Physics of Life

PHYS-468

The Structure of Life

Biological cells

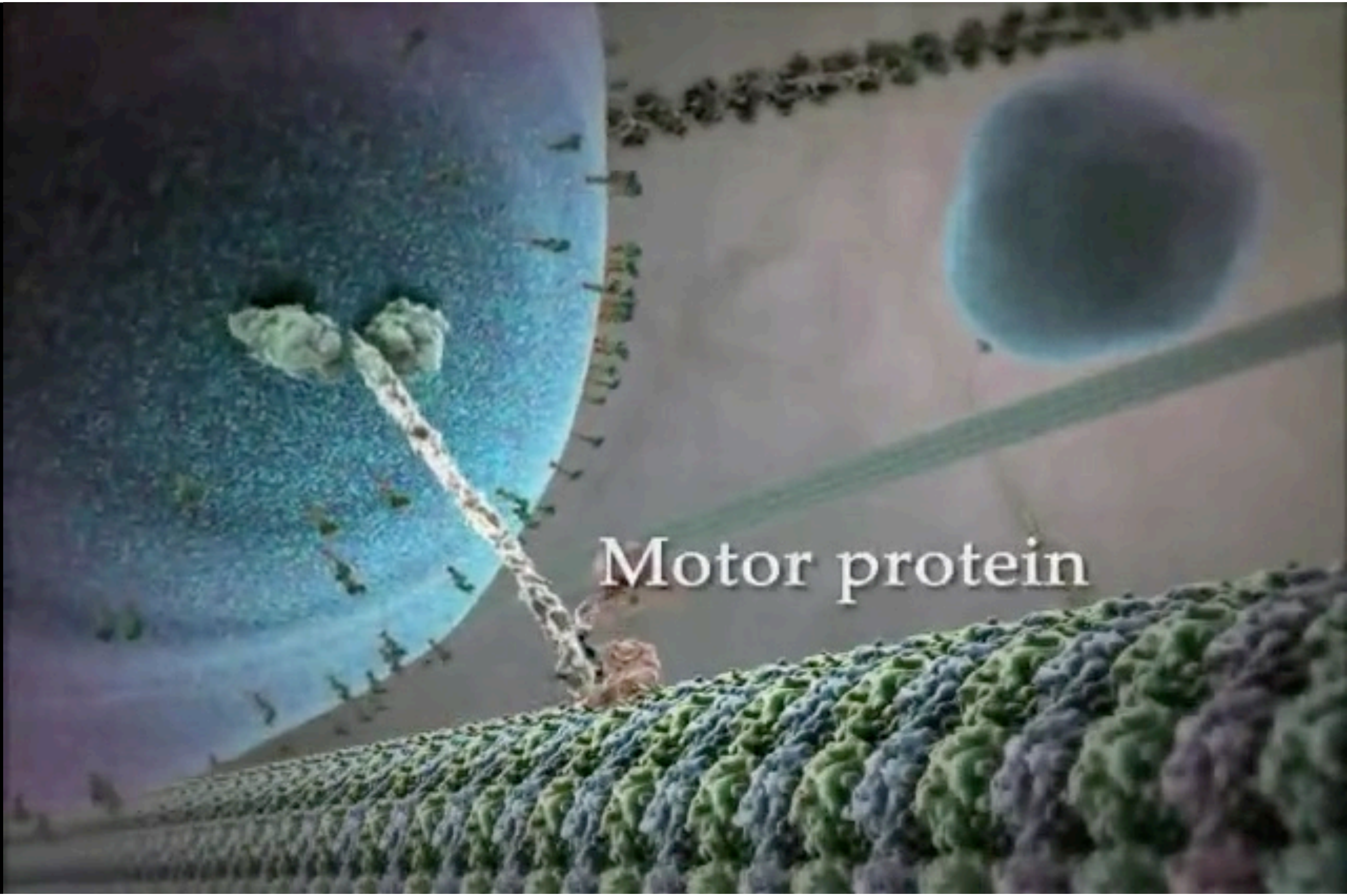
Biological cells are mechanical machines that follow the laws of physics:

- Mechanics
- Thermodynamics
- Electrostatics
- Quantum Dynamics

Cells feature

- Self-organization
- Communication
- Self-healing
- Self-protection
- Memory
- Regeneration
- Dynamics
- Variation
- Specialization

We are cells.

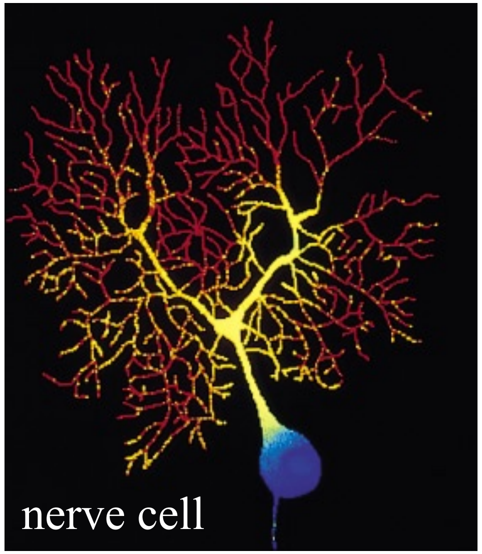


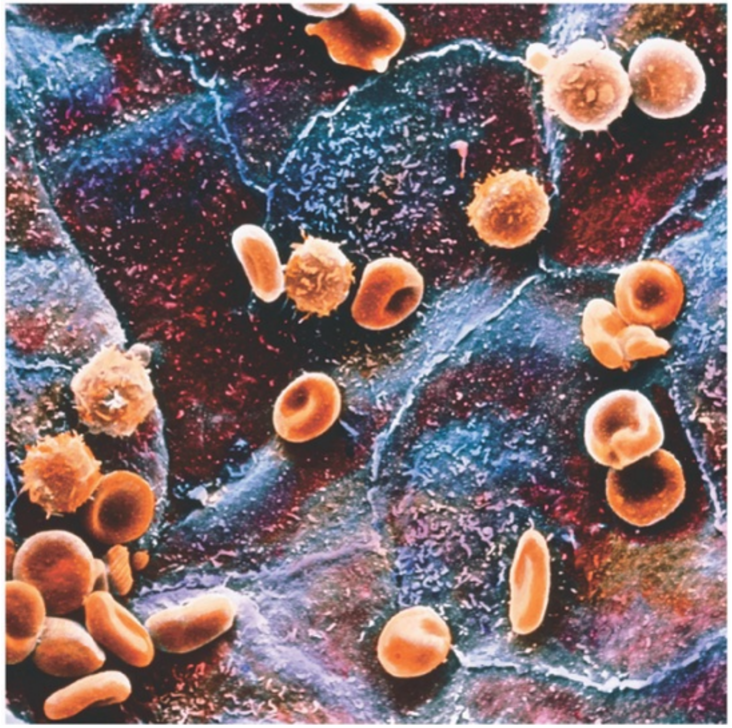
Cells are Us

A person contains about 100 trillion (10^{14}) cells.

There are about 200 different cell types in one person.

Cells have on average a diameter of 20 µm.
There are on average 50 cells per mm.





Red and white blood cells above vessel-forming cells.

The Cell Theory

The cell theory (proposed independently by Schleiden in 1838 and Schwann in 1839) is a cornerstone of biology.

All organisms are composed of one or more cells.

Cells are the smallest living things.

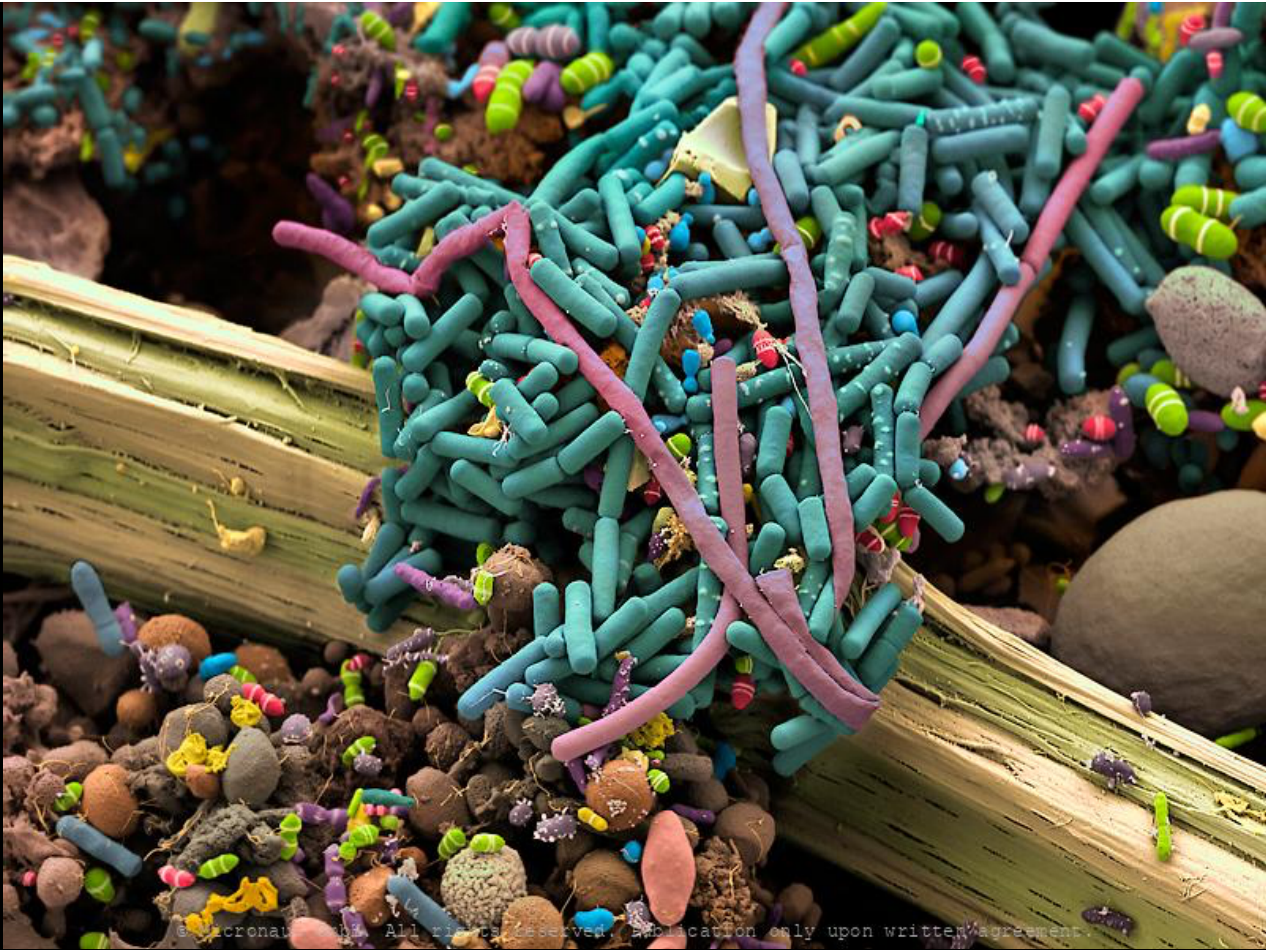
Cells arise only by division of previously existing cells.

All organisms living today are possibly the descendants of a single ancestral cell.

Matthias Jakob Schleiden
1904 – 1881

Theodor Schwann
1810 – 1882

Intestinal bacteria



Martin Oeggerli

aka.

micronaut.ch

Helicobacter Pylori bacteria on gut cells

Martin Oeggerli
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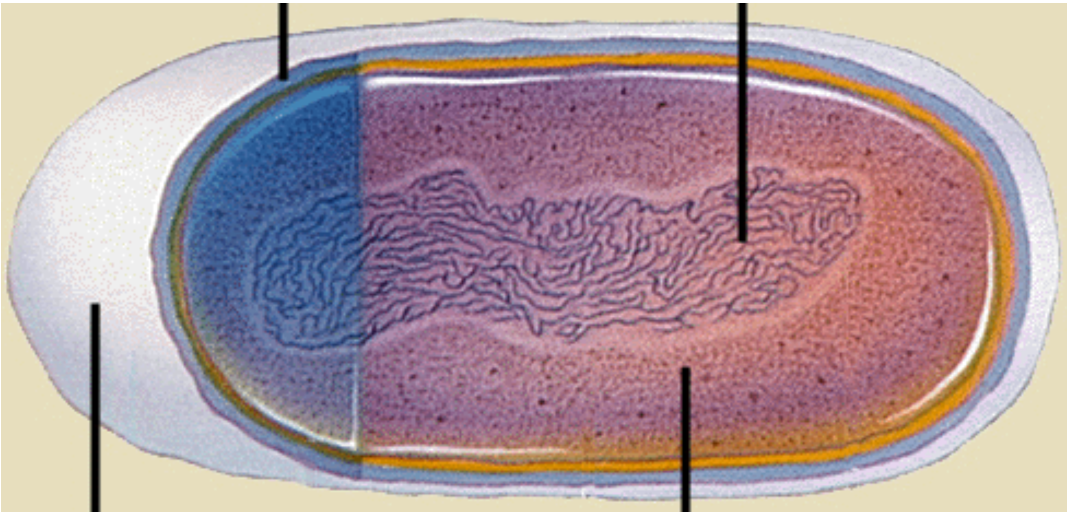
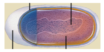
Two Fundamentally Different Types of Cells



A prokaryotic cell

A eukaryotic cell

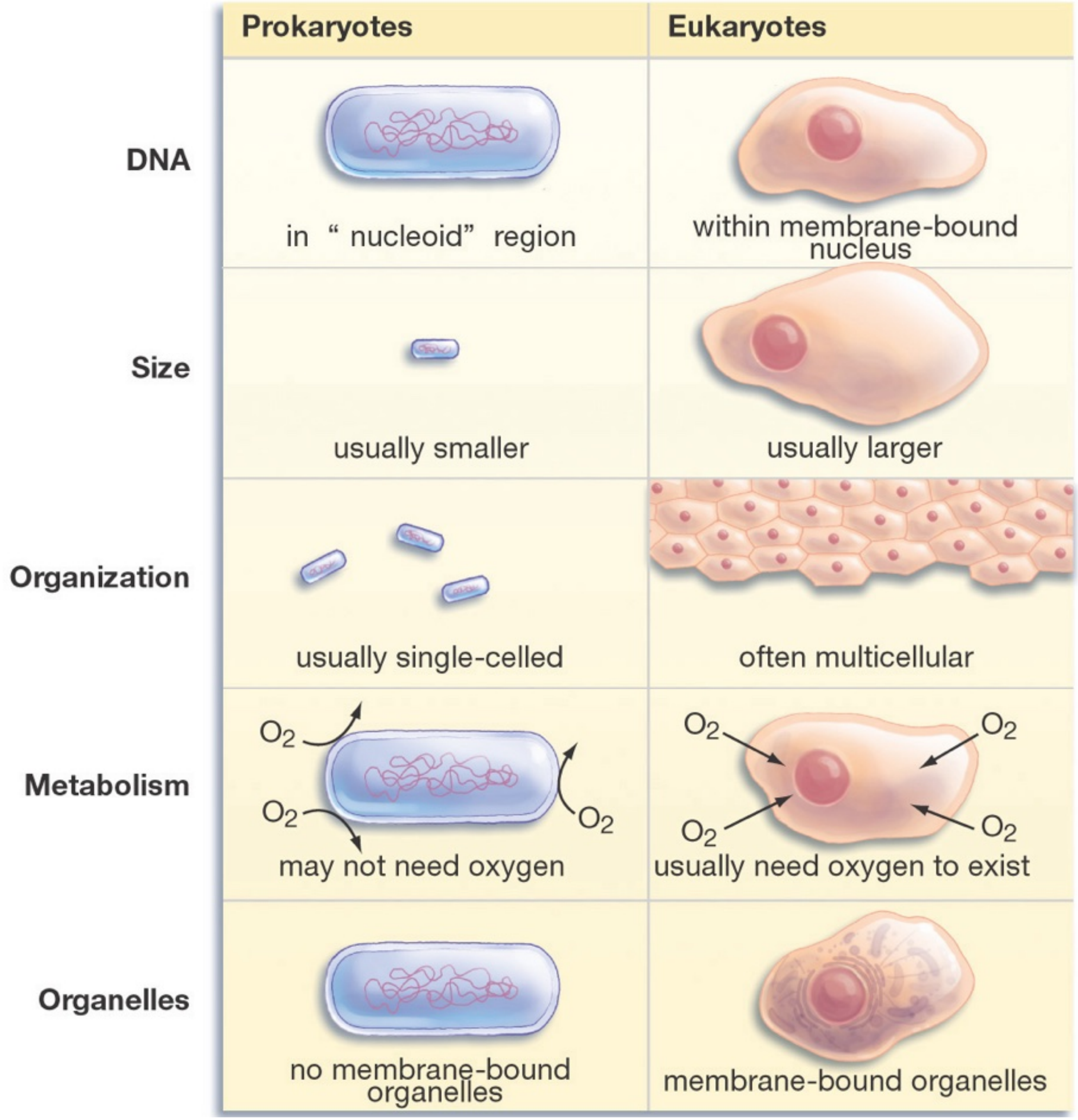
Two Fundamentally Different Types of Cells
…. at the same scale


A prokaryotic cell

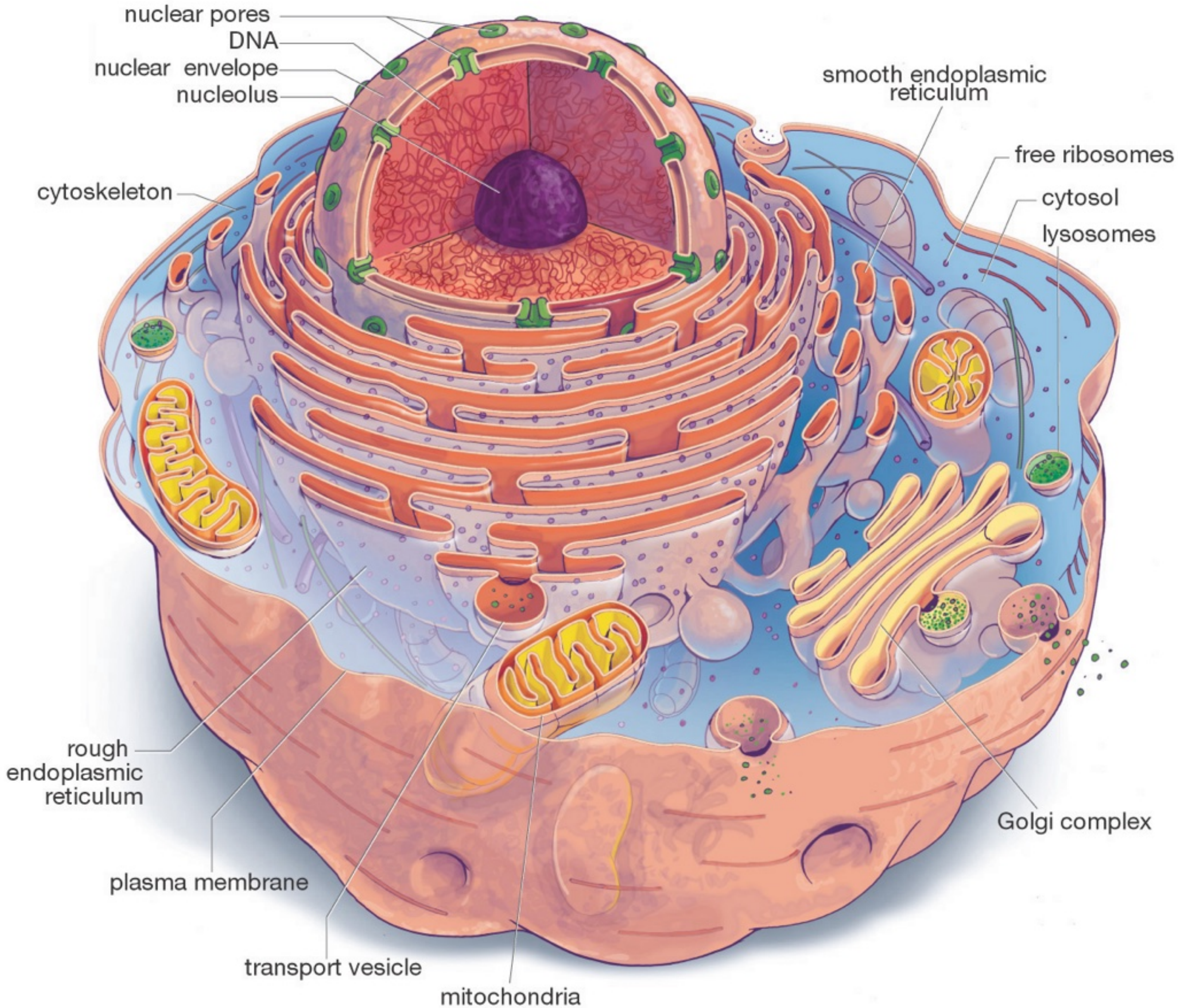

A eukaryotic cell

Us *vs*. Them

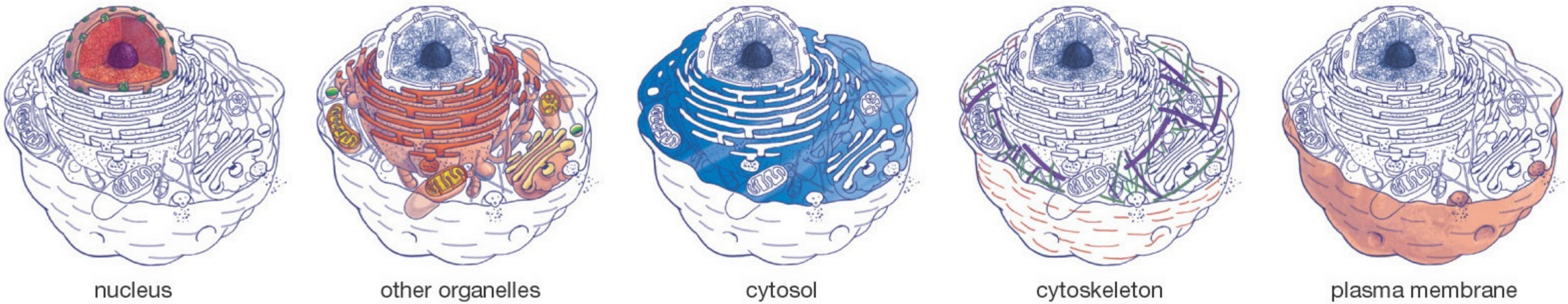
Eukaryotes and Prokaryotes

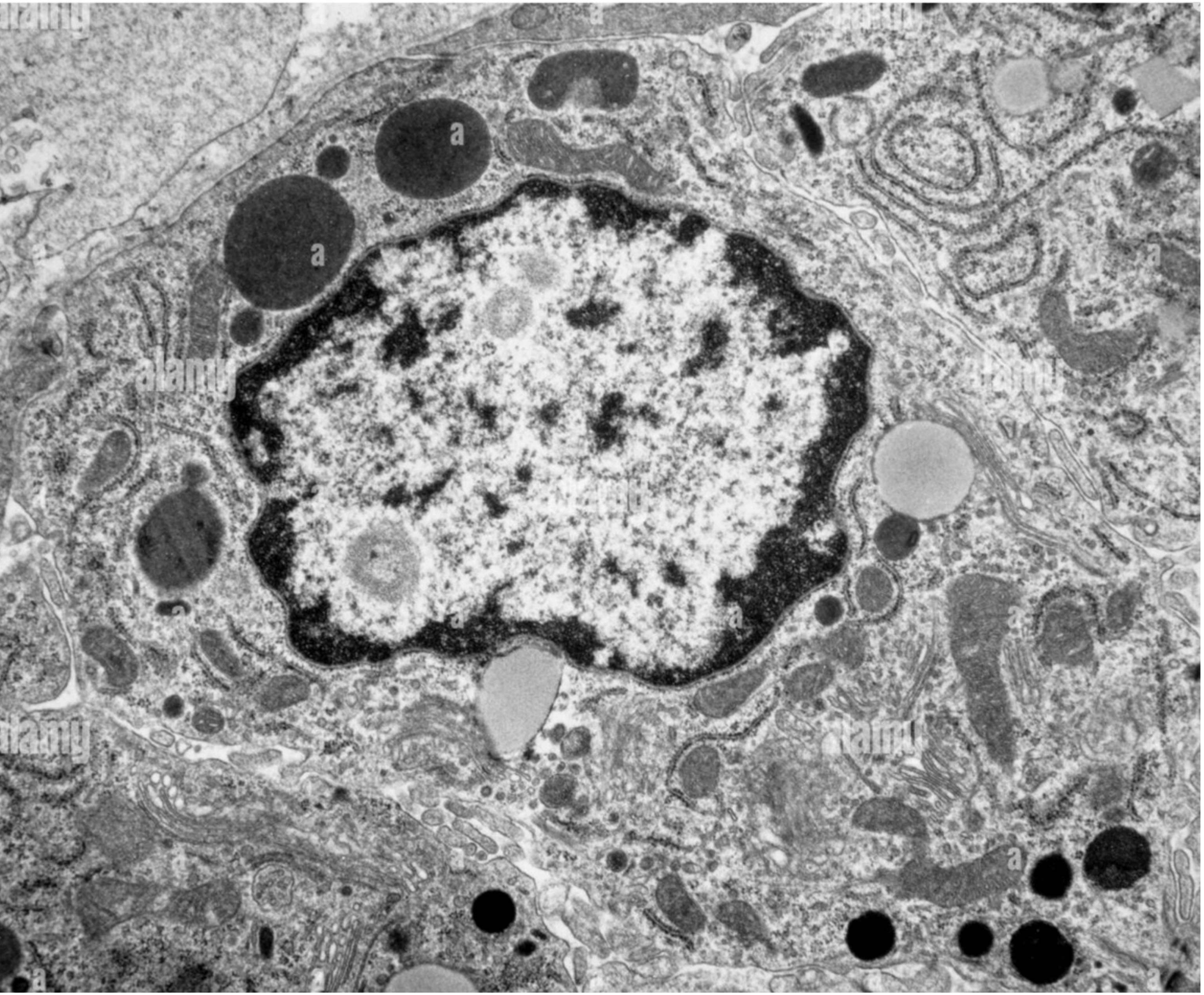


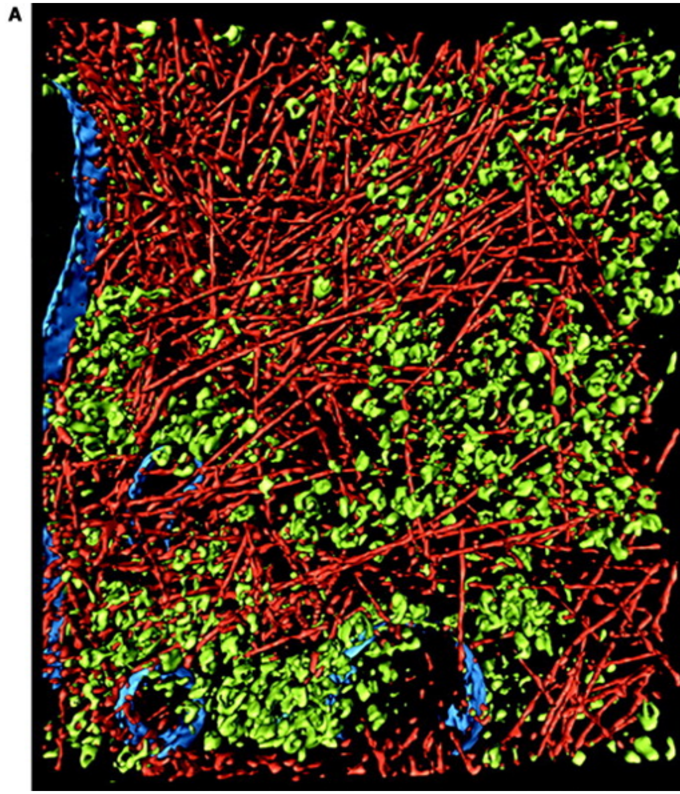
An Idealized Animal Cell



Major Divisions of the Eukaryotic Cell



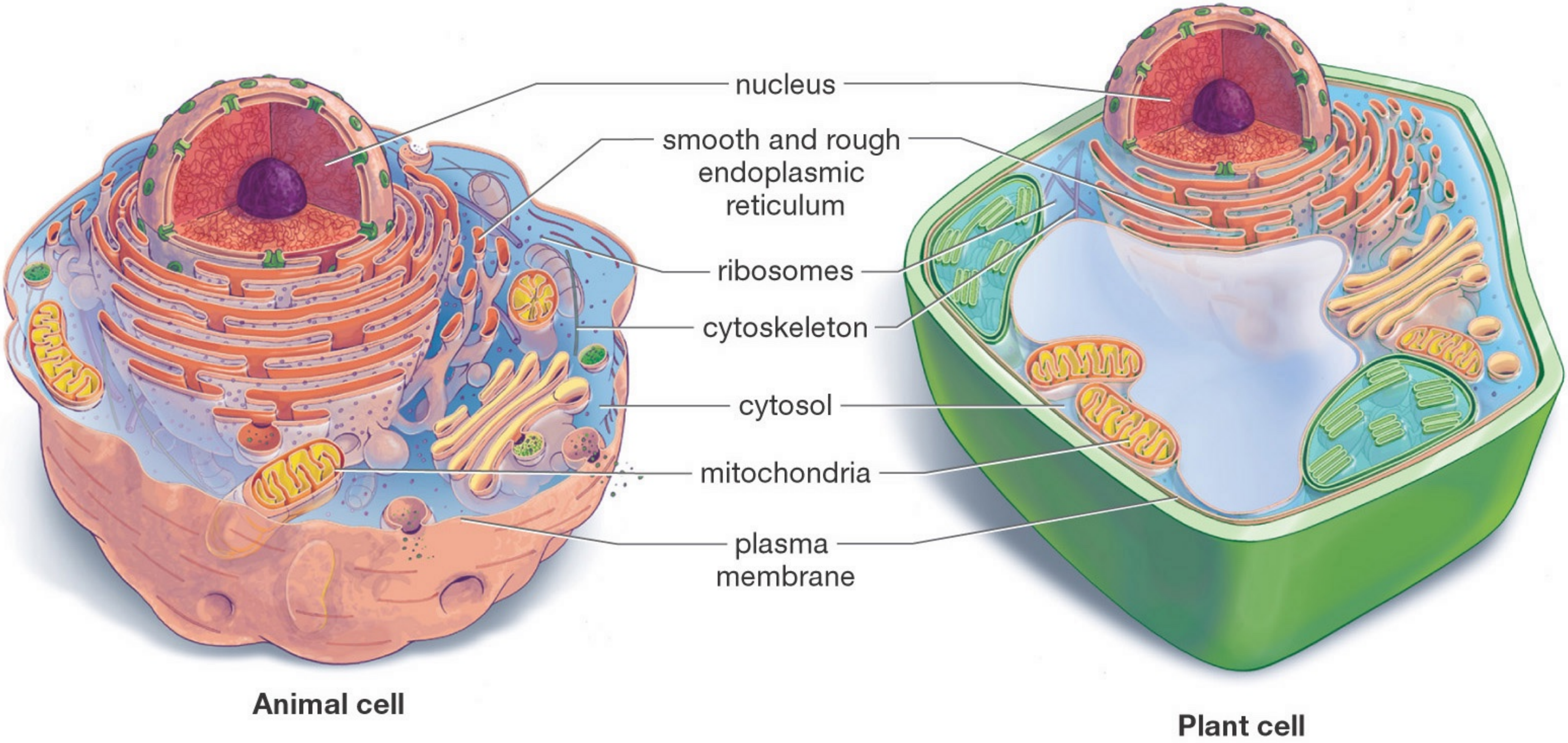




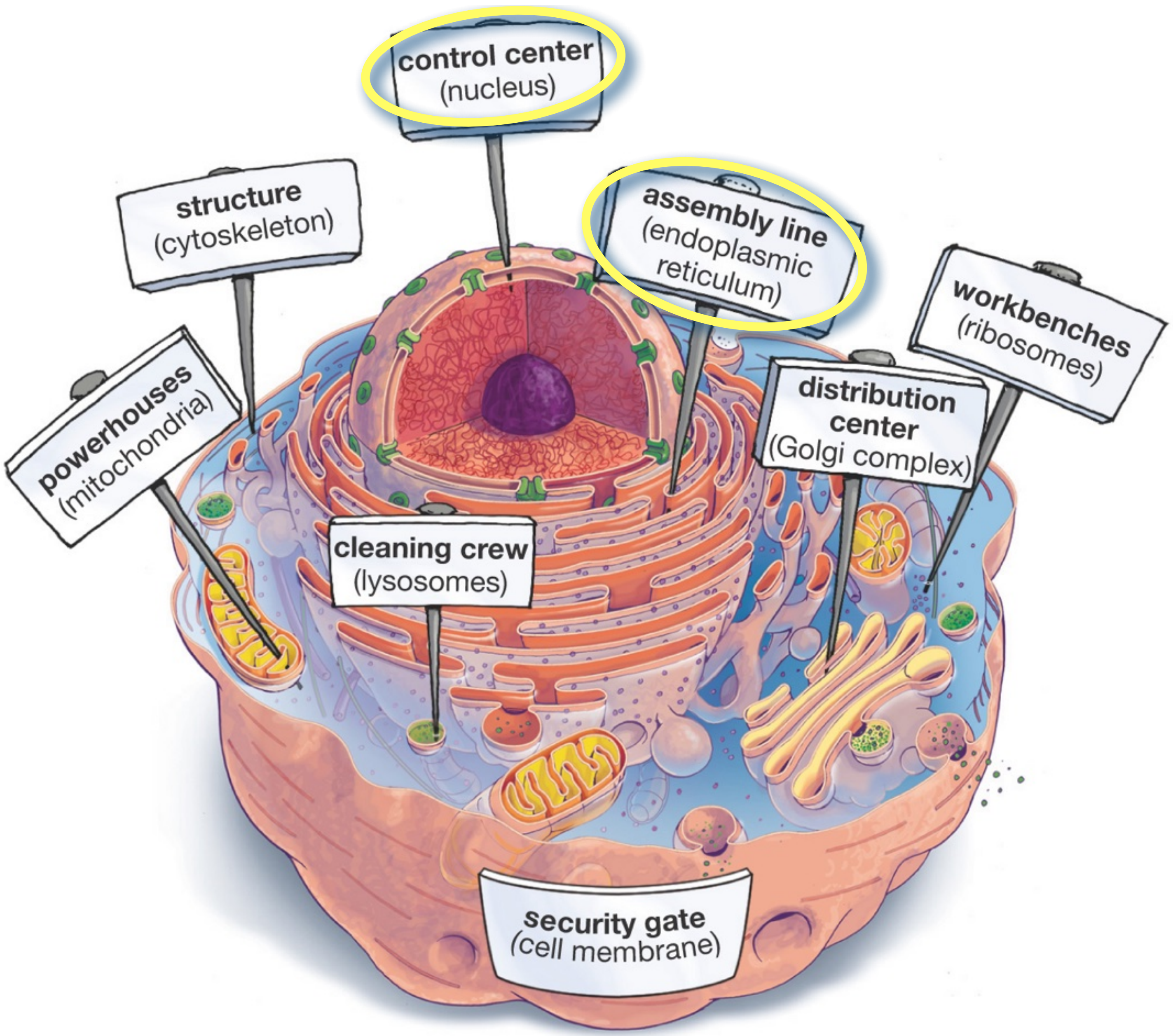
A 3D reconstruction of a cell, showing cytoskeleton (red), ribosomes (green), and membrane (blue)

It’s Crowded In There

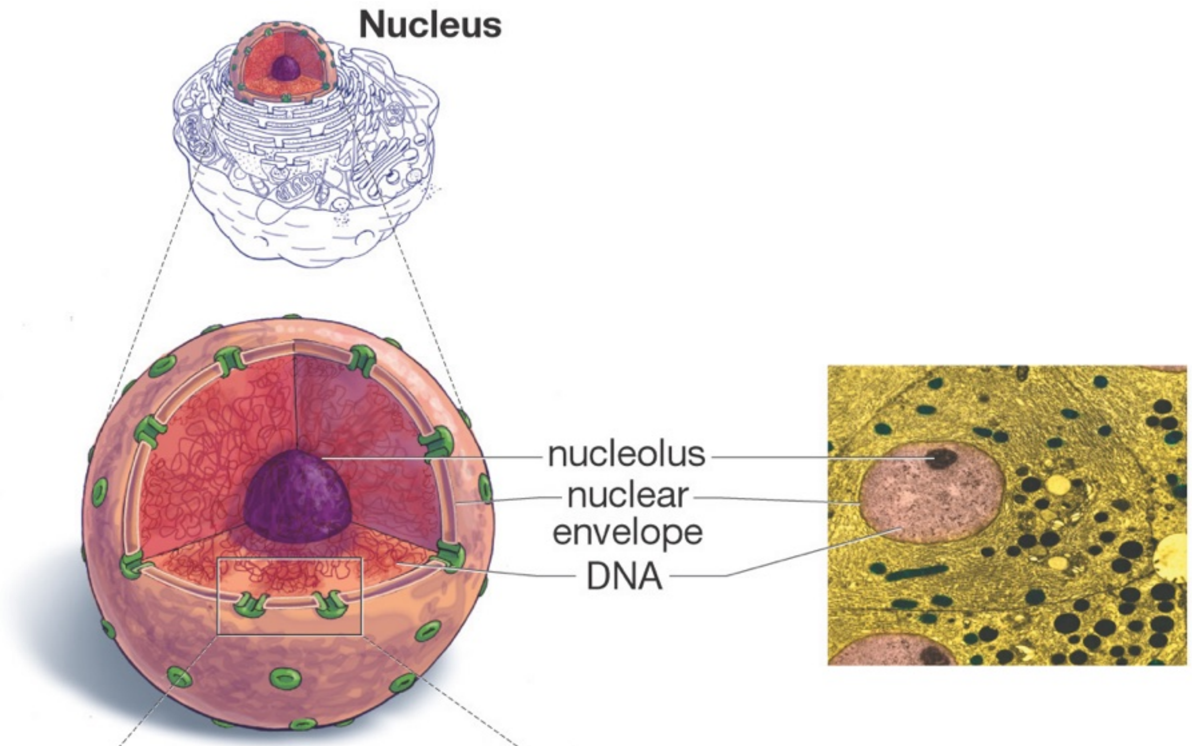
Animal and Plant Cells Have More Similarities Than Differences

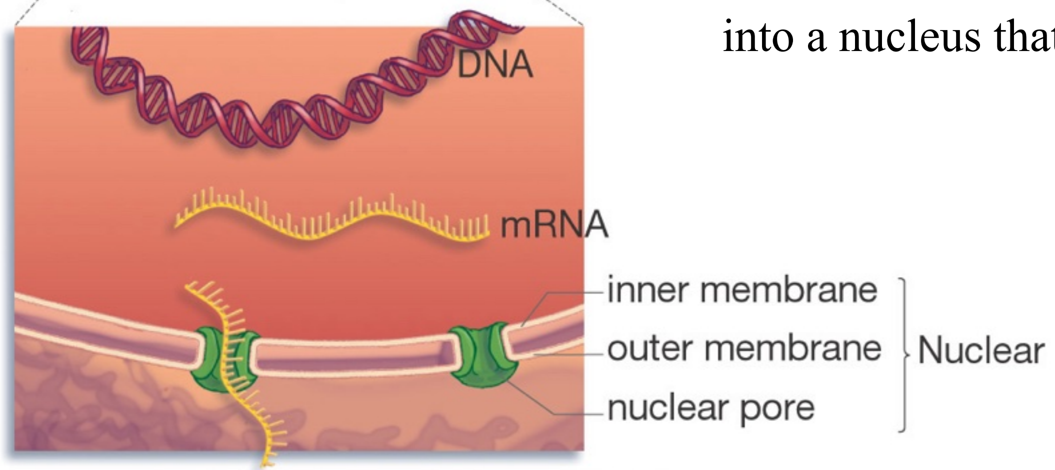


Cellular Anatomy



The Nucleus





Two meters of human DNA fits into a nucleus that's 5 μm across.

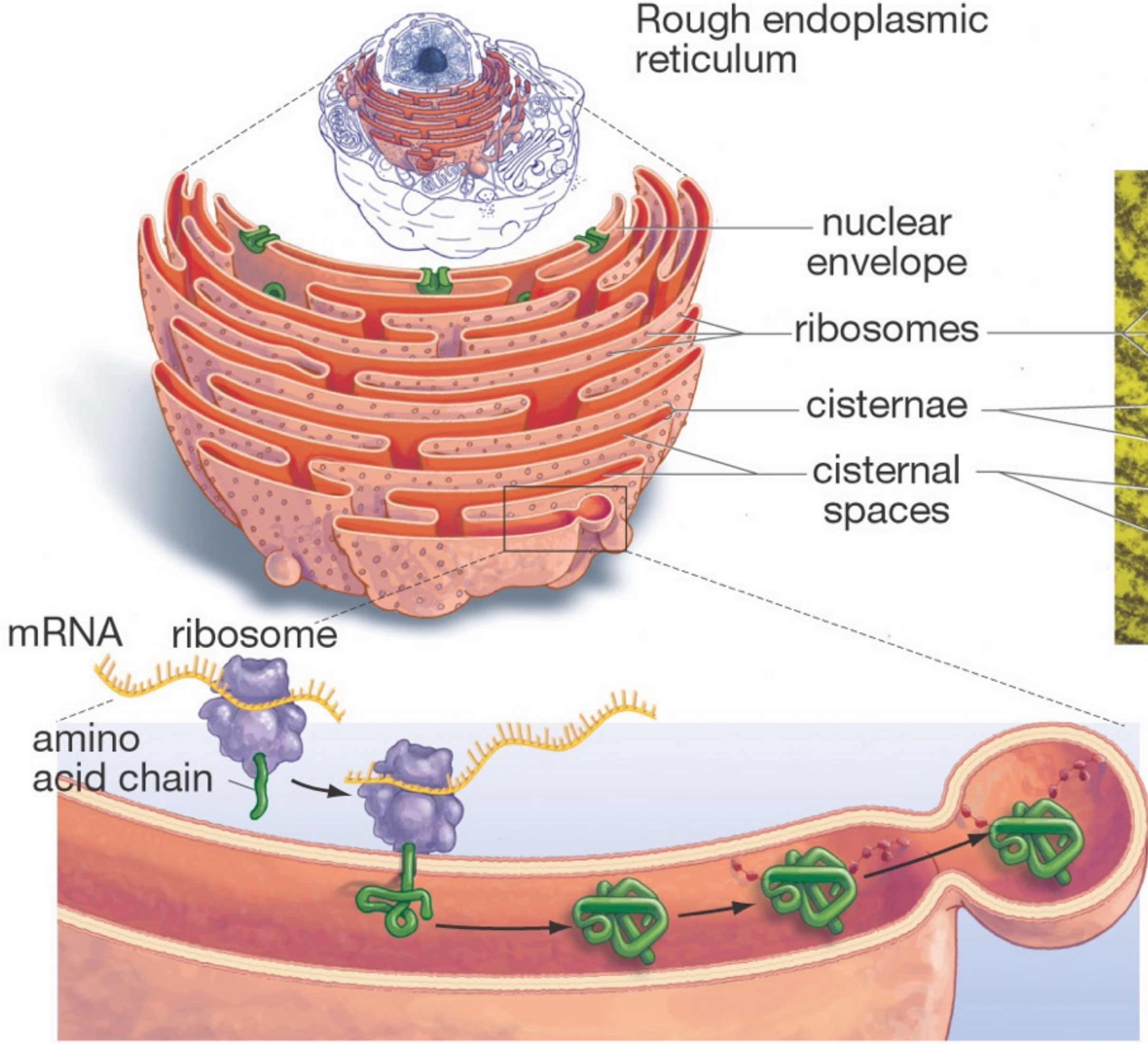
Ribosomes and the Endoplasmic Reticulum

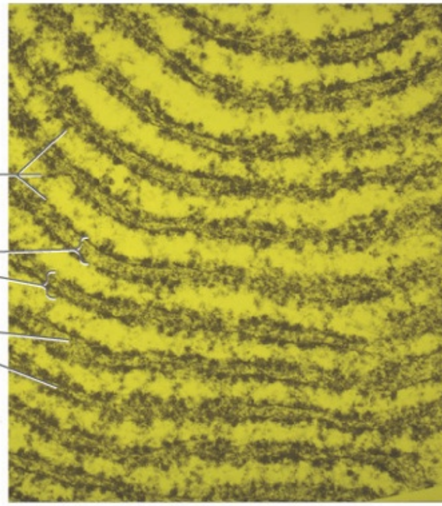
Functions:

Protein synthesis (about half the cell's proteins are made here).

Protein movement (trafficking)

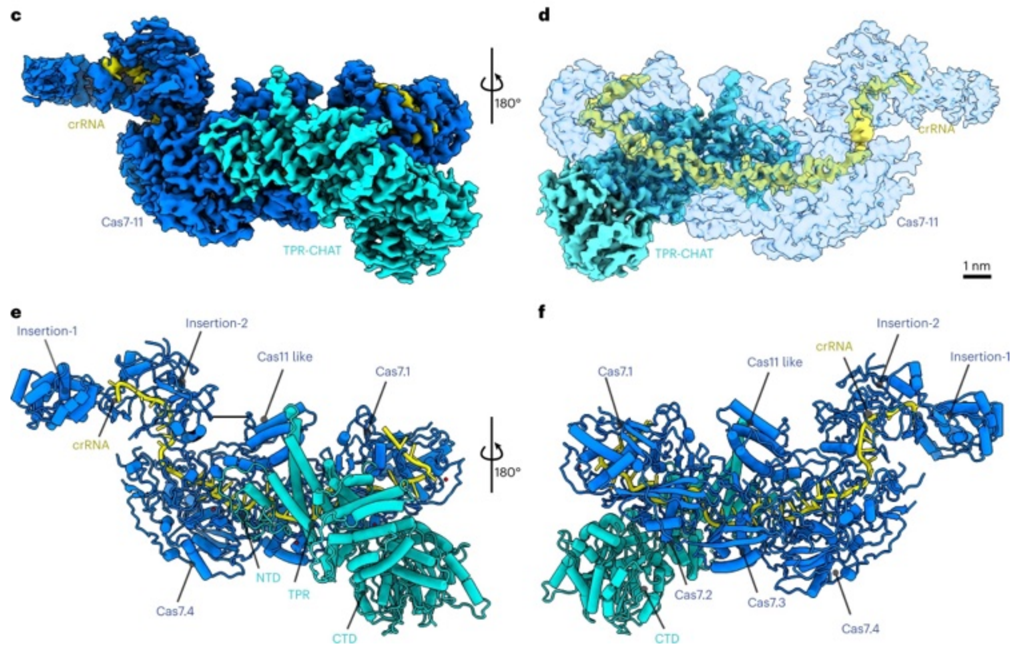
Protein "proofreading"





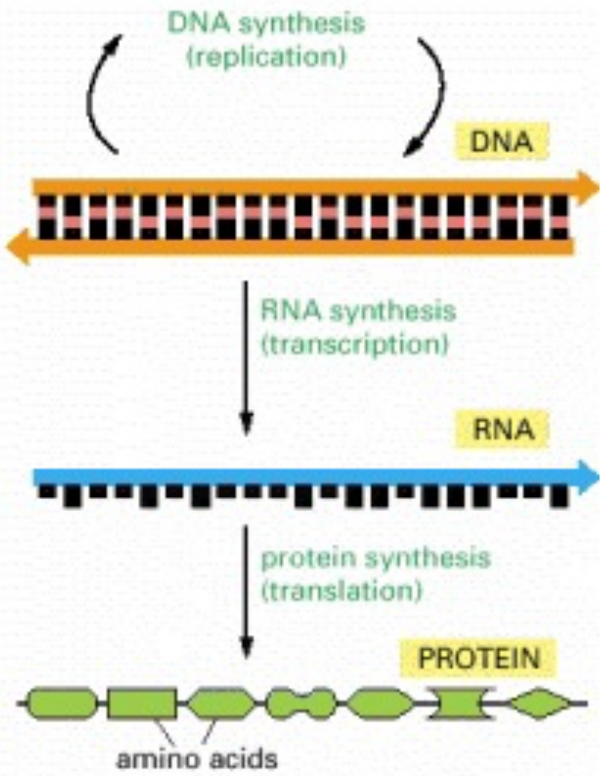
What are proteins?

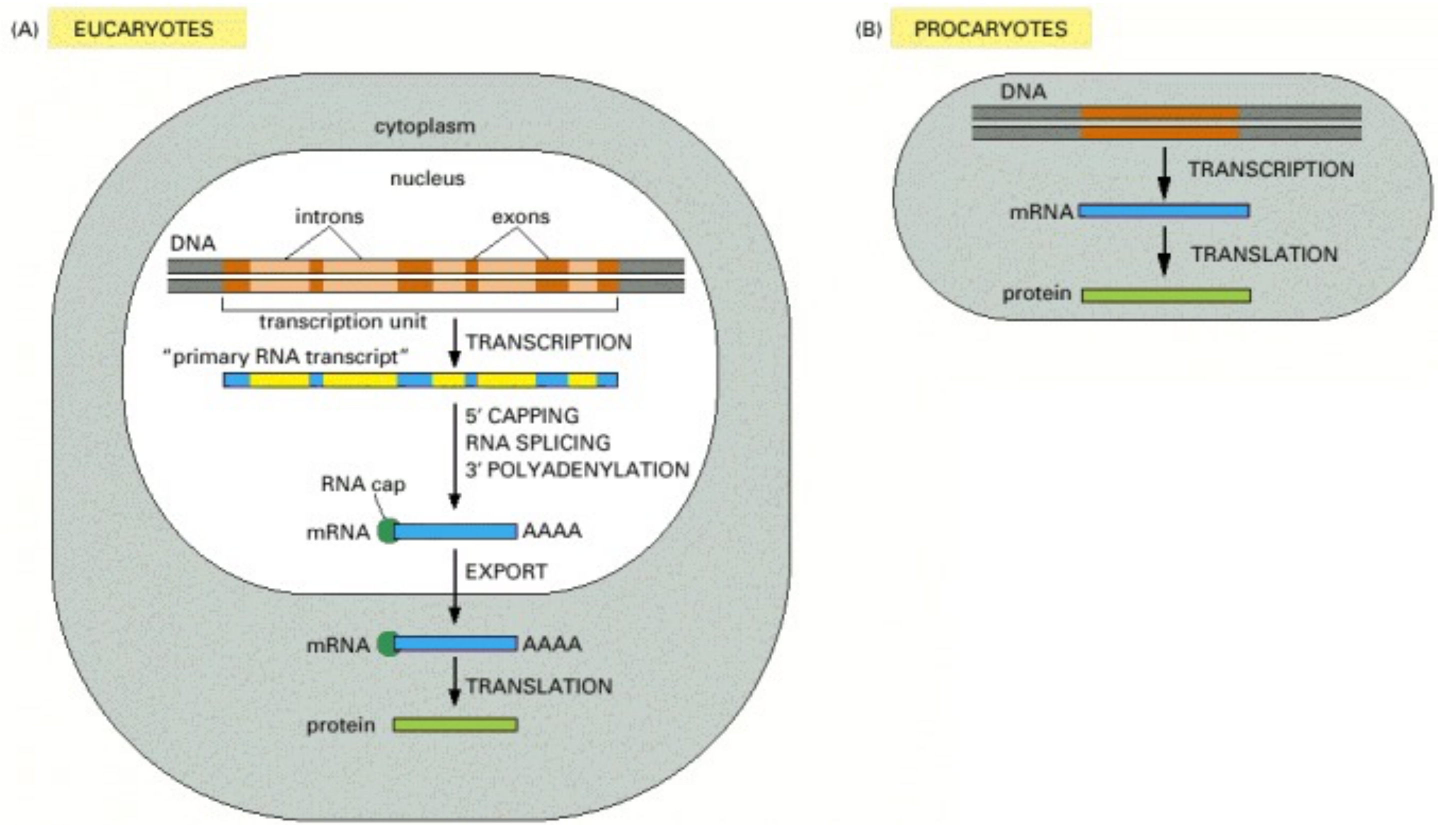
- Proteins are large & complex molecules
- Play many critical roles in the cells
- Made of amino acid
- Examples: antibody, several hormones, contractile proteins
  e.g. myosin, enzymes…



Ekundayo et al., Nature Structural & Molecular Biology 2023

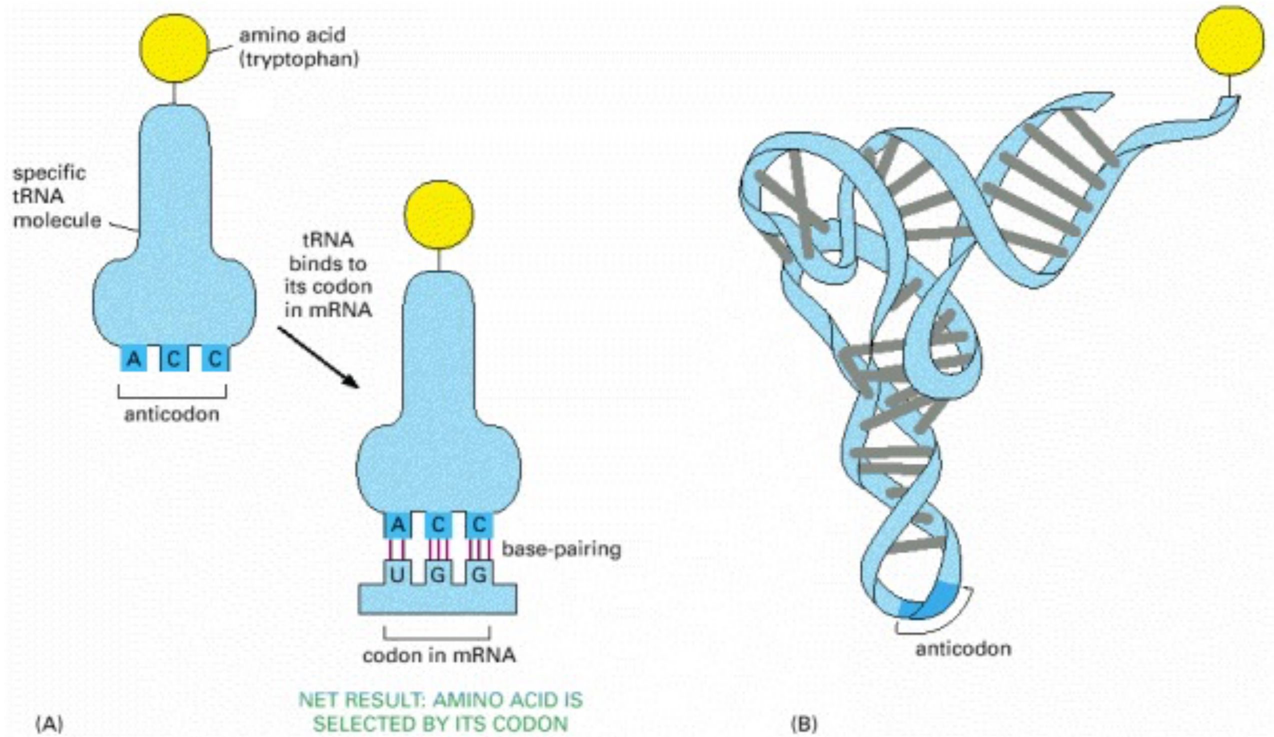
From DNA to mRNA to protein



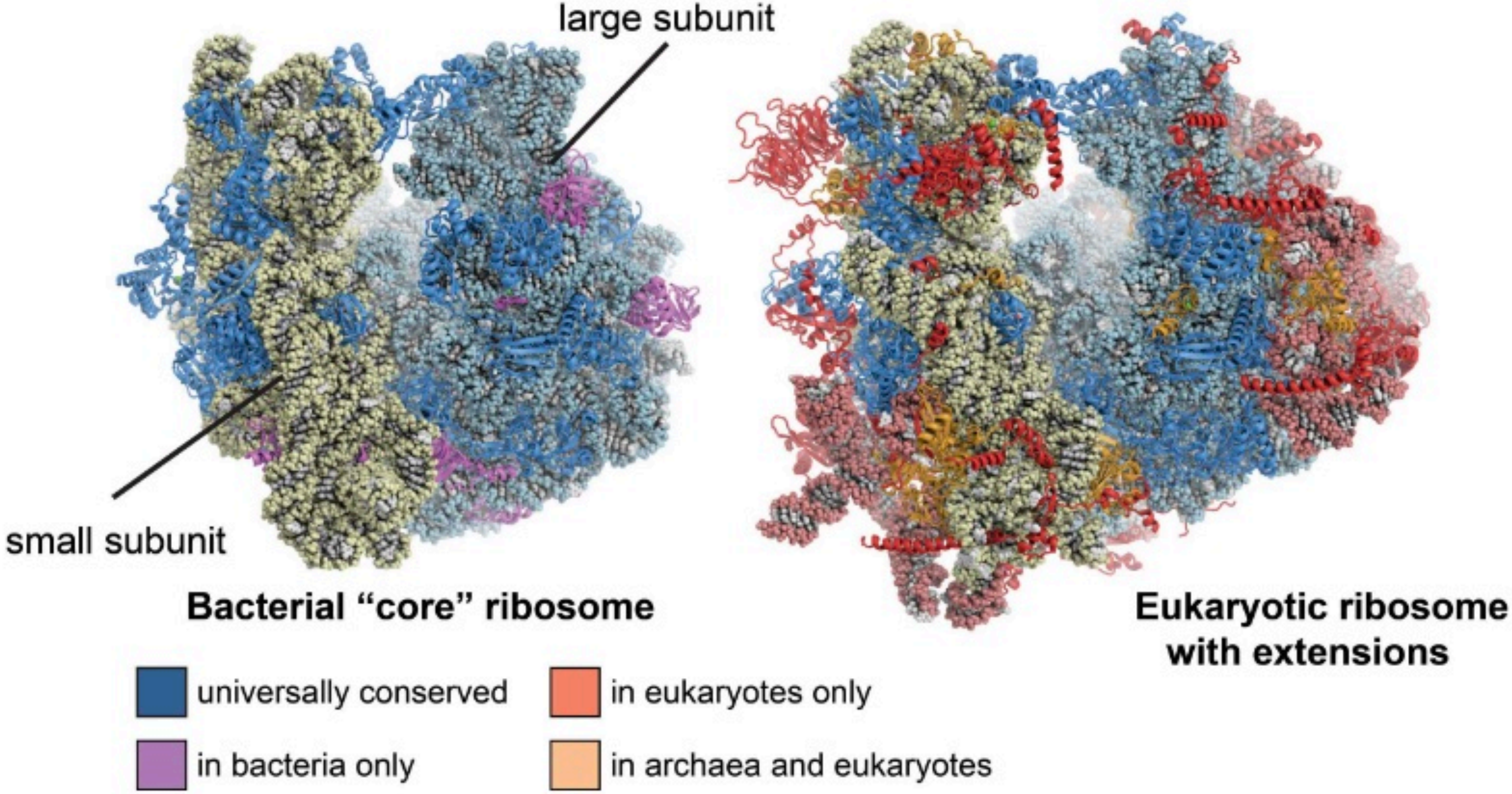


The genetic code - from 3 nucleotides to 1 amino acid

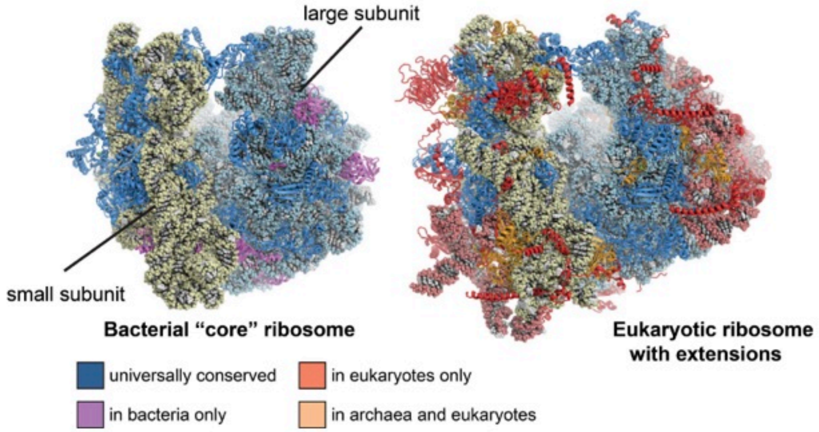
First letter	Second letter: U	C	A	G	Third letter
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
U	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
U	UUA Leu	UCA Ser	UAA Stop	UGA Stop	A
U	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
C	CUC Leu	CCC Pro	CAC His	CGC Arg	C
C	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
C	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
A	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
A	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
A	AUG Met	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
G	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
G	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
G	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

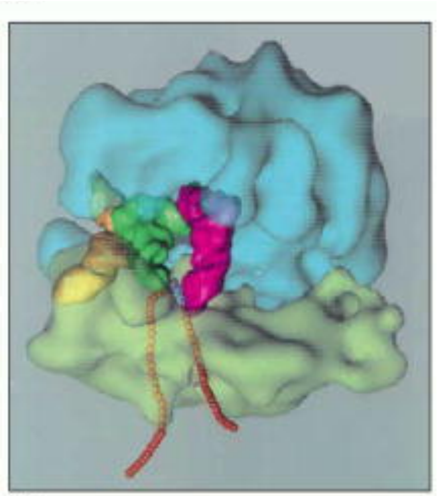


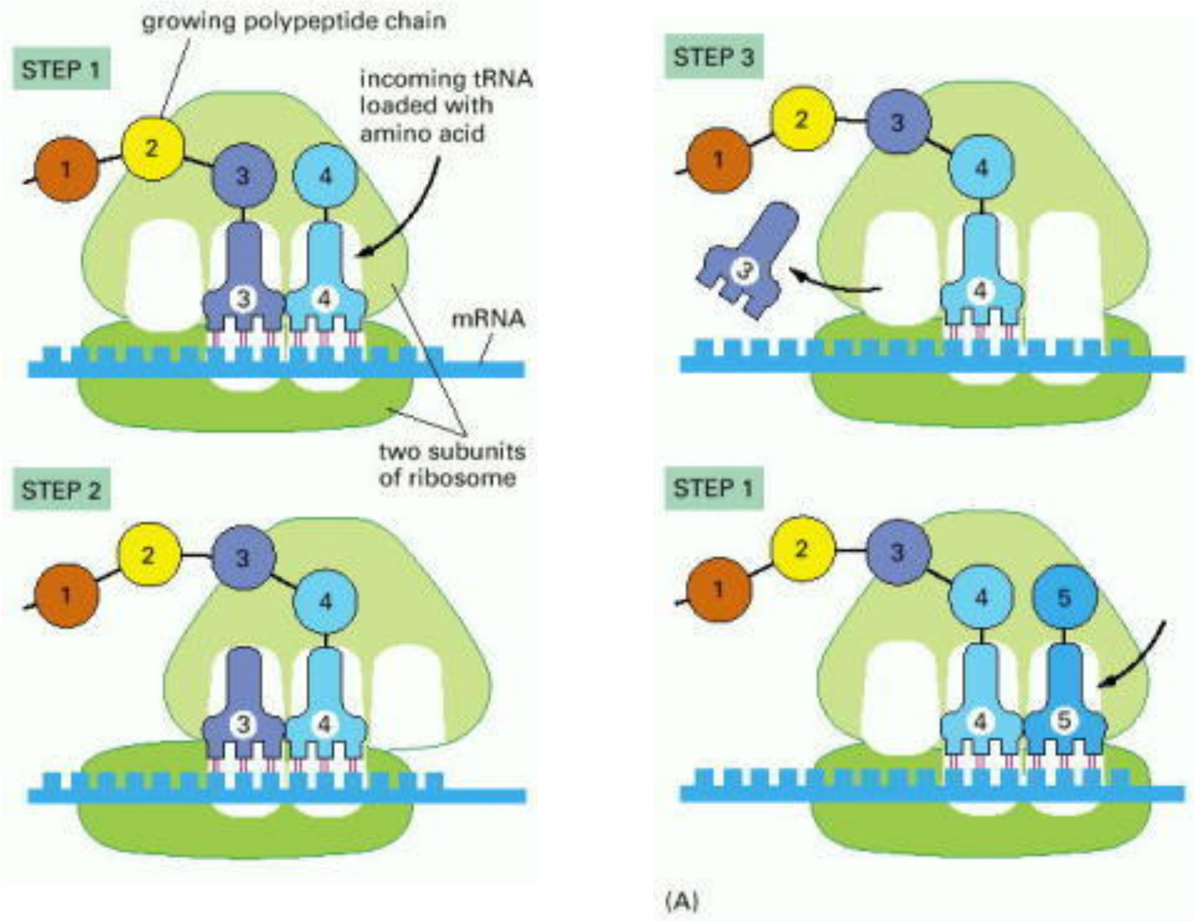
The role of the ribosome



The role of the ribosome




(B)

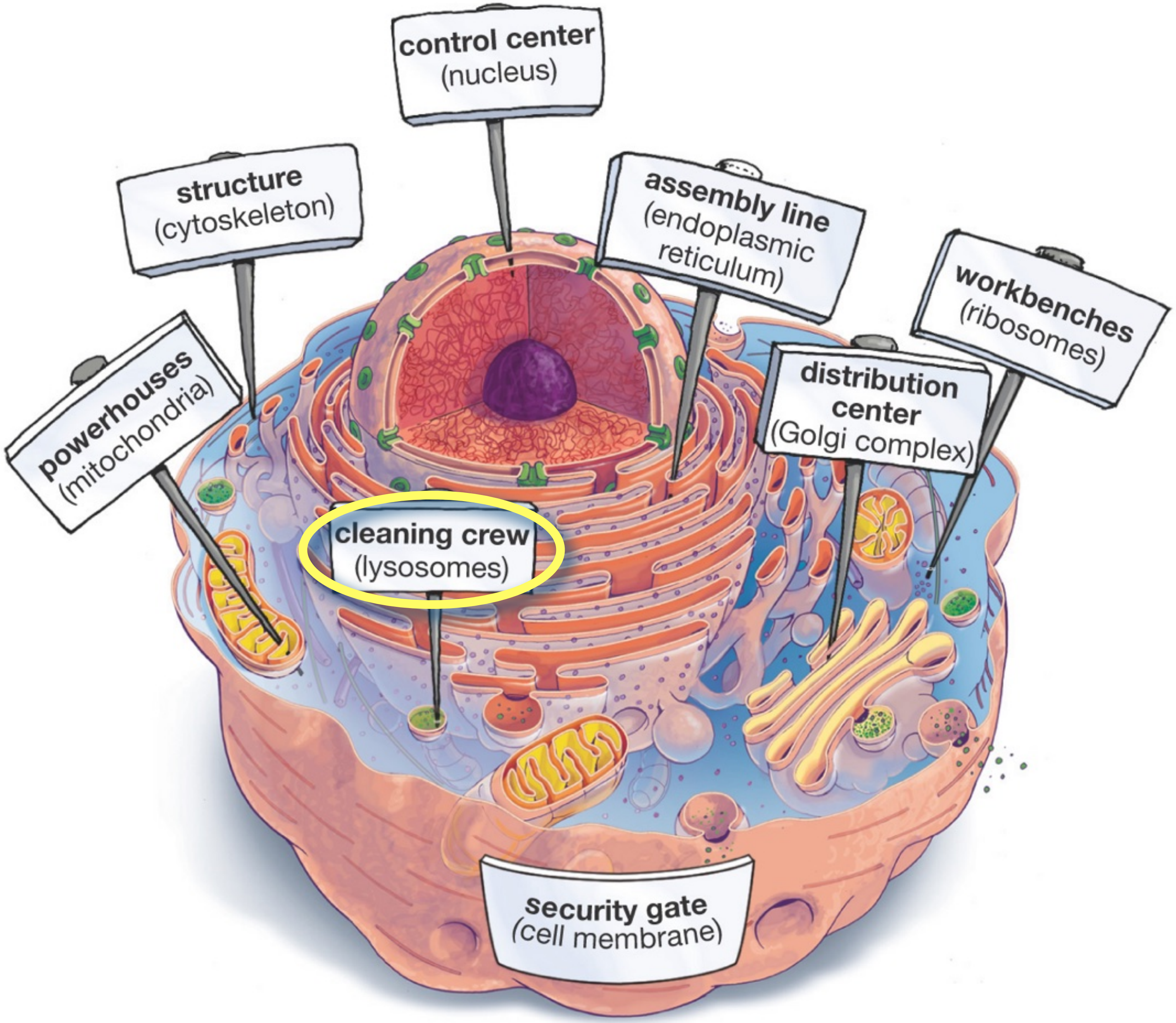


(A)

The Ban Lab ETHZ

https://www.youtube.com/watch?v=TfYf_rPWUdY

Cellular Anatomy



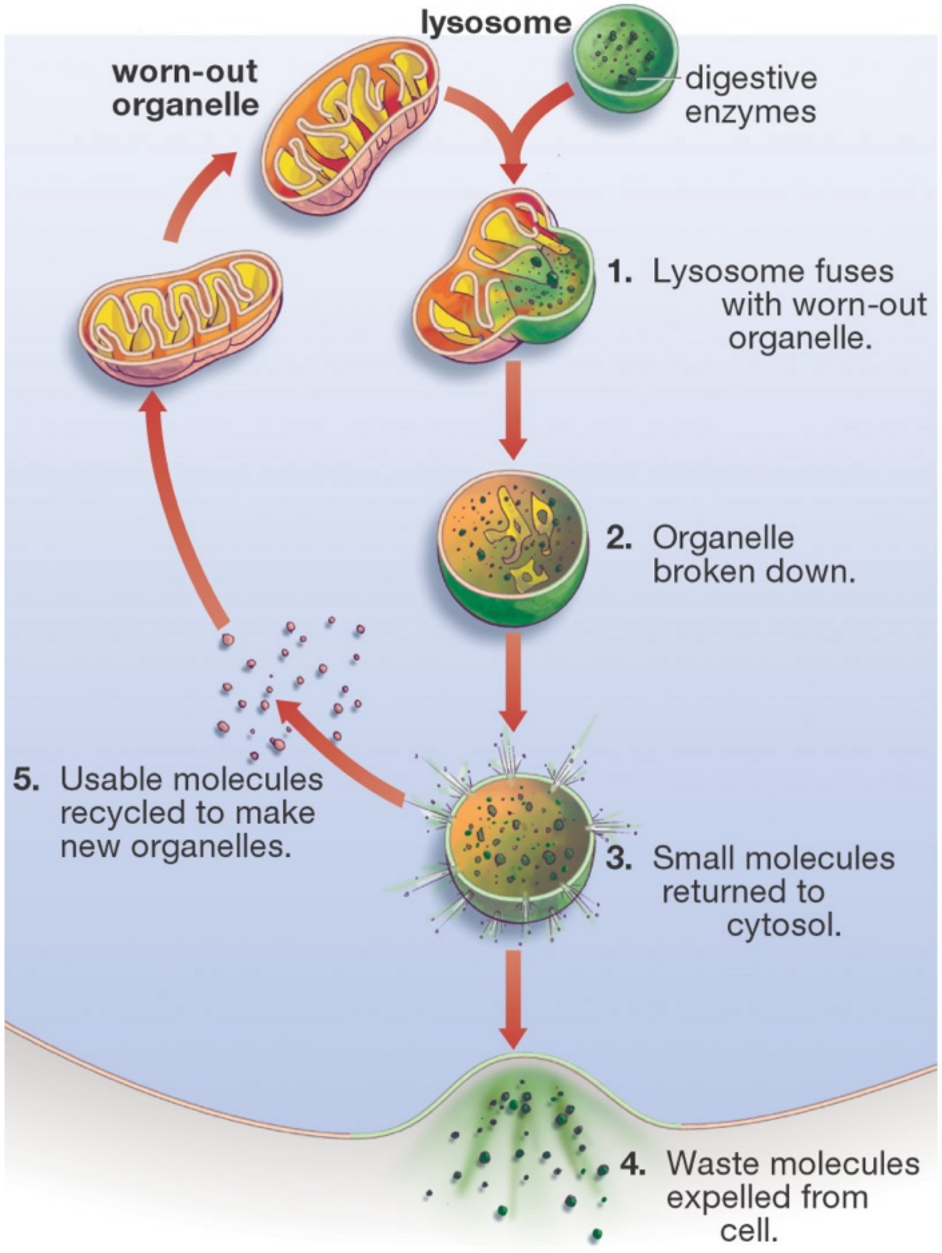
The Lysosome

Functions:

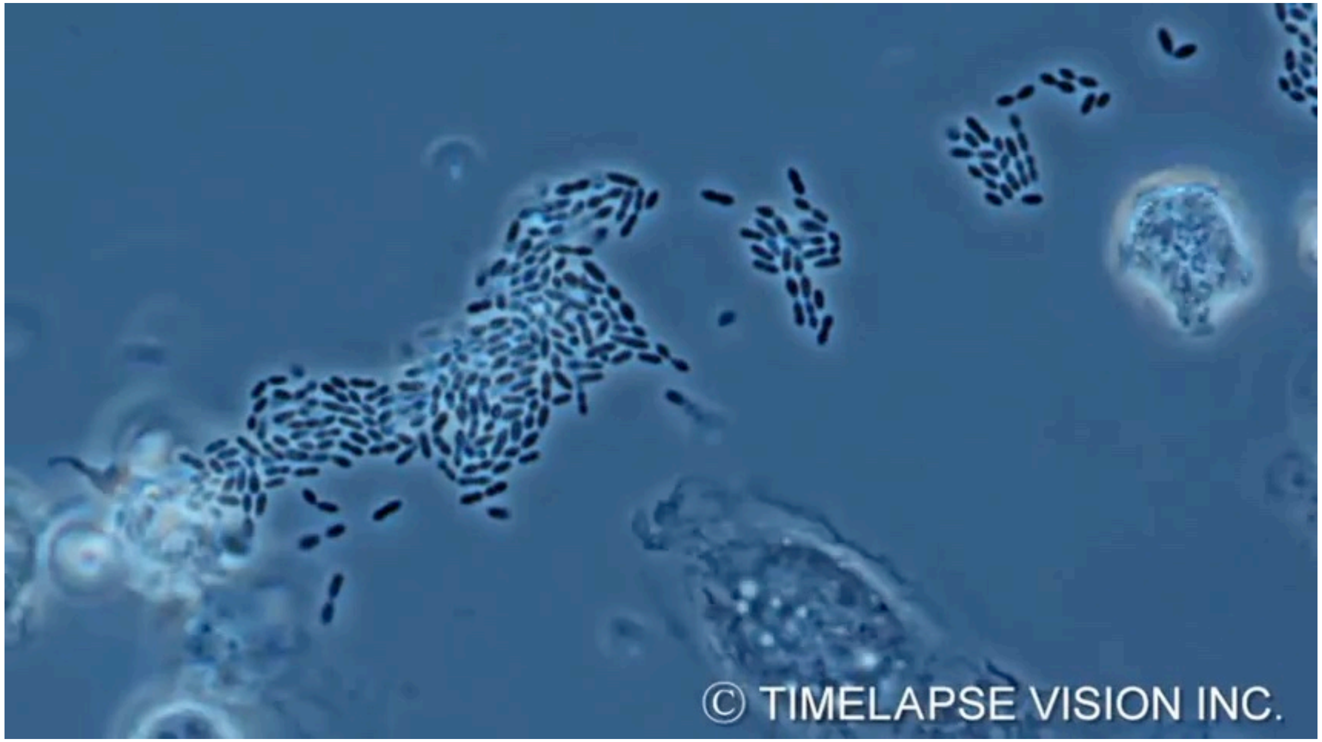
Digesting food or cellular invaders

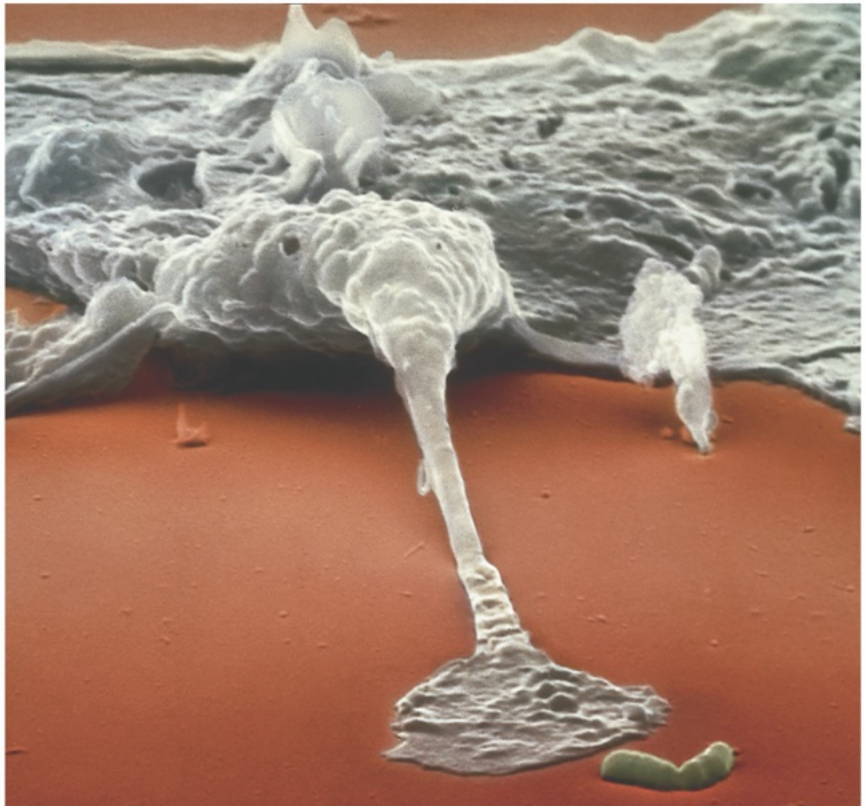
Recycling cellular components

(The lysosome is not found in plant cells)



The Lysosome





This bacterium about to be eaten by an immune system cell will spend the last minutes of its existence within the lysosome of this white blood cell.

Many Diseases are Caused by Lysosome Malfunction

Children's Hospital of Philadelphia

Conditions we treat

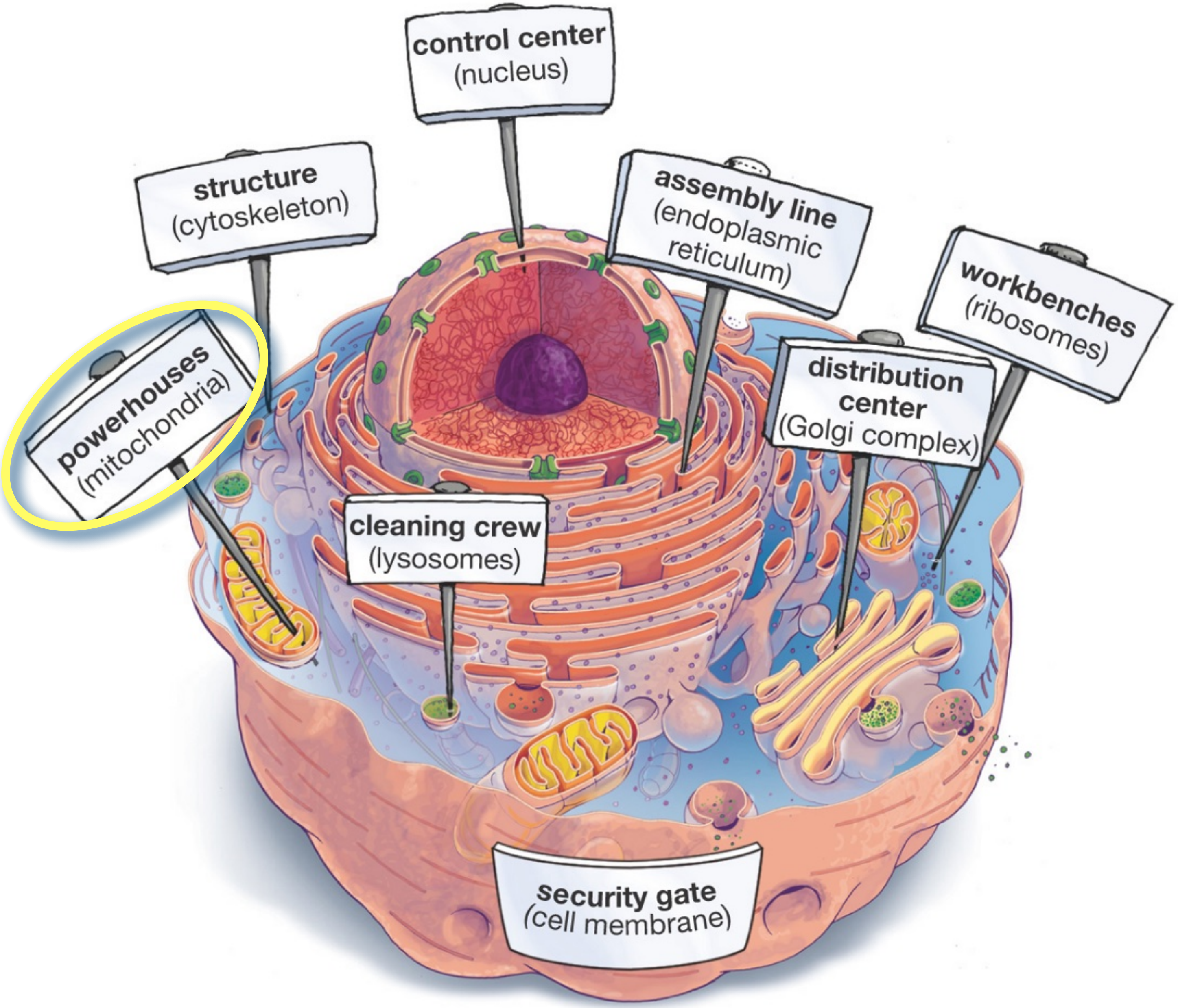
Lysosomal Storage Diseases are genetic disorders caused by enzyme deficiencies in the body. These deficiencies make it difficult for cells to process or break down metabolites. Accumulation of metabolites in the body can lead to organ dysfunction.

There are more than 50 LSD disorders, all of which are complex, chronic diseases that can involve multiple organs. LSDs can be present at birth or develop later in life. Many cases are difficult to diagnose, which can delay essential treatment and frustrate patients seeking answers.

LSDs

- Fabry disease
  (causes kidney and heart problems, pain and skin rash)
- Gaucher disease
  (causes the spleen to enlarge, anemia and bone lesions)
- Hurler syndrome
  (causes deformities of the skeleton and facial features, enlargement of the spleen and liver, joint stiffness)
- Mucopolysaccharidosis (MPS)
- Pompe disease (glycogen storage disease type II)
- Multiple sulfatase deficiency
- Mucolipidosis
- Wolman disease (Lysosomal acid lipase deficiency)
- Alpha-mannosidosis
- Gangliosidosis
- Niemann-Pick
- Danon disease
- Metachromatic leukodystrophy

Cellular Anatomy

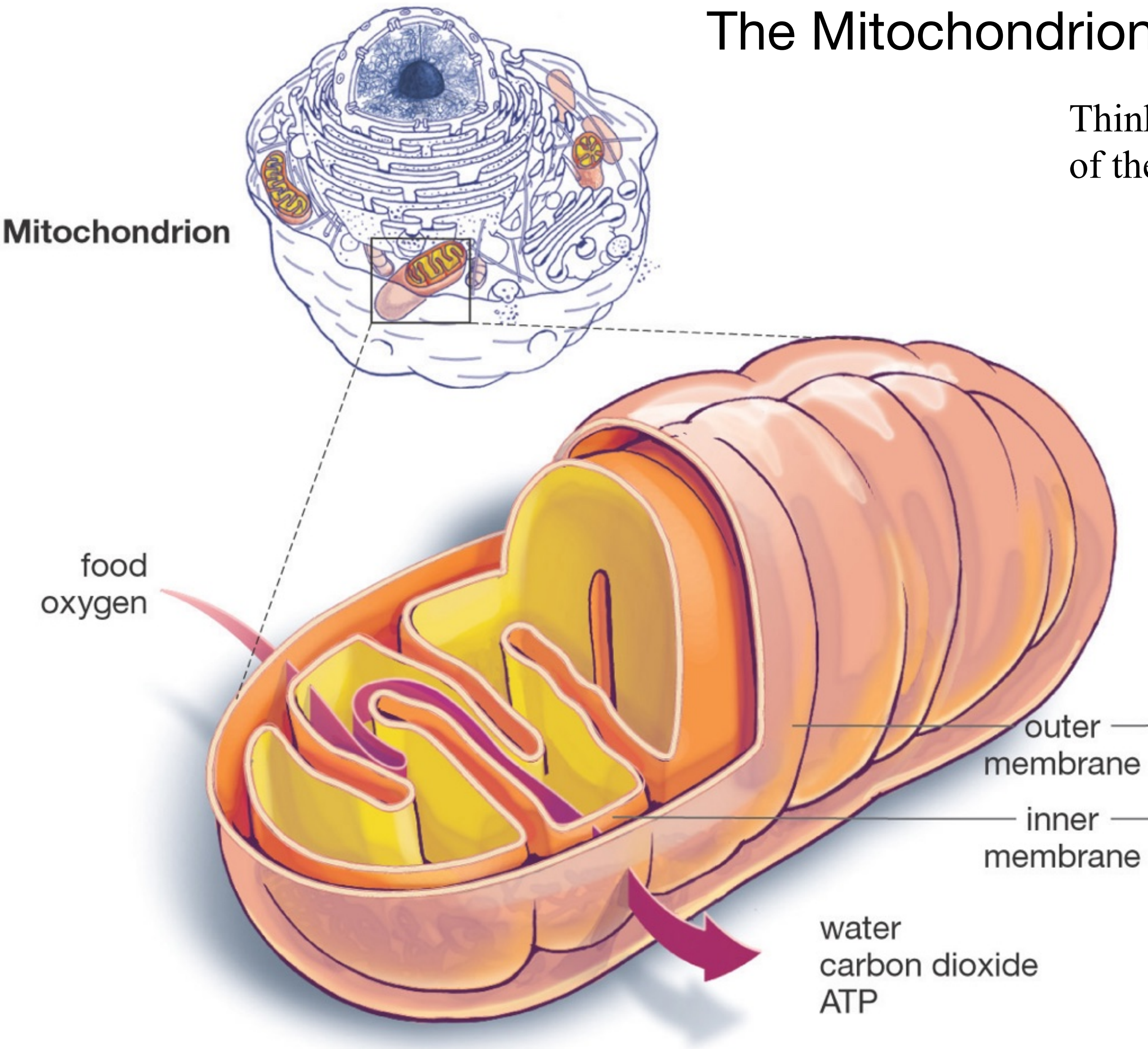


The Mitochondrion

Think of the mitochondrion as the powerhouse of the cell.

Both plant and animal cells contain many mitochondria.

(Mitochondria is the plural of mitochondrion)



The Mitochondrion

A class of diseases that causes muscle weakness and neurological disorders are due to malfunctioning mitochondria.

Worn out mitochondria are an important factor in aging.

Mitochondrial Diseases

We All Have Mitochondria.

Mitochondria exist in nearly every cell of the human body. It's responsible for creating 90% of the energy you need to sustain life and support organ function.

What Is Mitochondrial Disease?

When mitochondria cannot convert food and oxygen into life-sustaining energy, cell injury and even cell death follow. When this process is repeated throughout the body, organ systems begin to fail and even stop functioning.

Why Do Mitochondria Malfunction?

There is still so much to uncover, but this is what we do know. Mitochondrial disease is an inherited condition. Your mitochondria can also be affected by other genetic disorders and environmental factors. You can learn more about the biology behind mitochondrial disease **here**.

UNITED MITOCHONDRIAL DISEASE FOUNDATION®

How Mitochondrial Disease Affects the Body

The parts of your body that need the most energy – heart, brain, muscles – are most affected by mitochondrial disease. An affected individual may exhibit a spectrum of symptoms.

Brain
developmental delays, dementia, migraines, autistic features, seizure, stroke, atypical cerebral palsy, learning disabilities

Muscles
weakness/failure, cramping, reflux, vomiting, constipation, diarrhea, hypotonia, dysmotility

Nerves
fainting, zero reflexes, heat/cold intolerance, pain

Pancreas
diabetes, pancreatic failure, parathyroid failure

Kidneys
renal tube failure

Heart
defects, blockage, cardiomyopathy

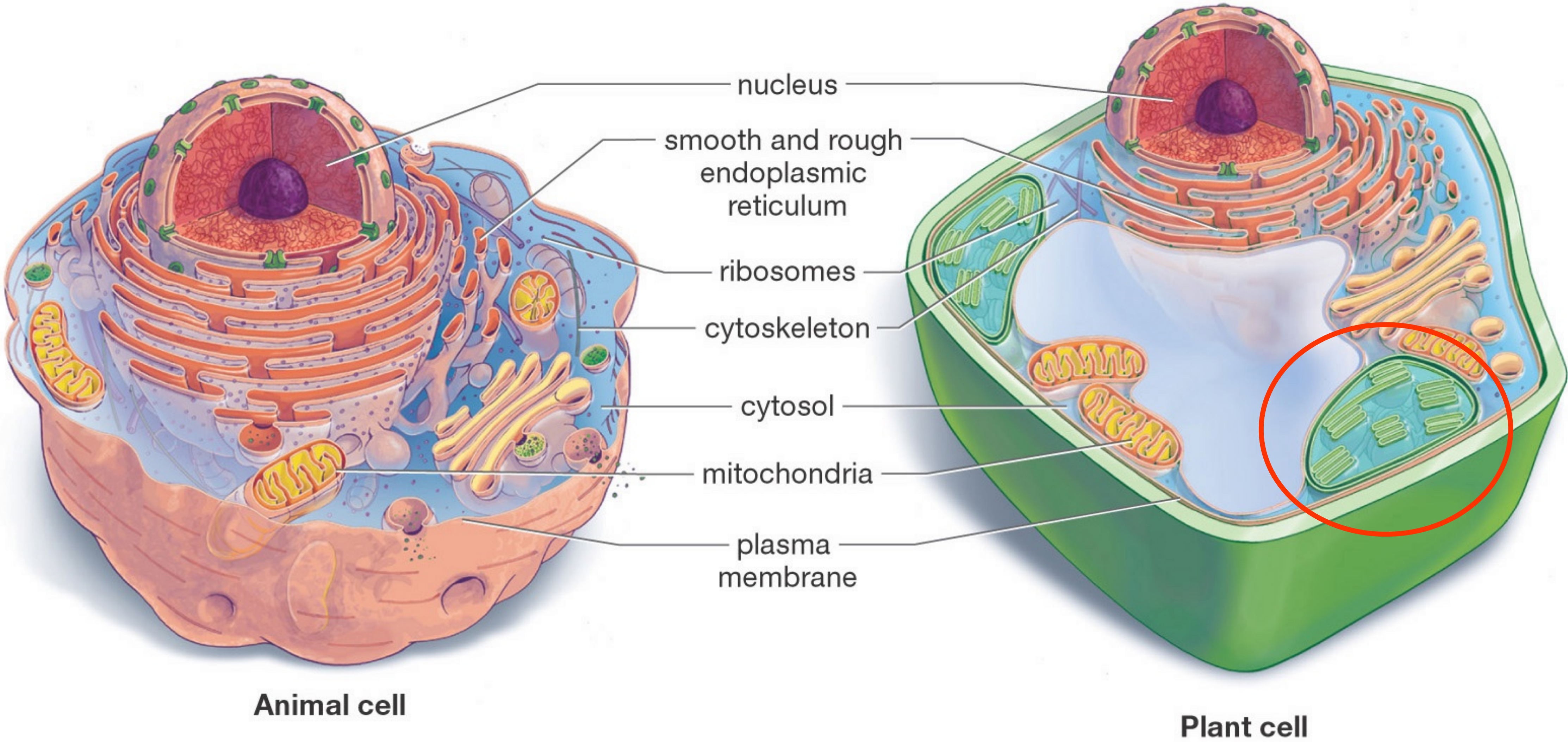
Liver
low blood sugar, liver failure

Ears
hearing loss

Eyes
vision loss, ptosis, optic atrophy, strabismus, ophthalmoplegia, retinitis pigmentosa

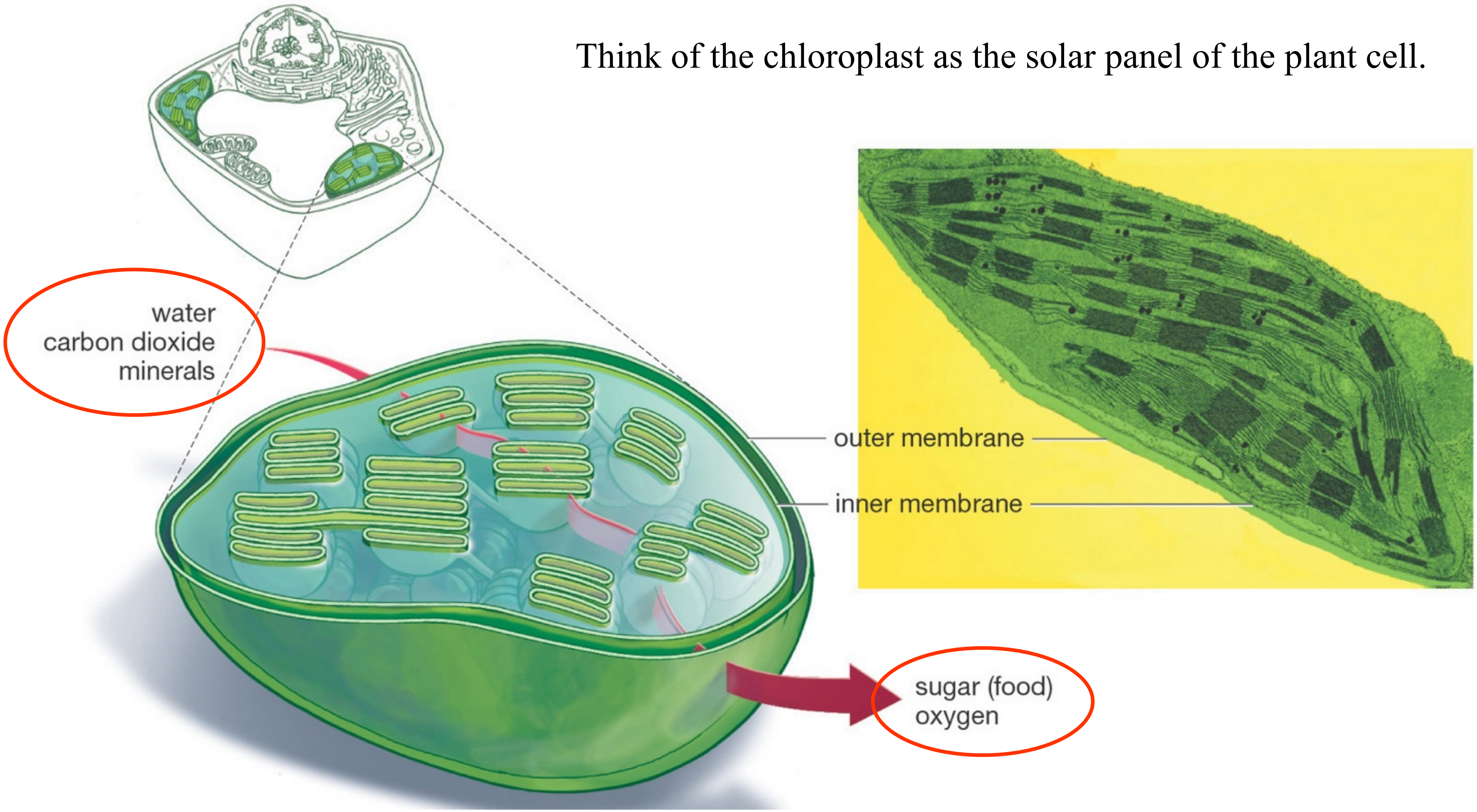
Systemic
failure to gain weight, fatigue, short stature, unexplained vomiting, respiratory problems

Animal *vs*. Plant Cells – Chloroplasts Are a Big Part of the Difference



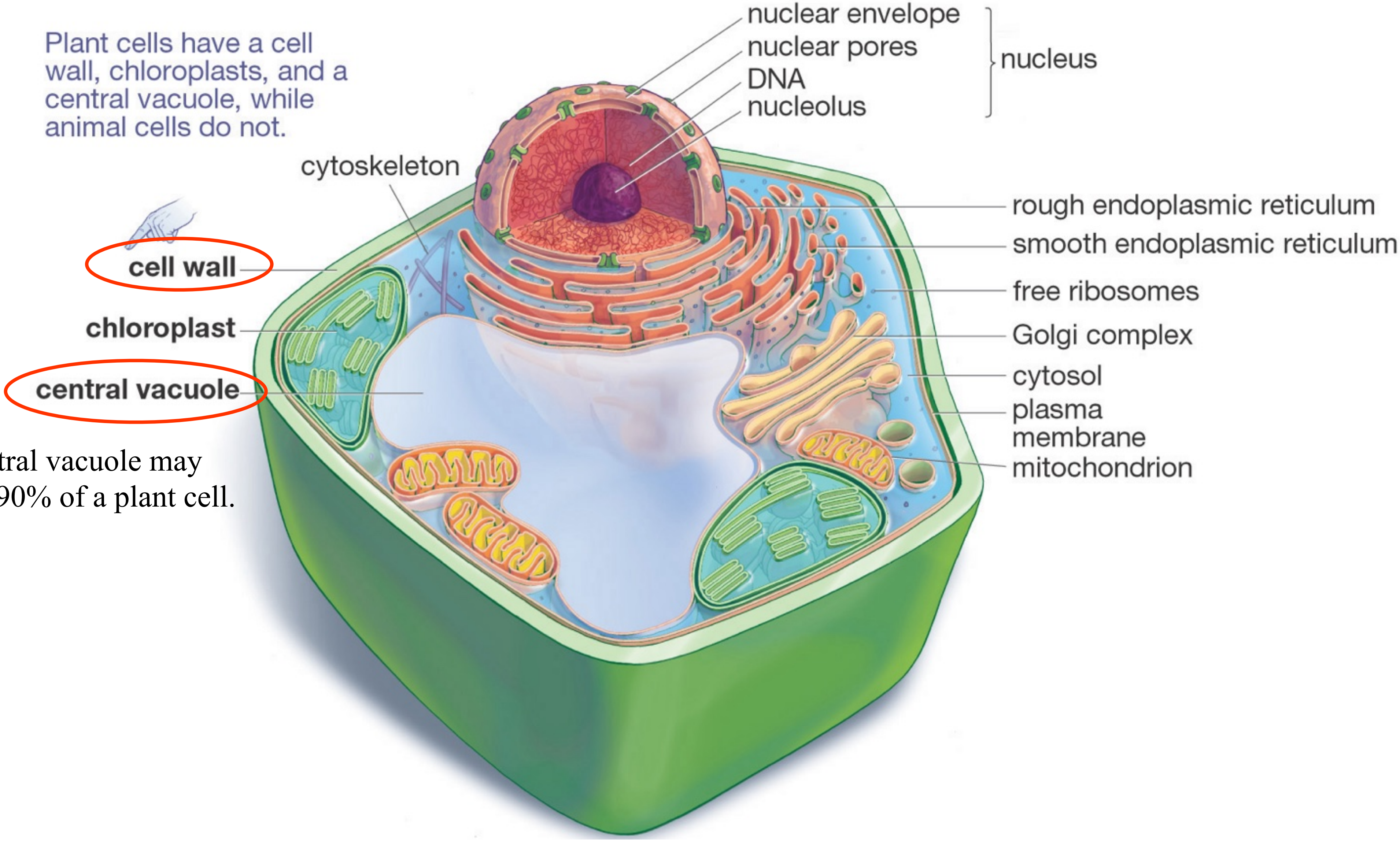
The Chloroplast

Think of the chloroplast as the solar panel of the plant cell.



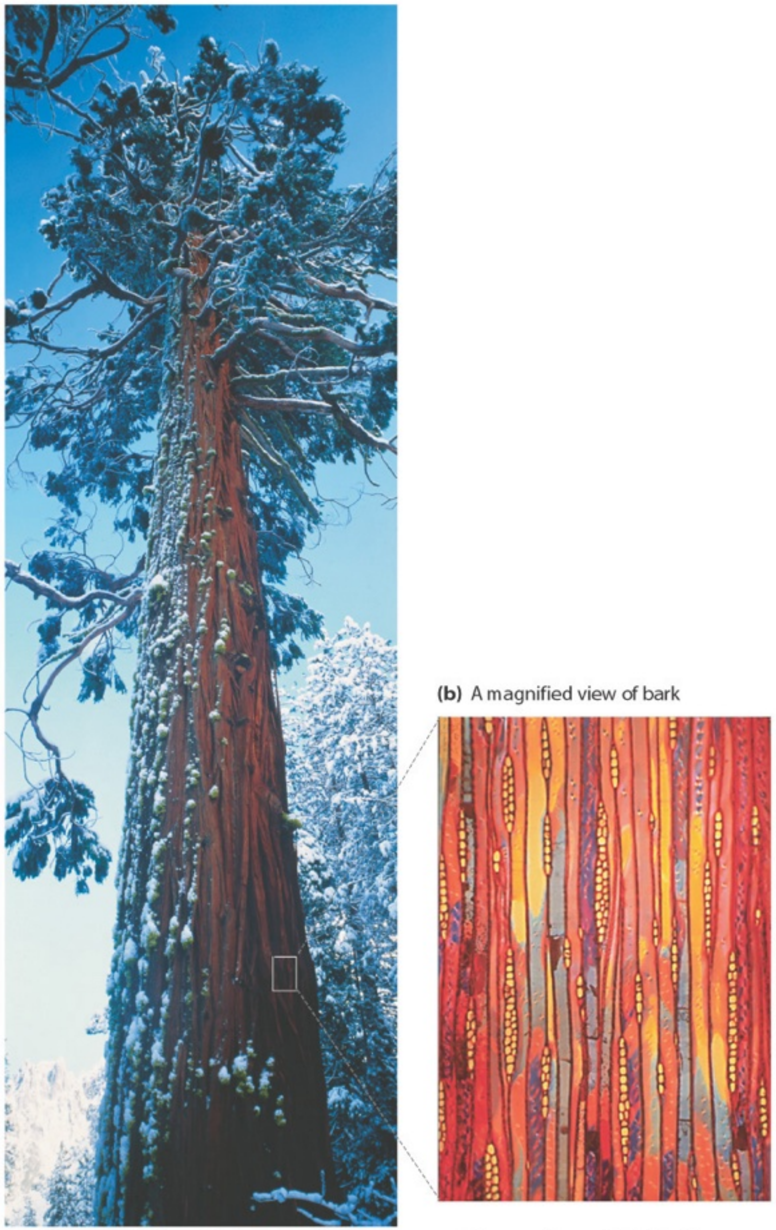
Only plants have chloroplasts, but animals reap the benefits too.

Two Other Unique Features of Plant Cells



The central vacuole may occupy 90% of a plant cell.

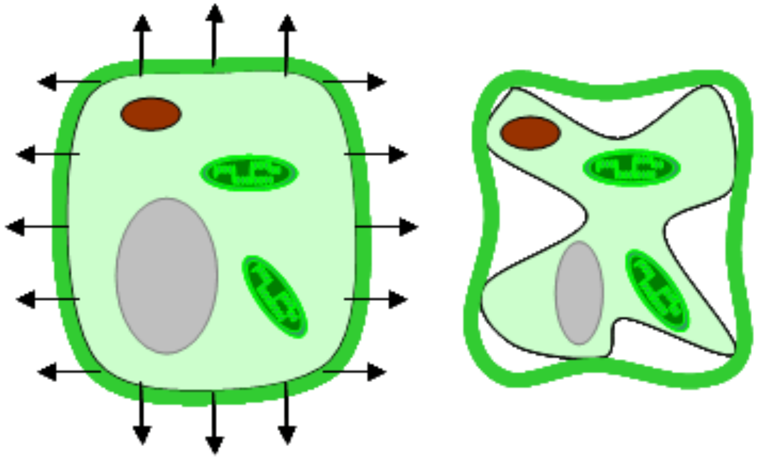
A Consequence of Cell Walls: the Great Strength of Woody Plants



(a) Wood is mostly cell walls

(b) A magnified view of bark

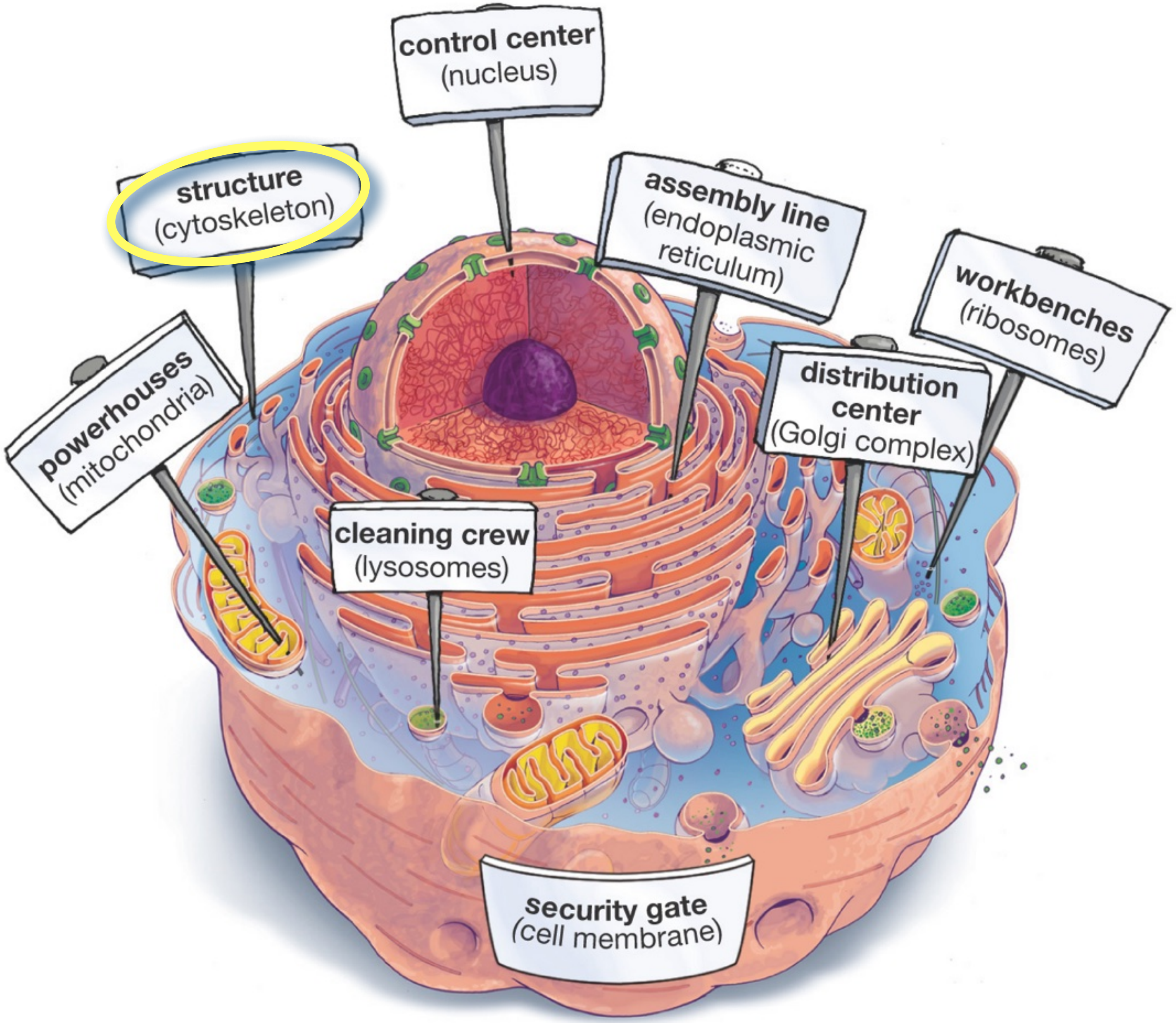
The Central Vacuole Controls Turgor Pressure



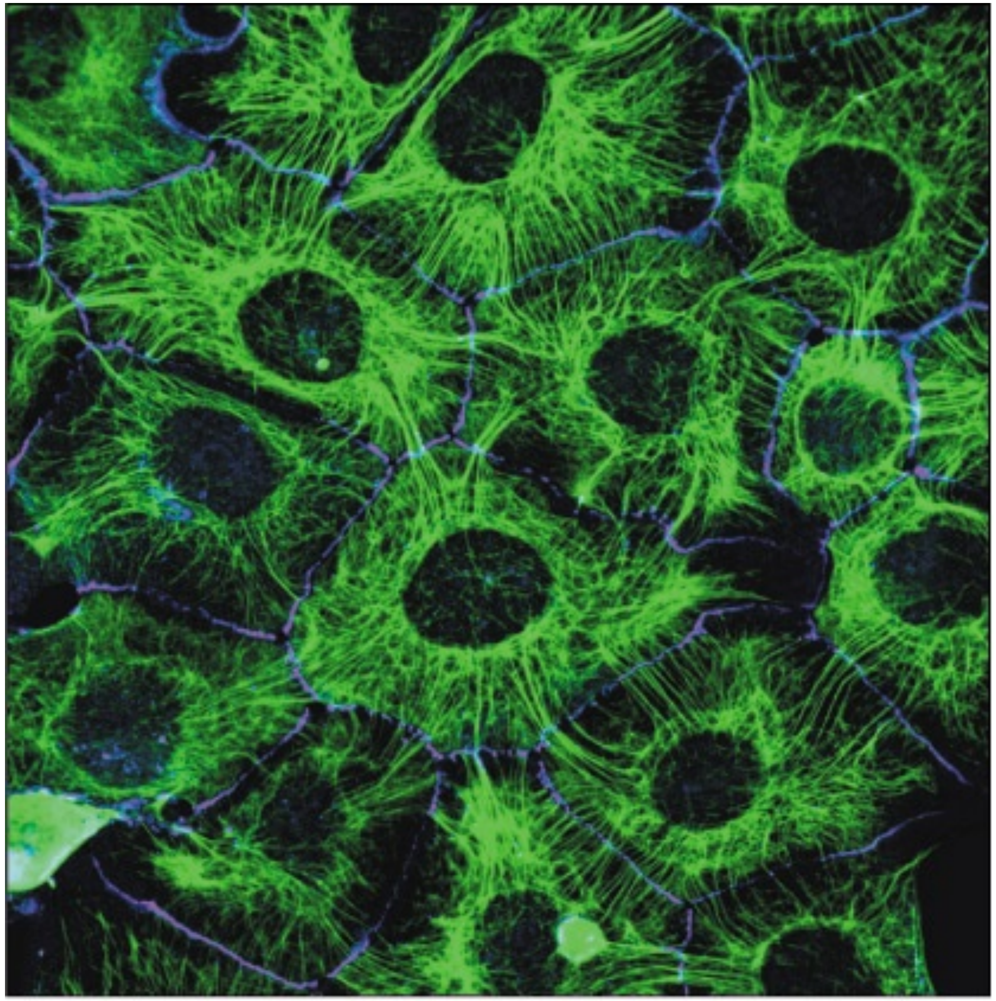
flaccid

turgid

Cellular Anatomy



The Cytoskeleton



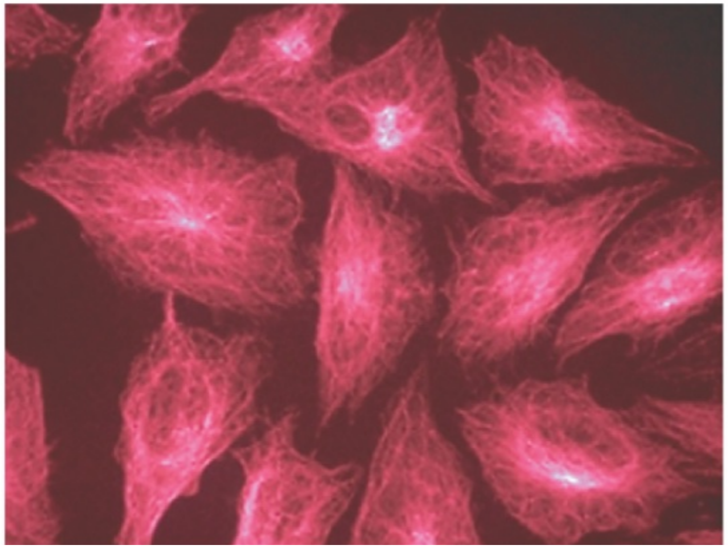
An animal cell cytoskeleton

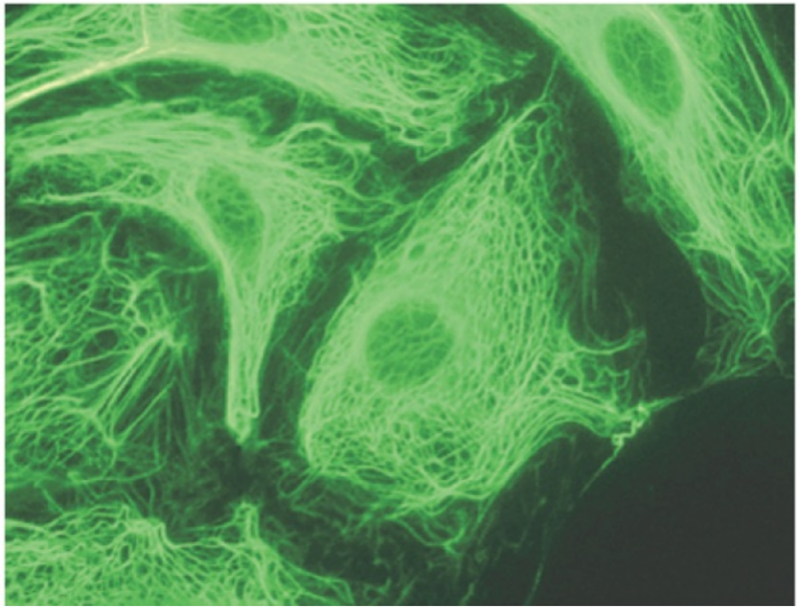
10 μm

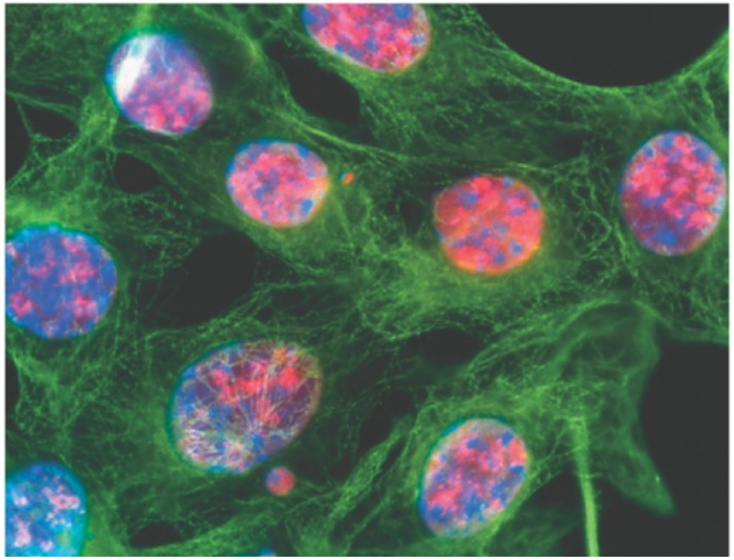
Figure 16–18. Molecular Biology of the Cell, 4th Edition

The name is misleading:
The cytoskeleton <u>is</u> the skeleton of the cell,
but it’s also like the muscular system,
able to change the shape of cells in a flash.

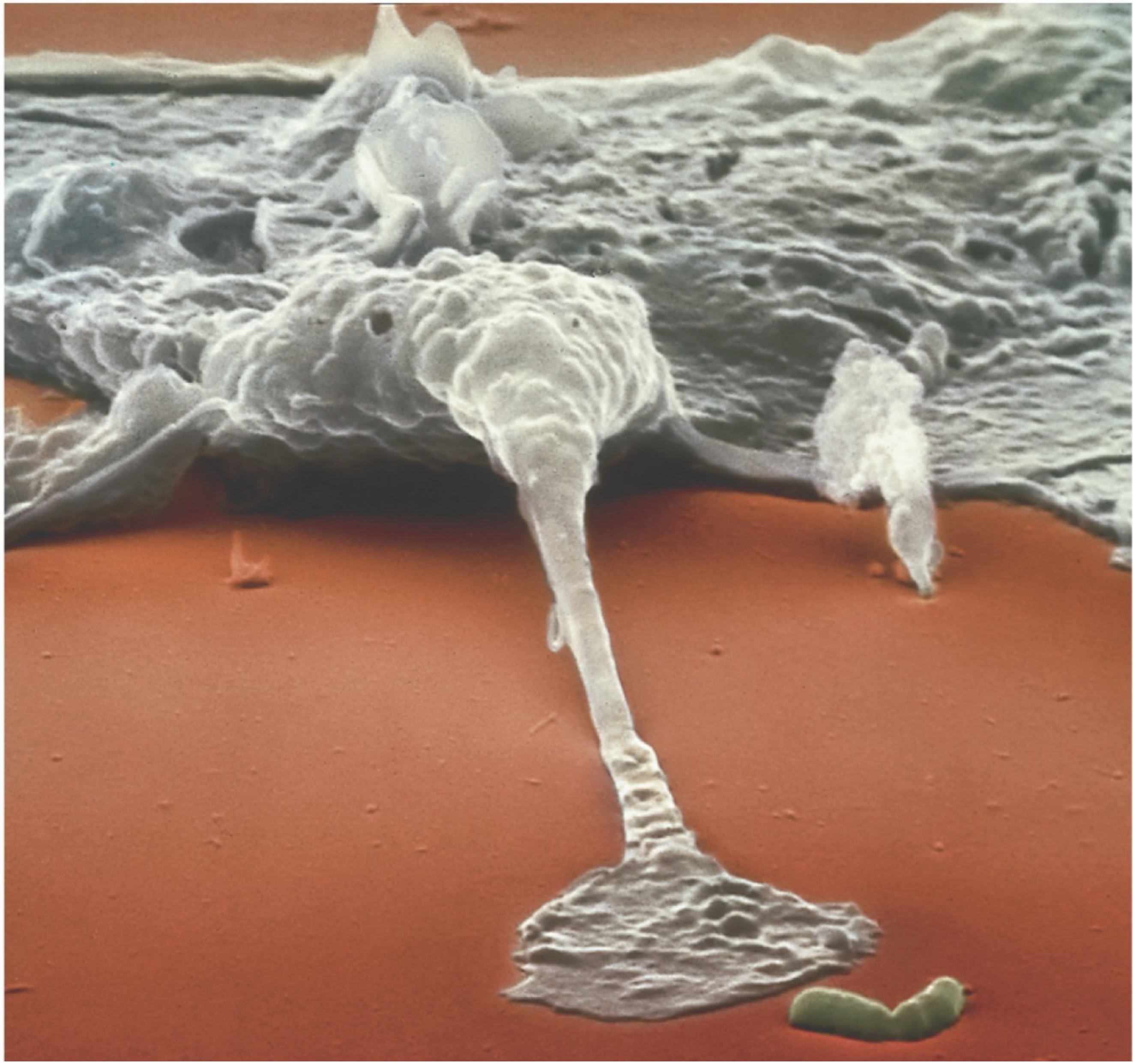
A Cytoskeleton Gallery







The Cytoskeleton in Action

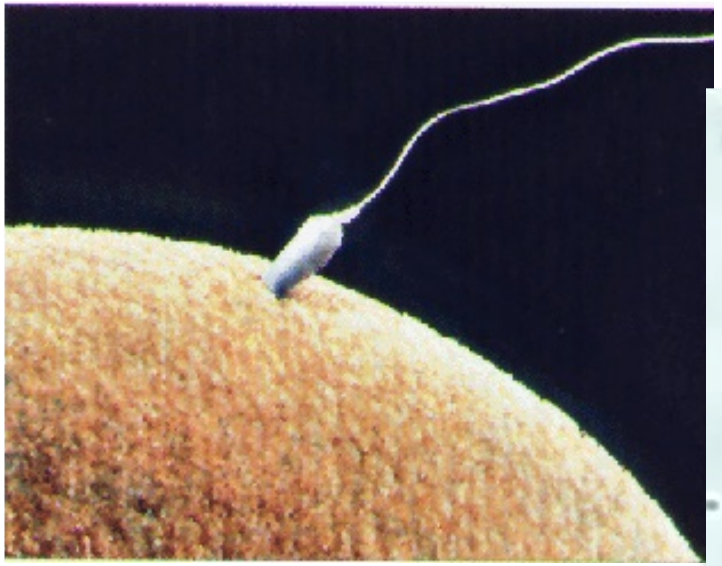


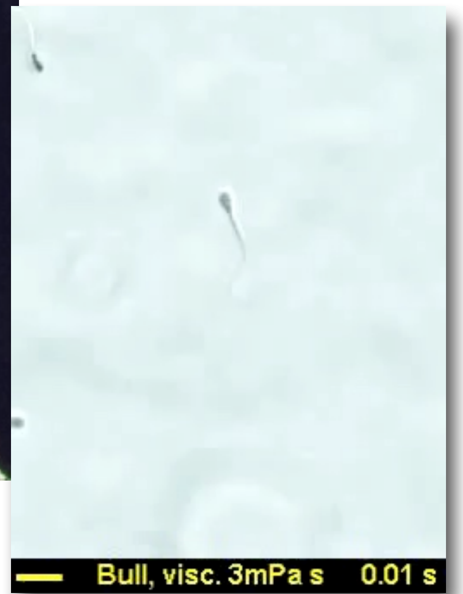
A white blood cell using the cytoskeleton to “reach out” for a hapless bacterium.

The Cytoskeleton in Action

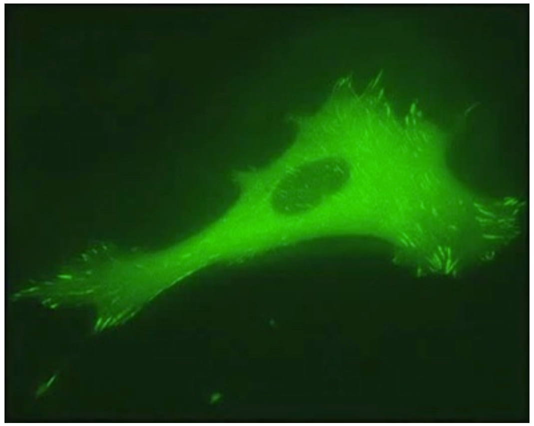
Cilia on a protozoan

Smoker's cough is due to destruction of cilia in the airways.



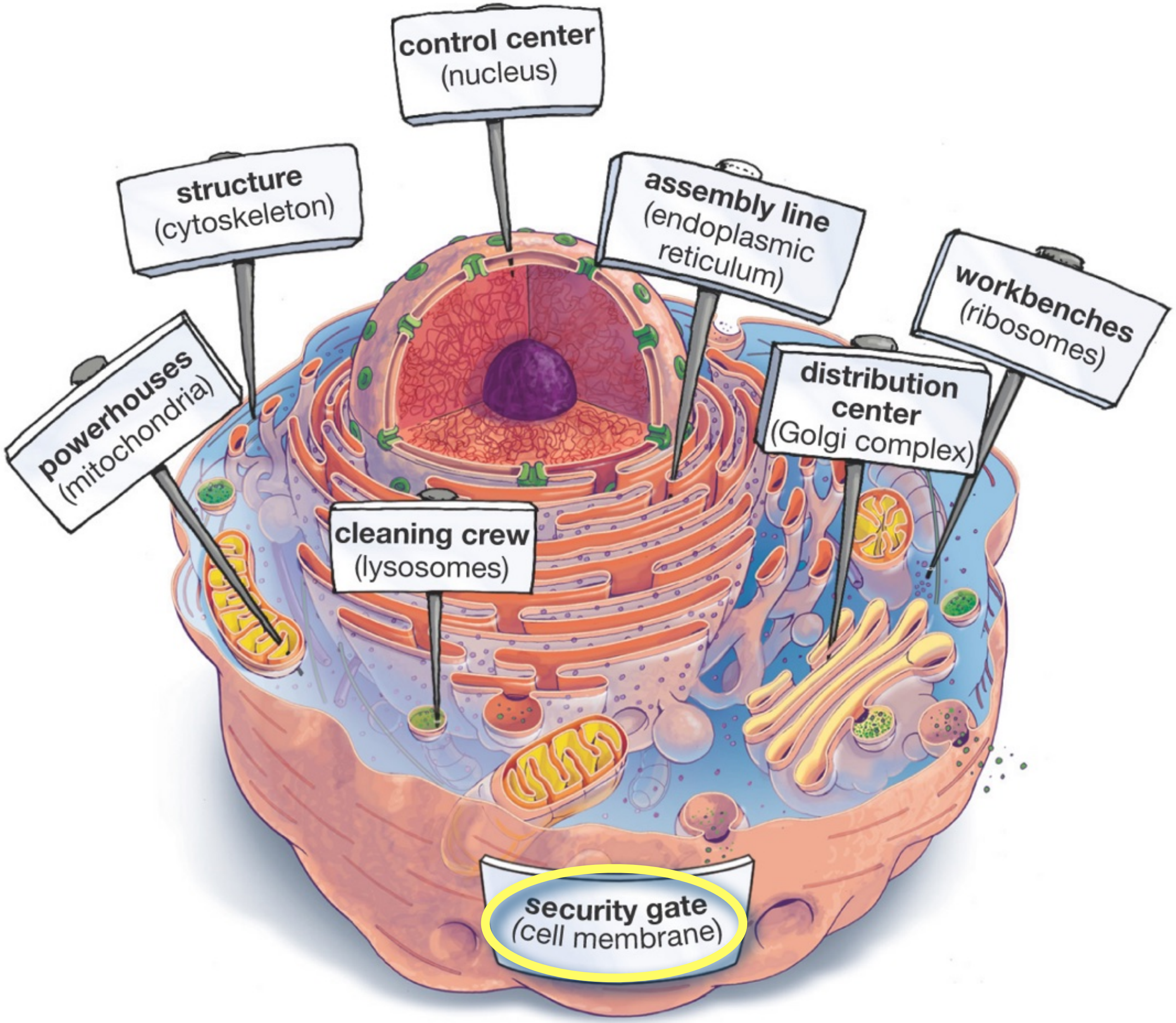


Beating sperm tail at fertilization

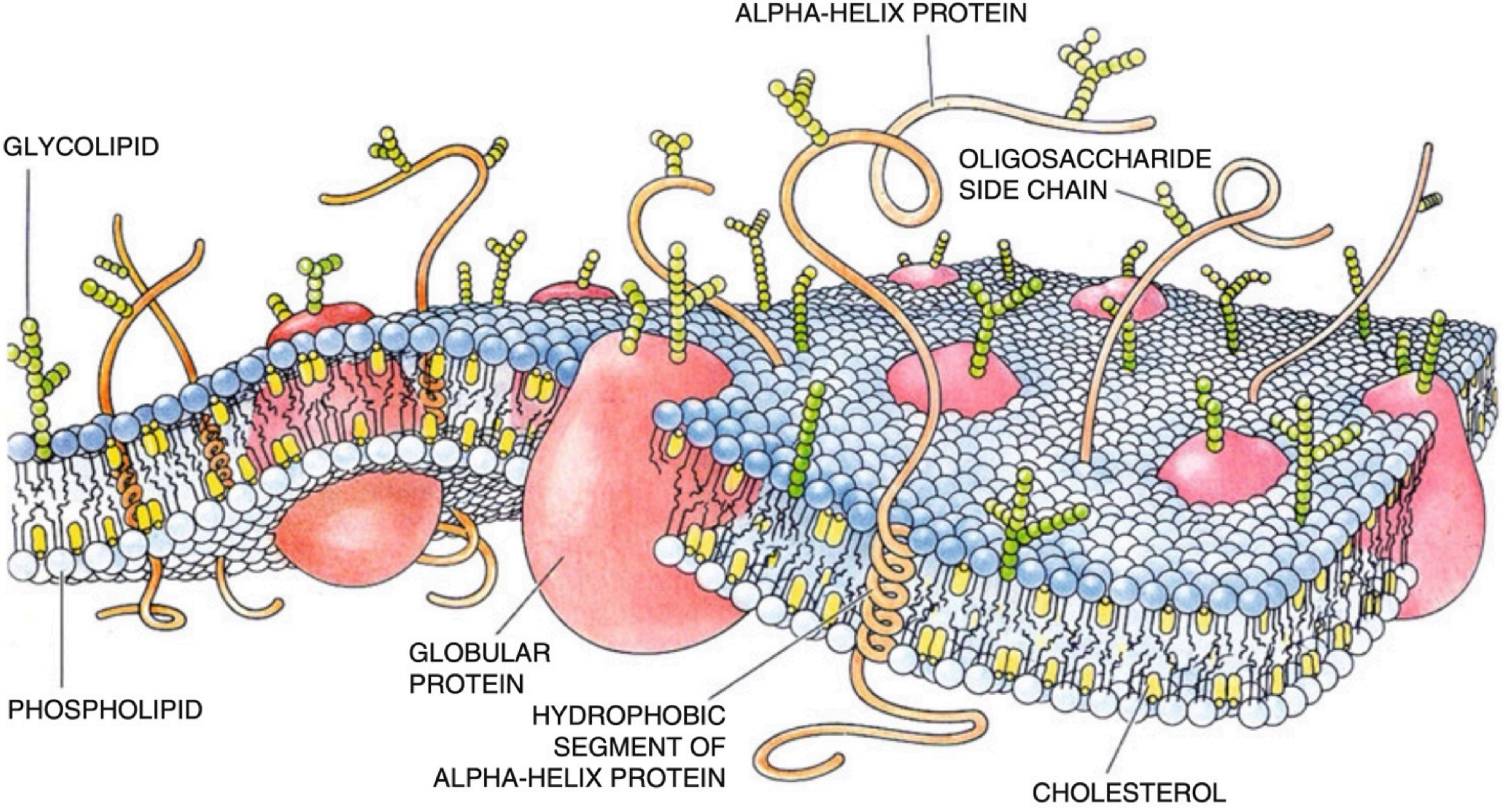


The actin cytoskeleton allows a cell to crawl

Cellular Anatomy



Biological Membranes



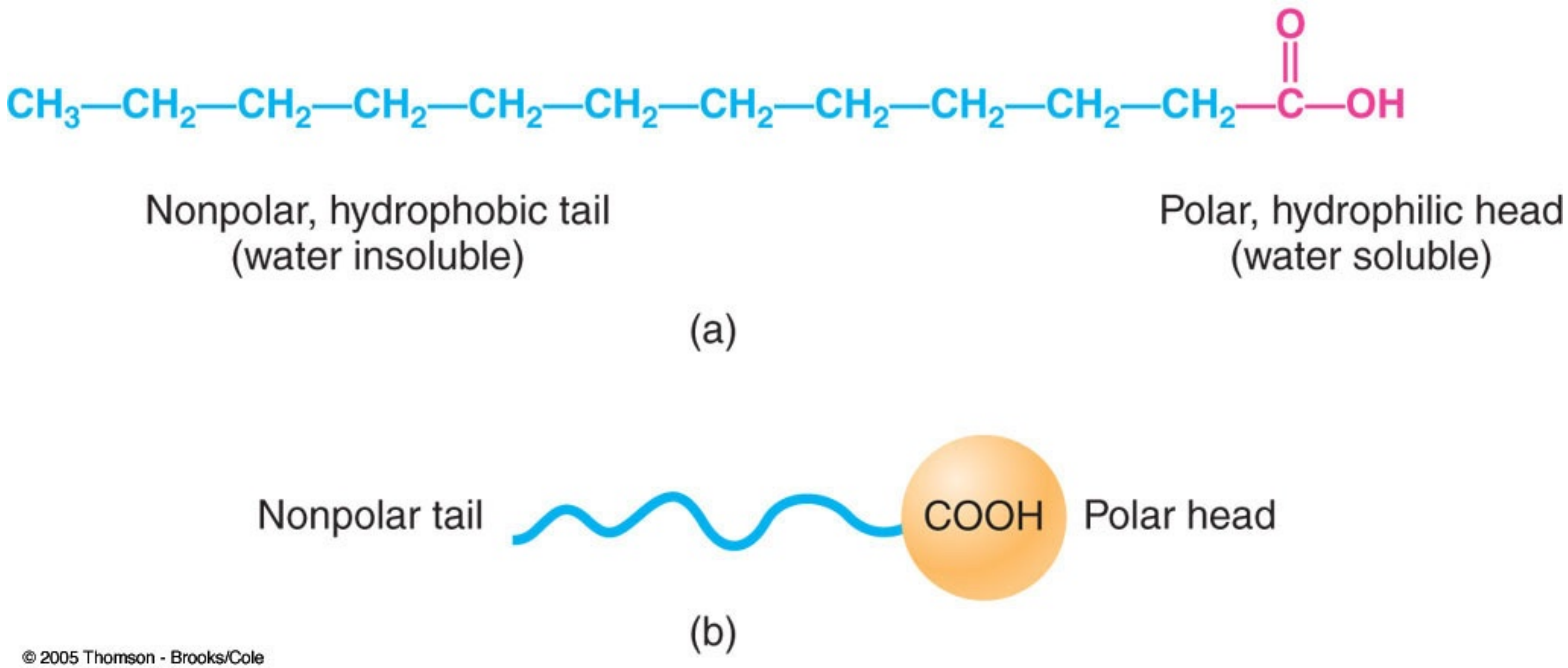
Singer-Nicolson model of fluid membrane, from (Bretscher 1985)

A biological compound that is not soluble in water, but is soluble in nonpolar substances

LIPID

- → fatty acids
- → waxes
- → steroids (e.g. cholesterol)
- → triglycerides
- → glycerophospholipids

FATTY ACIDS

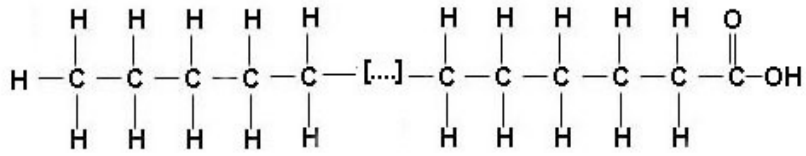

Nonpolar, hydrophobic tail
(water insoluble)
Polar, hydrophilic head
(water soluble)
(a)
Nonpolar tail
COOH
Polar head
(b)

FATTY ACIDS

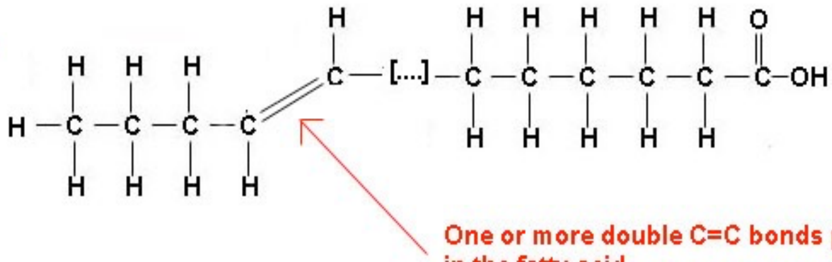
- Usually straight chains (no branching)
- Sizes usually range from C_{10} to C_{20}
- Usually have an even number of carbons
- Can be saturated (no C=C bonds) or unsaturated (has C=C bonds)

FATTY ACIDS

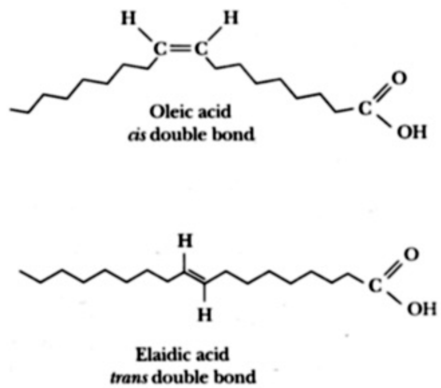
SATURATED
FATTY ACID



UNSATURATED
FATTY ACID

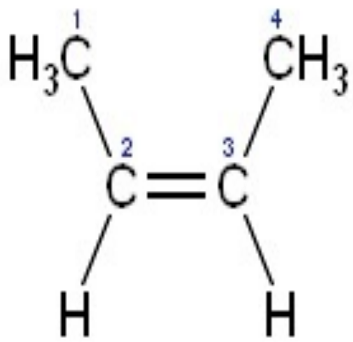


One or more double C=C bonds present in the fatty acid.
This puts a 'kink' in the molecule

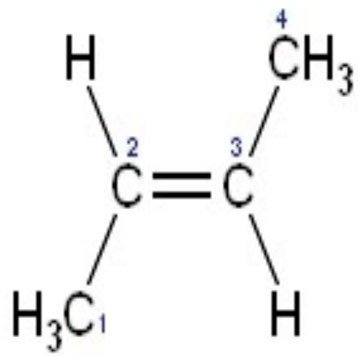


Structure of *cis* and *trans* monounsaturated C_{18} fatty acids.

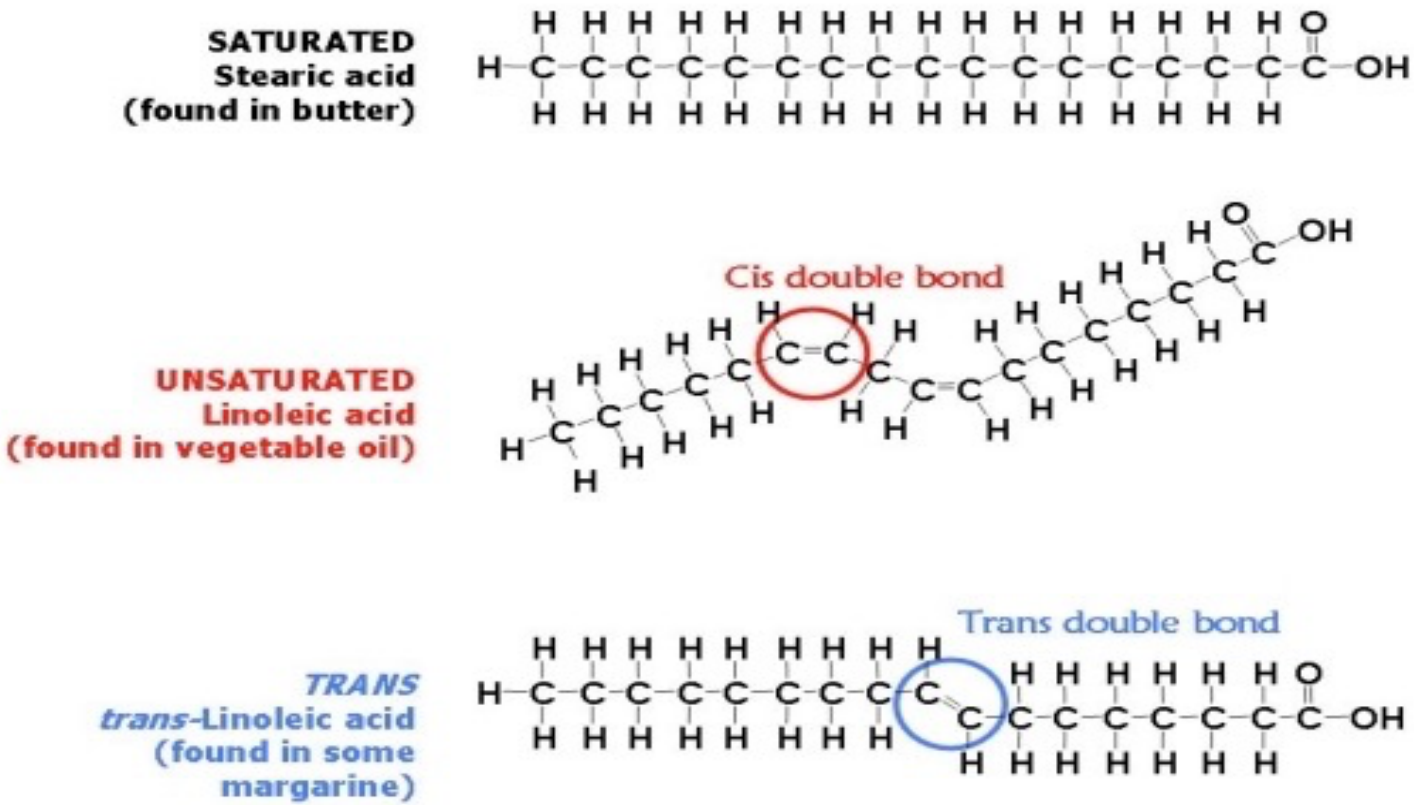
CIS ISOMER



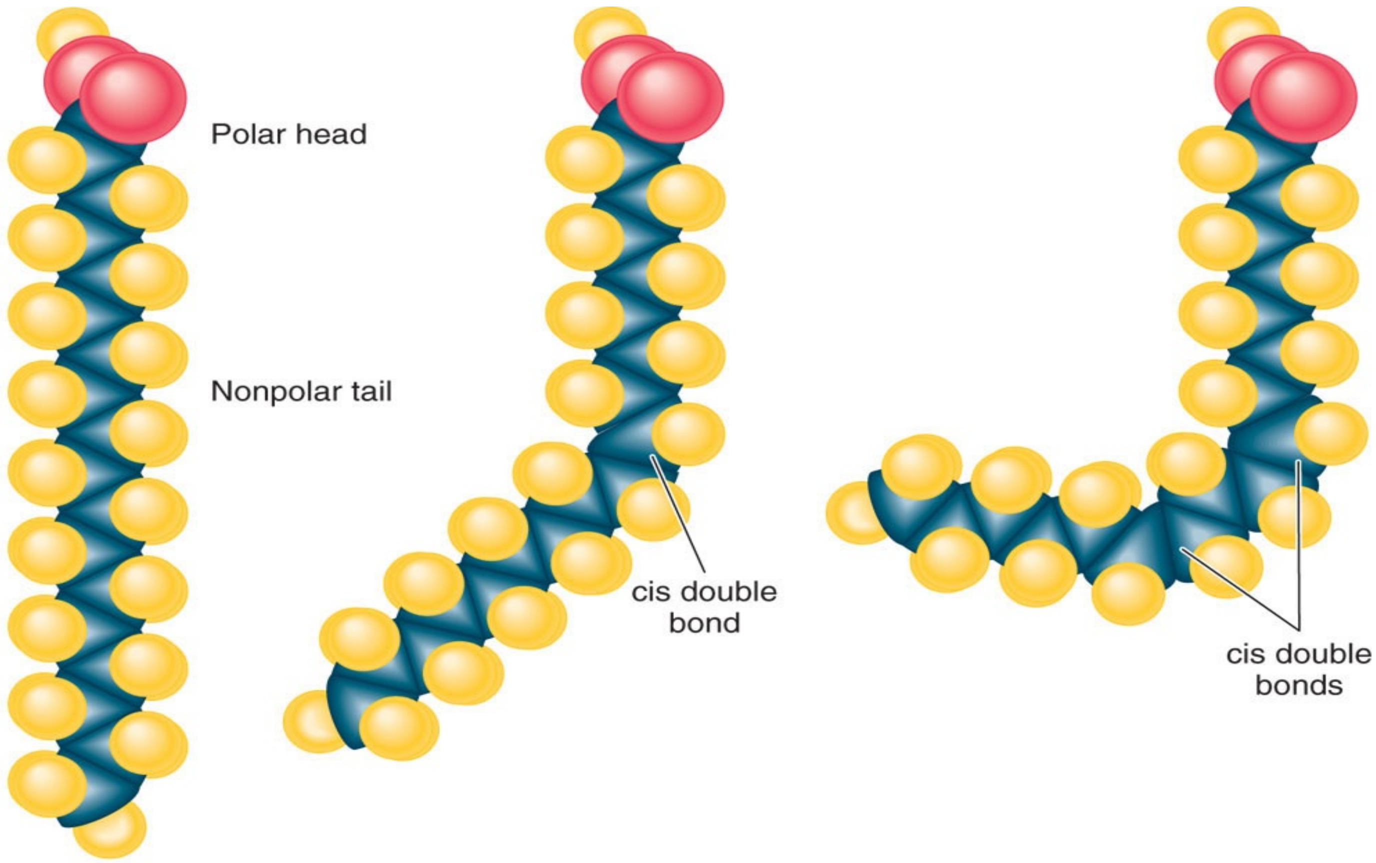
TRANS ISOMER



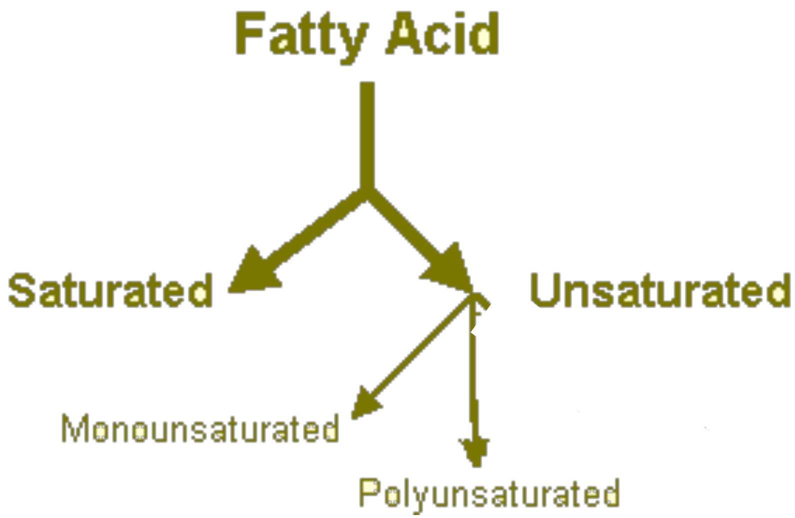
TRANS FATTY ACIDS



Molecular Shapes



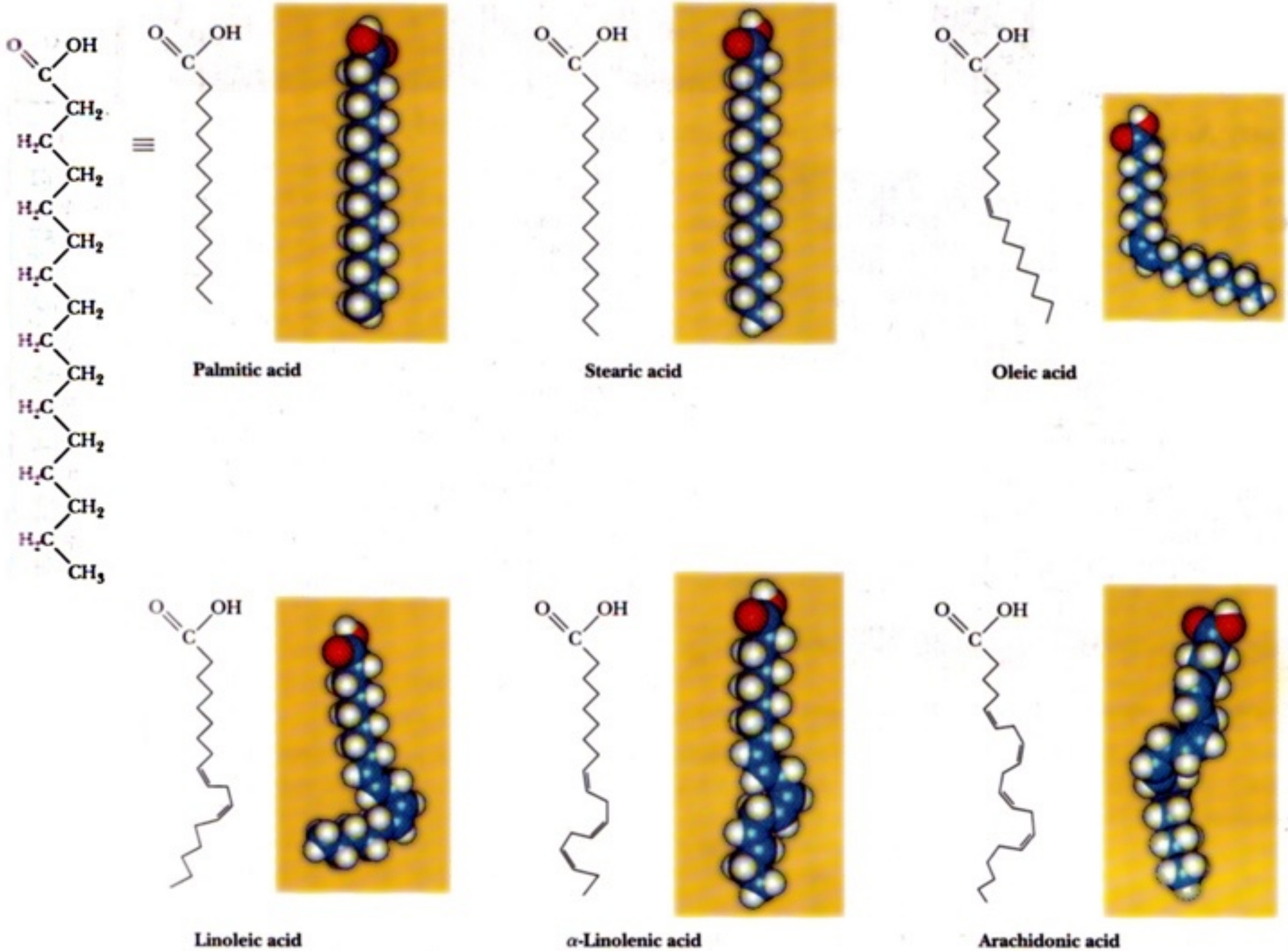
C=C causes “kinking” of the carbon chain



Monounsaturated – one C=C

Polyunsaturated- more than one C=C

FATTY ACIDS

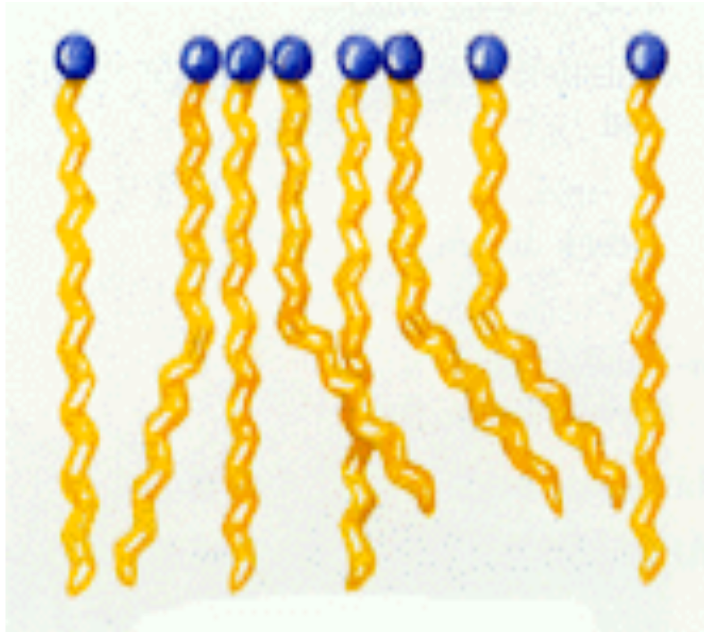

Palmitic acid
Stearic acid
Oleic acid
Linoleic acid
α-Linolenic acid
Arachidonic acid

FATTY ACIDS

Table 8.1

Common Biological Fatty Acids

Number of Carbons	Common Name	Systematic Name	Symbol	Structure
Saturated fatty acids				
12	Lauric acid	Dodecanoic acid	12:0	$CH_3(CH_2)_{10}COOH$
14	Myristic acid	Tetradecanoic acid	14:0	$CH_3(CH_2)_{12}COOH$
16	Palmitic acid	Hexadecanoic acid	16:0	$CH_3(CH_2)_{14}COOH$
18	Stearic acid	Octadecanoic acid	18:0	$CH_3(CH_2)_{16}COOH$
20	Arachidic acid	Eicosanoic acid	20:0	$CH_3(CH_2)_{18}COOH$
22	Behenic acid	Docosanoic acid	22:0	$CH_3(CH_2)_{20}COOH$
24	Lignoceric acid	Tetracosanoic acid	24:0	$CH_3(CH_2)_{22}COOH$
Unsaturated fatty acids (all double bonds are cis)				
16	Palmitoleic acid	9-Hexadecenoic acid	16:1	$CH_3(CH_2)_5CH{=}CH(CH_2)_7COOH$
18	Oleic acid	9-Octadecenoic acid	18:1	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$
18	Linoleic acid	9,12-Octadecadienoic acid	18:2	$CH_3(CH_2)_4(CH{=}CHCH_2)_2(CH_2)_6COO$
18	α-Linolenic acid	9,12,15-Octadecatrienoic acid	18:3	$CH_3CH_2(CH{=}CHCH_2)_3(CH_2)_6COOH$
18	γ-Linolenic acid	6,9,12-Octadecatrienoic acid	18:3	$CH_3(CH_2)_4(CH{=}CHCH_2)_3(CH_2)_3COO$
20	Arachidonic acid	5,8,11,14-Eicosatetraenoic acid	20:4	$CH_3(CH_2)_4(CH{=}CHCH_2)_4(CH_2)_2COO$
24	Nervonic acid	15-Tetracosenoic acid	24:1	$CH_3(CH_2)_7CH{=}CH(CH_2)_{13}COOH$



SATURATED

- Can pack closely together
- High Melting point
- Solid
- Animal fat

UNSATURATED

- Kinks prevent close contact
- Lower Melting point
- Liquid
- Plant and fish oil

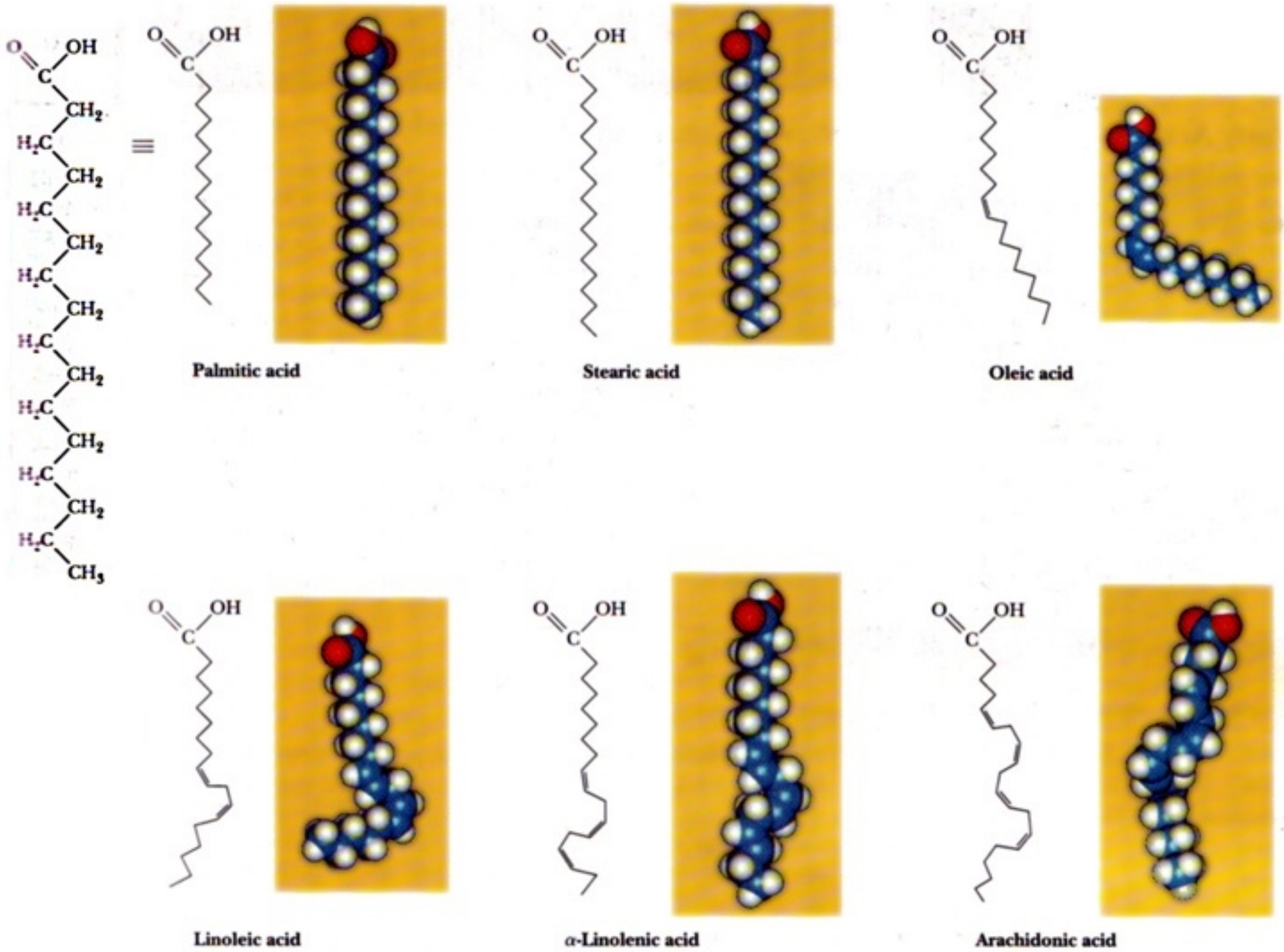
FATTY ACIDS

Fatty Acid Compositions of Some Dietary Lipids*

Source	Lauric and Myristic	Palmitic	Stearic	Oleic	Linoleic
Beef	5	24–32	20–25	37–43	2–3
Milk		25	12	33	3
Coconut	74	10	2	7	
Corn		8–12	3–4	19–49	34–62
Olive		9	2	84	4
Palm		39	4	40	8
Safflower		6	3	13	78
Soybean		9	6	20	52
Sunflower		6	1	21	66

Data from *Merck Index*, 10th ed. Rahway, NJ: Merck and Co.; and Wilson, E. D., et al., 1979, *Principles of Nutrition*, 4th ed. New York: Wiley.
*Values are percentages of total fatty acids.

FATTY ACIDS



O
OH
C
CH2
H2C
CH3
Palmitic acid
Stearic acid
Oleic acid
Linoleic acid
α-Linolenic acid
Arachidonic acid

WAXES

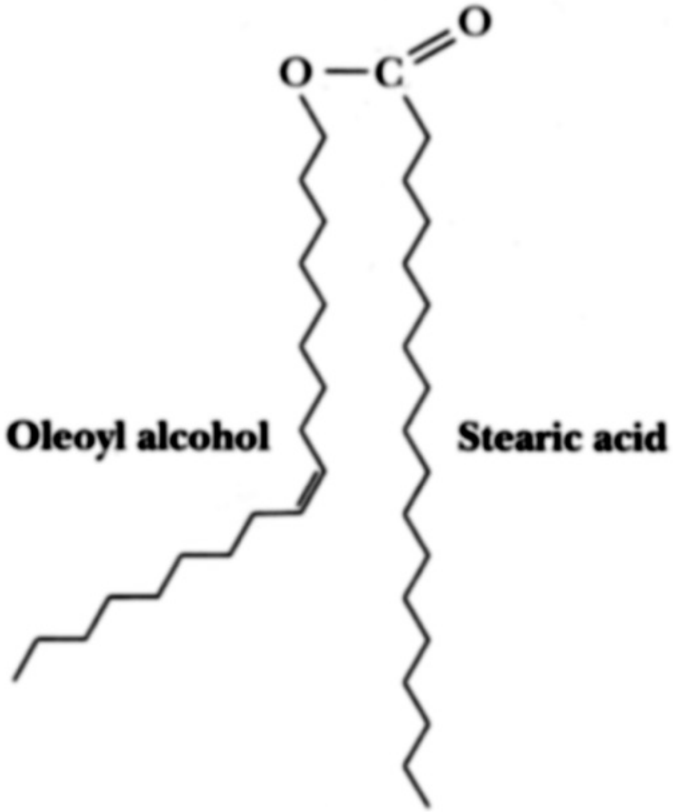


FIGURE 8.15 An example of a wax. Oleoyl alcohol is esterified to stearic acid in this case.

TRIGLYCERIDES

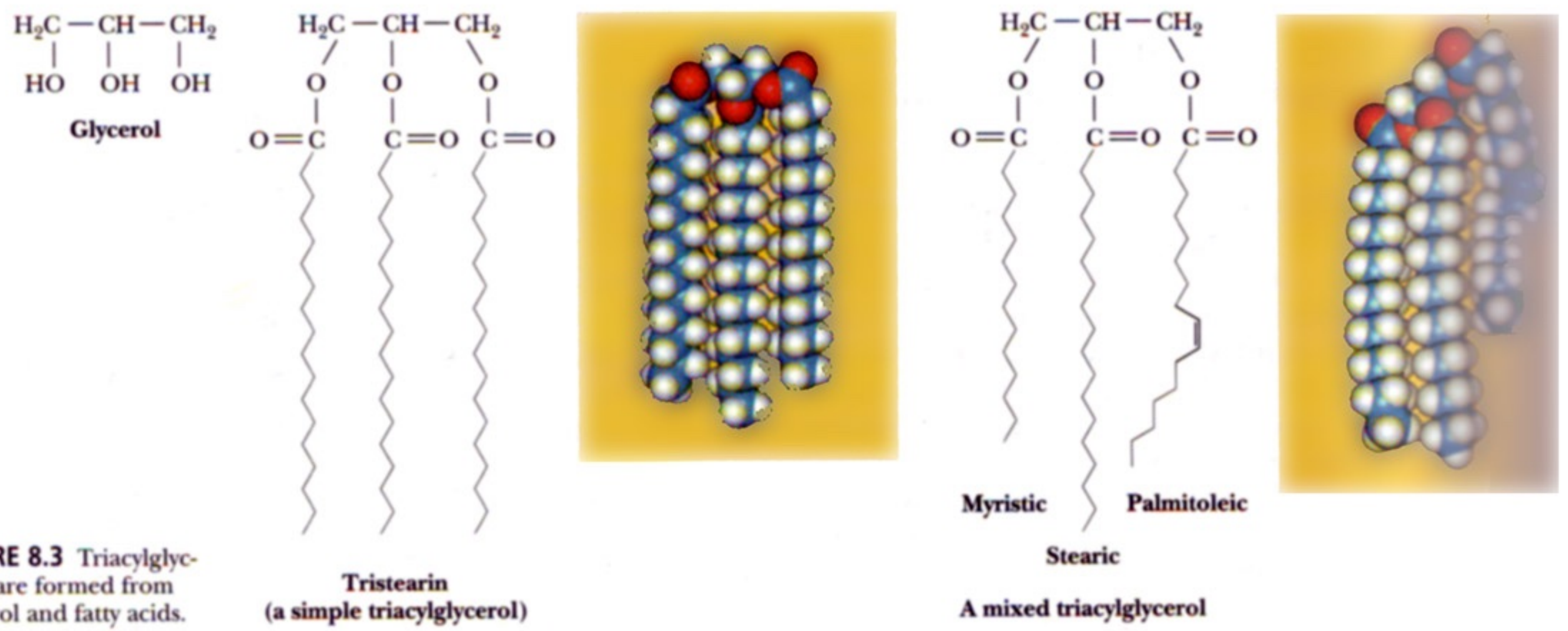
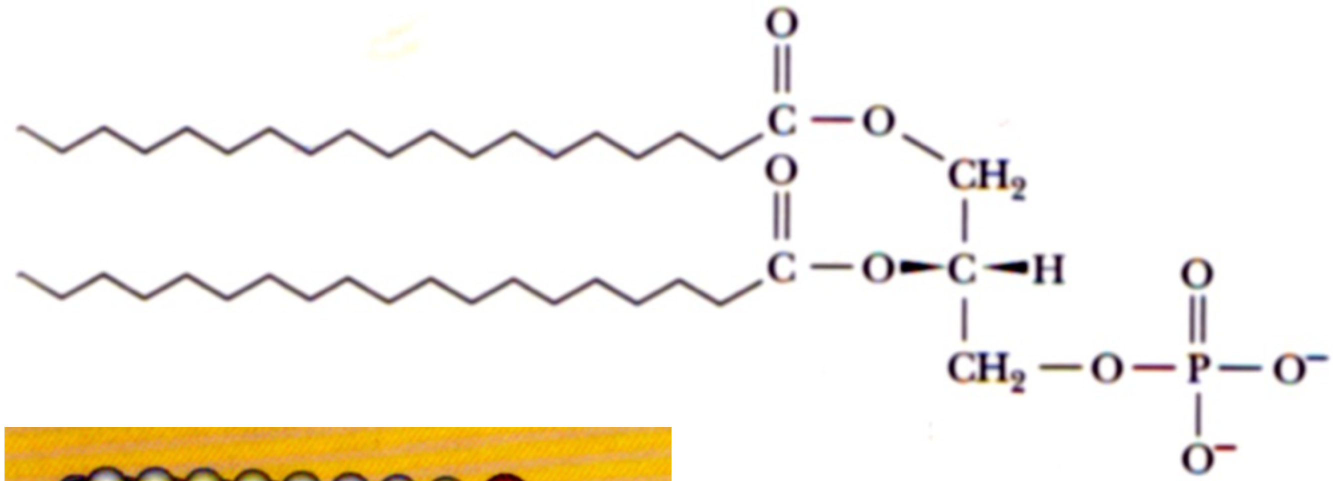
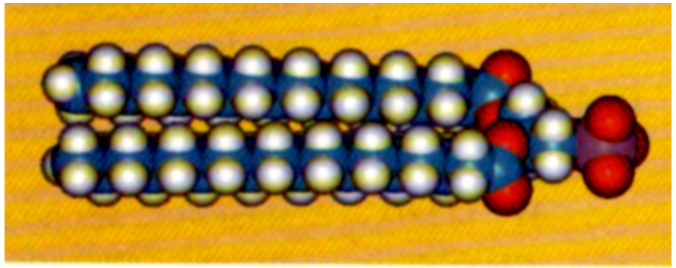


FIGURE 8.3 Triacylglycerols are formed from glycerol and fatty acids.

GLYCEROPHOSPHOLIPIDS

(the “membrane” lipids)

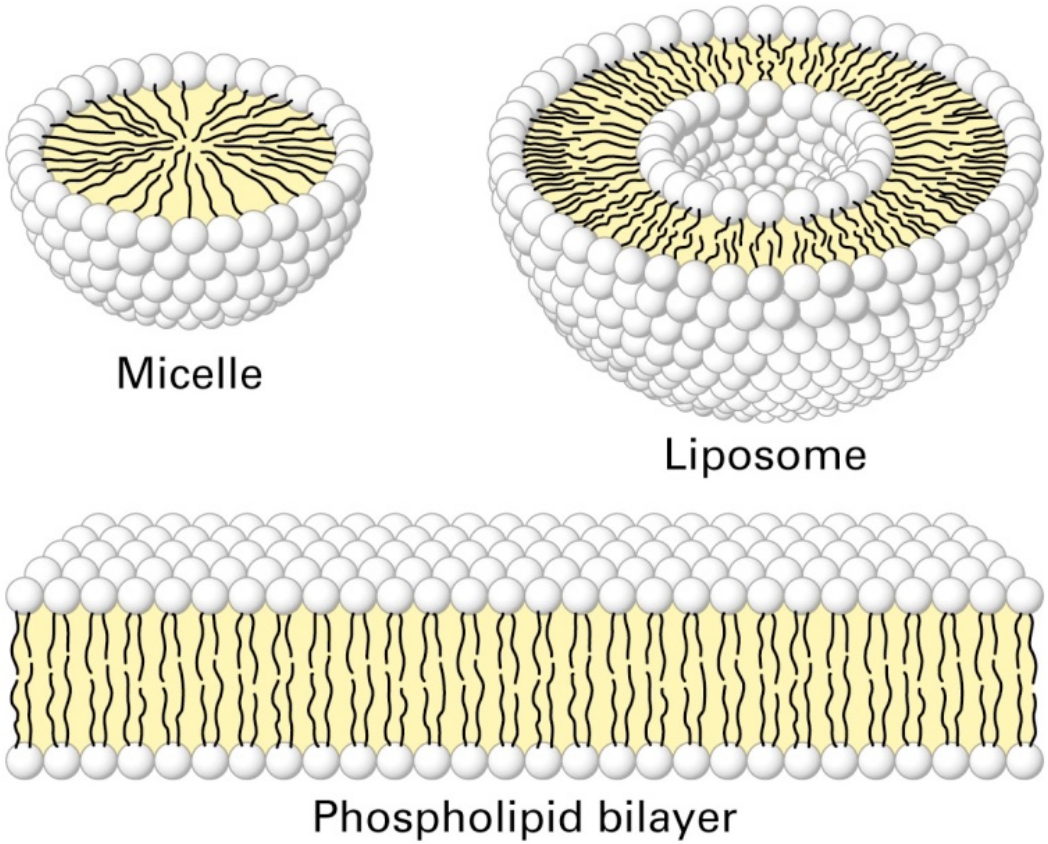




Phosphatidic Acid

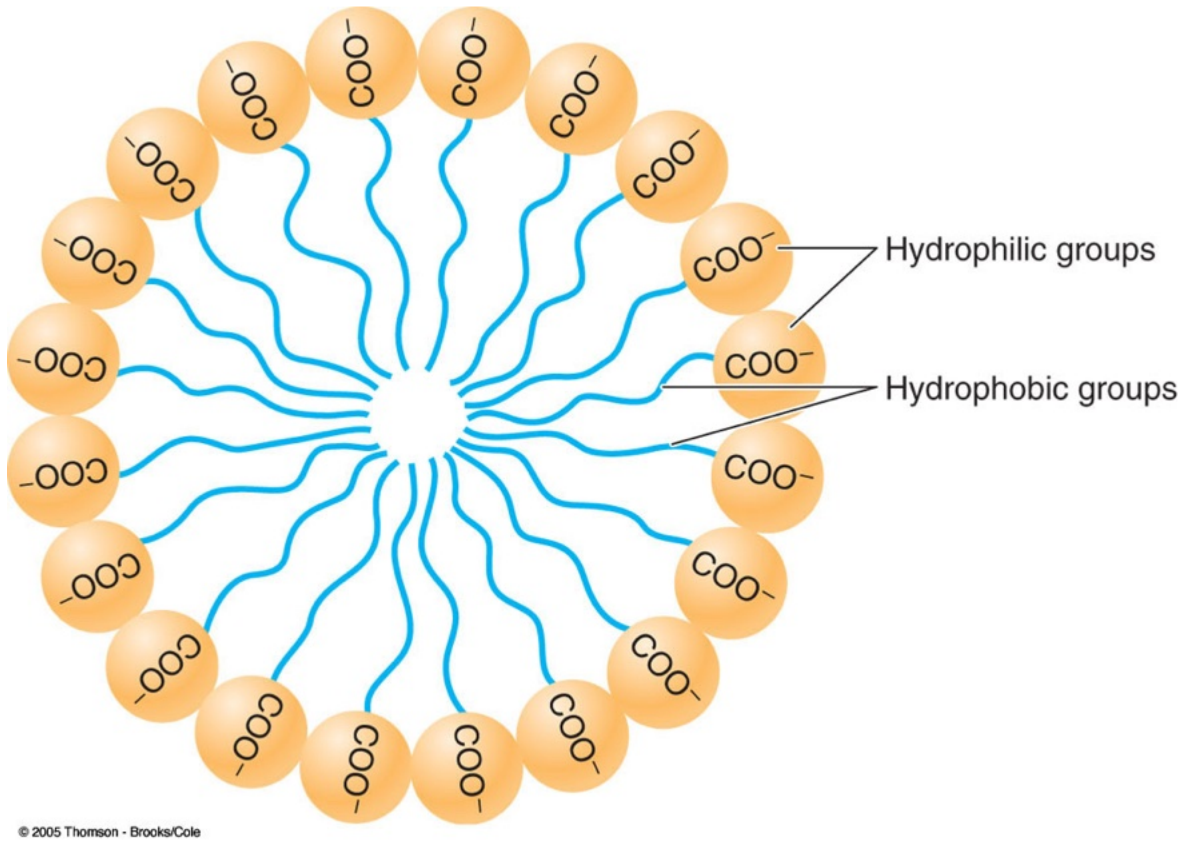
Belong to the class of phospholipids

Interactions between lipids and water can give rise to different structures



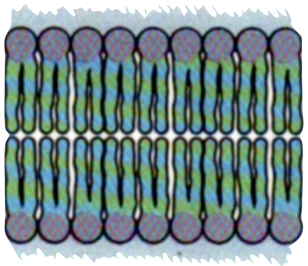
Why do lipids form a bilayer and not a micelle?
Two fatty acyl chains are too bulky to fit into the interior of a micelle

MICELLE – spherical cluster of molecules with the nonpolar portion in the middle and the polar portion on the outside

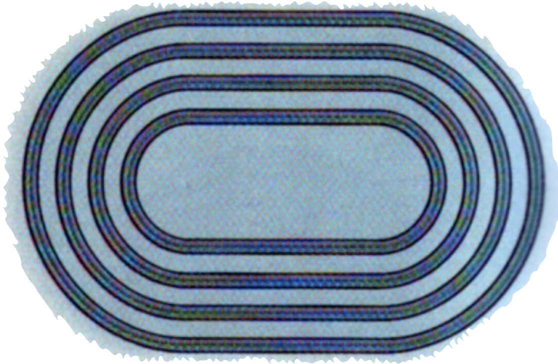


Vesicles

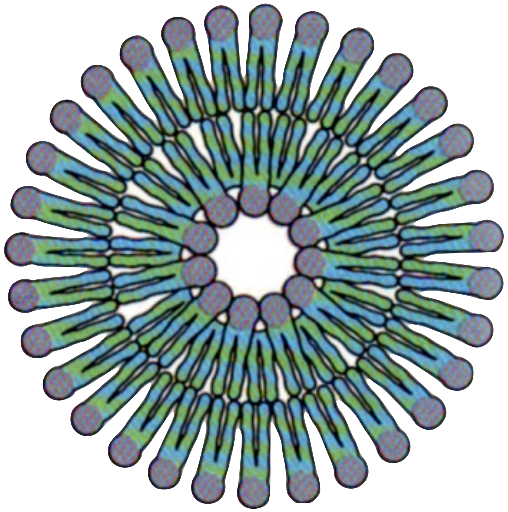
Bilayer



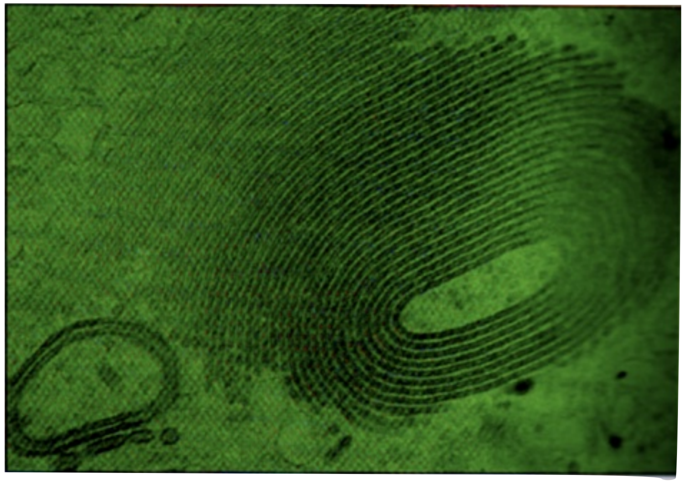
Multilamellar Vesicle



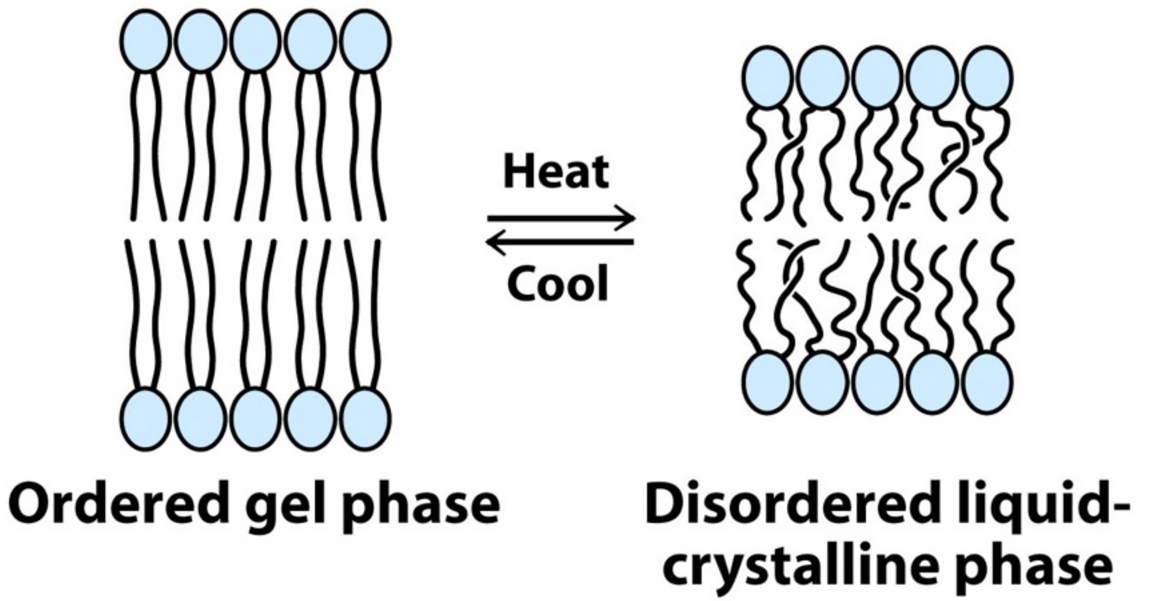
Unilamellar Vesicle

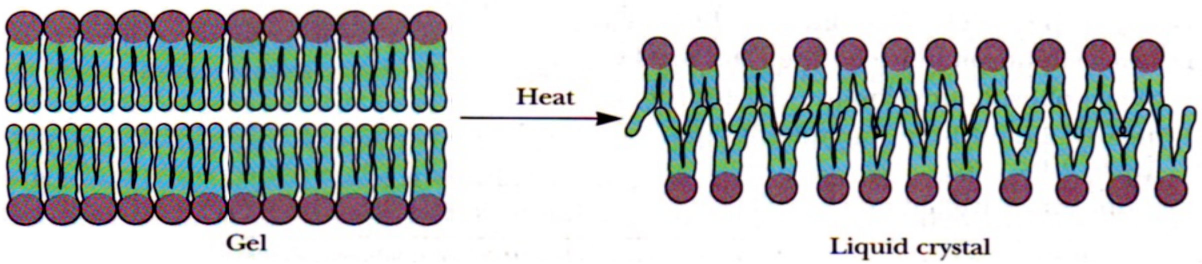


Electron Microscopy image of a multilamellar vesicle

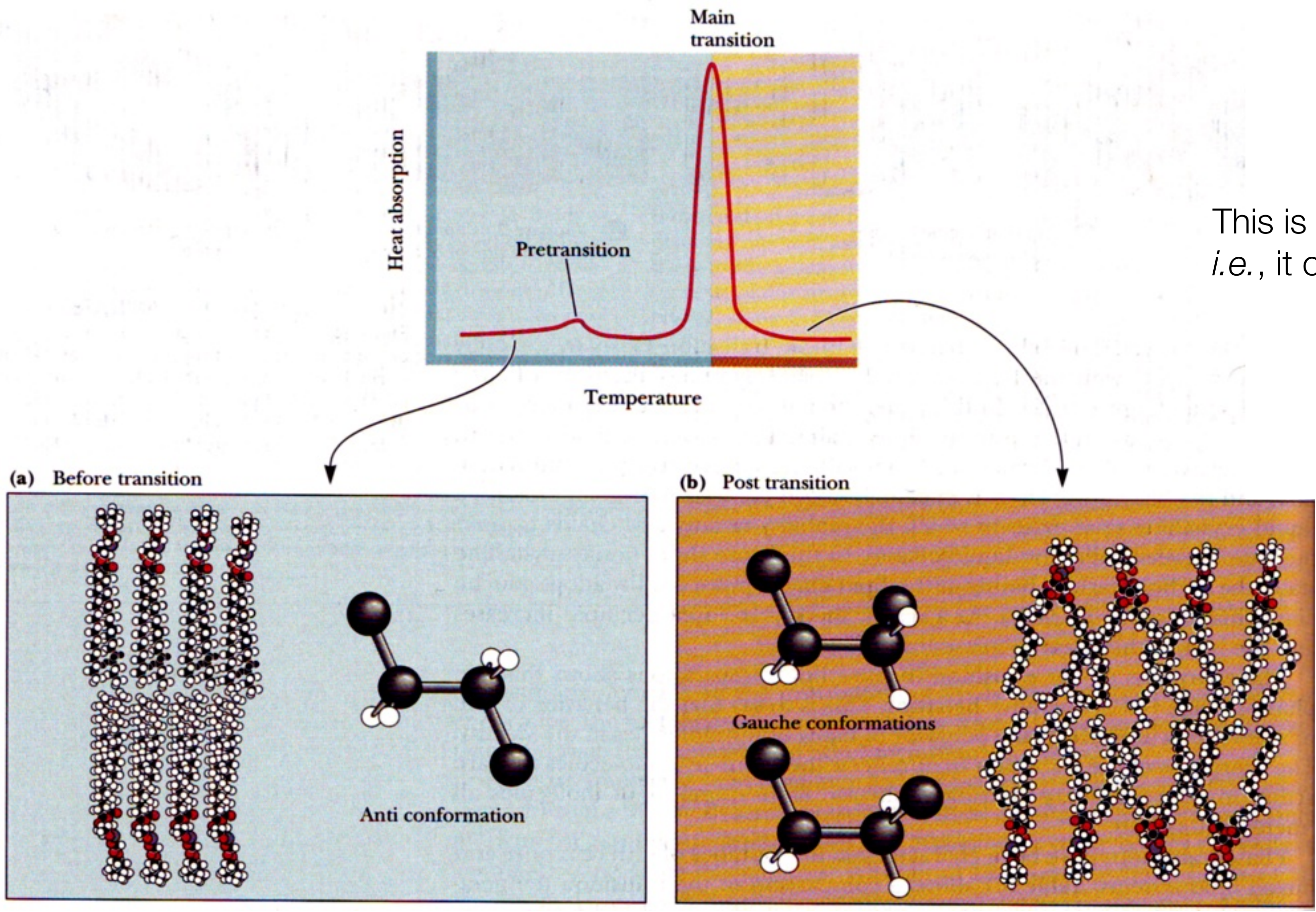


Membranes are fluid structures





Membrane Phase Transition

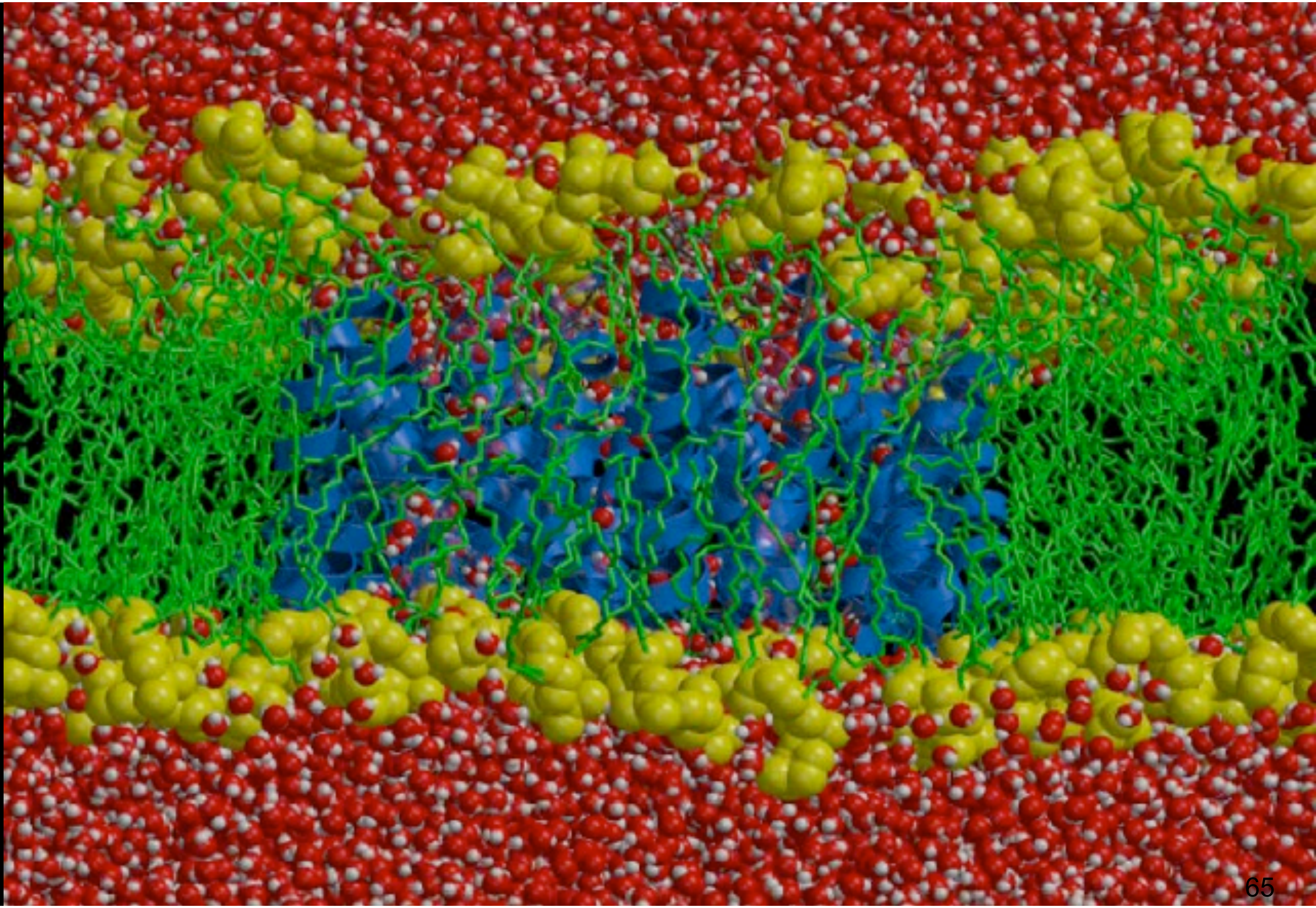


This is a first-order phase transition, *i.e.*, it occurs gradually.

Phase Transition Temperatures for Phospholipids in Water

Phospholipid	Transition Temperature (T_m), °C
Dipalmitoyl phosphatidic acid (Di 16:0 PA)	67
Dipalmitoyl phosphatidylethanolamine (Di 16:0 PE)	63.8
Dipalmitoyl phosphatidylcholine (Di 16:0 PC)	41.4
Dipalmitoyl phosphatidylglycerol (Di 16:0 PG)	41.0
Dilauroyl phosphatidylcholine (Di 14:0 PC)	23.6
Distearoyl phosphatidylcholine (Di 18:0 PC)	58
Dioleoyl phosphatidylcholine (Di 18:1 PC)	−22
1-Stearoyl-2-oleoyl-phosphatidylcholine (1-18:0, 2-18:1 PC)	3
Egg phosphatidylcholine (Egg PC)	−15

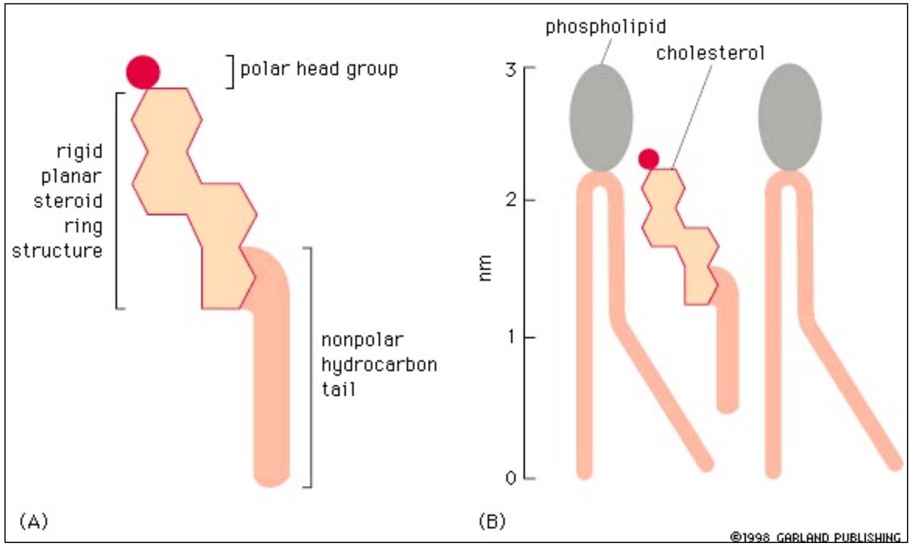
Adapted from Jain, M., and Wagner, R. C., 1980. *Introduction to Biological Membranes*. New York: John Wiley and Sons; and Martonosi, A., ed., 1982. *Membranes and Transport*, Vol. 1. New York: Plenum Press.

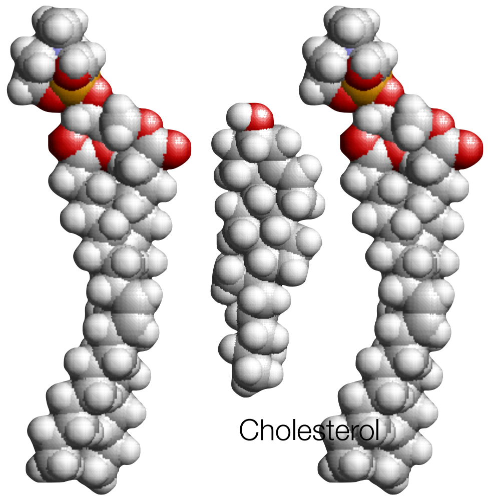


Membrane fluidity is important for:

- Fusion of membranes, *e.g.,* fusion of vesicles with organelles.
- Lateral diffusion of new lipids and new proteins in the membrane, so they are equally distributed.
- Lateral diffusion of proteins and other molecules in the membrane.
- Providing a flexible environment for membrane proteins to allow conformational changes or shuttling in signaling events.
- Proper separation of membranes during cell division.

Fluidity of the membrane depends on the lipid composition and cholesterol





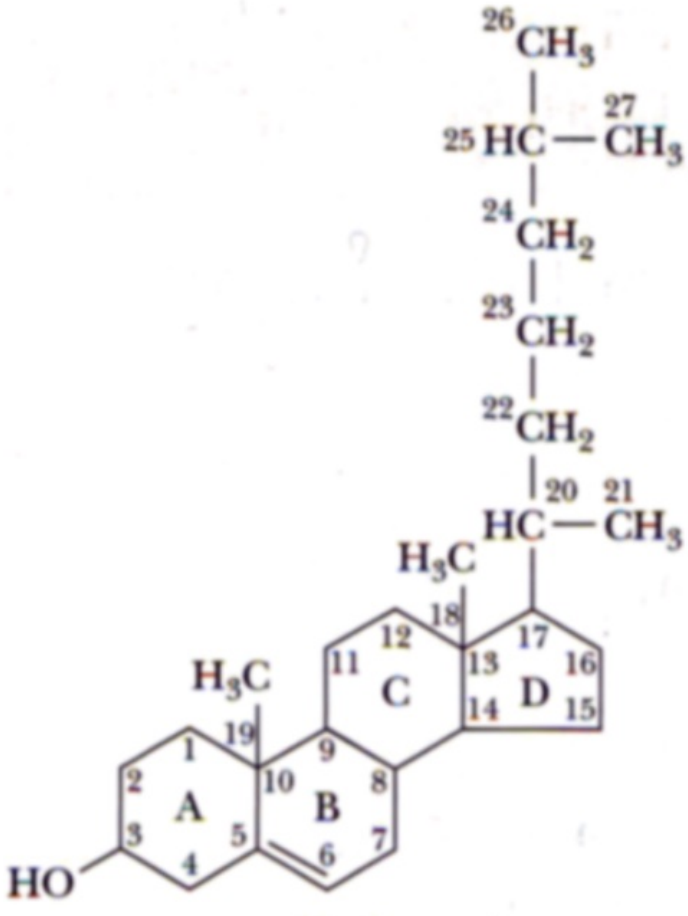
Factors that affect membrane fluidity:

- Length of the fatty acyl chains
- Degree of saturation of the fatty acyl chains
- Presence of cholesterol

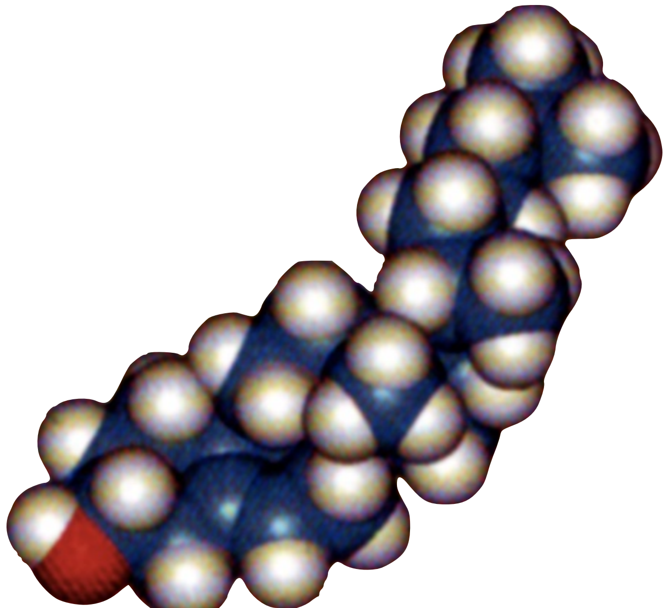
The rigid cholesterol ring system interferes with the close packing of phospholipid fatty acid tails and thus inhibits the transition from the liquid-crystal to the crystalline state upon temperature decrease.

At the same time, the rigid cholesterol makes the membrane somewhat less fluid.

CHOLESTEROL



Cholesterol



Transbilayer transport by flippases

- Energetic barriers to trans-bilayer lipid movement are high
- Lipid biosynthesis on one side of a membrane is coupled to catalyzed transport

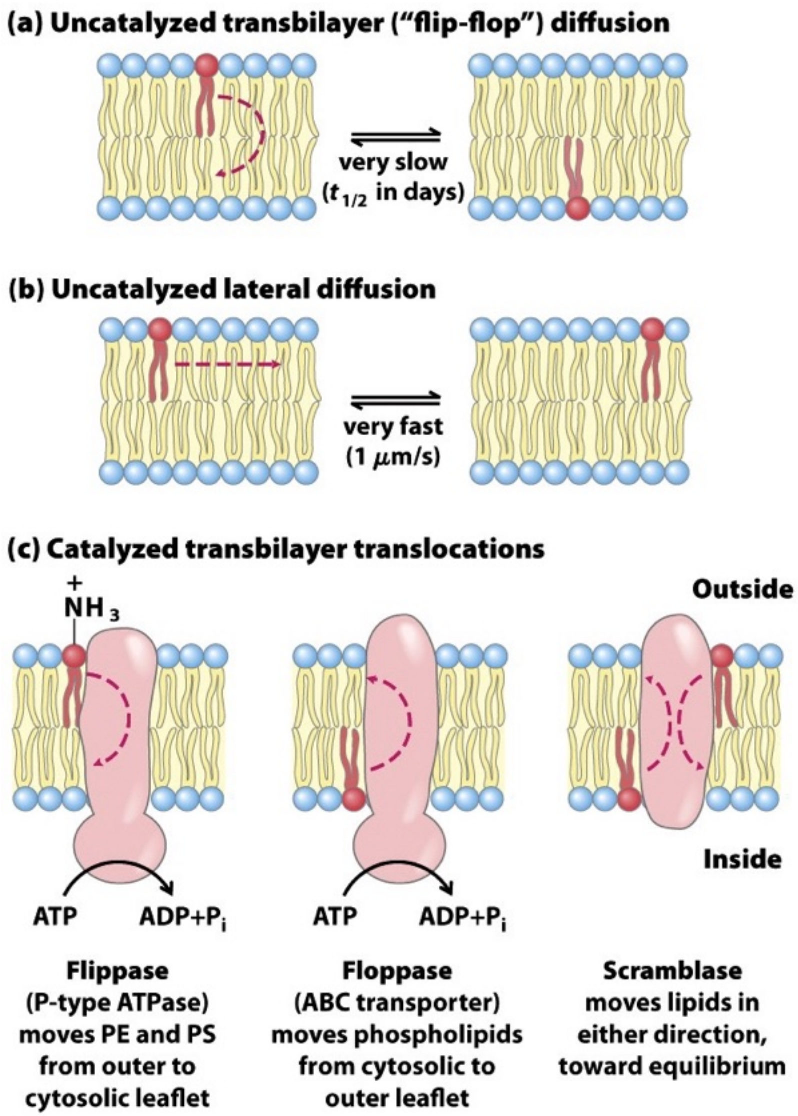


Figure 11-16
Lehninger Principles of Biochemistry, Fifth Edition

Lateral diffusion

- Lipids and proteins can diffuse in 2D
- Measured by Fluorescence Recovery After Photo-bleaching (FRAP)
  - **FRAP requires a fluorescent tag on a lipid or protein**
  - Photobleaching of a small area by intense light pulse makes a dark spot in the membrane
  - Fluorescence Recovery depends on diffusion of undamaged fluorophores to the bleached spot

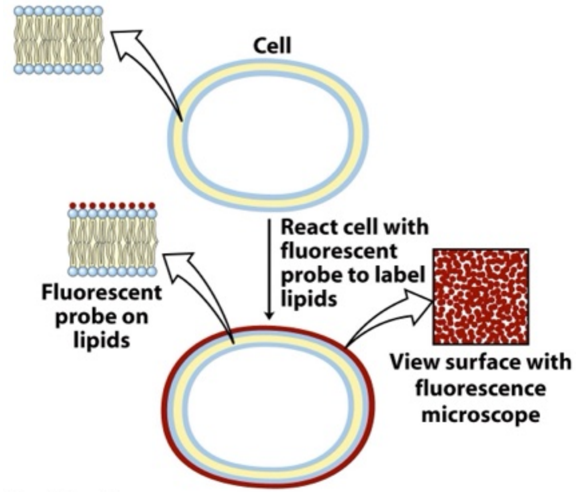
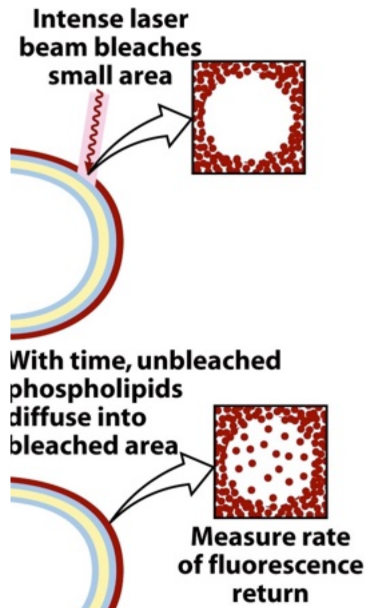


Figure 11-17 part 1
Lehninger Principles of Biochemistry, Fifth Edition



Lateral diffusion may be limited by protein networks

Cytoskeletal connections or membrane patches

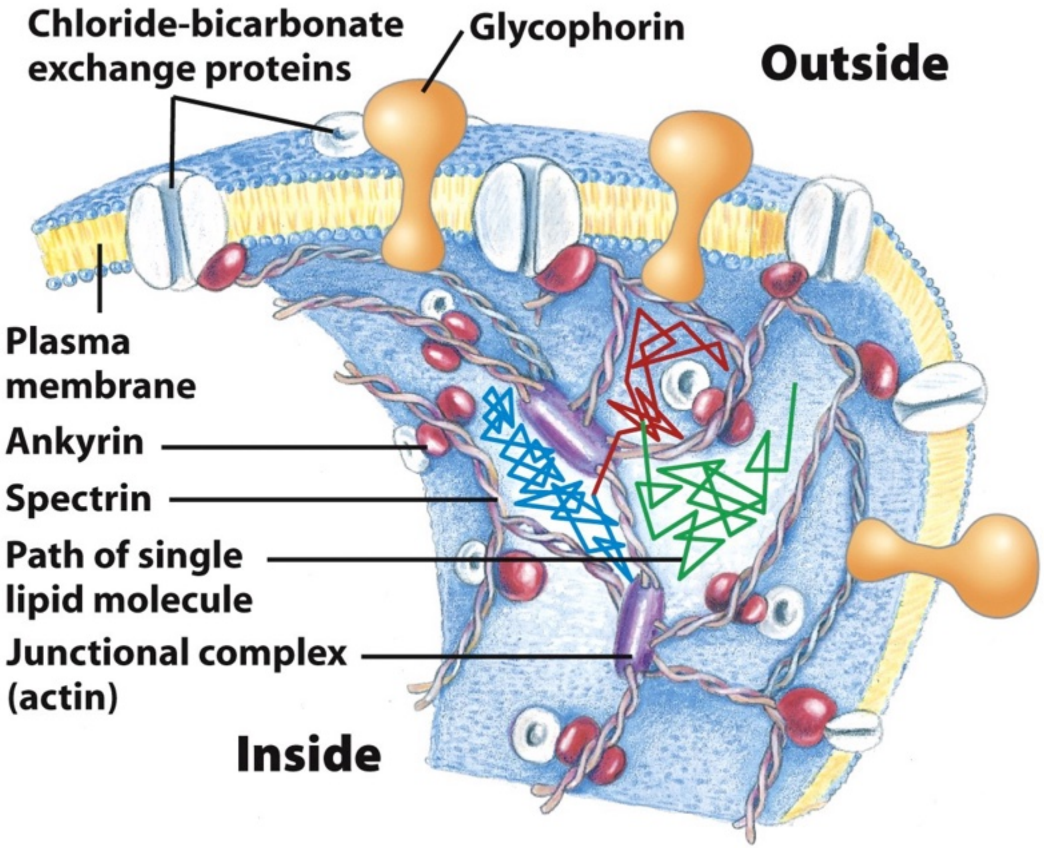
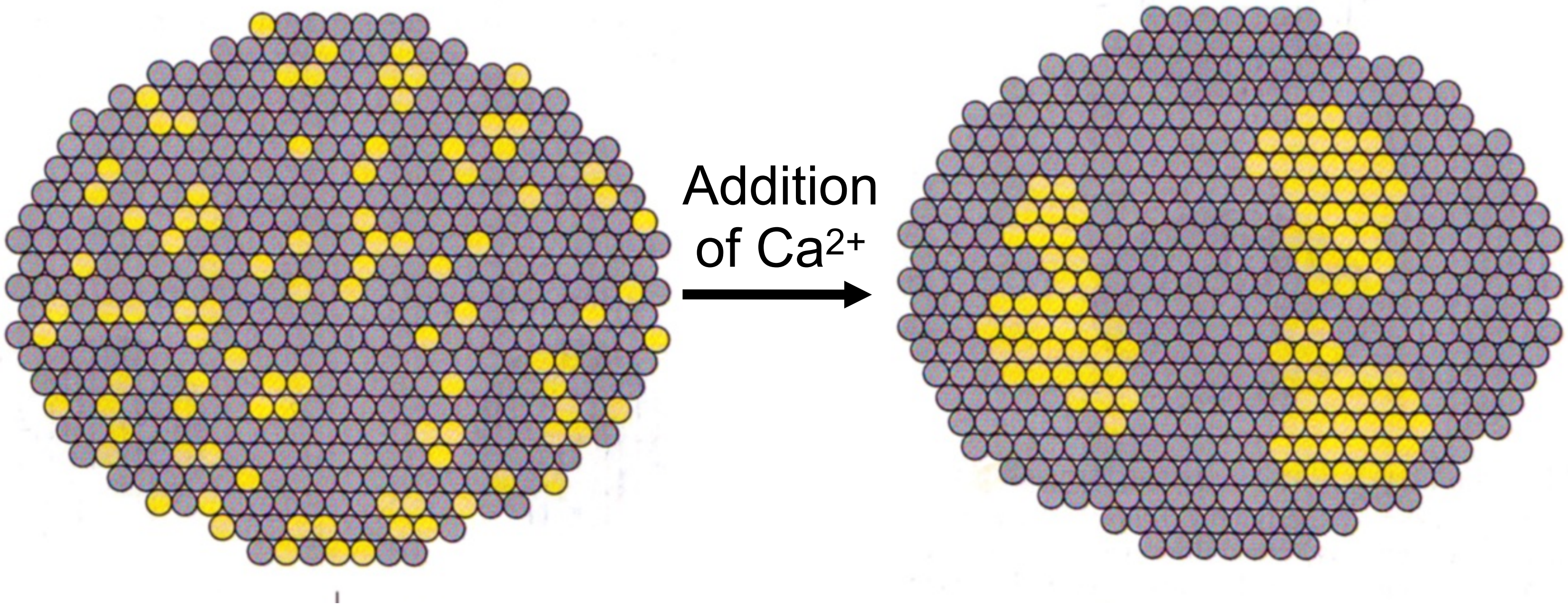


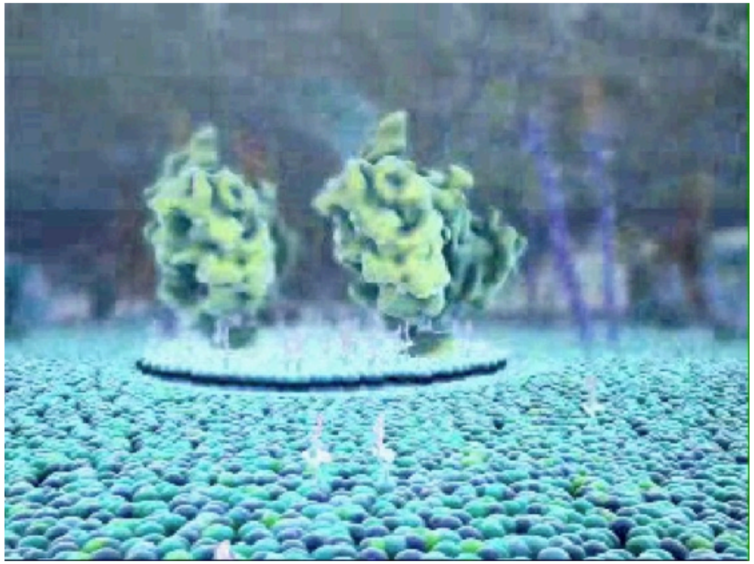
Figure 11-19
Lehninger Principles of Biochemistry, Fifth Edition

Lipids can undergo phase separation



Lipid Rafts

- Lipid Rafts can be formed by glyco-sphingolipid clusters in the outer membrane
- Cholesterol is also enriched in Lipid Rafts
- Glycosylphosphatidylinositol (GPI), palmitoyl or myristoyl anchors on proteins can anchor them to lipid rafts



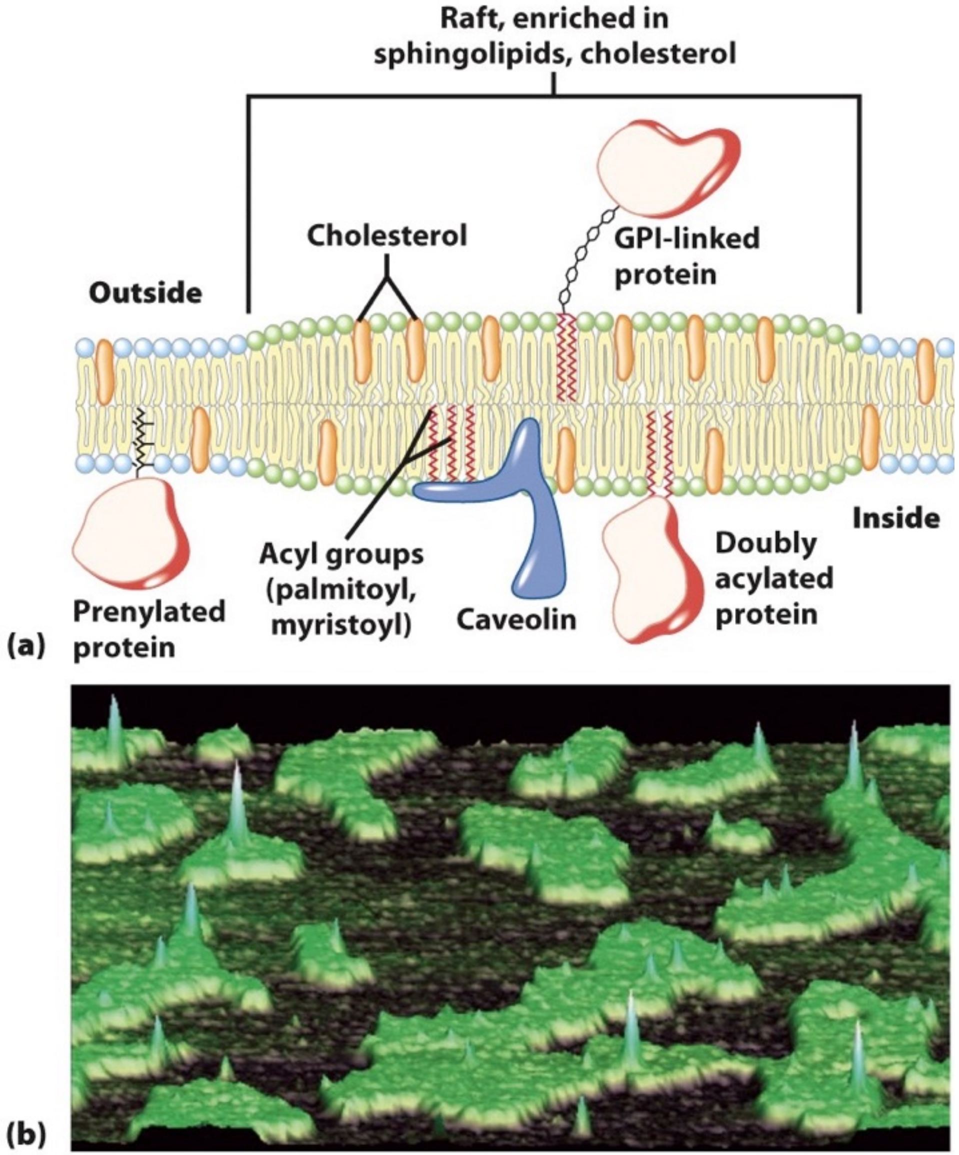
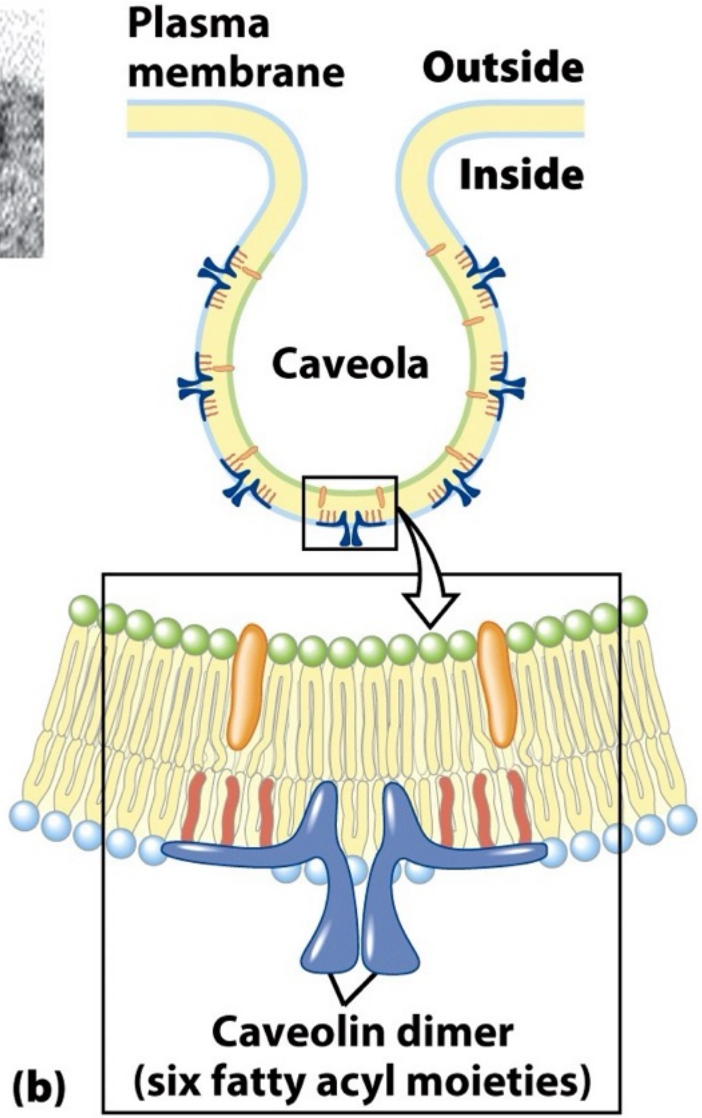


Figure 11-20
Lehninger Principles of Biochemistry, Fifth Edition

AFM image of a me

Caveolae



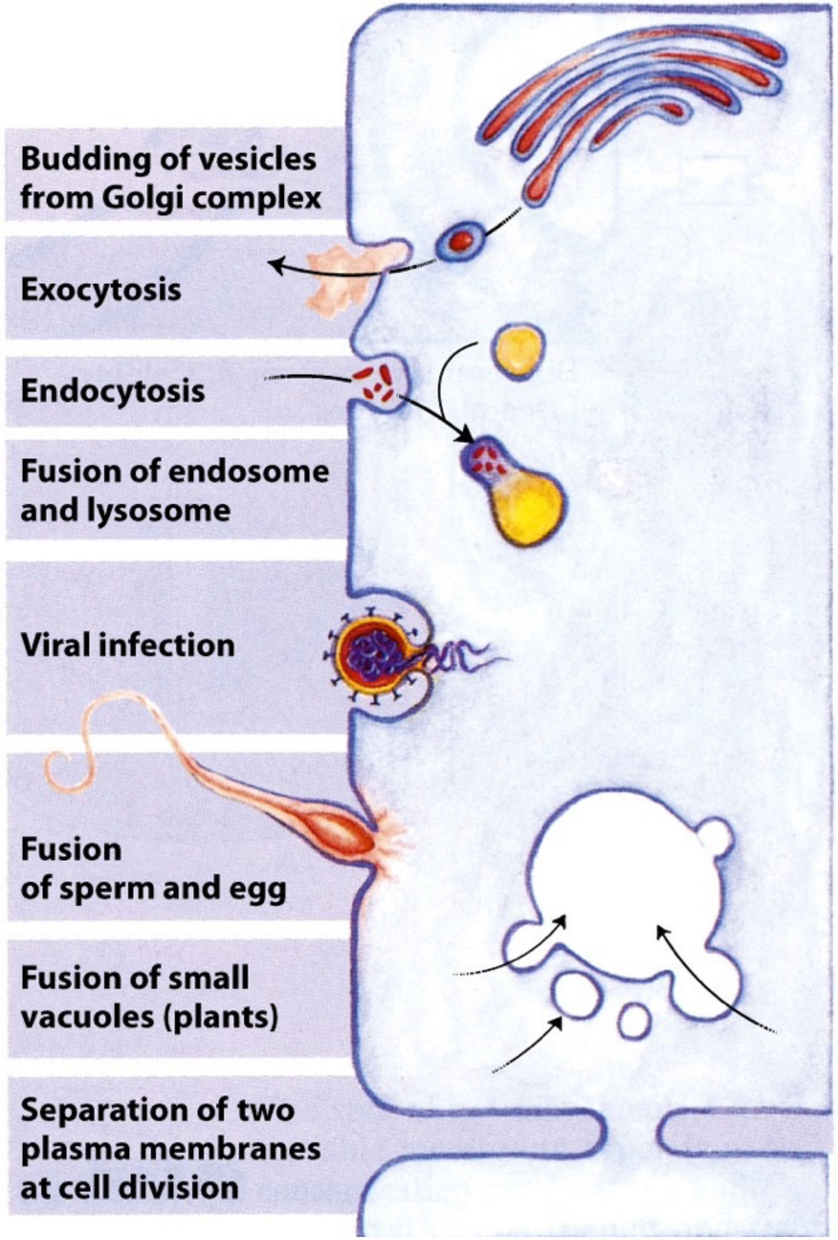
- Caveolin is an integral membrane protein.
- The dimeric caveolin binds to the inner membrane surface of cells *via* palmitoyl anchors, where it induces membrane curvature.
- Caveolae (as in cave) are formed on the extracellular side of the membrane

Figure 11-21
Lehninger Principles of Biochemistry, Fifth Edition

Membrane fusion

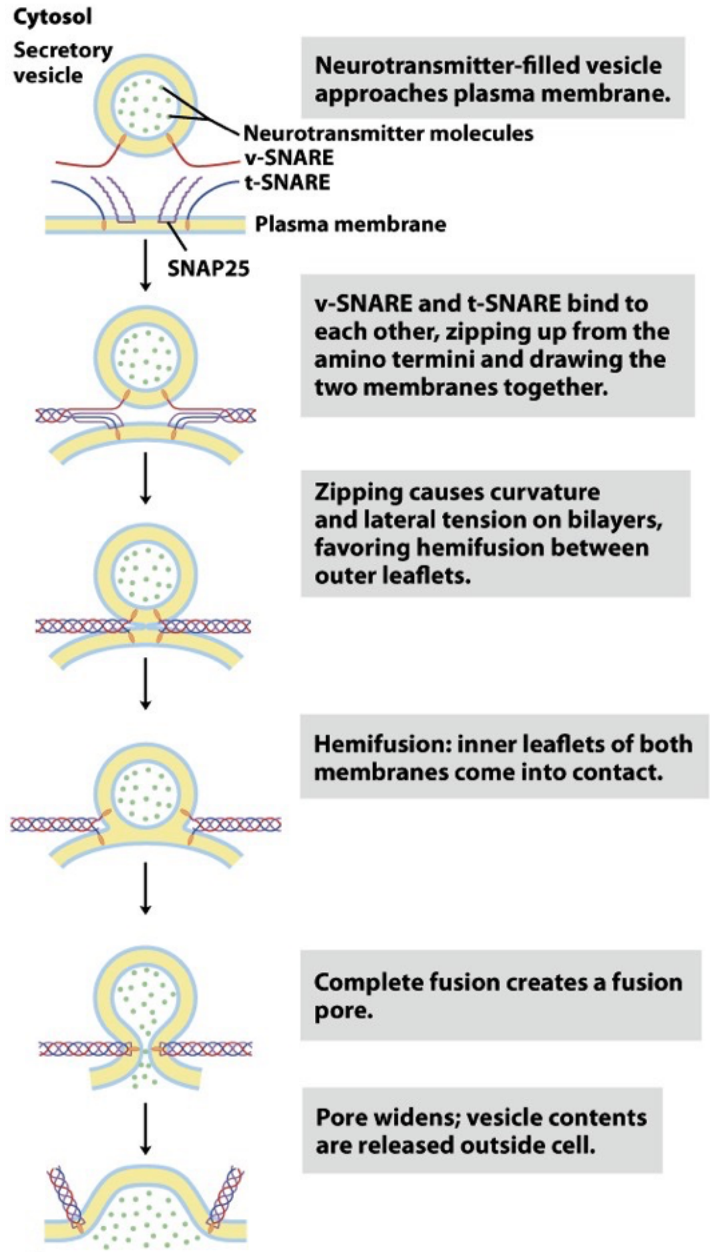
- Membrane budding (separation) and membrane fusion are two sides of the same coin

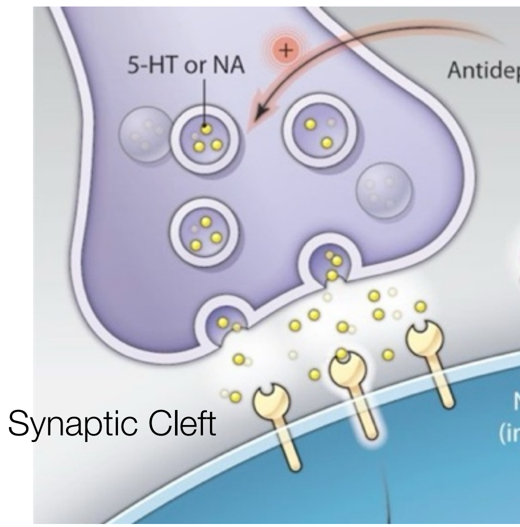
- Fusion
  1. Recognition
  2. Apposition
  3. Disruption
  4. Bilayer fusion



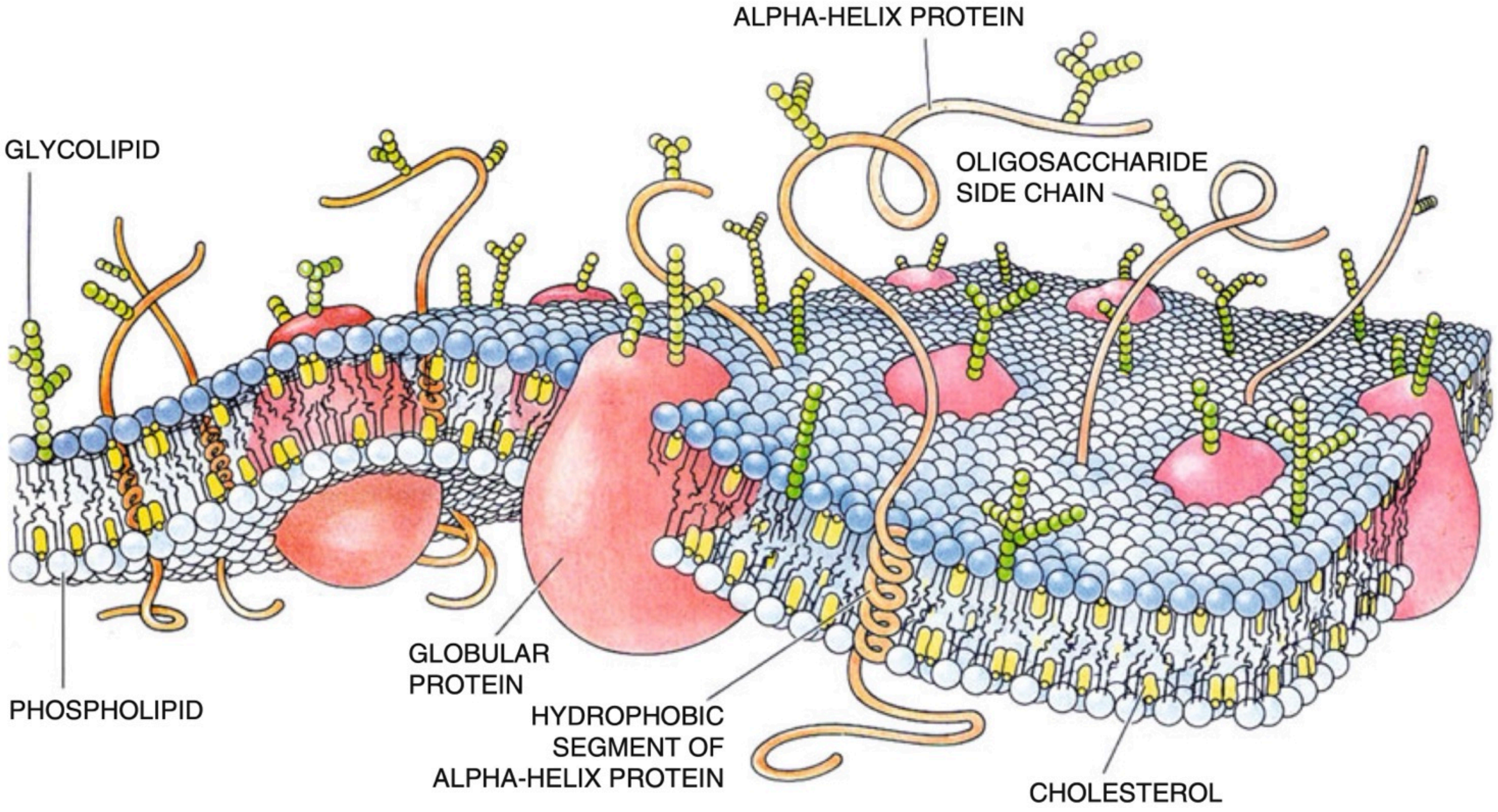
Neurotransmitter release due to vesicle fusion

- NSF = N-ethylmaleimide-Sensitive Factor
- SNAP = NSF Attachment Protein
- SNARE = Soluble NSF Attachment protein REceptor





Biological Membranes



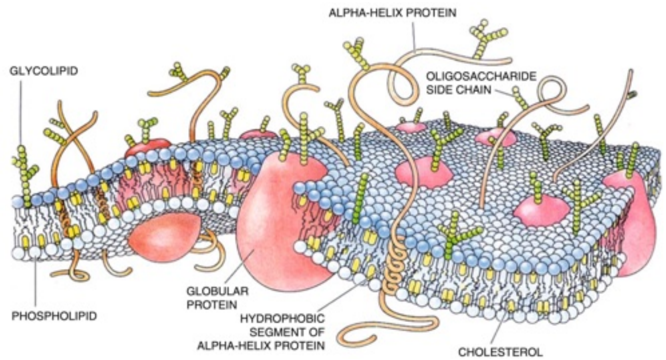
Singer-Nicolson model of fluid membrane, from (Bretscher 1985)

Fluid Membrane Model
(Singer & Nicolson, 1972)

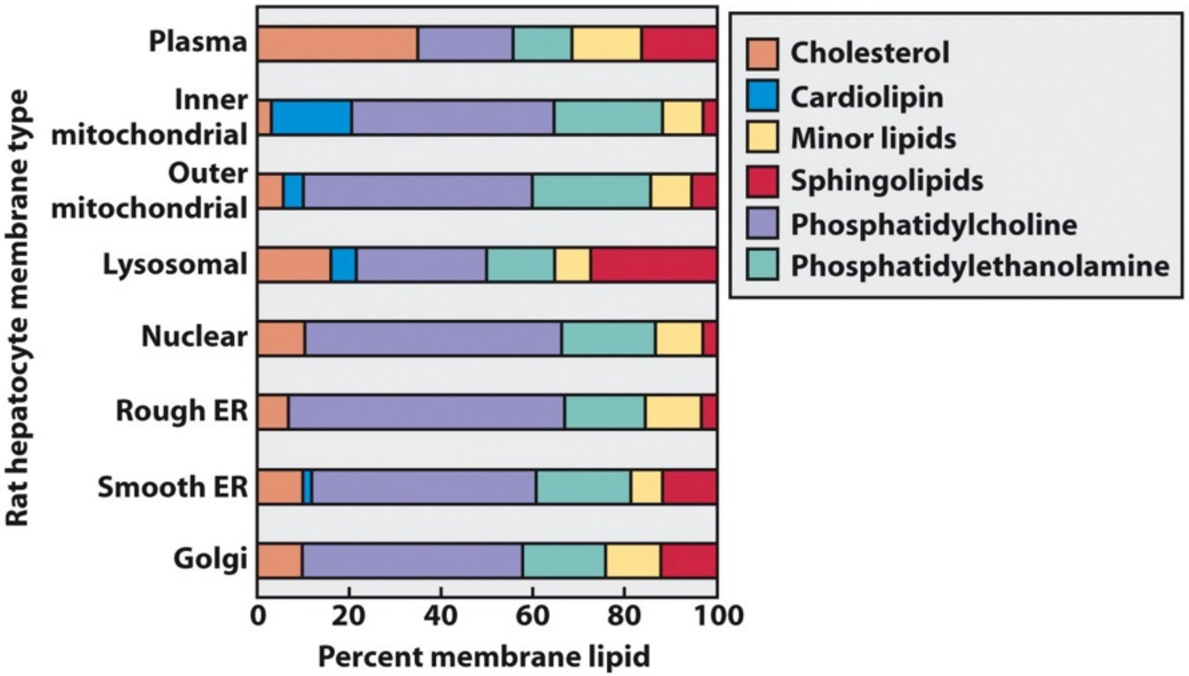
Membranes are two-dimensional arrangements of oriented lipids and proteins.

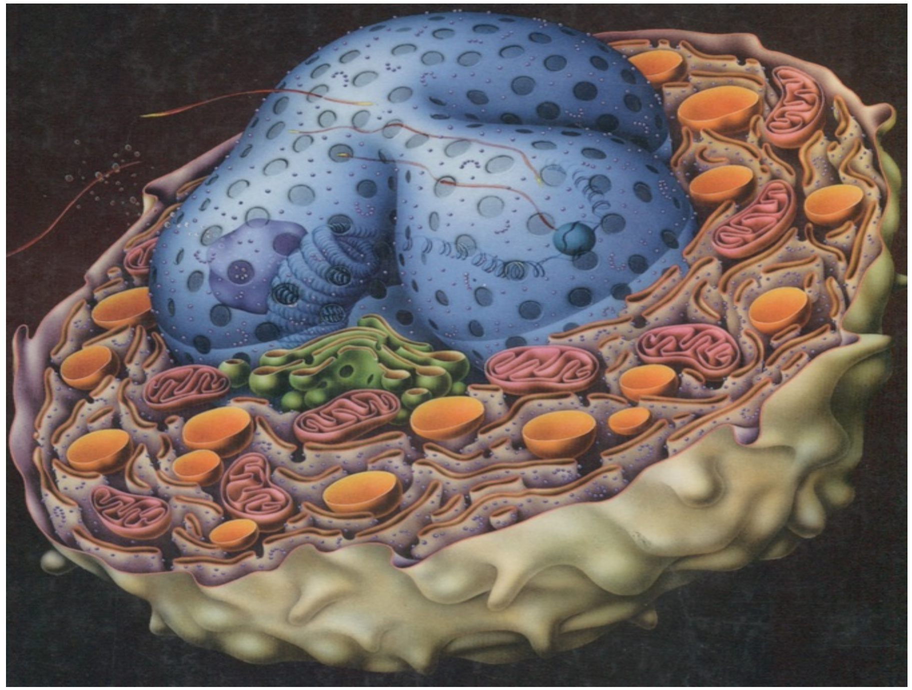
The lipid bilayer has a dual role; it forms a permeability barrier and interacts with proteins keeping them soluble and often regulating the protein activity.

Membrane proteins are free to diffuse laterally, but do not flip from one side of the membrane to the other.



Membranes contain specialized lipids and proteins





Typical membrane composition:

•Proteins 30-70%

•Phospholipids 7-40%

•Sterols 0-25%

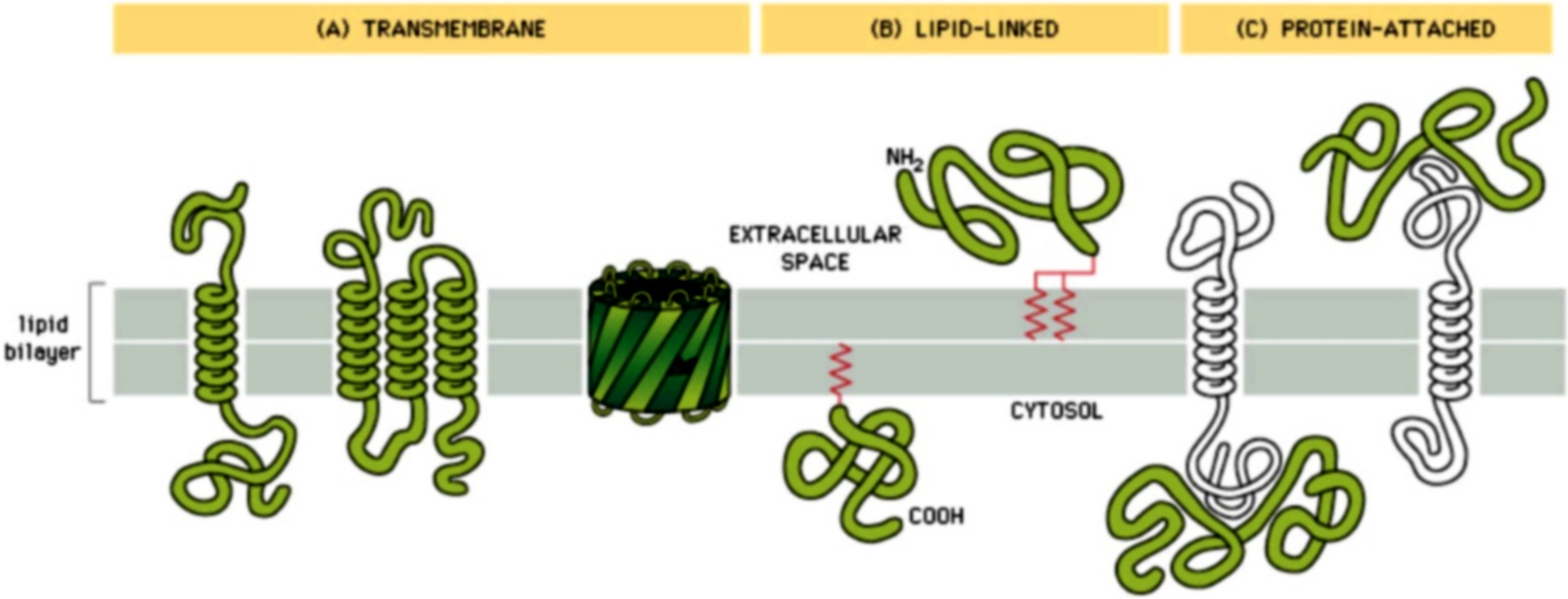
Many membranes are specialized:

•Photoreceptor disc membranes have >90% Rhodopsin

•Mitochondrial membranes are very protein rich

•Red Blood Cell membranes are transport optimized (flexible)

Membrane Proteins

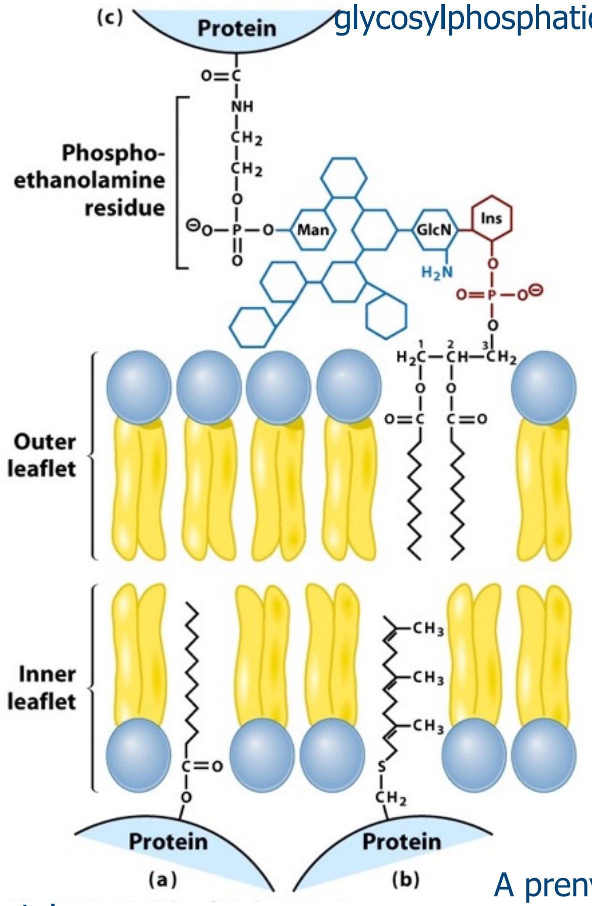


Integral (transmembrane) membrane proteins: span the membrane entirely one or several times and can only be removed from the membrane by detergent.

Peripheral proteins are either covalently linked to lipids or interact tightly with transmembrane proteins. These proteins can be removed from the membrane either by treatment with enzymes or certain reagents without disrupting the membrane integrity.

Proteins with membrane anchors

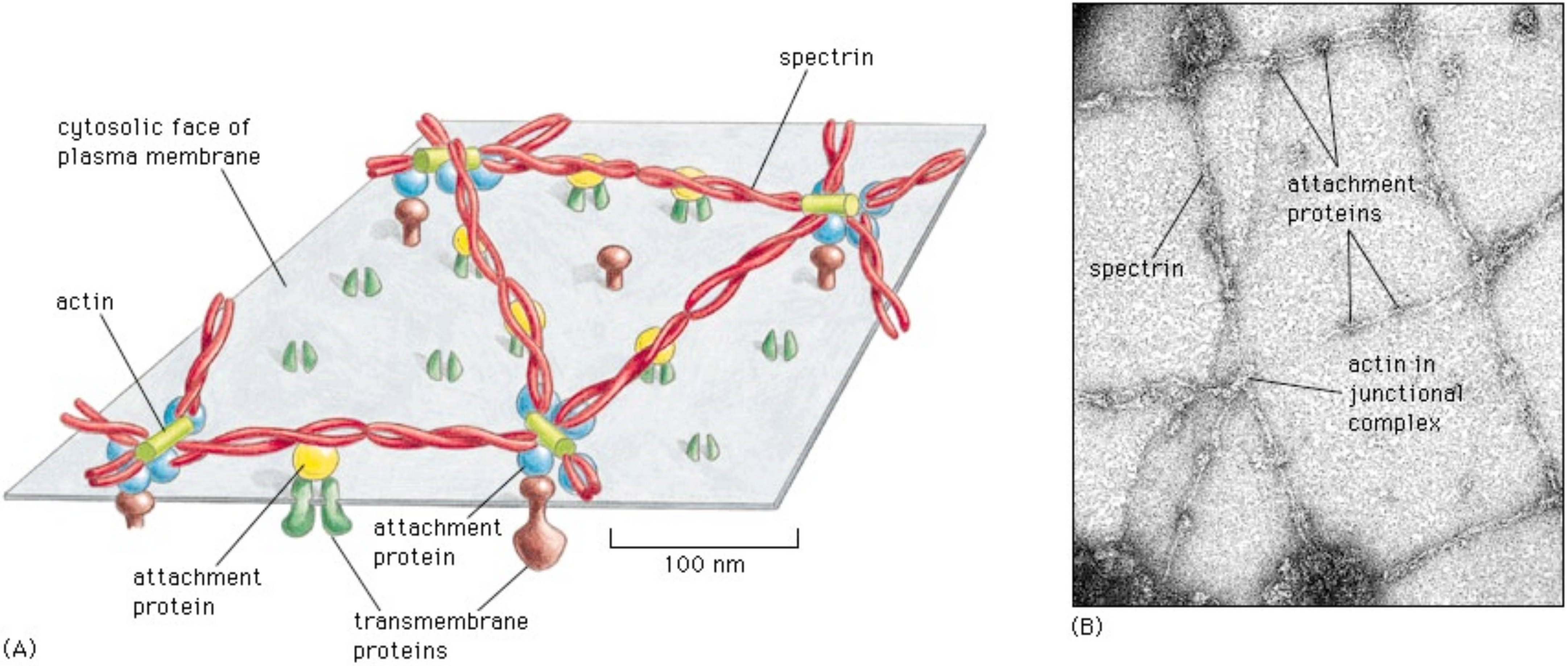
Protein anchored by glycosylphosphatidylinositol



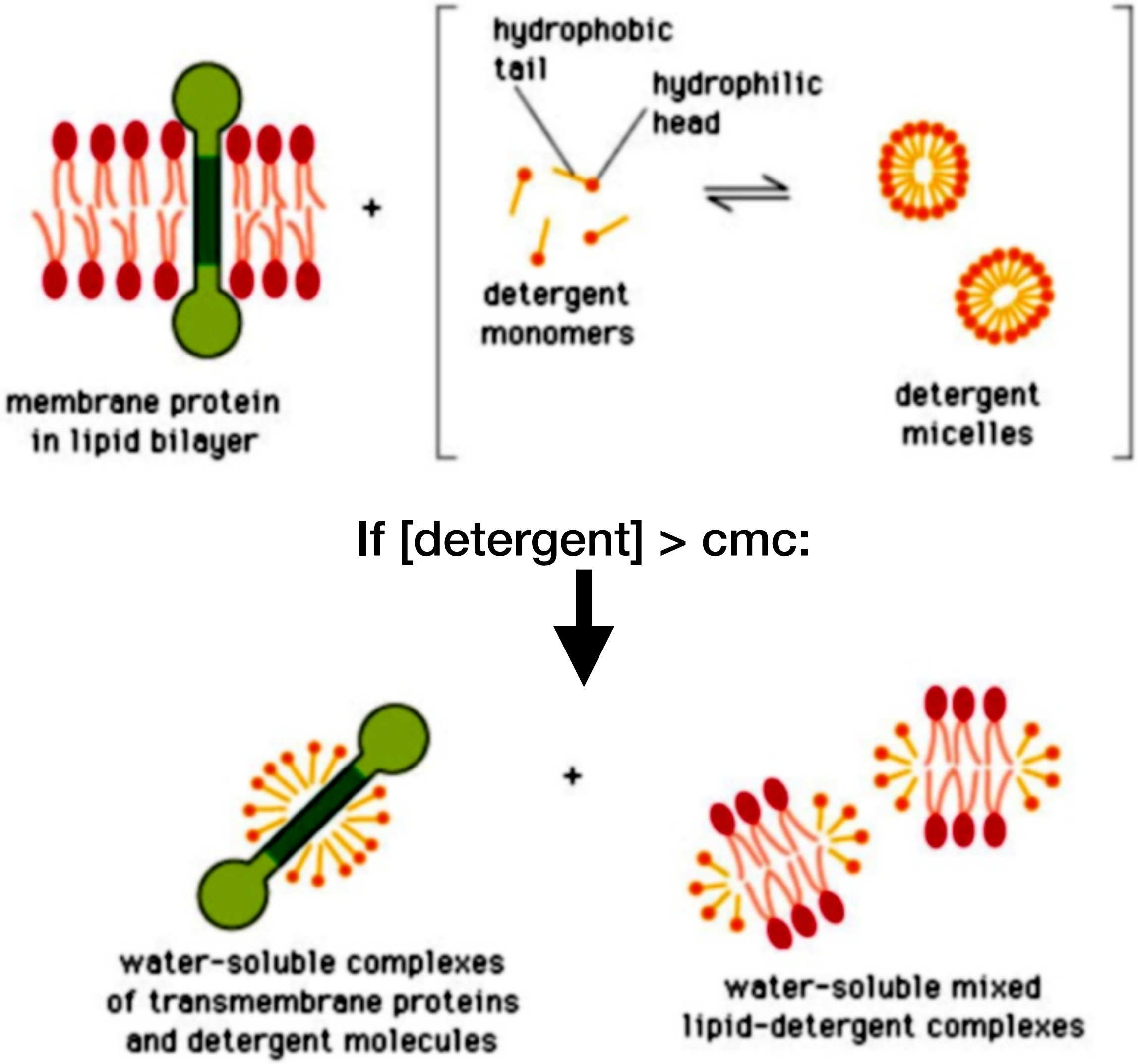
A fatty acyl-anchored protein

A prenyl-anchored membrane protein

The shape of the cell and the mechanical properties of the plasma membrane are determined by the cell cortex.



Detergents are used to disrupt the structure of the lipid bilayer and to isolate membrane proteins



Detergents

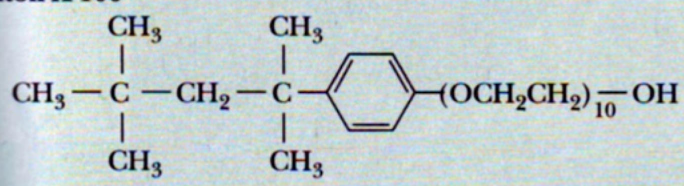
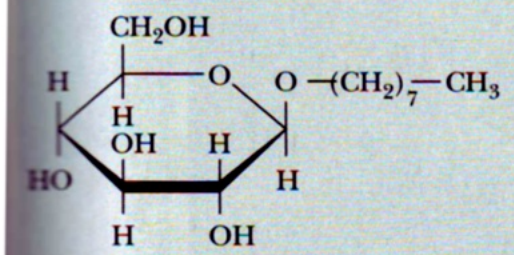
Structure	M_r	CMC	Micelle M_r
Triton X-100 	625	0.24 m*M*	90–95,000
Octyl glucoside 	292	25 m*M*	
$C_{12}E_8$ (Dodecyl octaoxyethylene ether) $C_{12}H_{25}-(OCH_2CH_2)_8-OH$	538	0.071 m*M*	

FIGURE 9.3 The structures of some common detergents and their physical properties. Micelles formed by detergents can be quite large. Triton X-100, for example, typically forms micelles with a total molecular mass of 90 to 95 kD. This corresponds to approximately 150 molecules of Triton X-100 per micelle.

Detergents

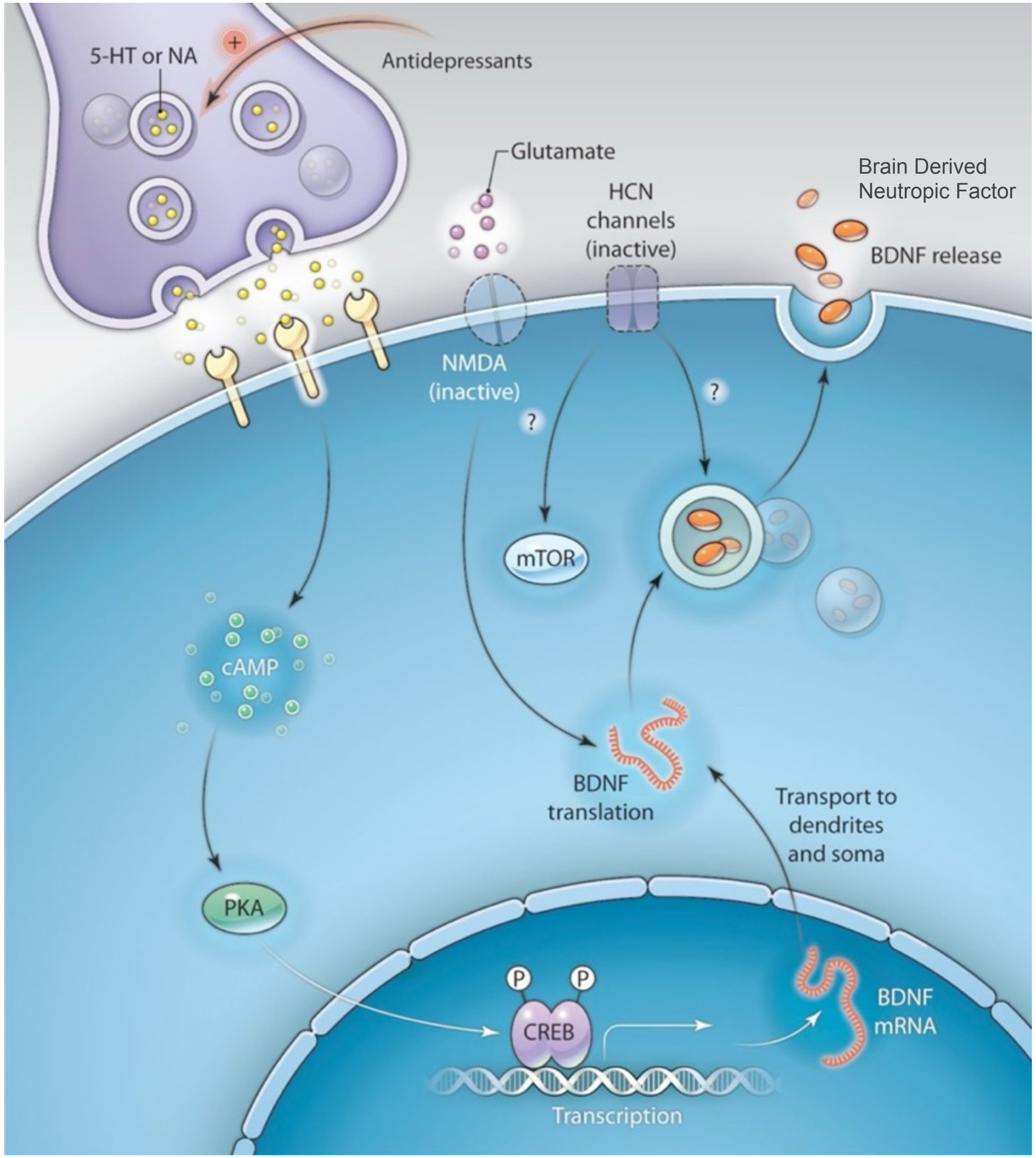
Name	Abreviation	M.W. (anhydrous)	CMC (mM)	CMC (%)	Aggregation No.	Average Micellar Weight (Da)
Non-ionic detergents						
APO-10		218.3	4.6	0.100	131	28,000
APO-12		246.4	0.568	0.013	2232	500,000
Big CHAP		878.1	2.9	0.25	10	8,800
Big CHAP, Deoxy		862.1	1.1-1.4	0.12	8-16	10,500
BRIJ® 35	Brij-35	627	0.09	0.0056	40	49,000
$C_{12}E_5$		406.6	0.064	0.002	-	-
$C_{12}E_6$		450.7	0.087	0.0039	-	-
$C_{12}E_8$	$C_{12}E_8$	538.8	0.11	0.0059	123	66,000
$C_{12}E_9$	$C_{12}E_9$	582.8	0.08	0.0046	-	83,000
Cyclohexyl-*n*-ethyl-β-D-maltoside		452.5	120	5.43	-	-
Cyclohexyl-*n*-hexyl-β-D-maltoside		508.6	0.56	0.0284	63	32,000
Cyclohexyl-*n*-methyl-β-D-maltoside		438.5	340	14.909	-	-
7-Cyclohexyl-1-heptyl-β-D-maltoside	Cymal-7	522.5	0.19	0.00992	150	78,300
n-Decanoylsucrose		496.6	2.5	0.124	-	-
n-Decyl-β-D-maltopyranoside	DM	482.6	1.6	0.087	69	-
n-Decyl-β-D-thiomaltoside	DTM	498.6	0.9	0.0448	-	-
Digitonin		1229.3	<0.5		60	74,000
n-Dodecanoylsucrose		524.6	0.3	0.0157	-	-
n-Dodecyl-β-D-glucopyranoside		348.5	0.19	0.0066	200	70,000
n-Dodecyl-β-D-maltoside	DDM	510.6	0.1-0.6	0.009	98	50,000
Dodecyl-trimethyl-ammonium chloride	DTAC	264	17.0	0.488	50	13,200
n-Heptyl-β-D-glucopyranoside		278.3	70	1.9	-	-
n-Heptyl-β-D-thioglucopyranoside	HTG	294.4	79	2.325	-	-

Detergents

Name	Abreviation	M.W. (anhydrous)	CMC (mM)	CMC (%)	Aggregation No.	Average Micellar Weight (Da)
n-Nonyl-β-D-glucopyranoside	NG	306.4	6.5	0.2	133	-
Methyl 6-O-(N-heptylcarbamoyl)-α-D-glucopyranoside	Hecameg	335.4	19.5	0.654		
Nonidet P-40 (octylphenoxypolyethoxyethanol), now IGEPAL CA-630	Nonidet P-40	558.7	0.25	0.014	149	90,000
NP-40 (nonylphenoxypolyethoxyethanol)	NP-40	603.0	0.05-0.3	0.05-0.3	100-155	76,600
n-Octanoyl-β-D-glucosylamine	NOGA	305.4	80	2.443	-	-
n-Octanoylsucrose		468.5	24.4	1.143	-	-
n-Octyl-β-D-glucopyranoside	OG	292.4	10-21	0.3-0.6	84	25,000
n-Octyl-β-D-maltopyranoside		454.5	19.5	0.89	84	38,000
n-Octyl-β-D-thioglycopyranoside	OTG	308.4	9	0.277	-	-
n-Octylpolyoxyethylene	Octyl-POE	174.3	6.6	0.115		
TRITON® X-100	TX-100	625	0.01-0.016	0.015	100-155	80,000
TWEEN® 20	Tween 20	1228	0.059	0.0072	-	-
TWEEN® 80	Tween 80	1310	0.012	0.00157	60	79,000
n-Undecyl-β-D-maltoside	UDM	496.6	0.59	0.0292	-	-
Ionic Detergents						
Amphipol A8-35		9-10	-	20	-	-
Cetyltrimethylammonium Bromide	CTAB	364.5	1.0	0.0364	170	62,000
Cholic Acid, Sodium Salt	Cholate	430.6	9-15		2.0	900

Detergents

Name	Abreviation	M.W. (anhydrous)	CMC (mM)	CMC (%)	Aggregation No.	Average Micellar Weight (Da)
Ionic Detergents						
Amphipol A8-35		9-10	-	20	-	-
Cetyltrimethylammonium Bromide	CTAB	364.5	1.0	0.0364	170	62,000
Cholic Acid, Sodium Salt	Cholate	430.6	9-15		2.0	900
Deoxycholic Acid, Sodium Salt, Na-deoxycholate	DOC	414.6	4-8	0.24	22	1600-4100
Lauroylsarcosine, Sodium Salt		293.4	14.57	0.427	2.0	600
Taurocholic Acid, Sodium Salt		537.7	3-11		4	2100
Zwitterionic Detergents						
CHAPS	CHAPS	614.9	6-10	0.49	10	6000
CHAPSO		630.9	8	0.5	11	7000
Diheptanoyl-*sn*-Glycero-3-Phosphocholine	DHPC	481.5	1.4	0.07	100	50,000
Lauryldimethylamine Oxide, 30% Solution	LDAO	229.4	1-2	0.023	76	17,000
ZWITTERGENT® 3-08 Detergent		279.6	330	10.9	-	-
ZWITTERGENT® 3-10 Detergent		307.6	25-40	1.2	41	12,500
ZWITTERGENT® 3-12 Detergent		335.6	2-4	0.094	55	18,500
ZWITTERGENT® 3-14 Detergent		363.6	0.1-0.4	0.007	83	30,000
ZWITTERGENT® 3-16 Detergent		391.6	0.01-0.06	0.0011	155	60,000



Shah,
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