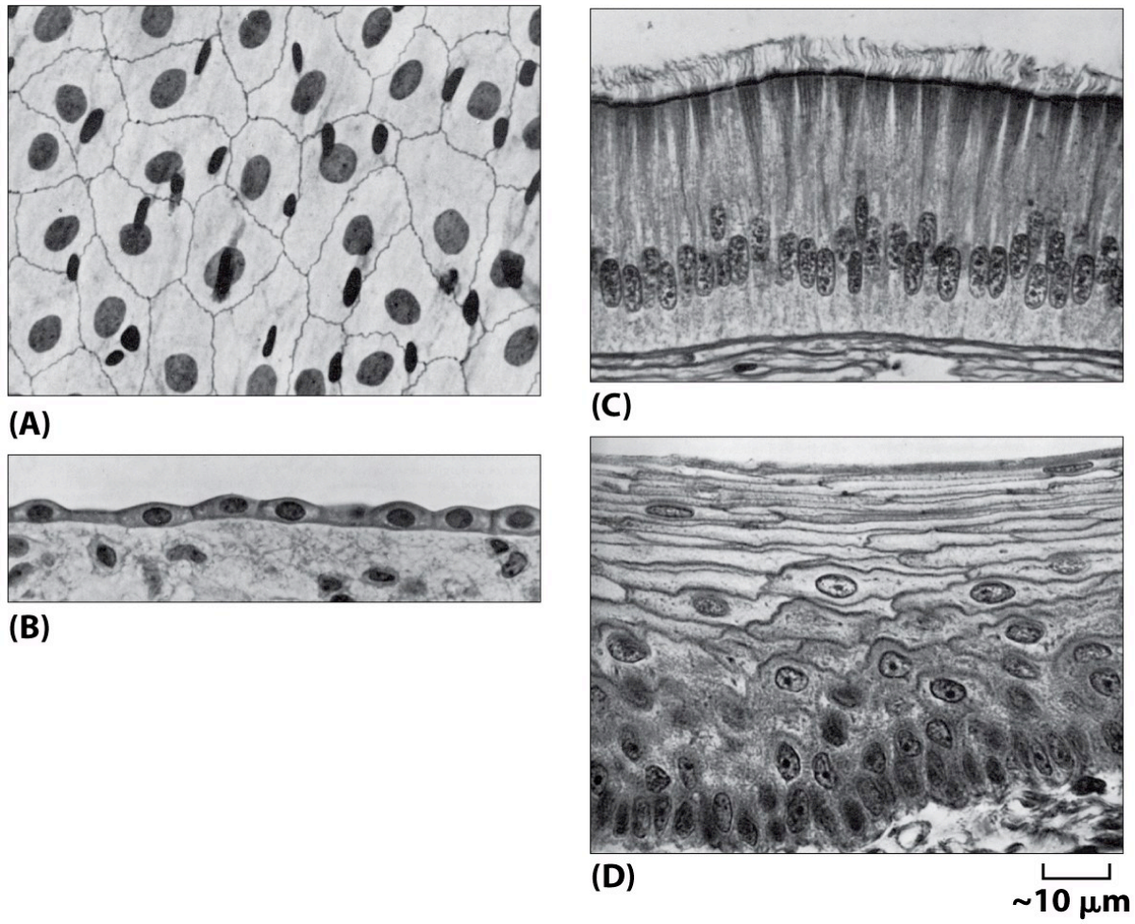


Figure 2.30 Physical Biology of the Cell (© Garland Science 2009)

intestines

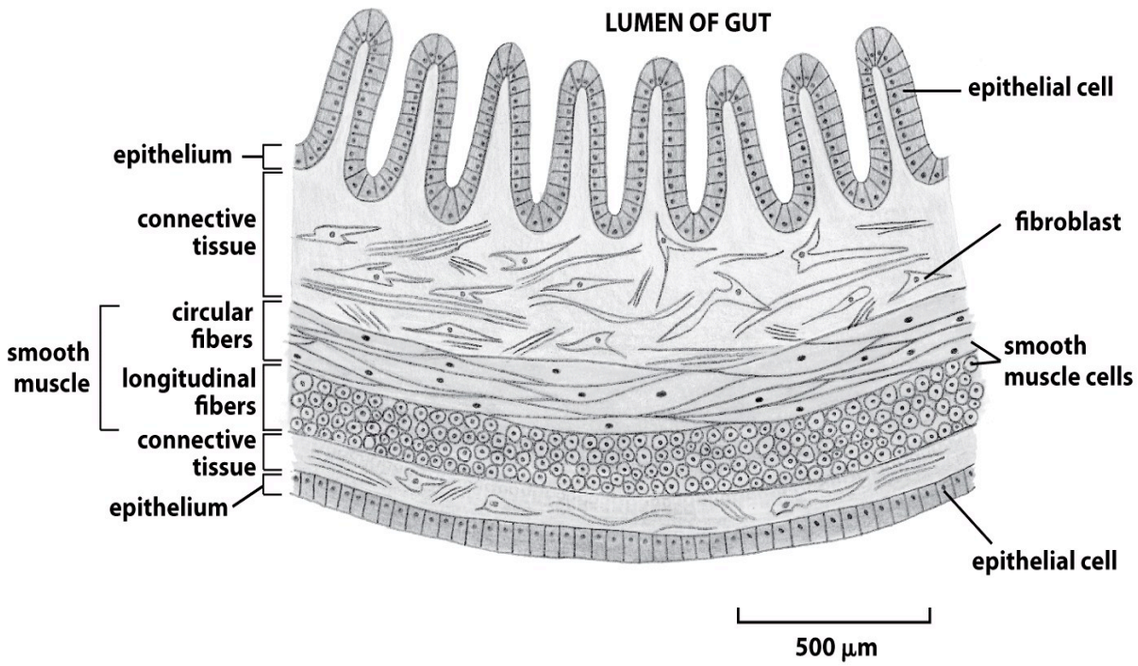


Figure 2.31 Physical Biology of the Cell (© Garland Science 2009)

Cell communication and cooperation:

cellular-networks

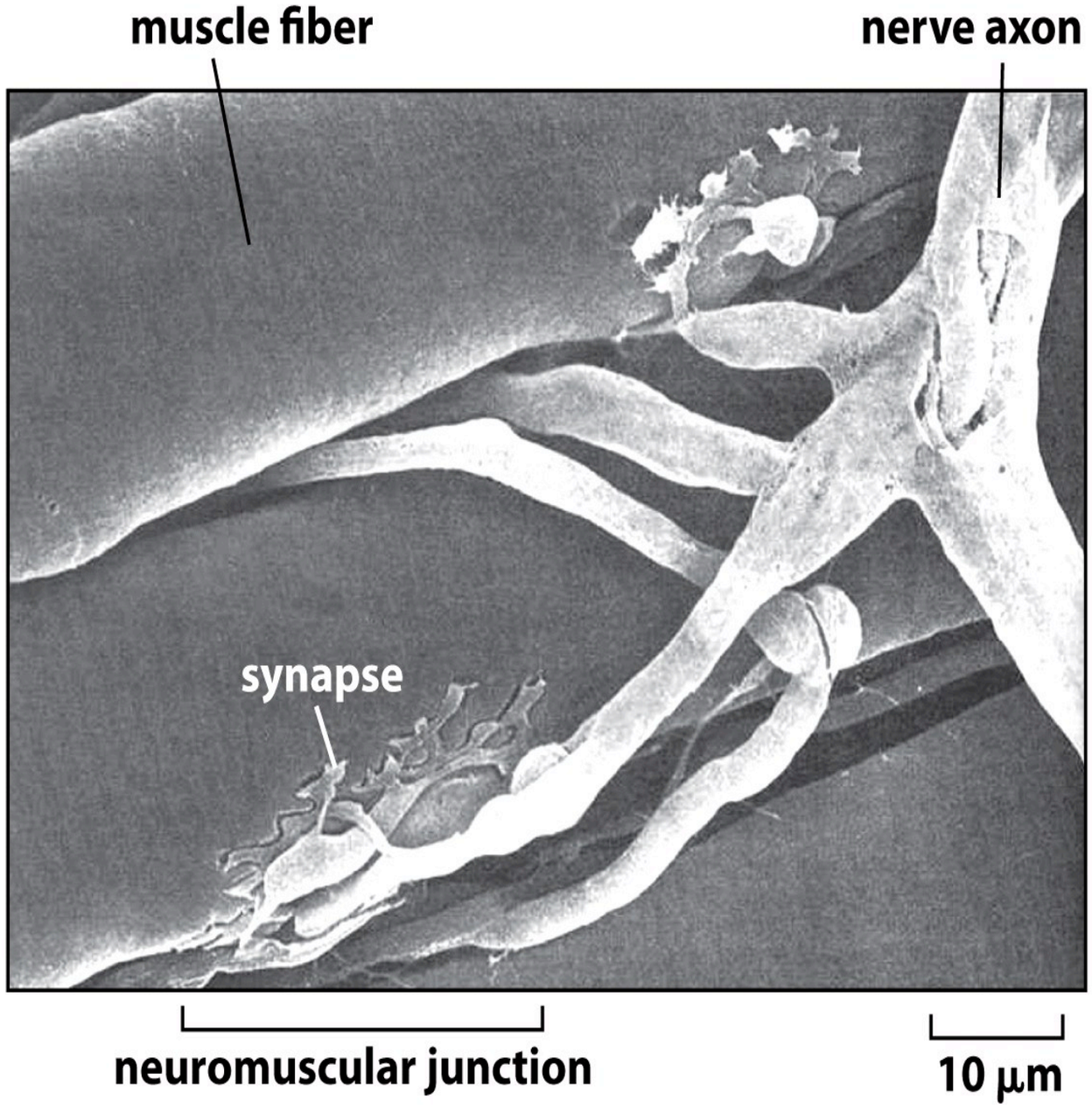


Figure 2.33 Physical Biology of the Cell (© Garland Science 2009)

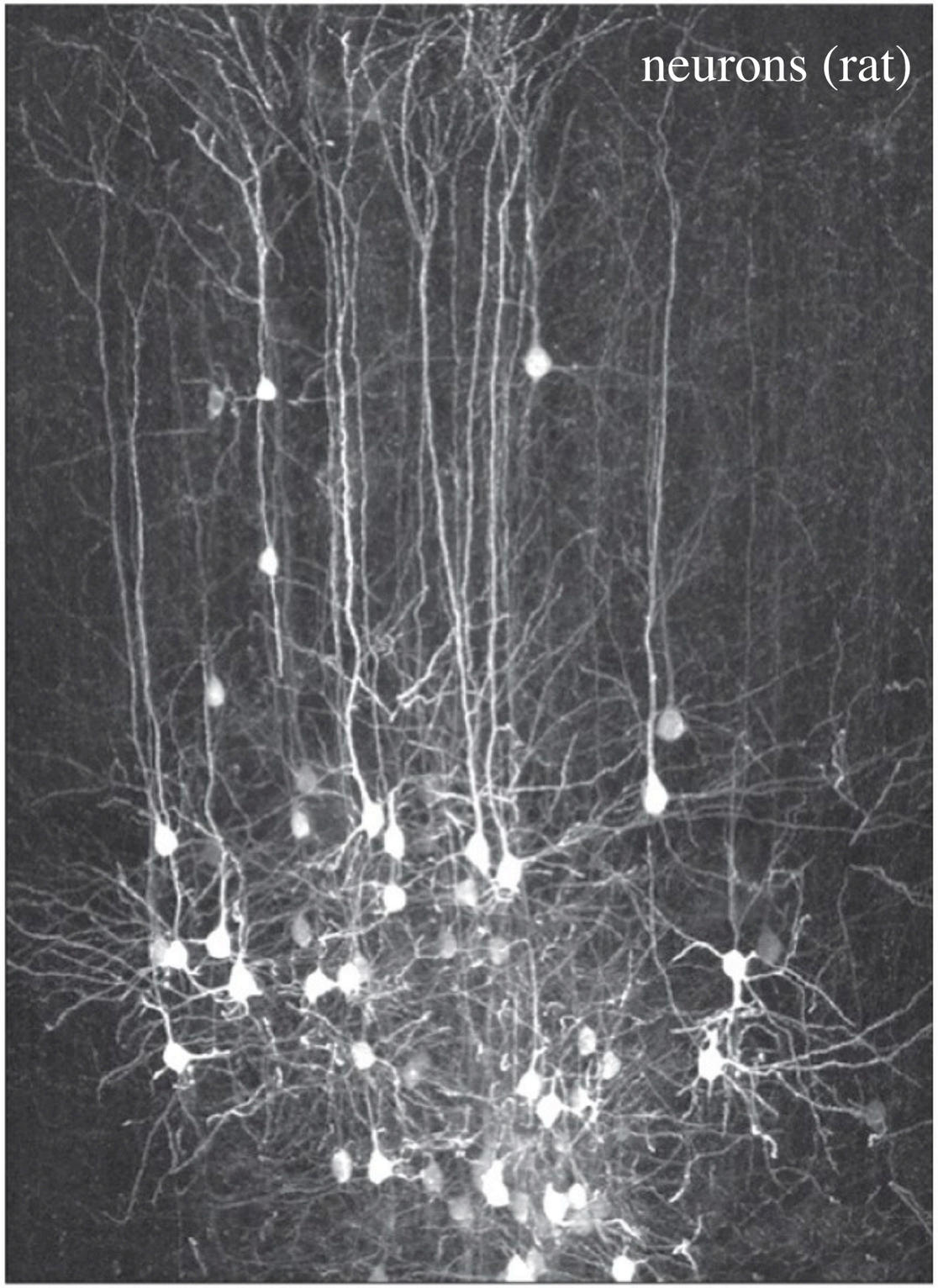


Figure 2.32 Physical Biology of the Cell (© Garland Science 2009)

Cell communication and cooperation:

development

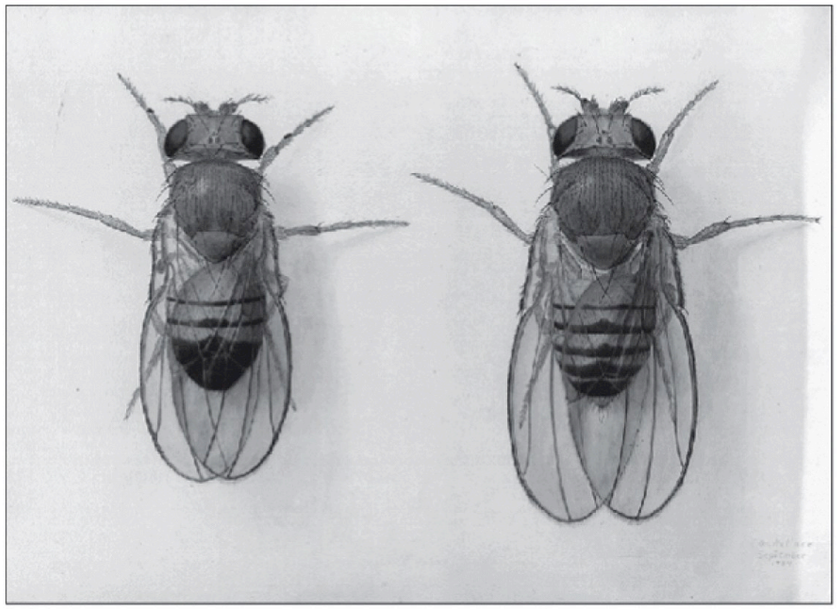
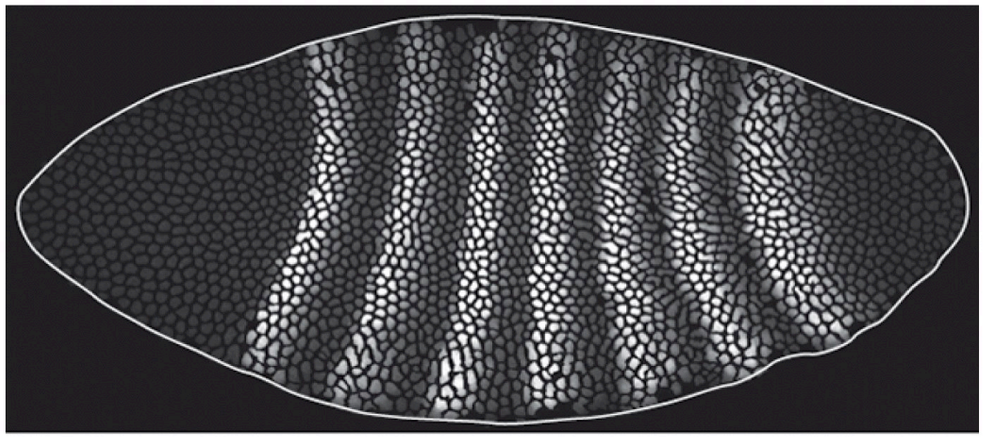


Figure 2.34 Physical Biology of the Cell (© Garland Science 2009)

Figure 2.36 Physical Biology of the Cell (© Garland Science 2009)



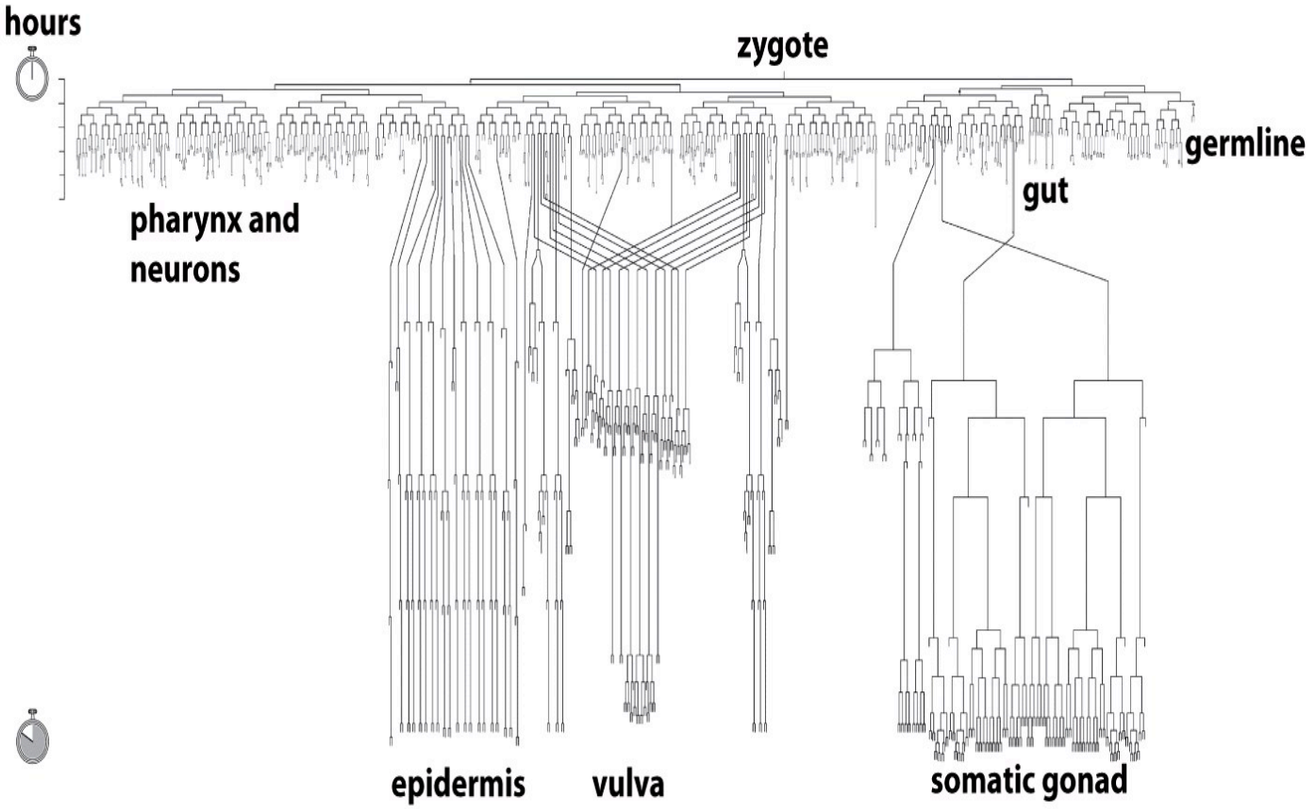
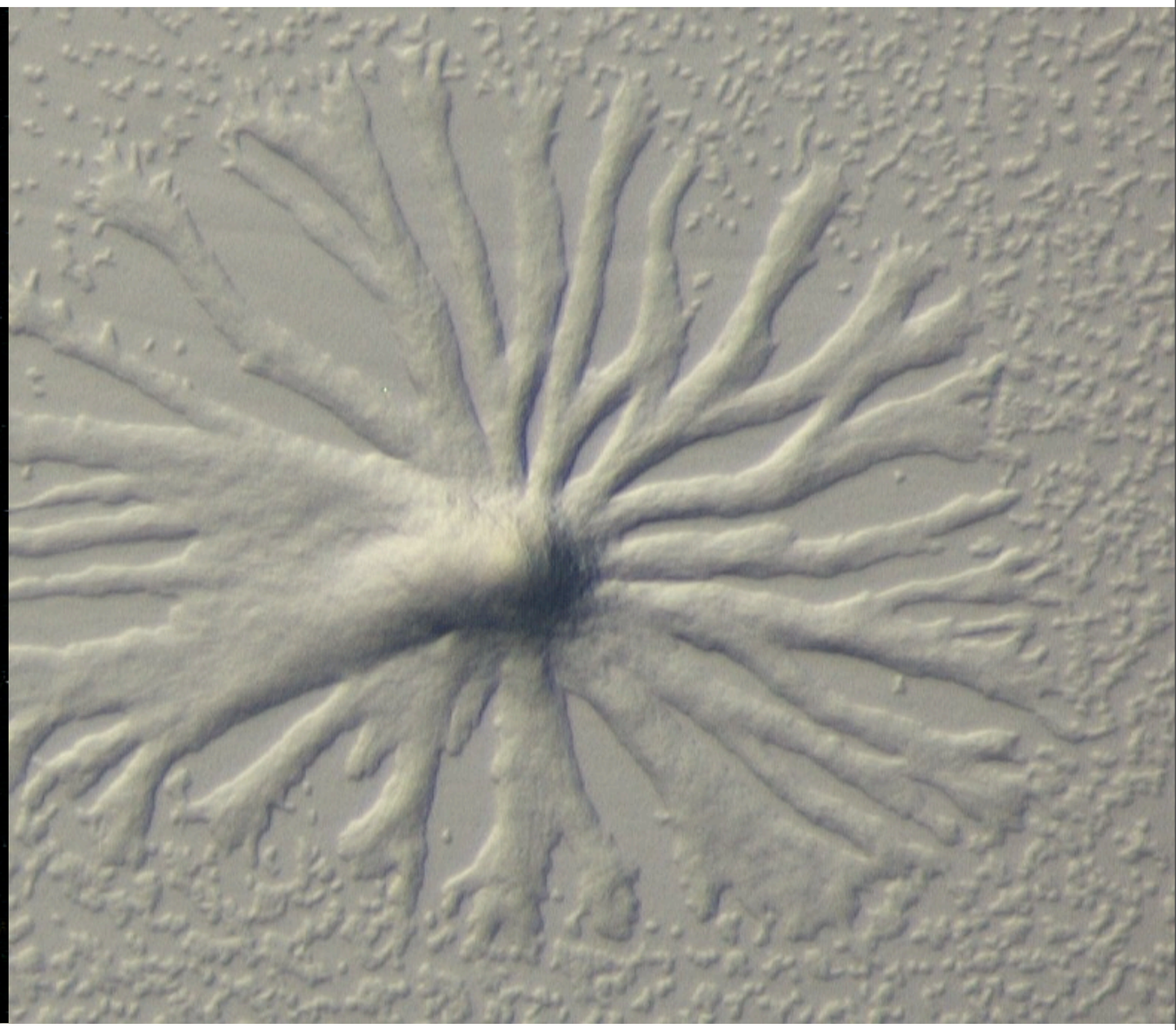
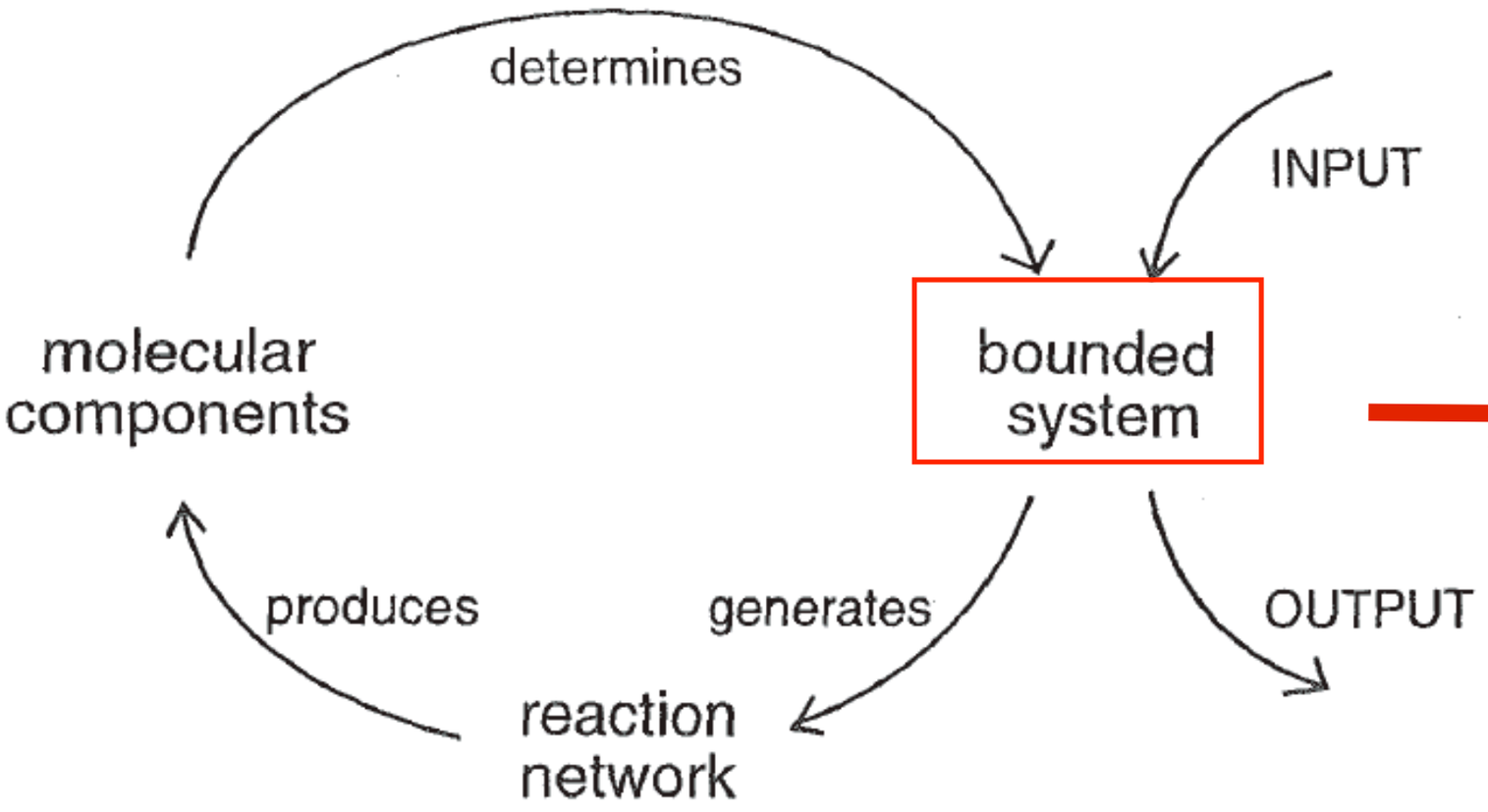


Figure 2.37 Physical Biology of the Cell (© Garland Science 2009)

Higher level structures: “colonies of organisms”

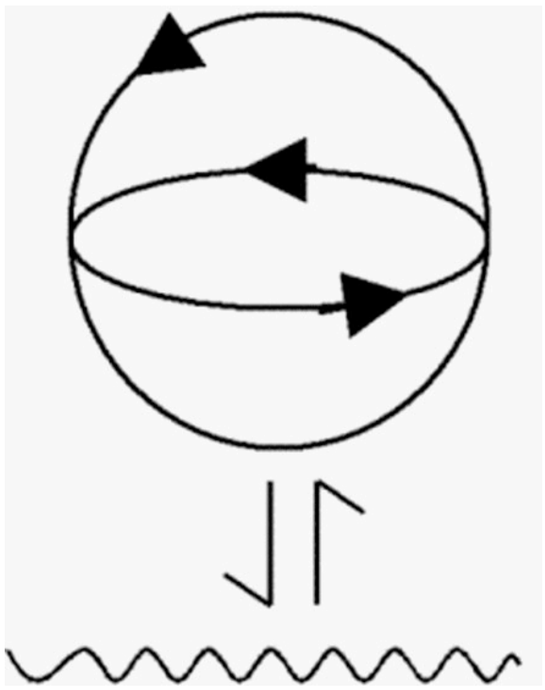


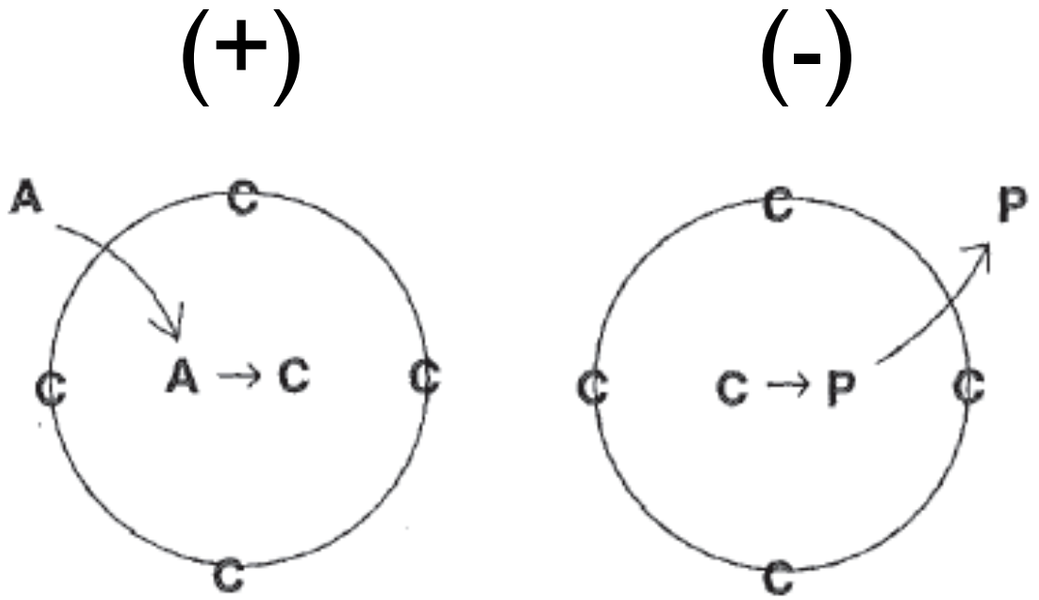
What are cells? First order auto-poietic units?



the self: **individuality**

metabolism.

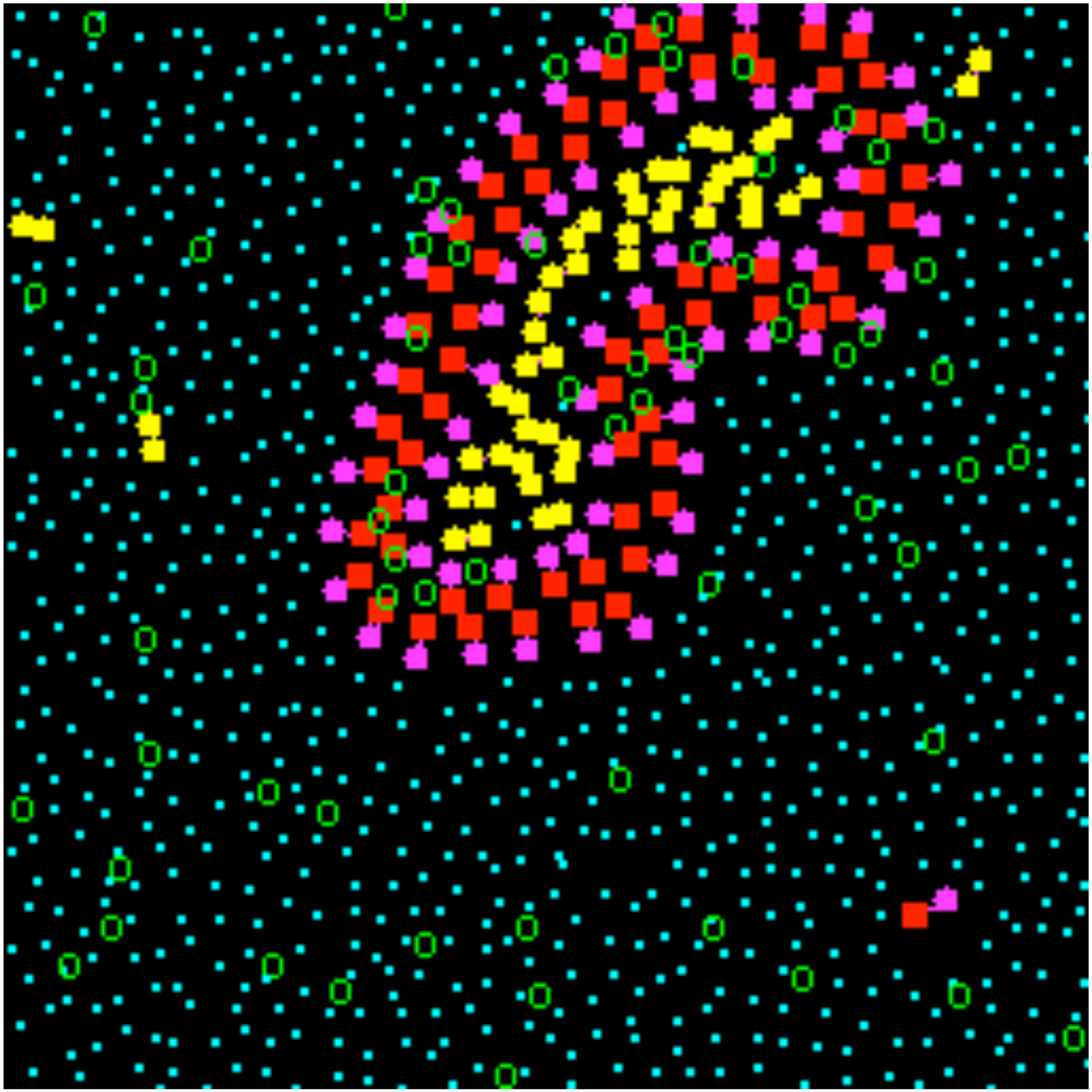




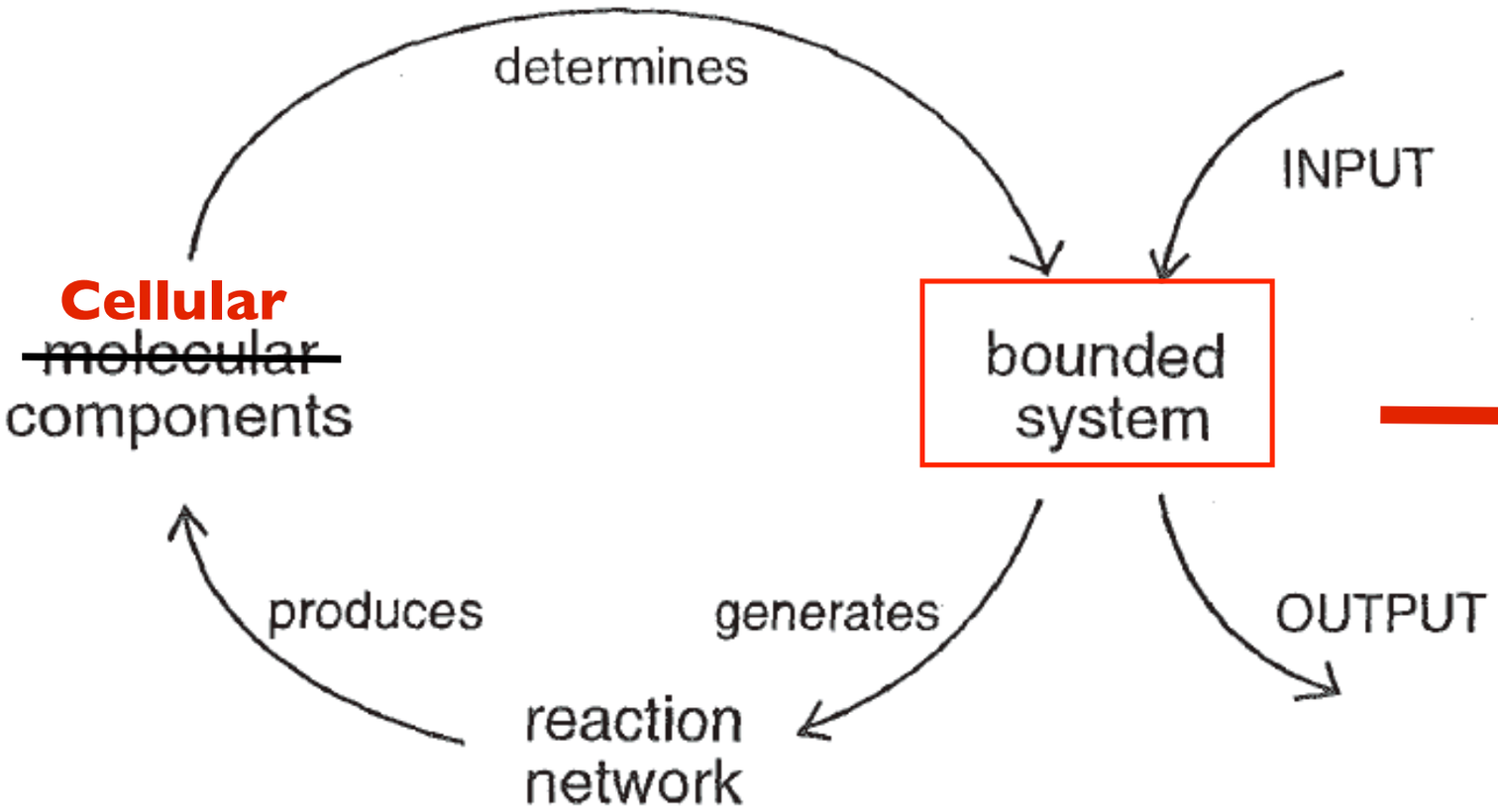
The two basic operations in a minimal autopoietic unit.

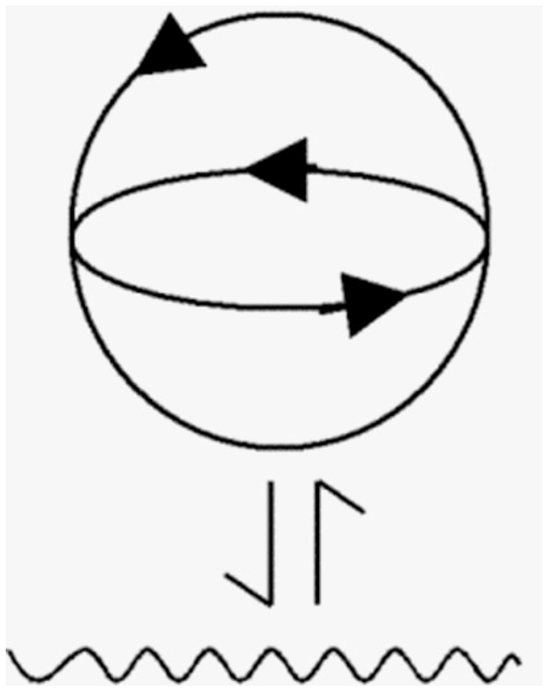
(+) anabolism
(-) catabolism

Maturana & Varela, 1973



What are multi-cellulars?





Higher order autopoietic units?

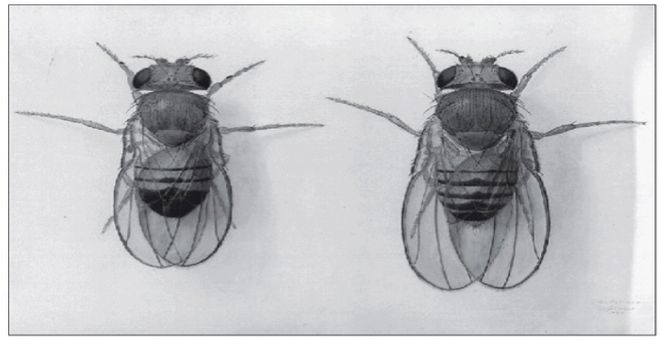
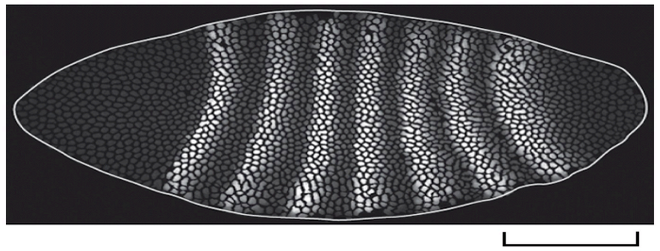
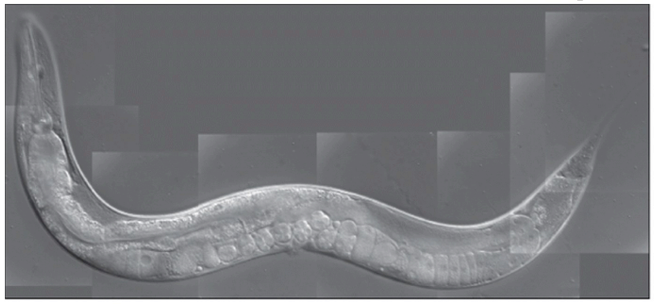
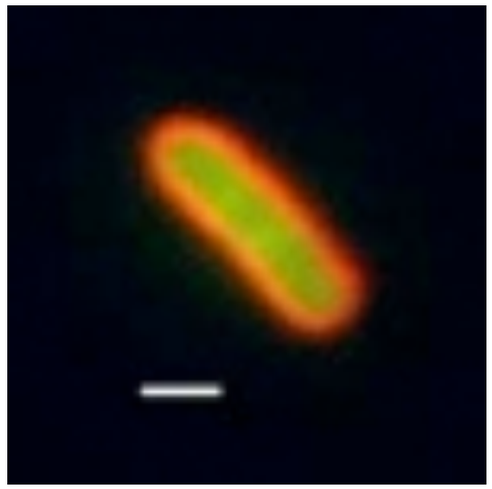
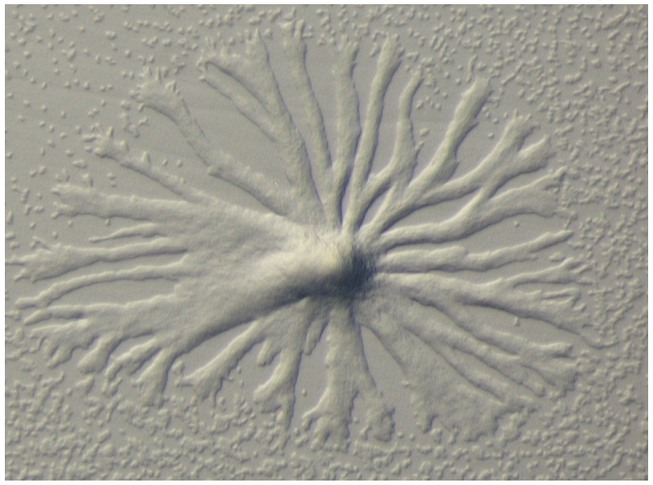


Figure 2.34 Physical Biology of the Cell (© Garland Science 2009)

the self: **individuality**