

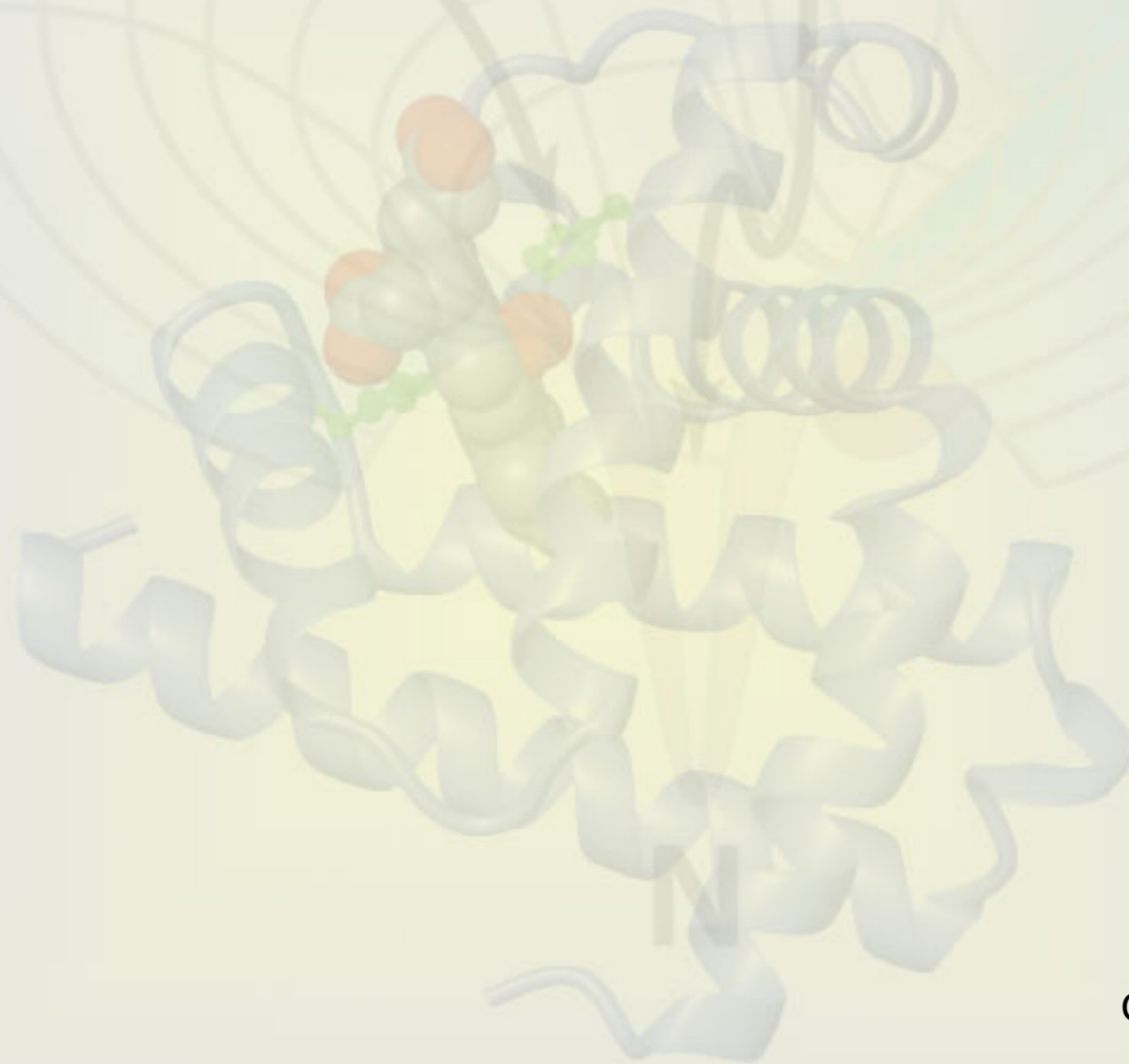
Chem 352 - Lecture 8

Lipids, Membranes, and Cellular Transport

Question for the Day: *Why do phospholipids, when placed in water, spontaneously assemble to form membranes?*

Introduction to Lipids

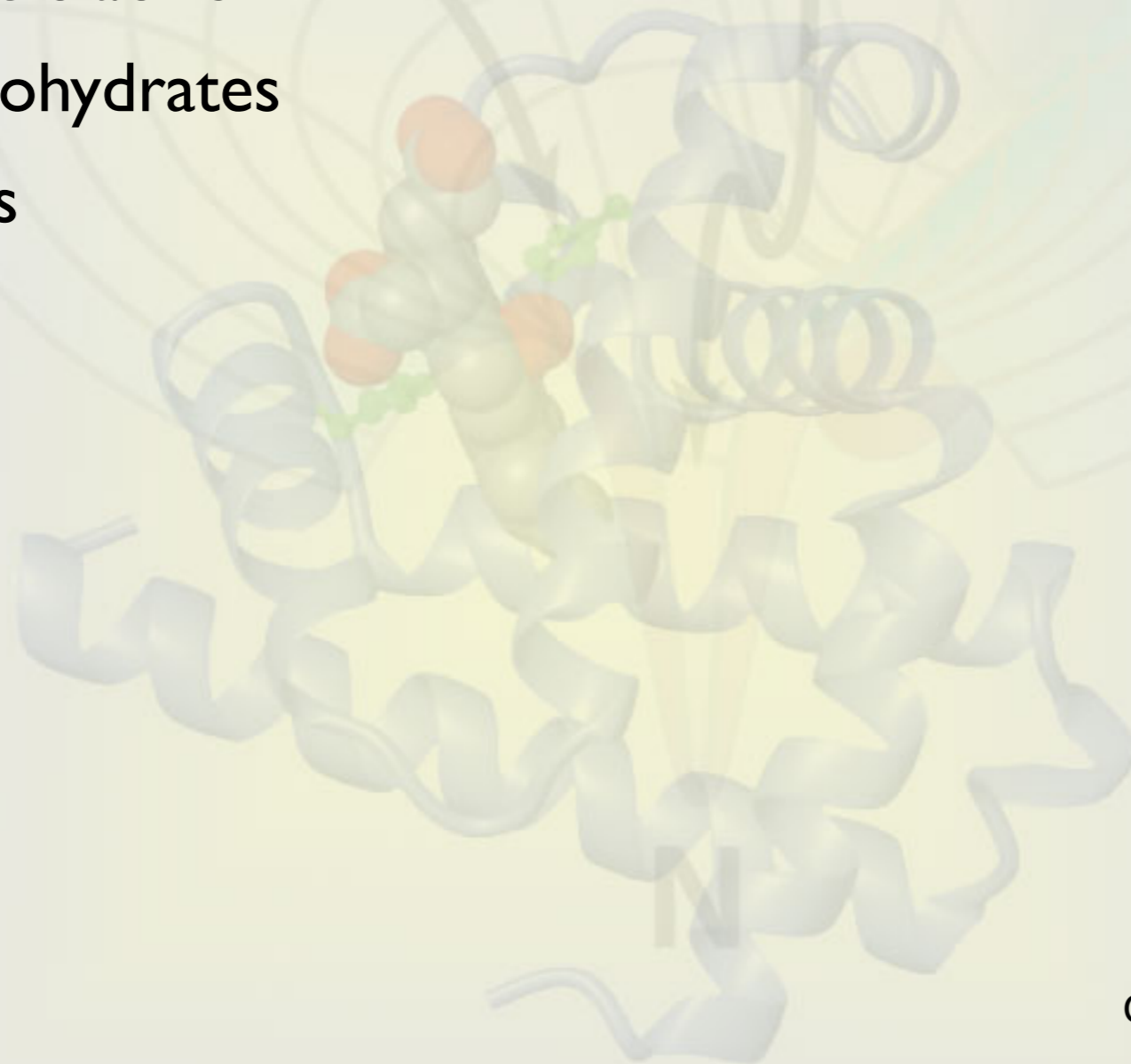
Lipids are one of the four major classes of biological molecules, which include,



Introduction to Lipids

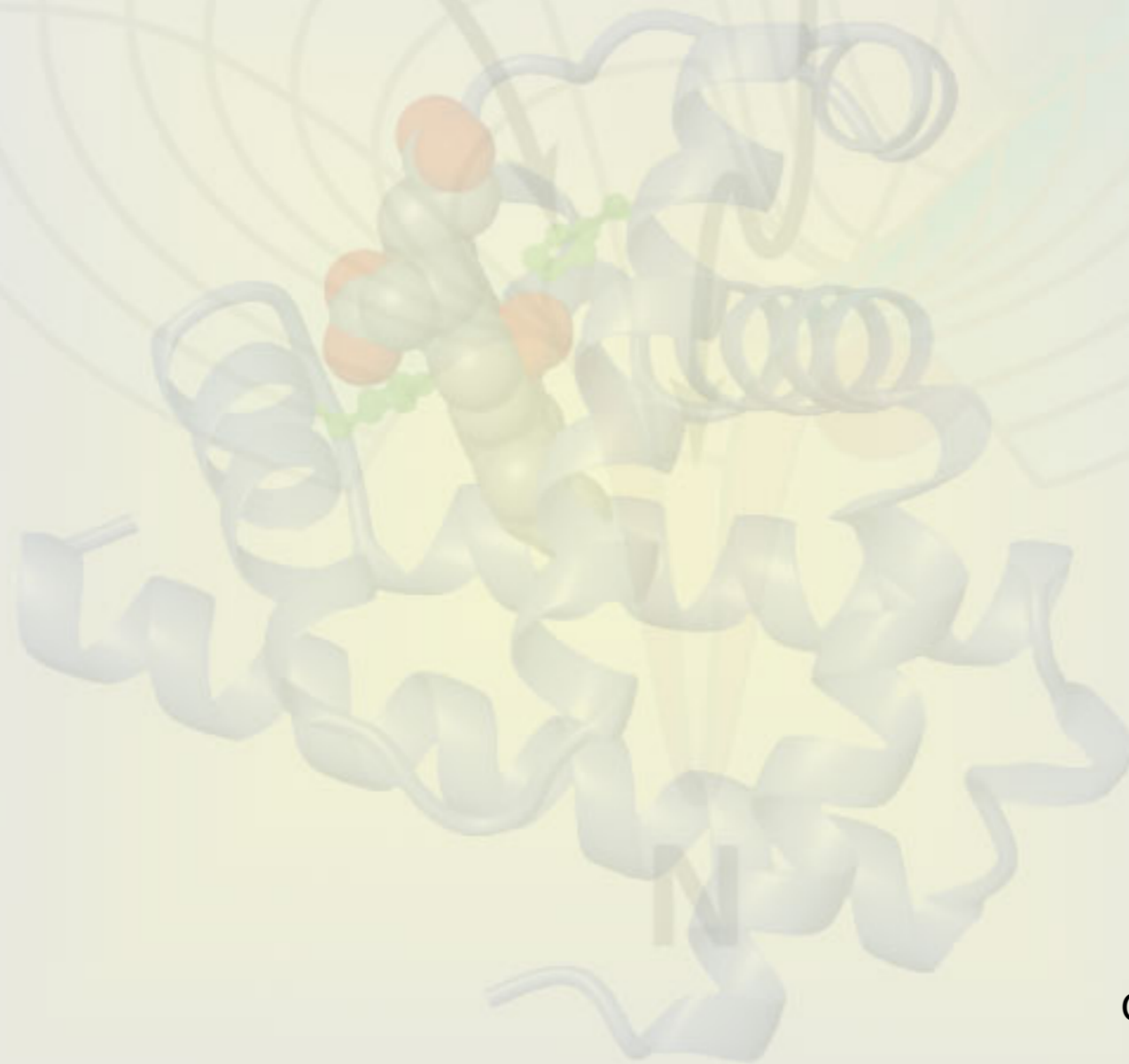
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- ✦ Proteins
- ✦ Nucleic acids
- ✦ Carbohydrates
- ✦ Lipids



Introduction

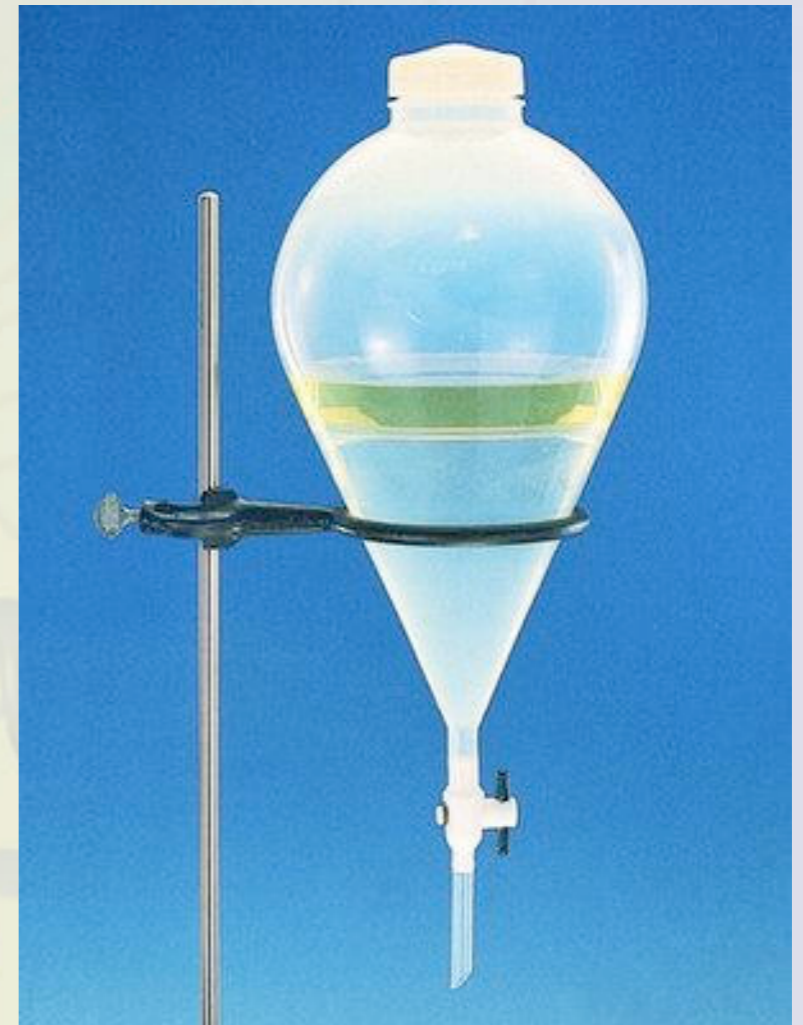
Lipids are defined by a physical property instead of a chemical one.



Introduction

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- ✦ Lipids are the non-polar components of a cell which can be extracted with organic solvents



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- ✦ Lipids are the non-polar components of a cell which can be extracted with organic solvents
- ✦ While all lipids contain a large non-polar moiety, not all are entirely non-polar.

Introduction

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- ♦ Lipids are the non-polar compounds that are extracted with organic solvents.
- ♦ While all lipids contain a large non-polar moiety, not all are entirely non-polar.

Dictionary

moi·e·ty | 'moiədē | noun (plural moieties)
formal or technical

each of two parts into which a thing is or can be divided: *the tax was to be delivered in two moieties.*

Dictionary

Wikipedia

Siri Know

moiety

Introduction

Lipids are
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- ♦ Lipids are
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phys

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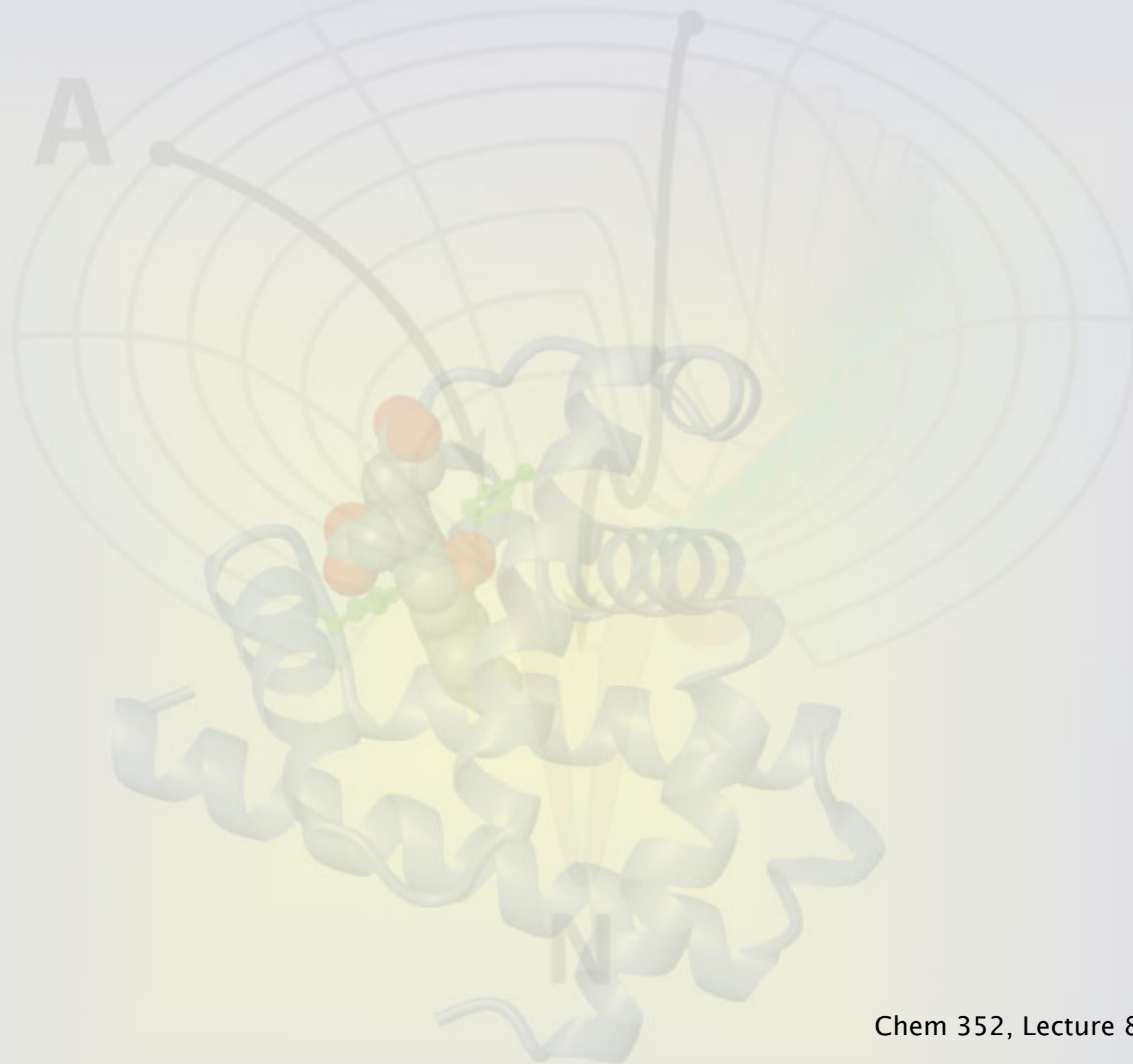
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- ✦ Lipids are the non-polar components of a cell which can be extracted with organic solvents
- ✦ While all lipids contain a large non-polar moiety, not all are entirely non-polar.

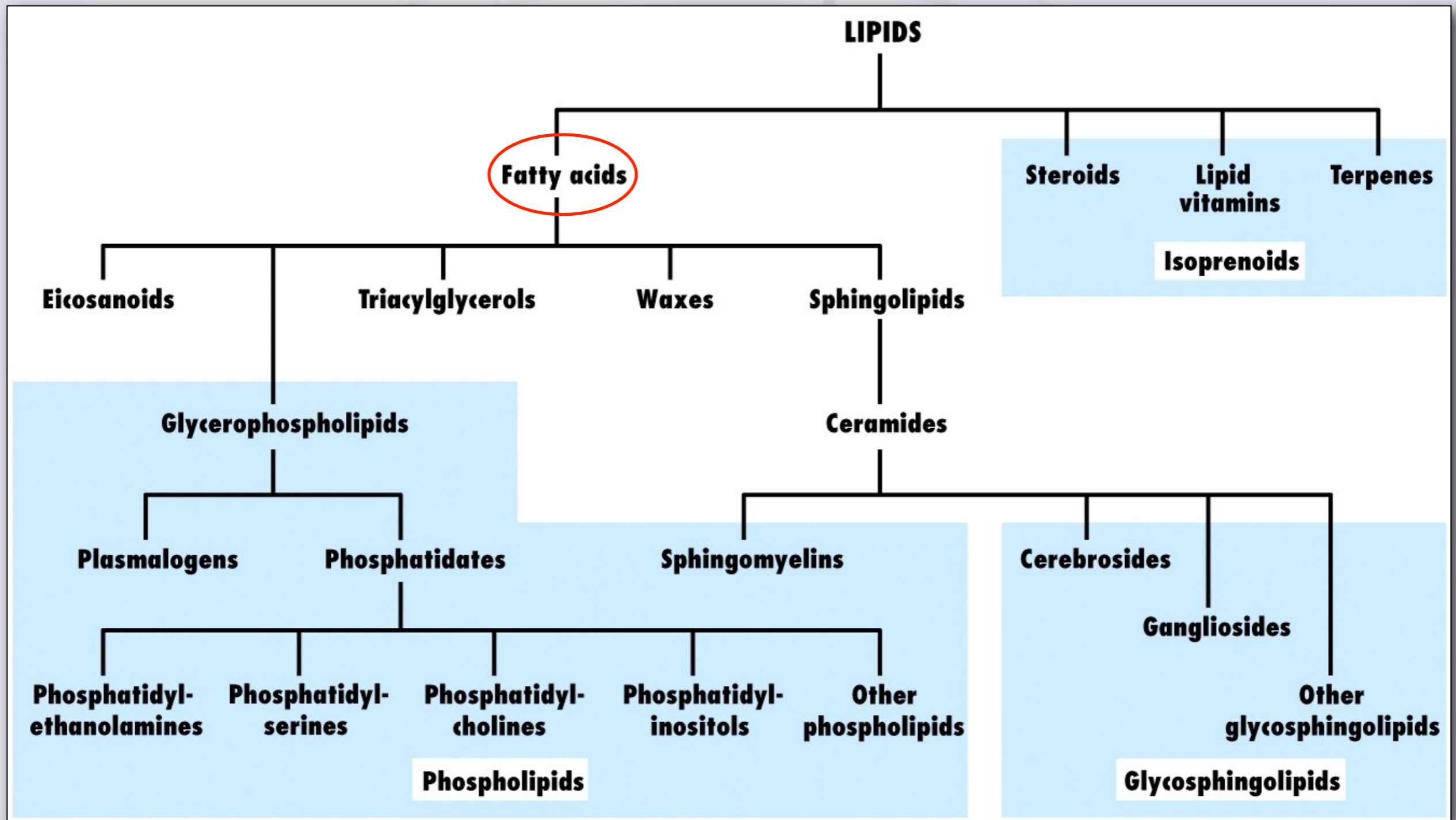
Lipids come in many different flavors (structures and functions)

Unlike the the other classes of biomolecule, lipids do not form large, covalent polymers.

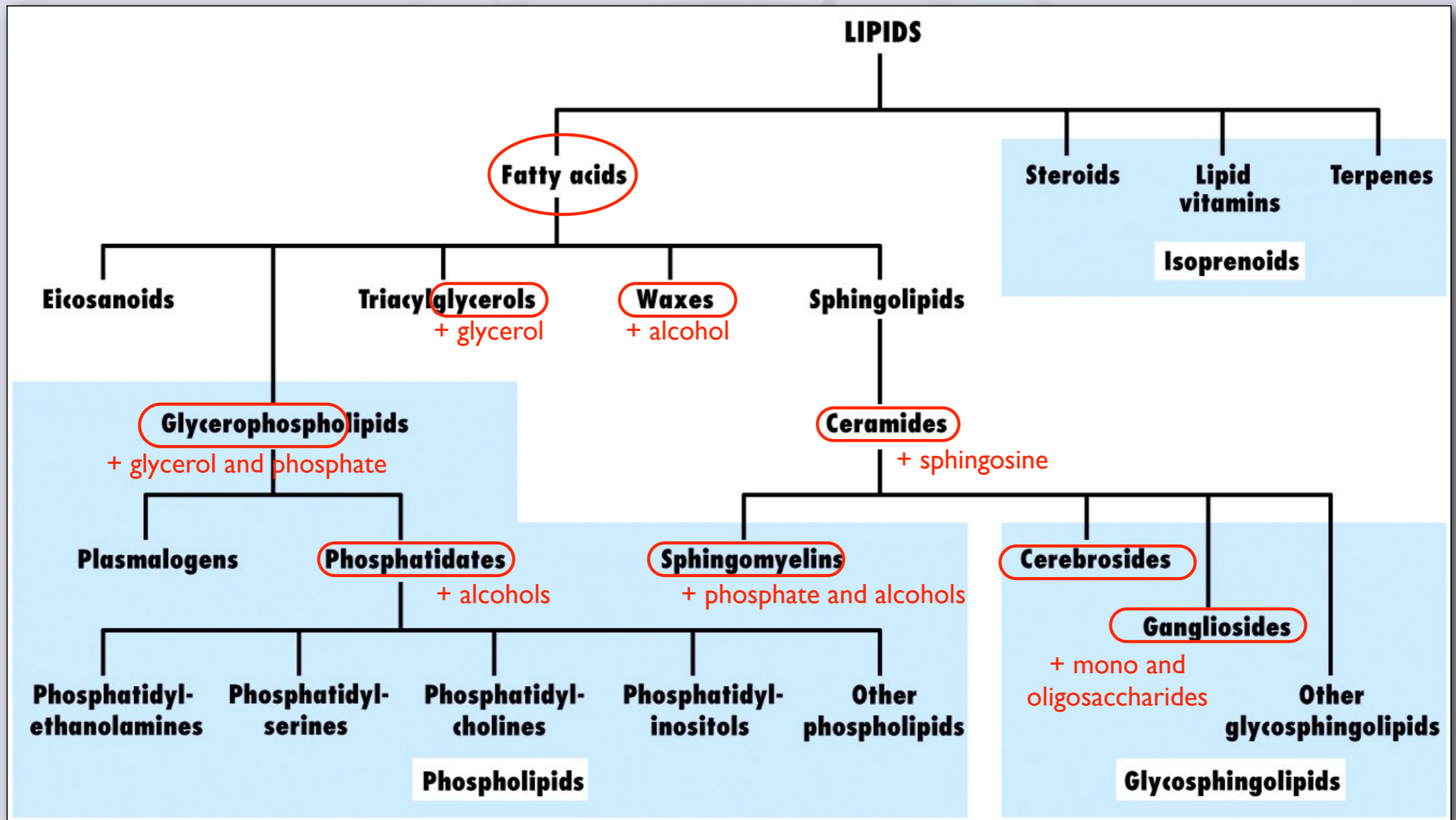
Introduction



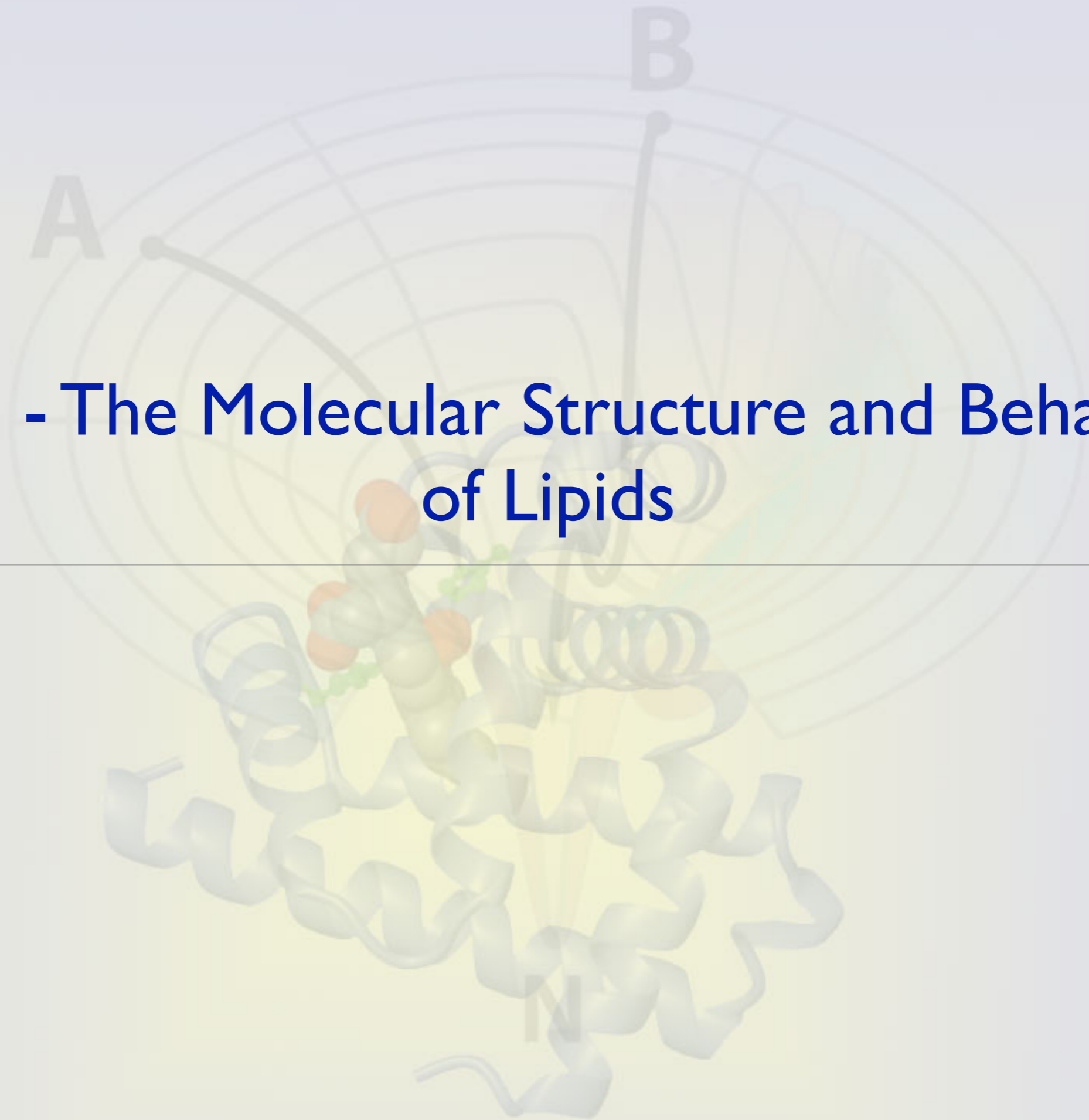
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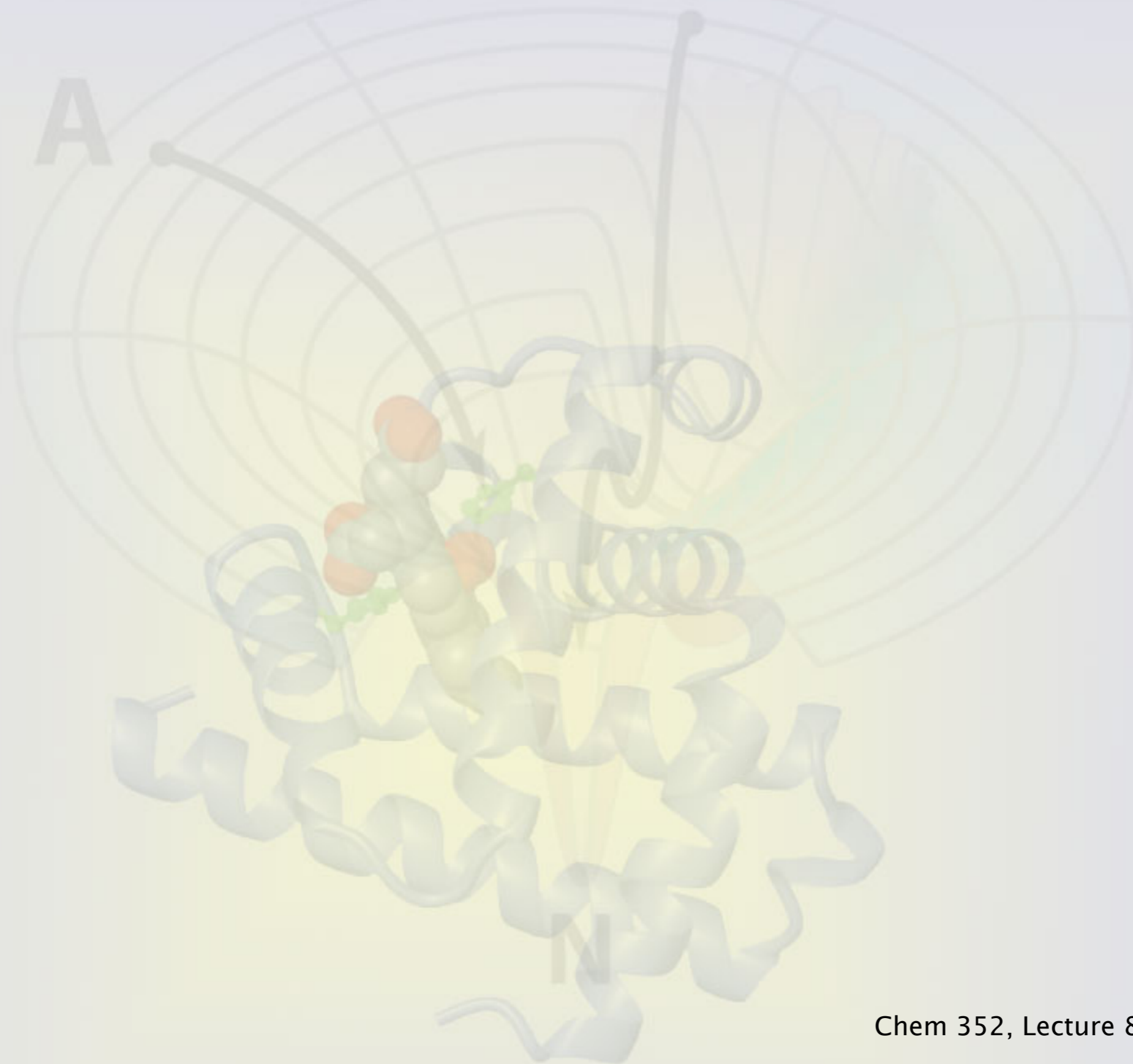
Introduction



10.1 - The Molecular Structure and Behavior of Lipids



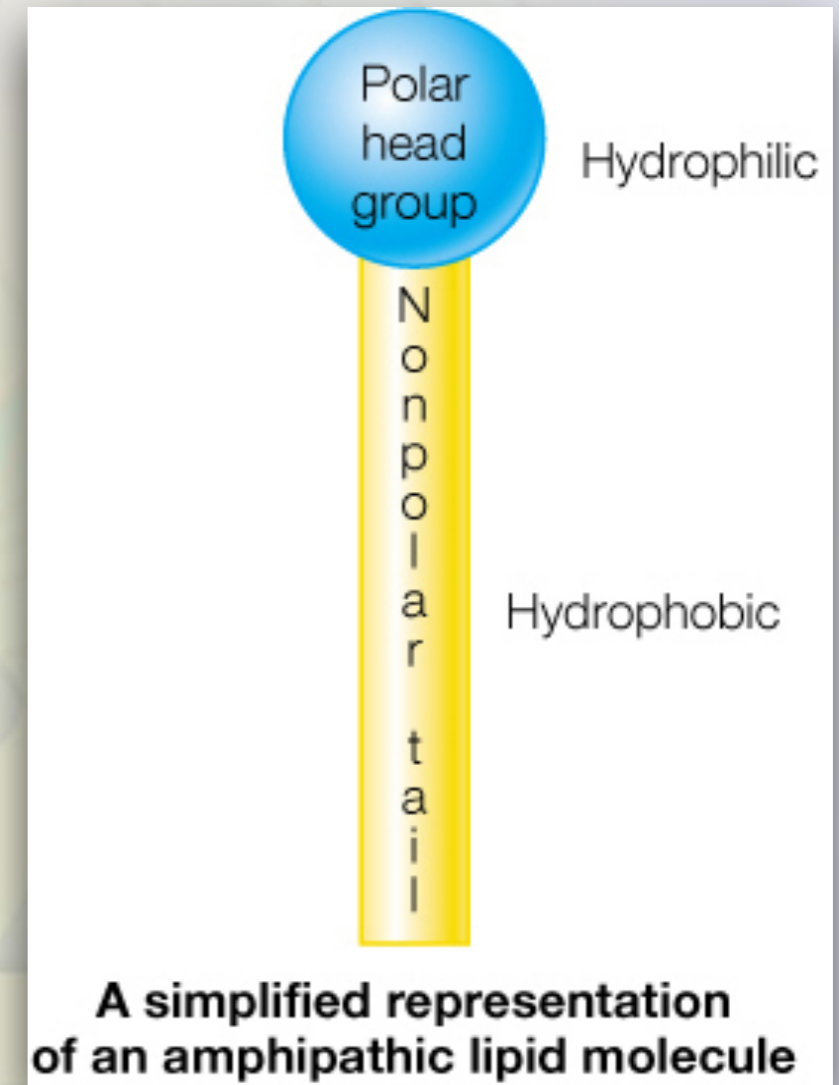
Structure and Behavior



Structure and Behavior

Lipids are generally non-polar and therefore hydrophobic and insoluble in water

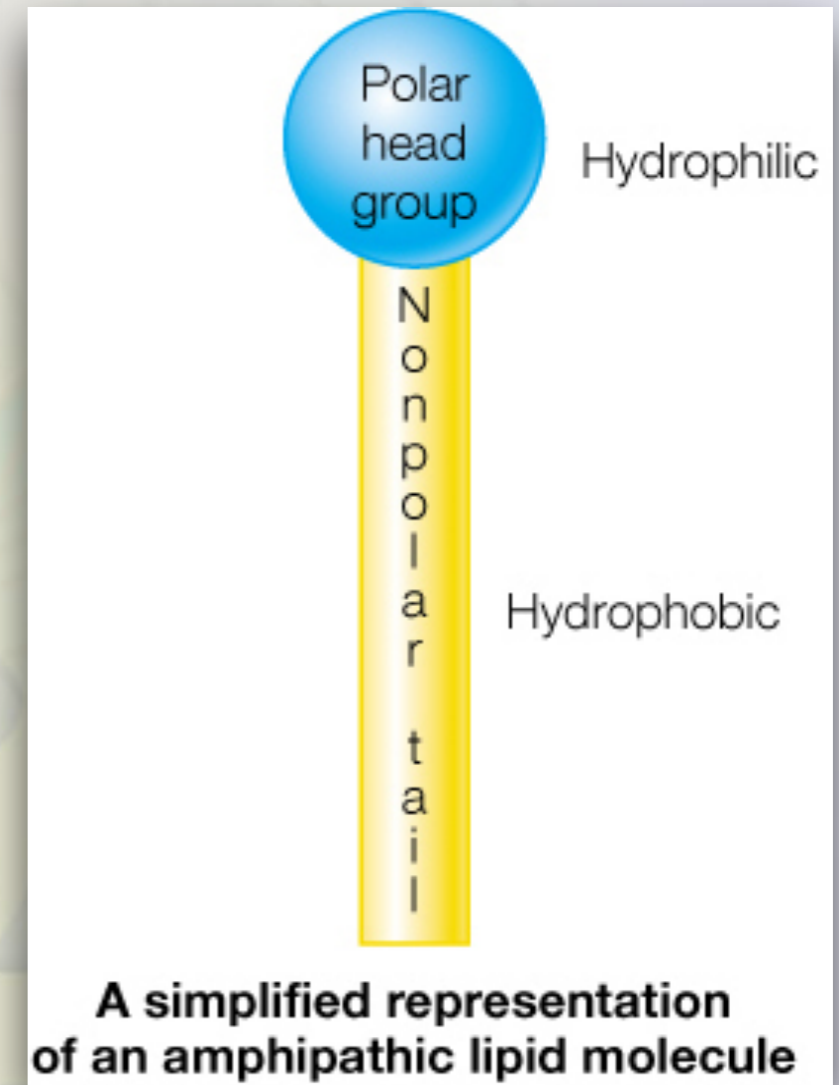
- ✦ However, they often have a hydrophilic component that is segregated from the hydrophobic one.



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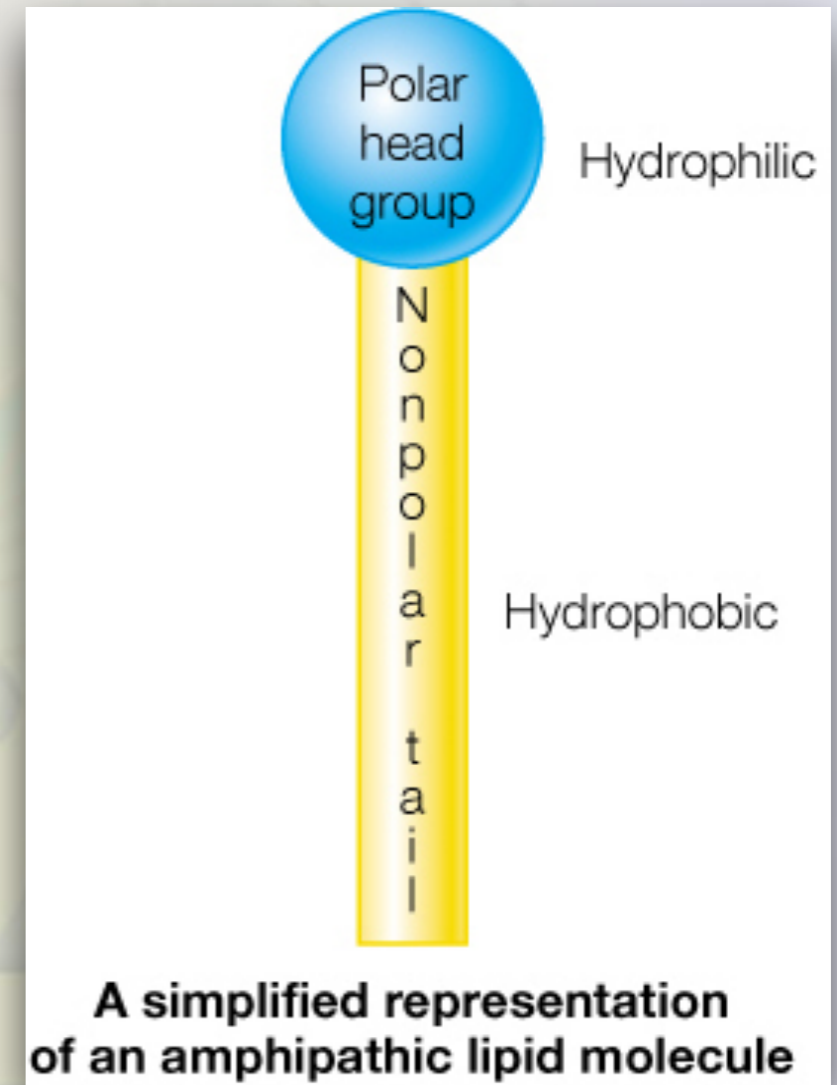
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- ✦ Molecules that are both hydrophobic and hydrophilic are said to be *amphipathic*.



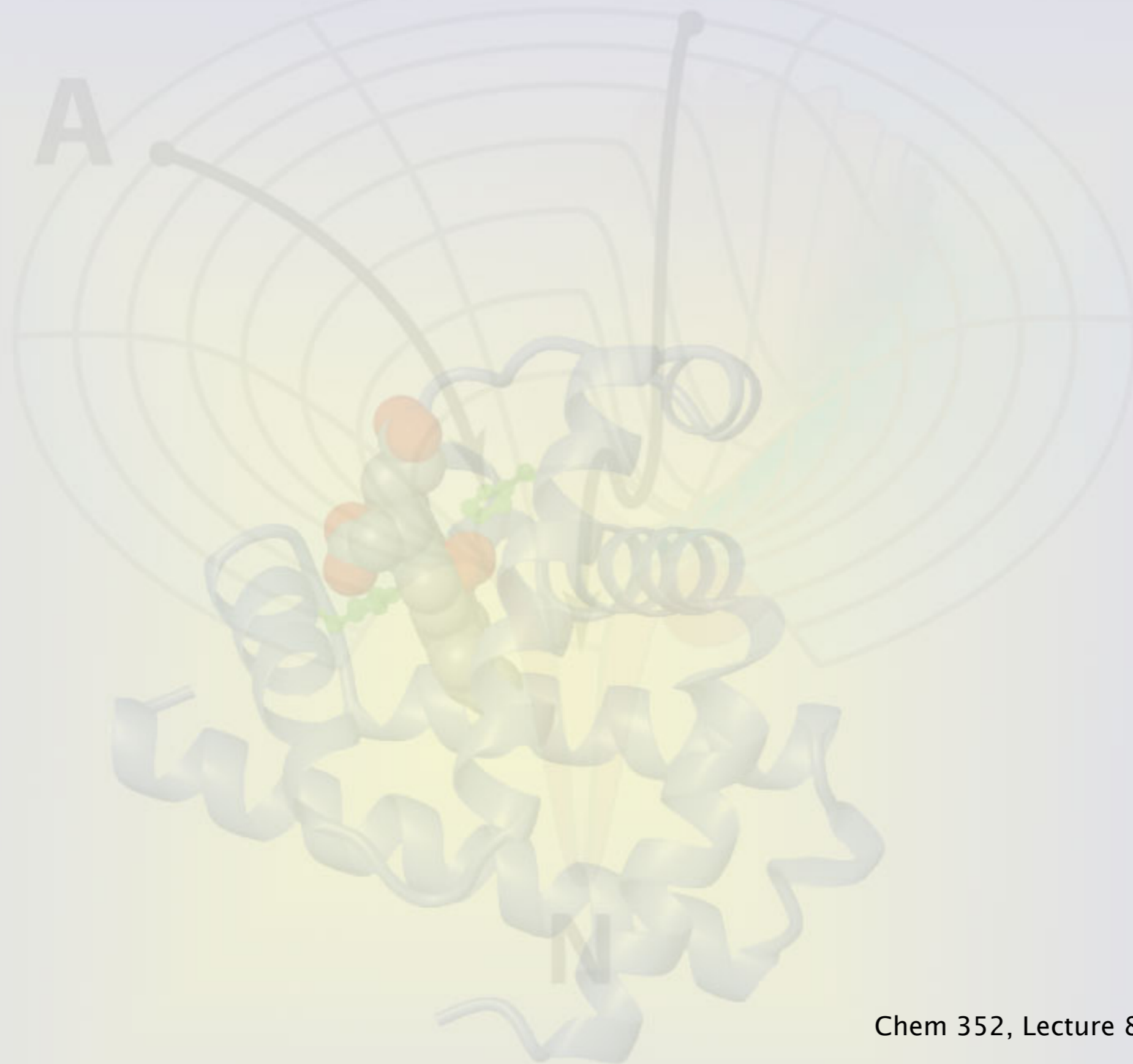
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Lipids are generally non-polar and therefore hydrophobic and insoluble in water

- ✦ However, they often have a hydrophilic component that is segregated from the hydrophobic one.
- ✦ Molecules that are both hydrophobic and hydrophilic are said to be *amphipathic*.
- ✦ When placed in a an aqueous environment, amphipathic molecules often aggregate to form structures such as
 - micelles
 - lipid bilayers
 - vesicles

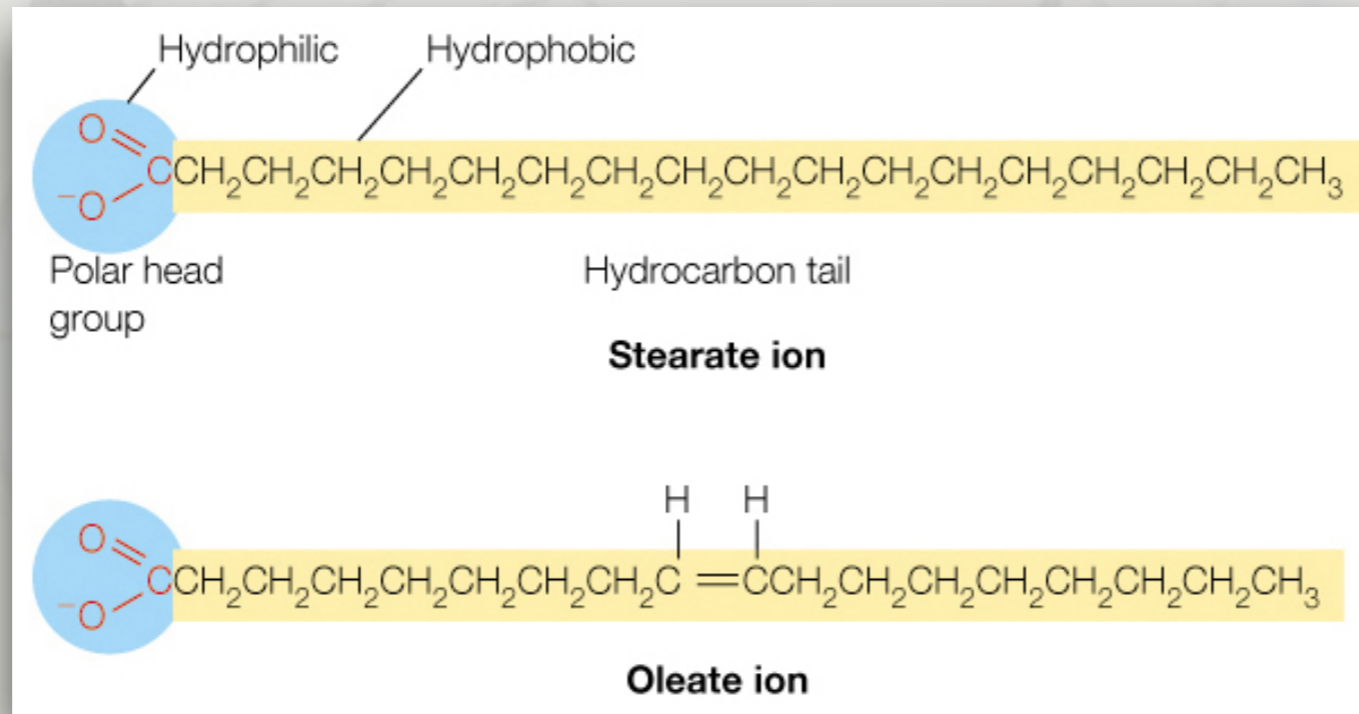


Structure and Behavior



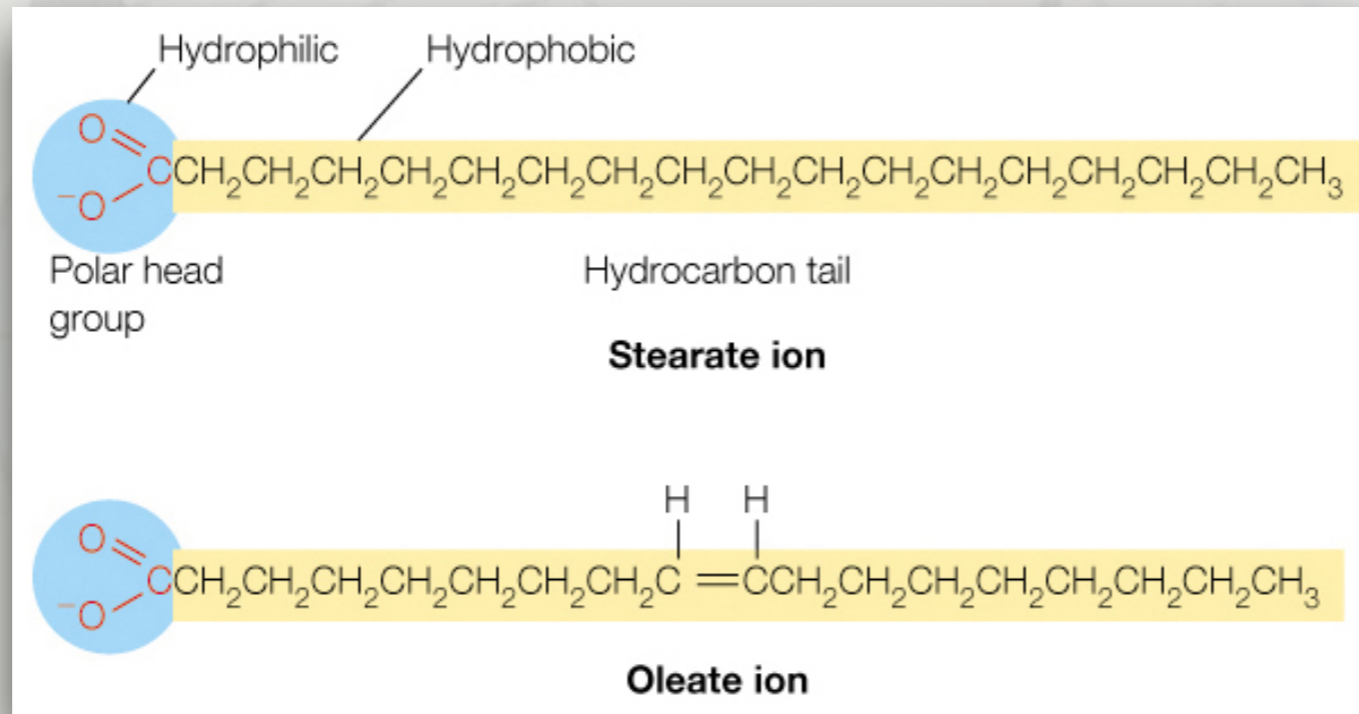
Structure and Behavior

The simplest examples are the *fatty acids*.



Structure and Behavior

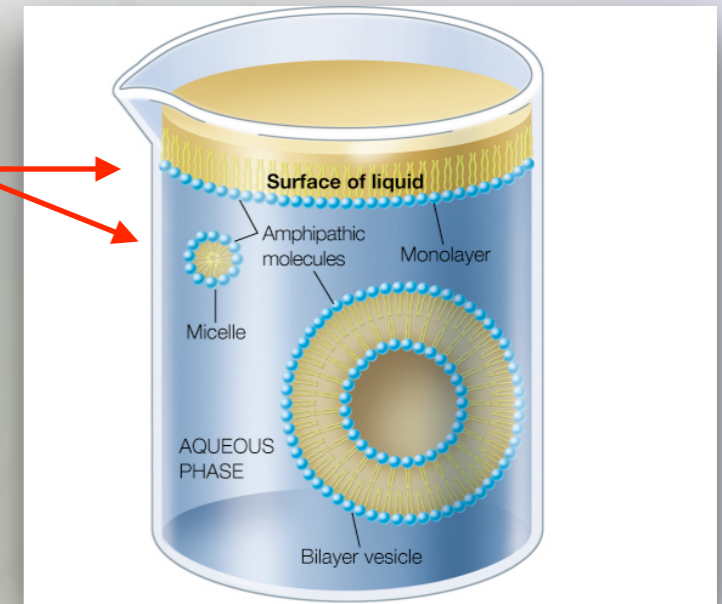
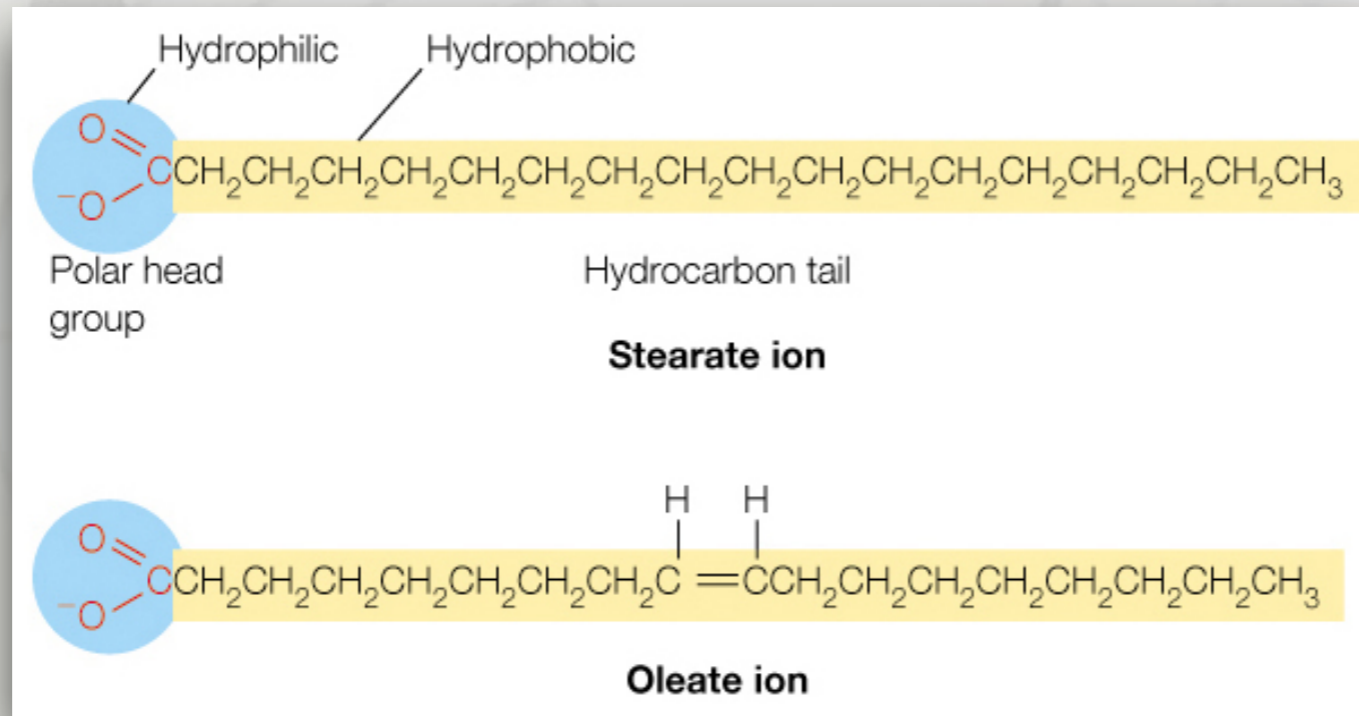
The simplest examples are the *fatty acids*.



- ♦ The the carboxylic acid group has a $pK_a \approx 4.5$, and so is in its negatively charged, carboxylate form at neutral pH values.
 - The carboxylate forms of fatty acids are also called “soaps”

Structure and Behavior

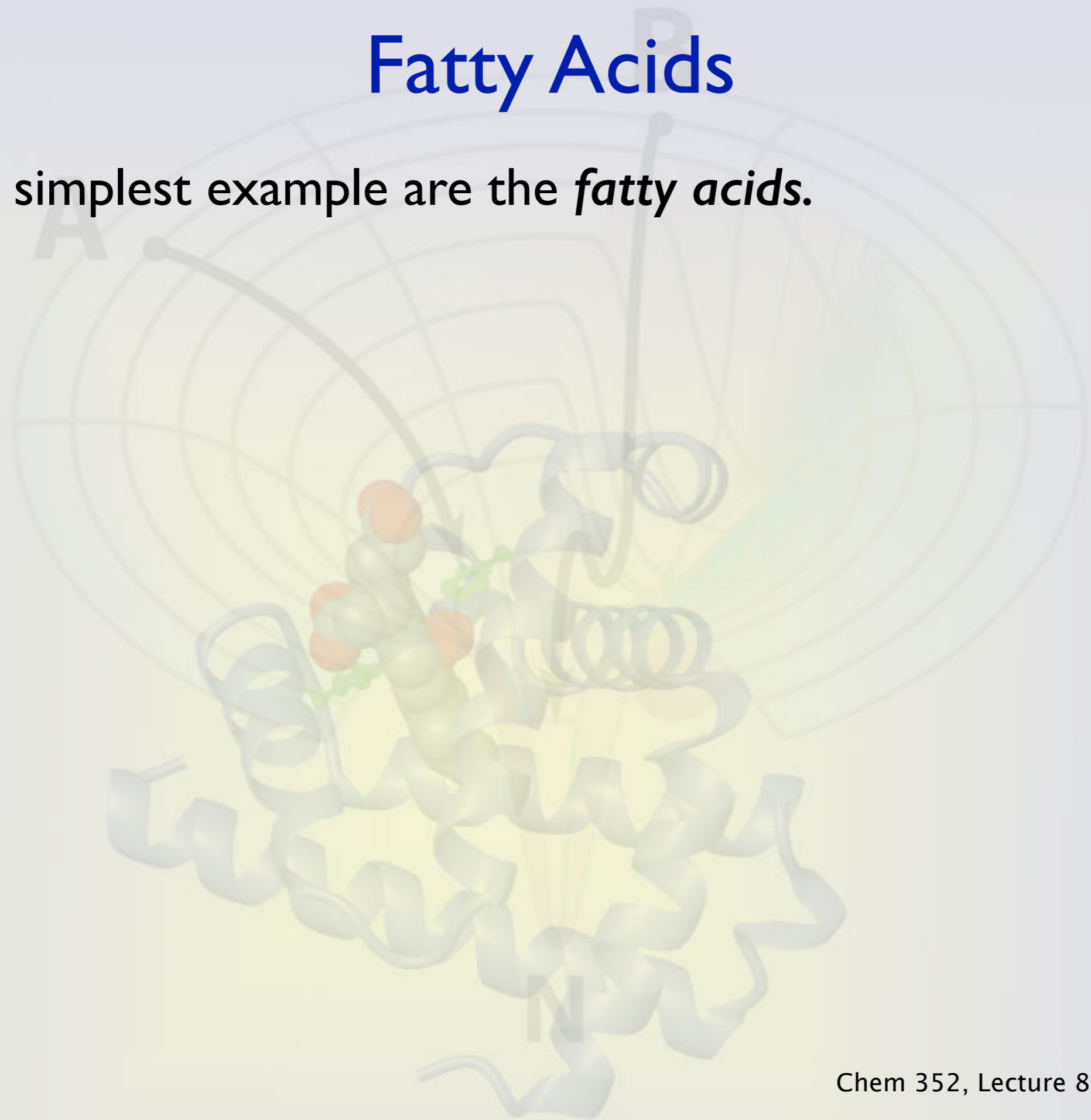
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- ♦ The the carboxylic acid group has a $pK_a \approx 4.5$, and so is in its negatively charged, carboxylate form at neutral pH values.
 - The carboxylate forms of fatty acids are also called “soaps”
 - ... and when placed in water, they aggregate to form *micelles* and surface monolayers.

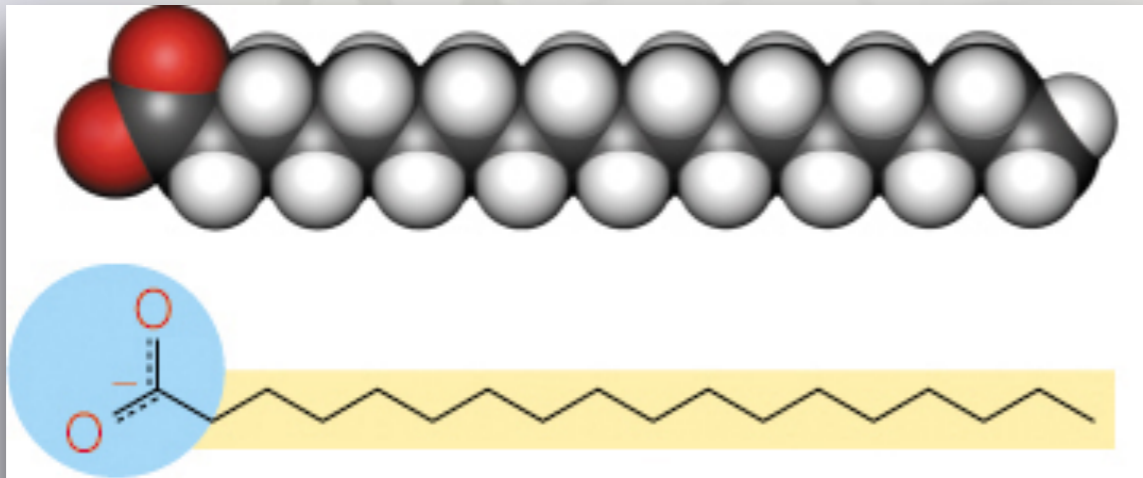
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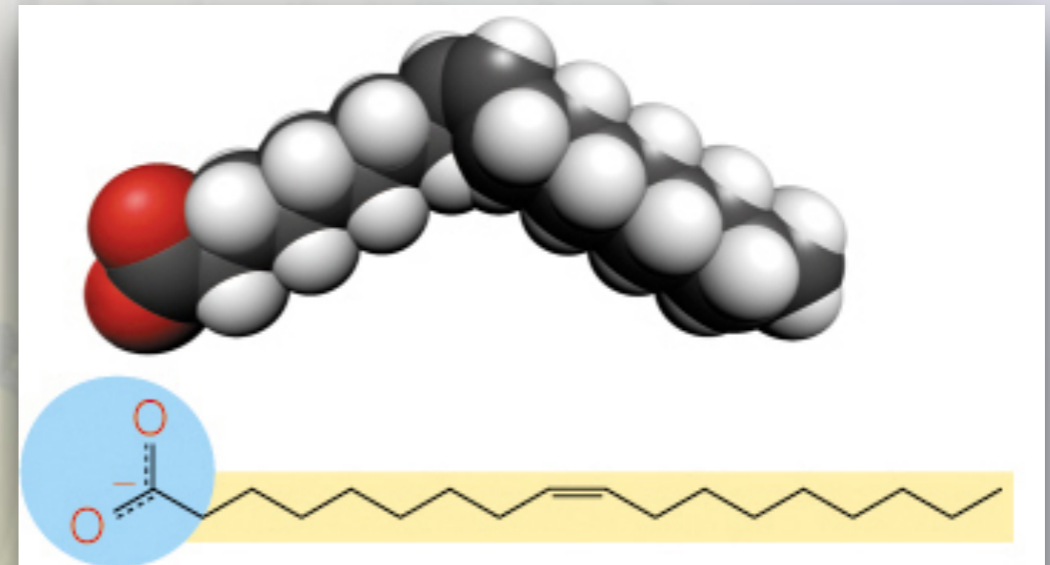


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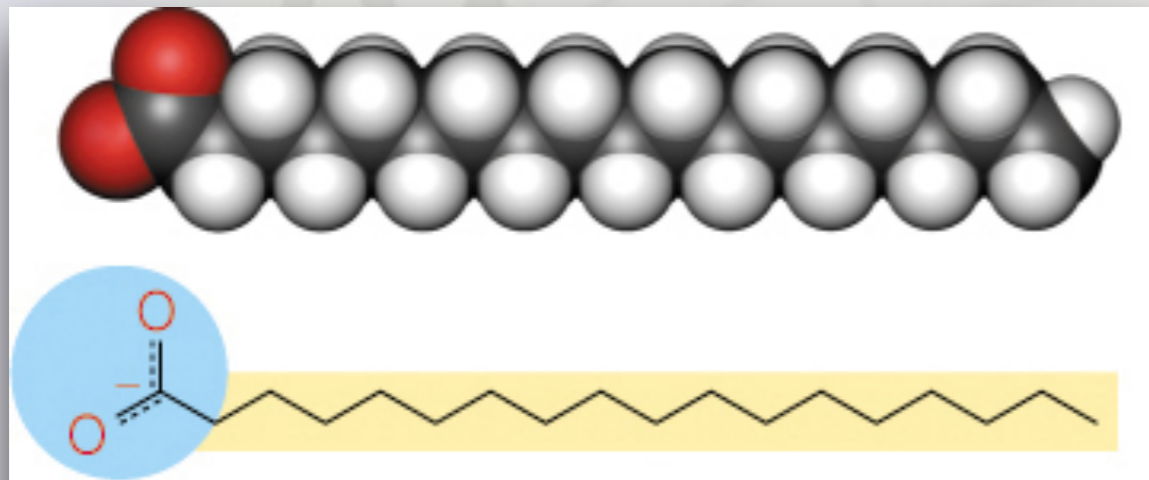
(a) **Stearate ion.** Stearate (the anionic, deprotonated form of stearic acid) is a saturated fatty acid.



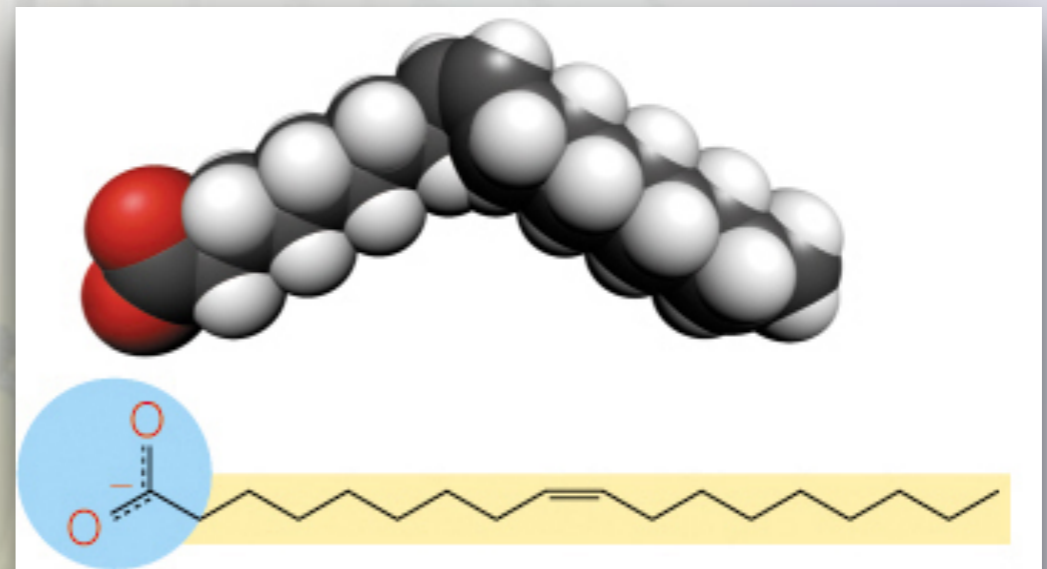
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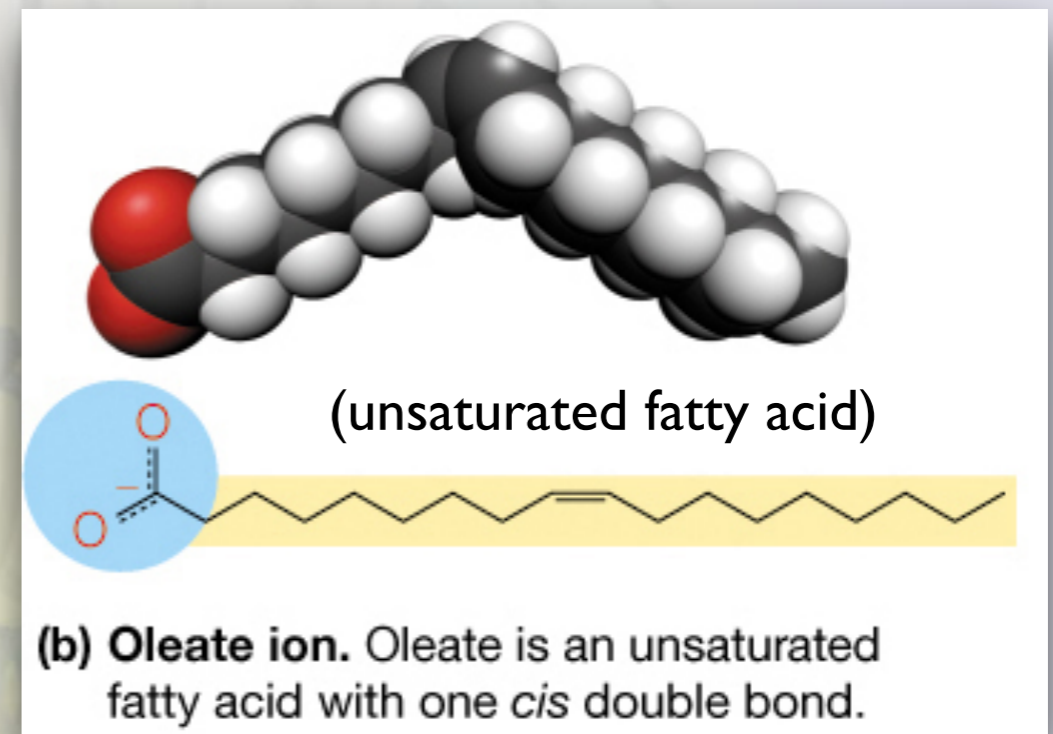
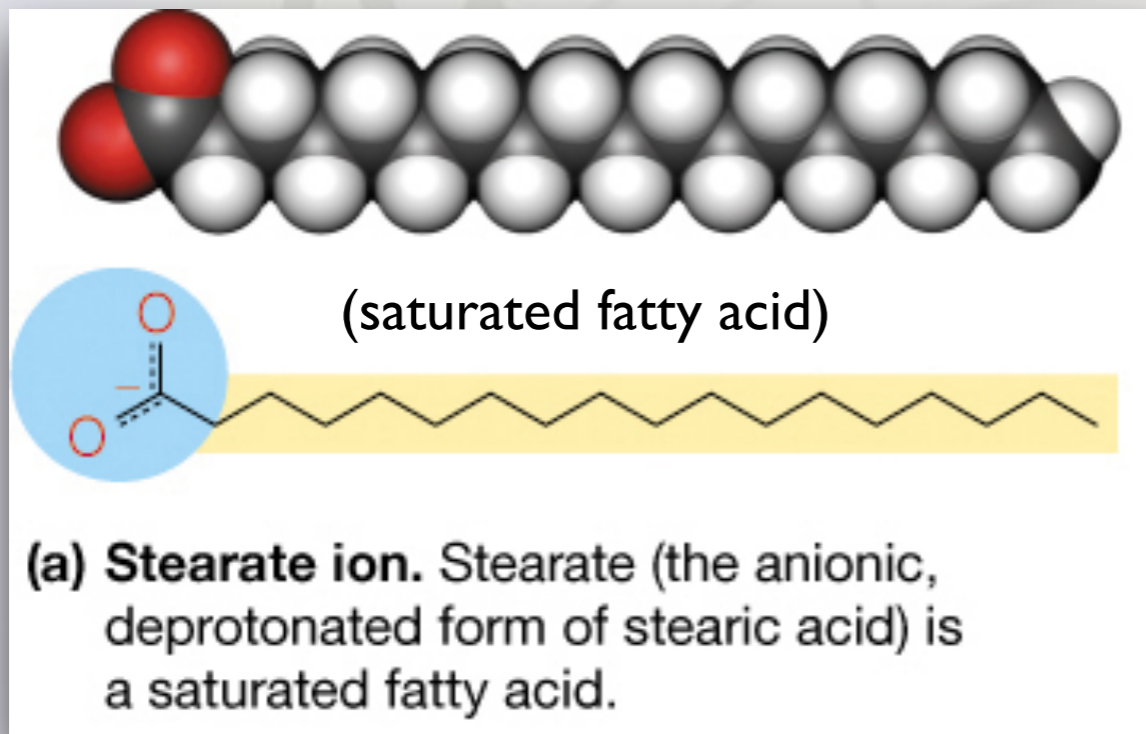


(b) **Oleate ion.** Oleate is an unsaturated fatty acid with one *cis* double bond.

- ✦ Fatty acids containing double bonds are referred to as *unsaturated fatty acids*.
- ✦ The double bonds in naturally occurring unsaturated fatty acids are *cis*.
 - This produces a kink in the hydrophobic tail

Fatty Acids

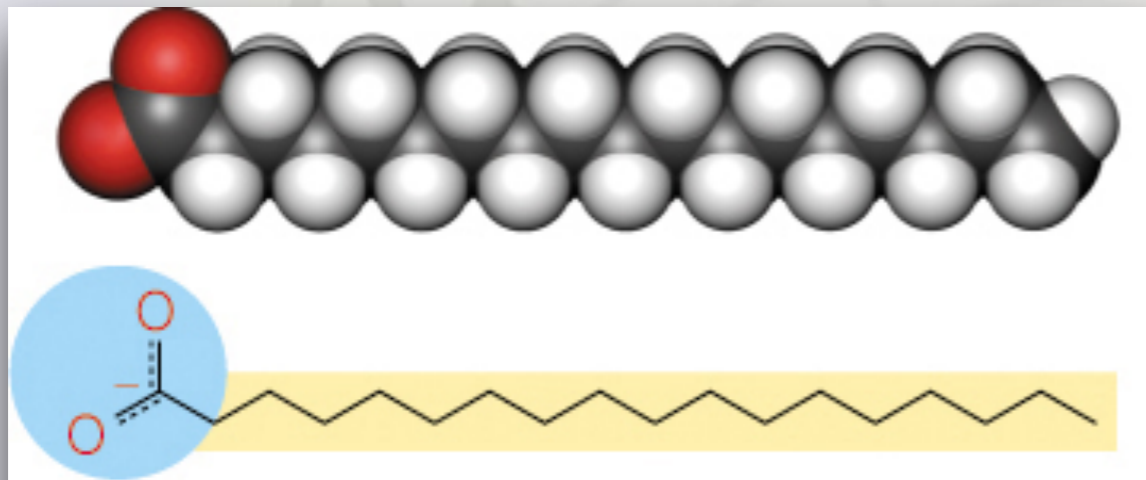
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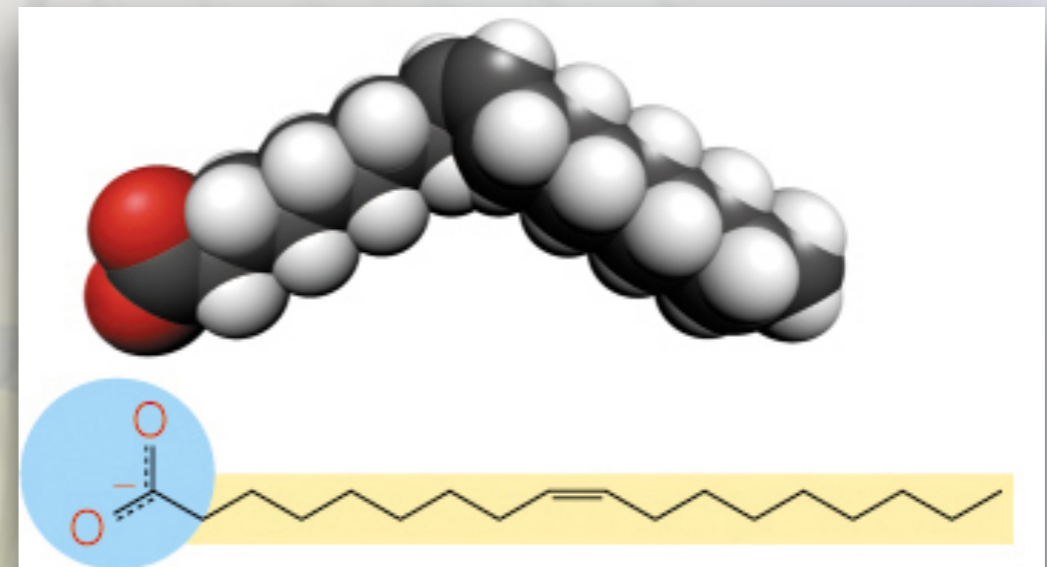
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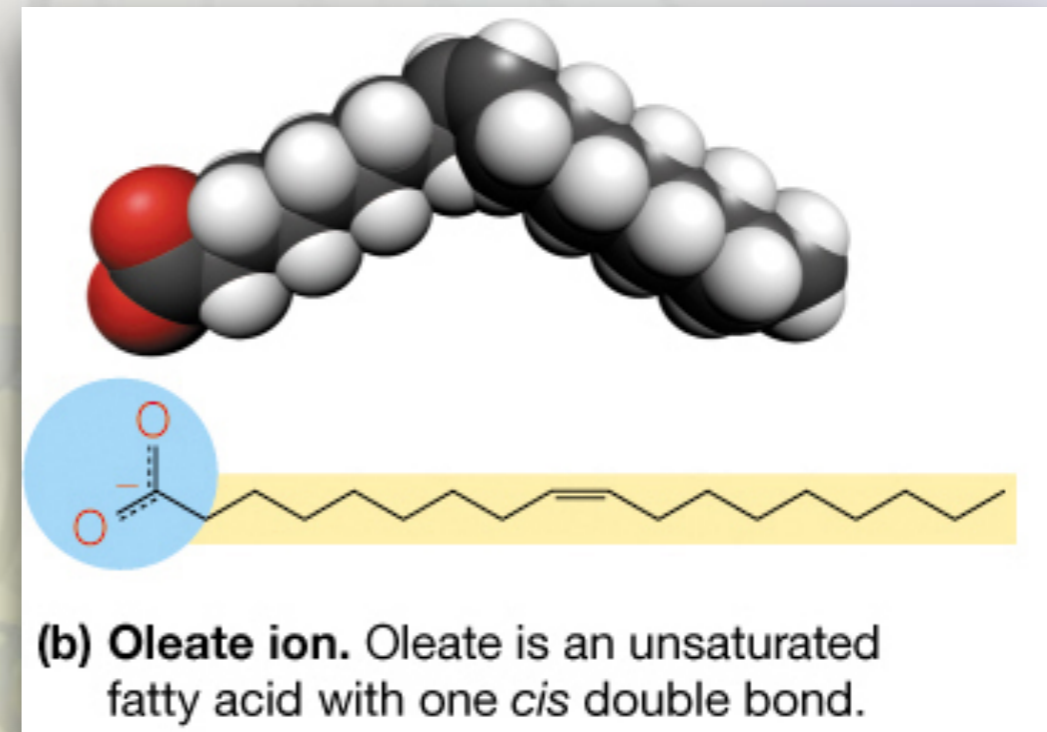
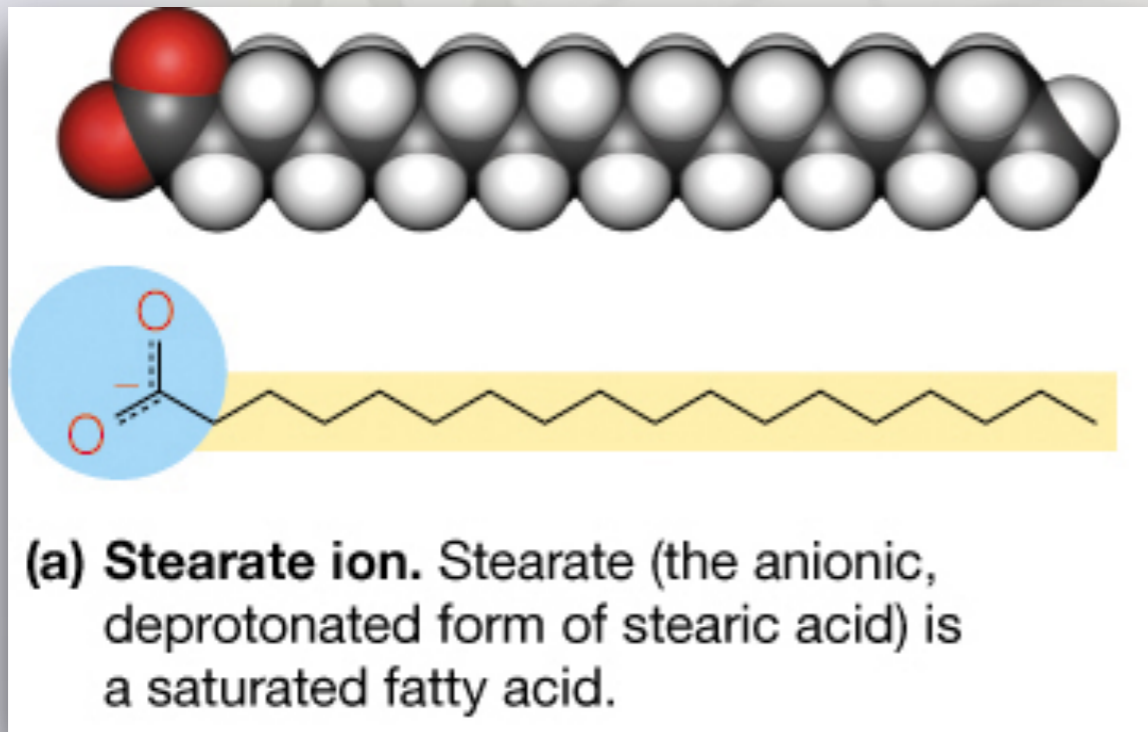
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(b) Oleate ion. Oleate is an unsaturated fatty acid with one *cis* double bond.

Fatty Acids

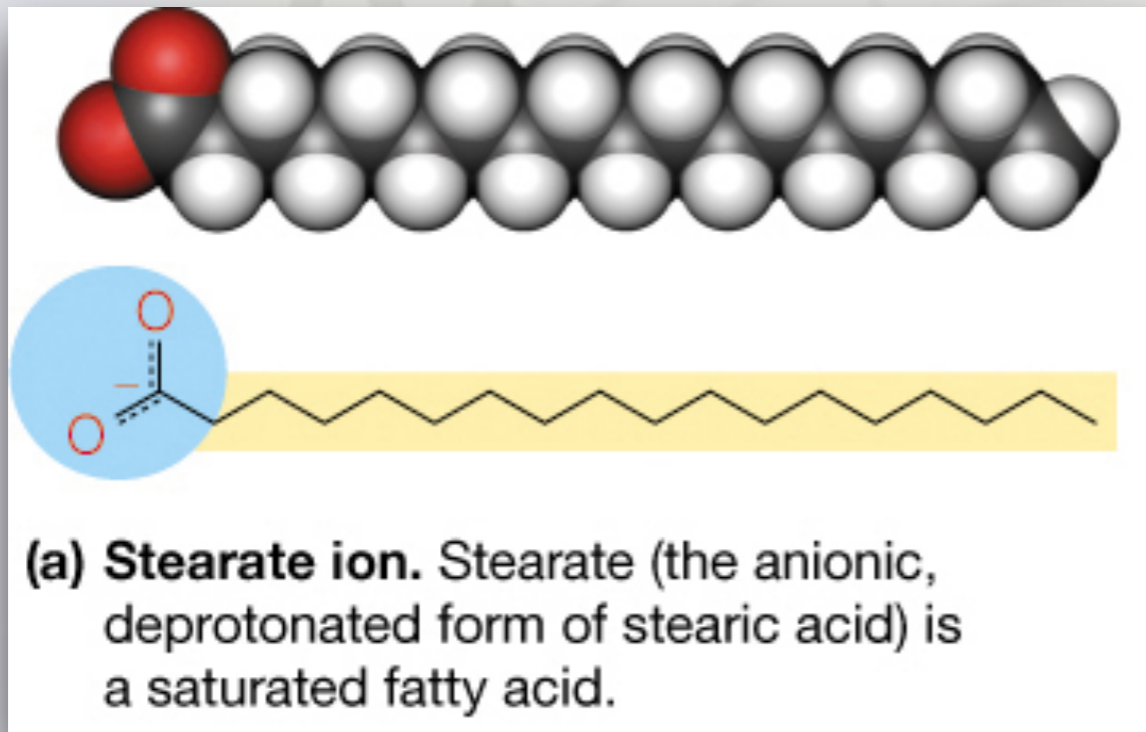
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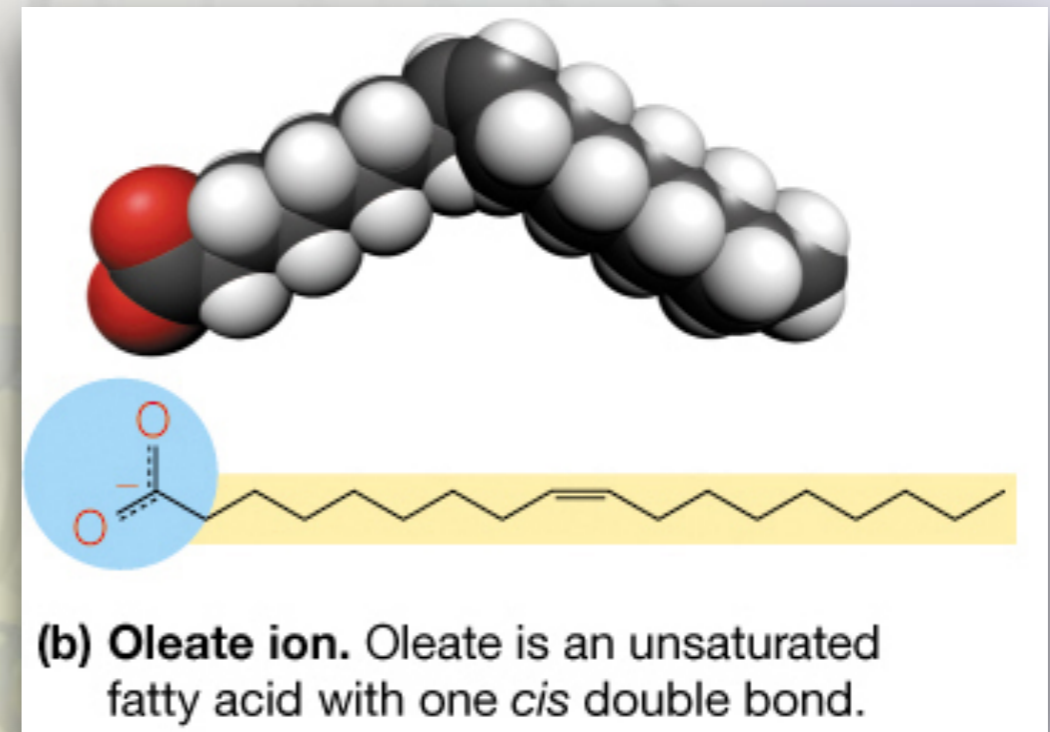
- ♦ Most naturally occurring fatty acids also contain an even number of carbon atoms:

Fatty Acids

The simplest examples are the *fatty acids*.



18:0



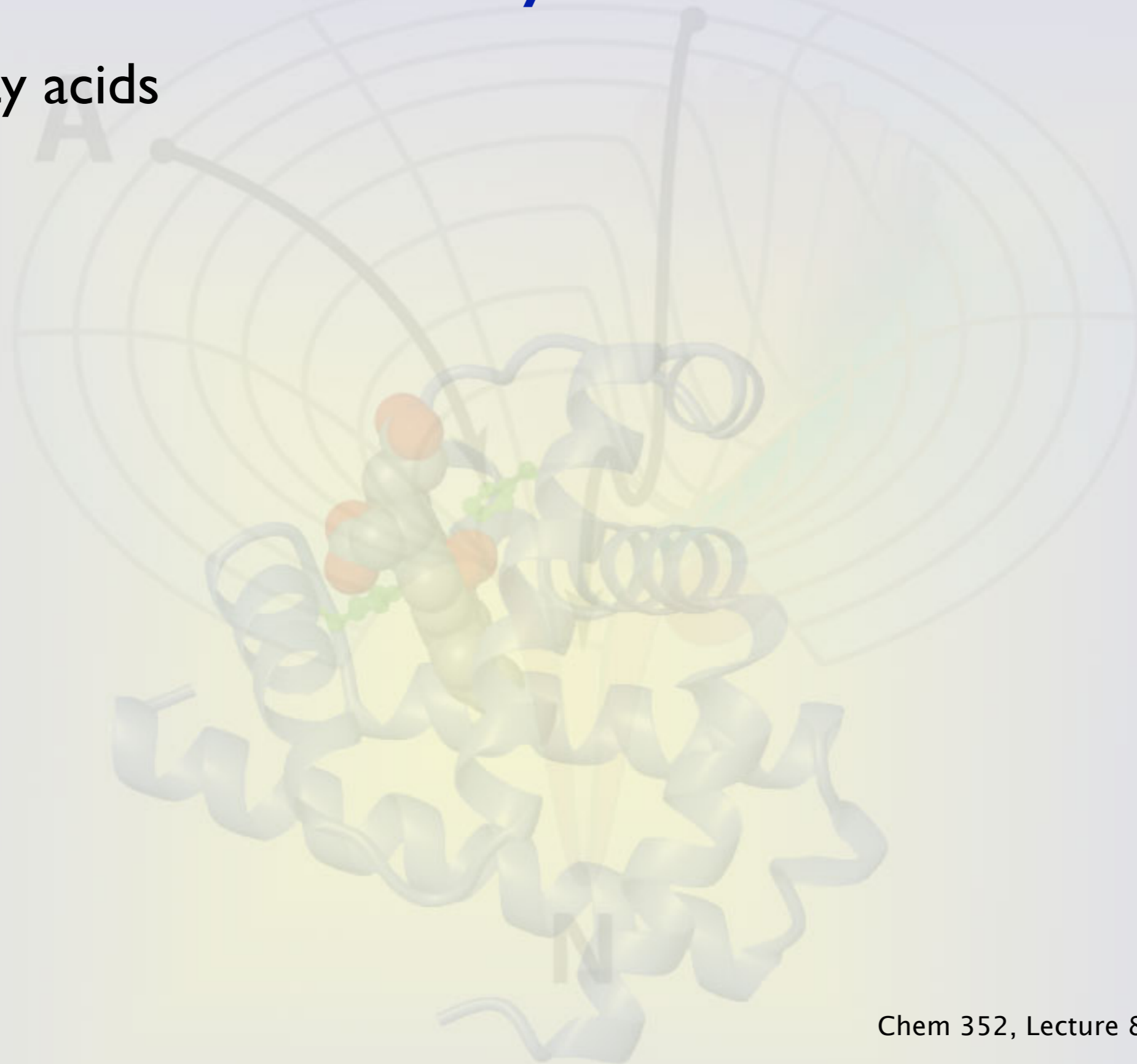
18:1c Δ 9

- ♦ Most naturally occurring fatty acids also contain an even number of carbon atoms:
- ♦ There is a shorthand convention used to indicate the number of carbon atoms, the number of double bonds and their locations.

number of carbon atoms : number of double bonds c Δ location of double bonds

Fatty Acids

Fatty acids



Fatty Acids

Fatty acids

TABLE 10.1 Some biologically important fatty acids

Common Name	Systematic Name	Abbreviation	Structure	Melting Point (°C)
Saturated Fatty Acids				
Capric acid	Decanoic acid	10:0	CH ₃ (CH ₂) ₈ COOH	31.6
Lauric acid	Dodecanoic acid	12:0	CH ₃ (CH ₂) ₁₀ COOH	44.2
Myristic acid	Tetradecanoic acid	14:0	CH ₃ (CH ₂) ₁₂ COOH	53.9
Palmitic acid	Hexadecanoic acid	16:0	CH ₃ (CH ₂) ₁₄ COOH	63.1
Stearic acid	Octadecanoic acid	18:0	CH ₃ (CH ₂) ₁₆ COOH	69.6
Arachidic acid	Eicosanoic acid	20:0	CH ₃ (CH ₂) ₁₈ COOH	76.5
Behenic acid	Docosanoic acid	22:0	CH ₃ (CH ₂) ₂₀ COOH	81.5
Lignoceric acid	Tetracosanoic acid	24:0	CH ₃ (CH ₂) ₂₂ COOH	86.0
Cerotic acid	Hexacosanoic acid	26:0	CH ₃ (CH ₂) ₂₄ COOH	88.5
Unsaturated Fatty Acids				
Palmitoleic acid	<i>cis</i> -9-Hexadecenoic acid	16:1cΔ9	CH ₃ (CH ₂) ₅ CH=CH(CH ₂) ₇ COOH	0
Oleic acid	<i>cis</i> -9-Octadecenoic acid	18:1cΔ9	CH ₃ (CH ₂) ₇ CH=CH(CH ₂) ₇ COOH	16
Linoleic acid	<i>cis,cis</i> -9,12-Octadecenoic acid	18:2cΔ9,12	CH ₃ (CH ₂) ₄ CH=CHCH ₂ CH=CH(CH ₂) ₇ COOH	5
Linolenic acid	all- <i>cis</i> -9,12,15-Octadecenoic acid	18:3cΔ9,12,15	CH ₃ CH ₂ CH=CHCH ₂ CH=CHCH ₂ CH=CH(CH ₂) ₇ COOH	-11
Arachidonic acid	all- <i>cis</i> -5,8,11,14-Eicosatetraenoic acid	20:4cΔ5,8,11,14	CH ₃ (CH ₂) ₄ CH=CHCH ₂ CH=CHCH ₂ CH=CHCH ₂ CH=CH(CH ₂) ₃ COOH	-50

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Unsaturated Fatty Acids				
Palmitoleic acid	<i>cis</i> -9-Hexadecenoic acid		$\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$	0
Oleic acid	<i>cis</i> -9-Octadecenoic acid	18:1cΔ9	$\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$	16
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Linolenic acid	all- <i>cis</i> -9,12,15-Octadecenoic acid	18:3c	$\text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}_2\text{CH}=\text{CHCH}_2\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$	-11
Arachidonic acid	all- <i>cis</i> -5,8,11,14-Eicosatetraenoic acid	20:4cΔ5,8,11,14	$\text{CH}_3(\text{CH}_2)_4\text{CH}=\text{CHCH}_2\text{CH}=\text{CHCH}_2\text{CH}=\text{CHCH}_2\text{CH}=\text{CH}(\text{CH}_2)_3\text{COOH}$	-50

Observe the dramatic effect that the presence of *cis*-double bonds has on the melting points.

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Linolenic acid	all- <i>cis</i> -9,12,15-Octadecenoic acid	18:3cΔ9,12,15	$\text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}_2\text{CH}=\text{CHCH}_2\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$	-11
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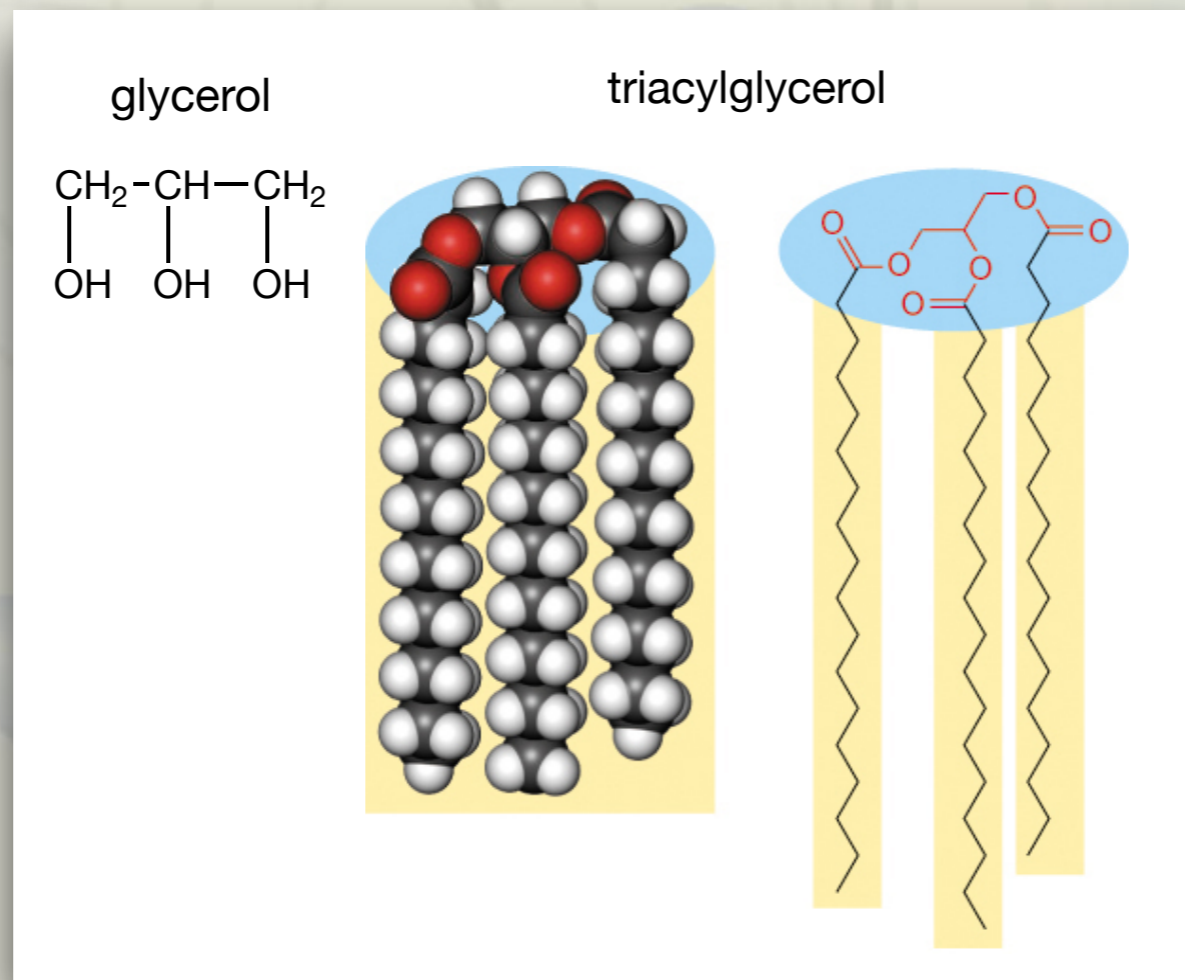
Triacylglycerols



Triacylglycerols

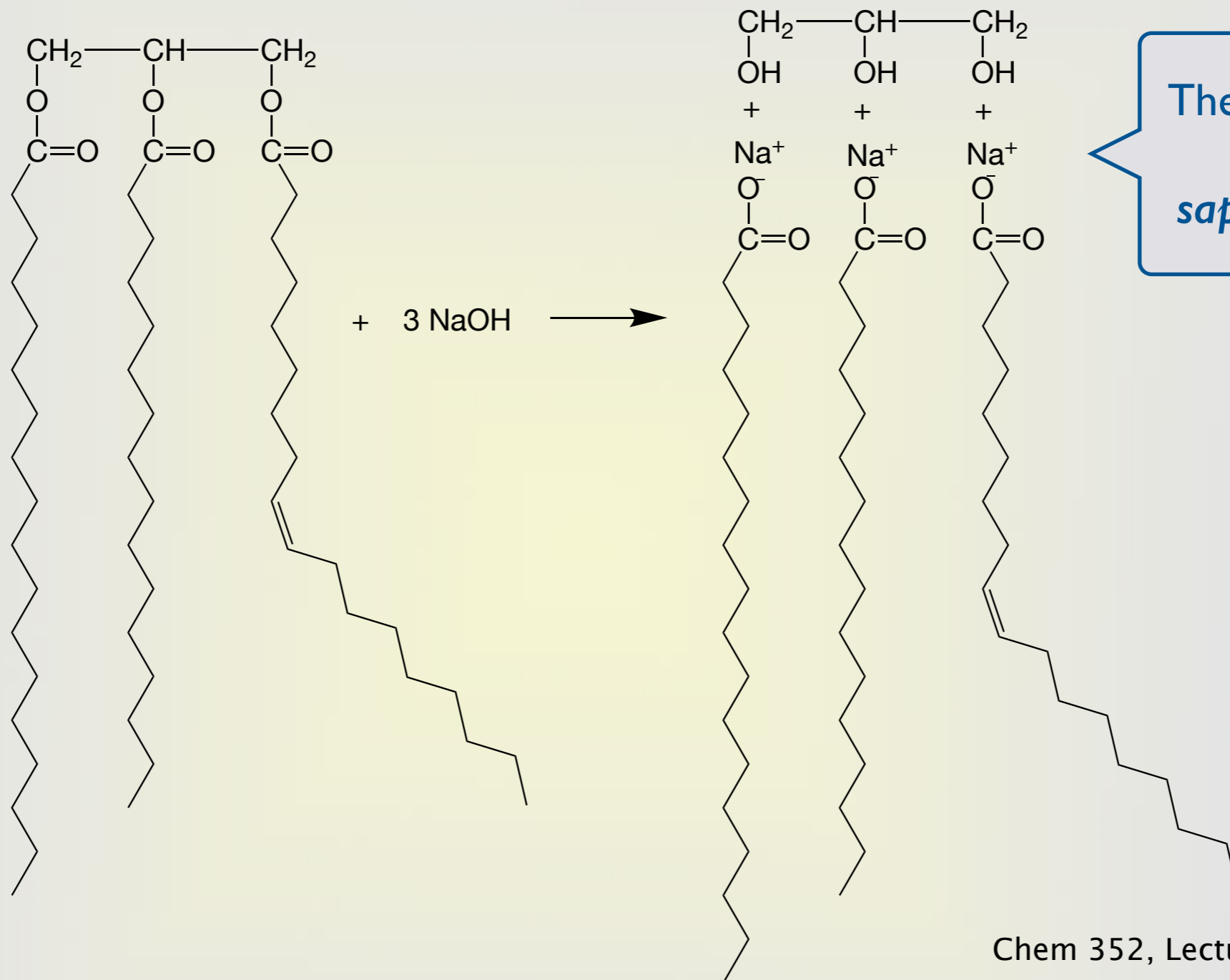
Fatty acids are used by many organisms to store metabolic energy.

- ♦ In this capacity, three fatty acids are combined with a glycerol molecule through esterification to produce *triacylglycerols*.



They are commonly referred to as *fats* and *oils*

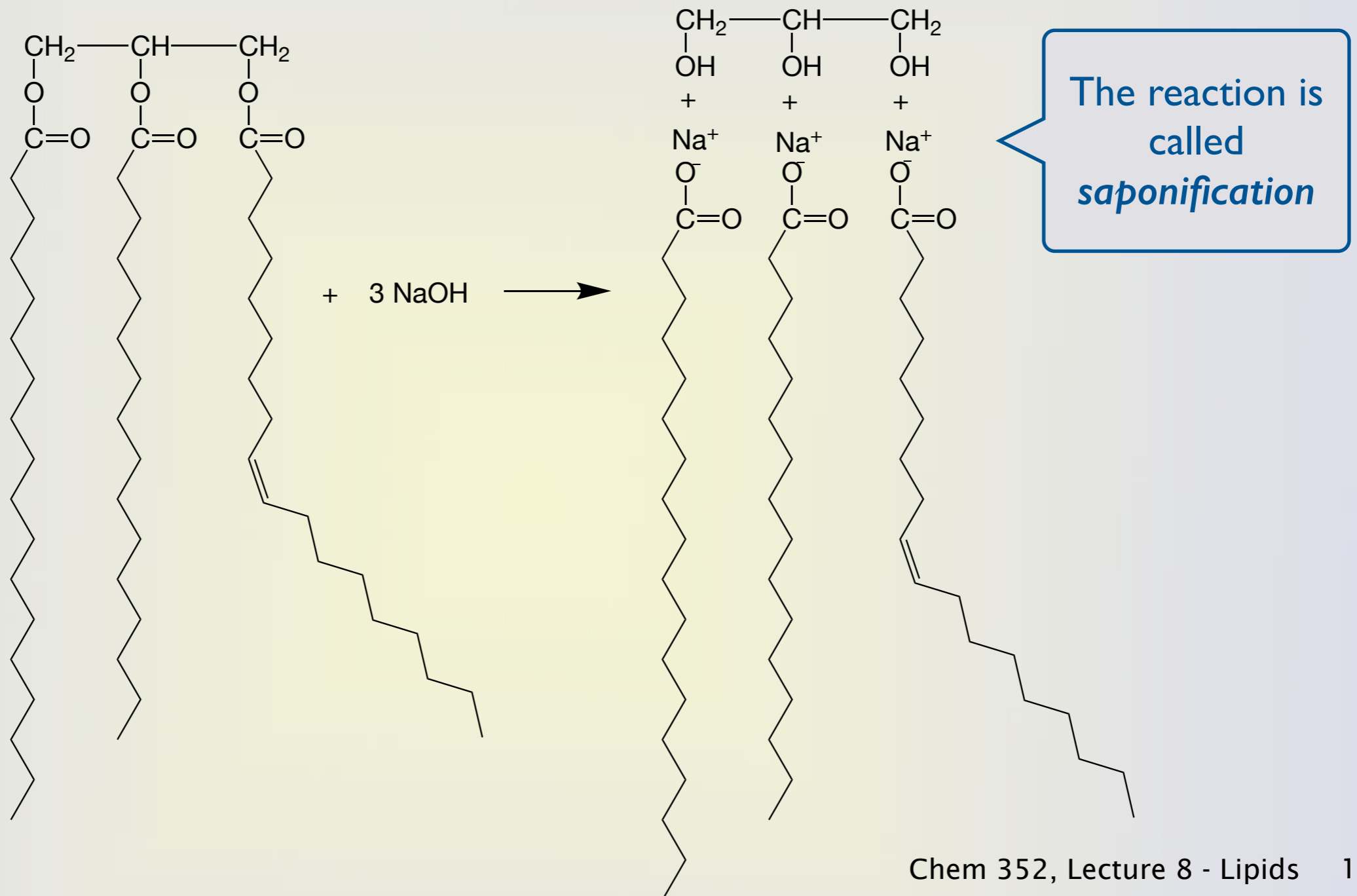
Triacylglycerols



The reaction is called *saponification*

Triacylglycerols

Soaps are produced from fats and oils by hydrolyzing the esters with a strong base, such as NaOH or KOH.



Triacylglycerols

Triacylglycerols

The fatty acid composition of a triacylglycerol determines whether they are solids (fats) or liquids (oils).

TABLE 10.2 Composition of some natural fats in percent of total fatty acids

Number of C Atoms in Chain	Percent Present in:		
	Olive Oil	Butter ^a	Beef Fat
Saturated			
4-12	2	11	2
14	2	10	2
16	13	26	29
18	3	11	21
Unsaturated			
16-18	80	40	46

^aNumbers do not total 100% because the substance contains small amounts of other fatty acids.

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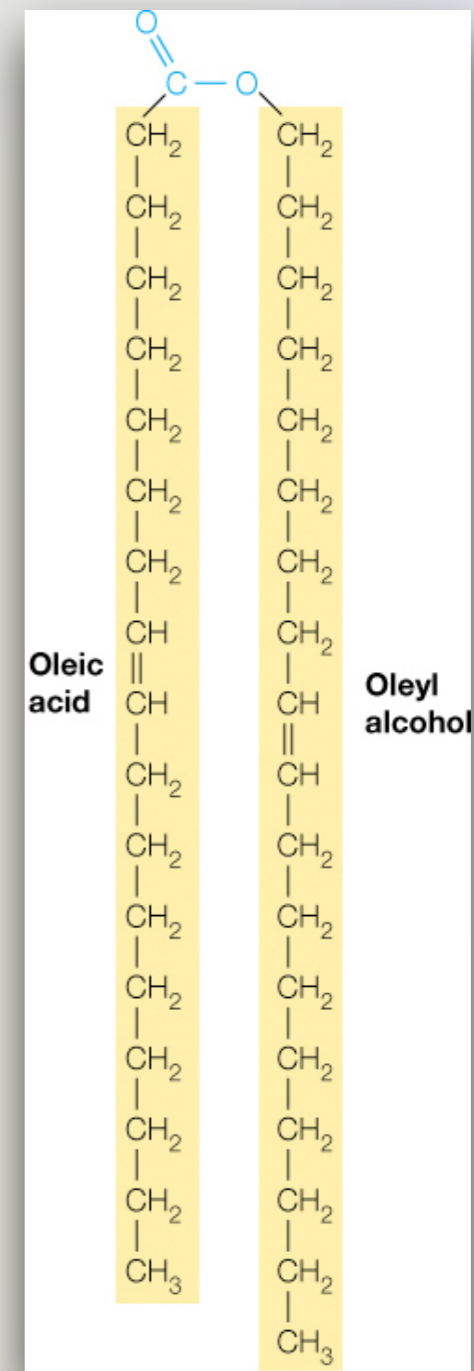
- ✦ A hydrogenation reaction can be used to convert liquid plant oils into “spreadable” plant oils.
- ✦ In addition to saturating unsaturated fatty acids, the reaction can also isomerize *cis* double bonds to *trans* double bonds to produce trans fatty acids.

Waxes

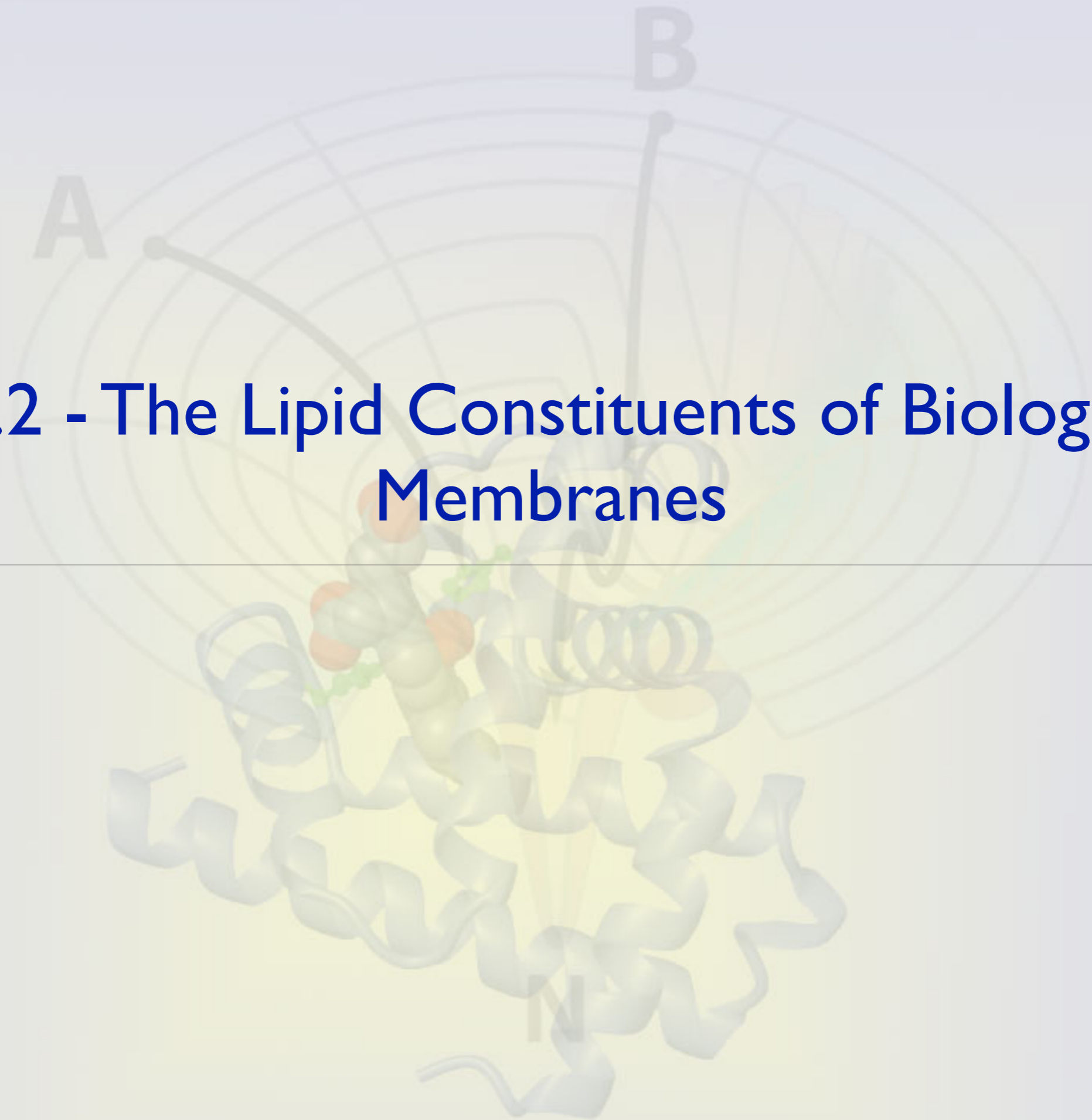
Waxes

Waxes are made by esterification of fatty acids with long chain alcohol.

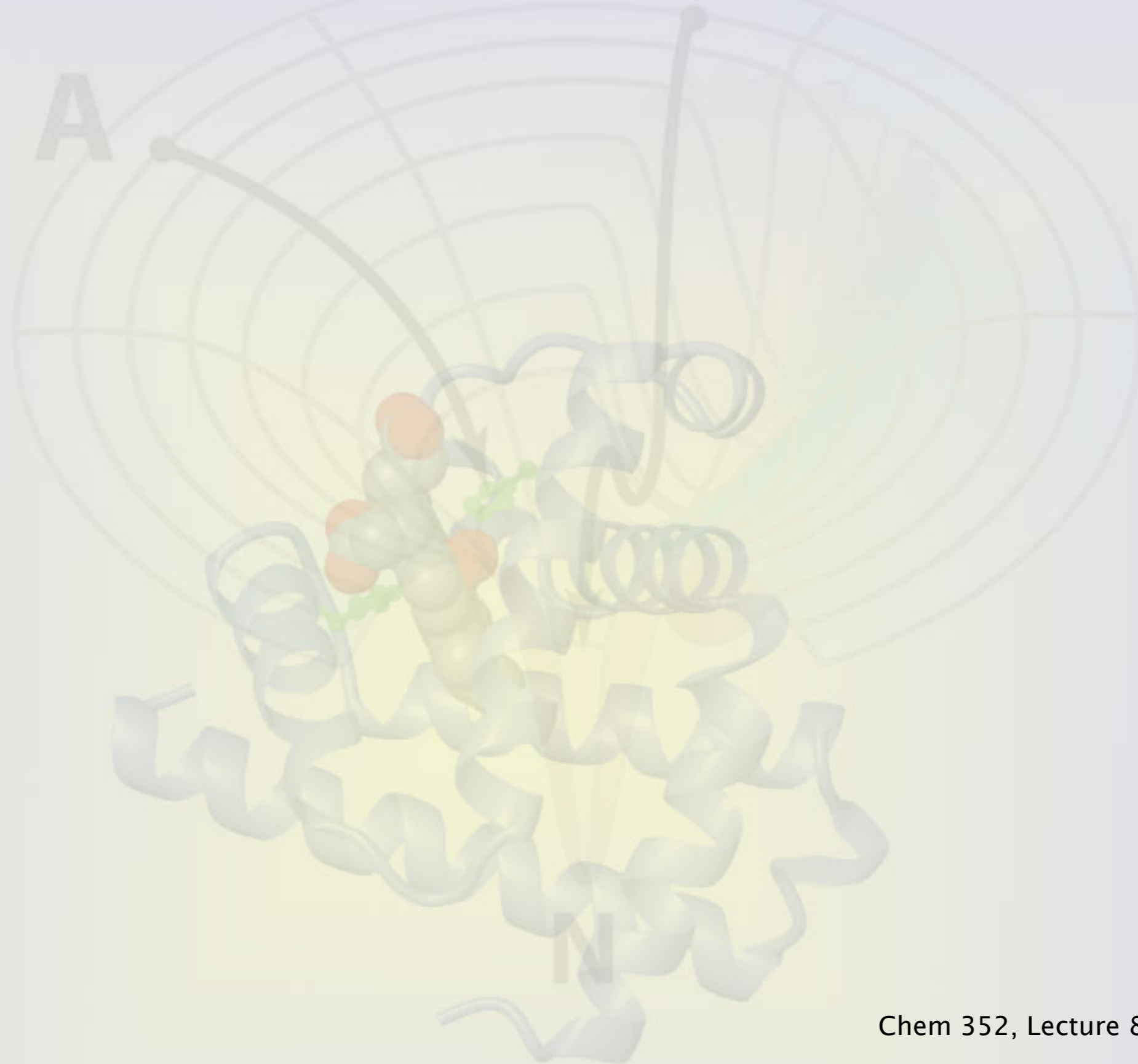
- ♦ They are used by some plants and animals as water repellents.



10.2 - The Lipid Constituents of Biological Membranes

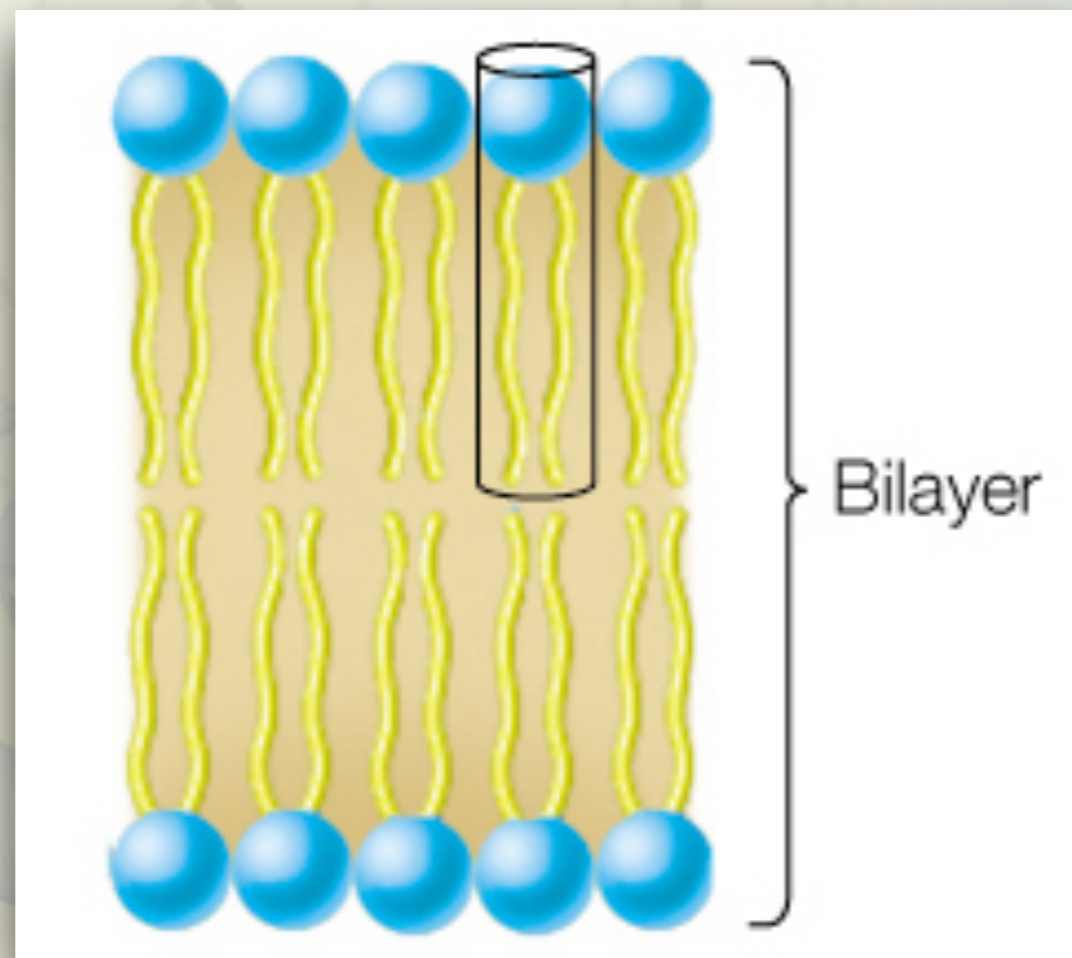


Lipid Constituents of Biological Membranes



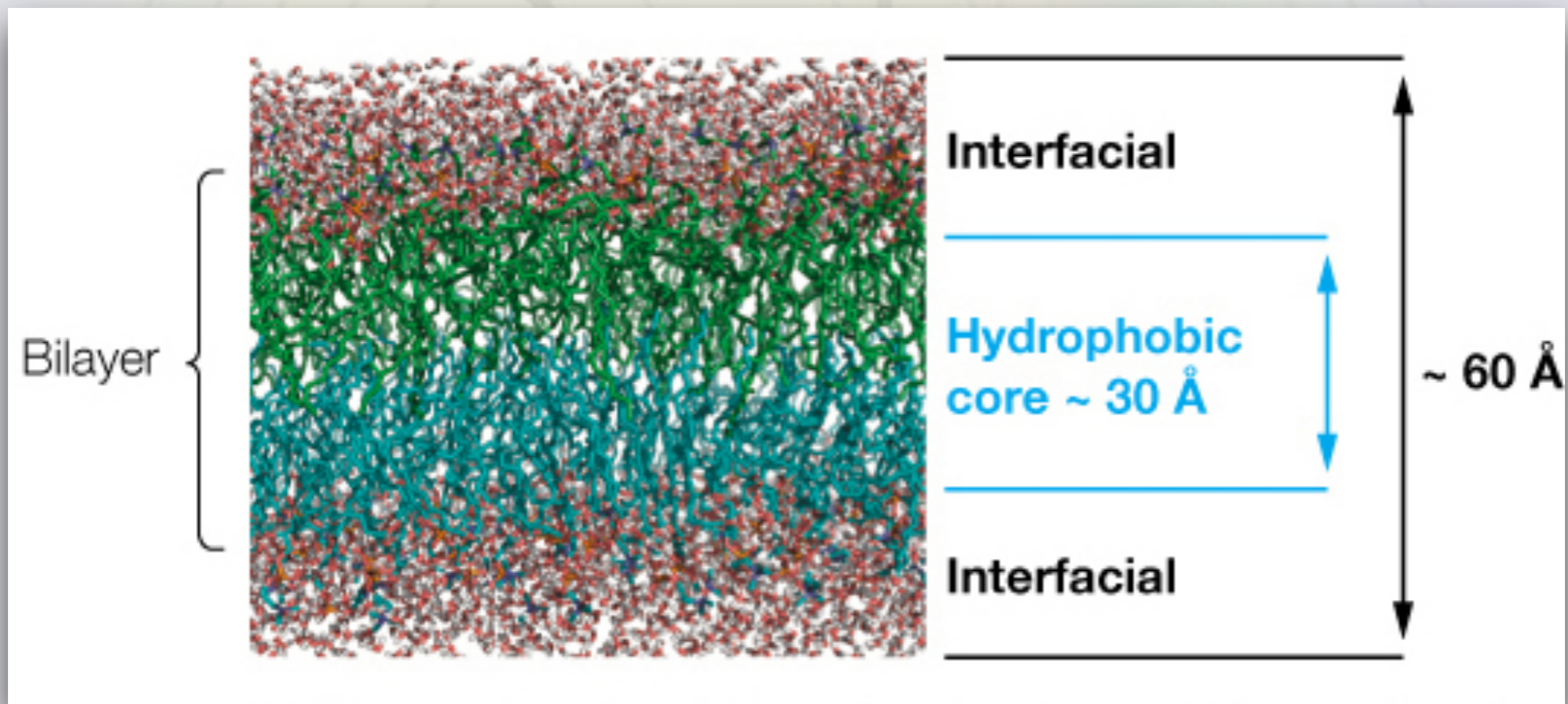
Lipid Constituents of Biological Membranes

Biological membranes are made from lipids that form *lipid bilayers* in the presence of water.



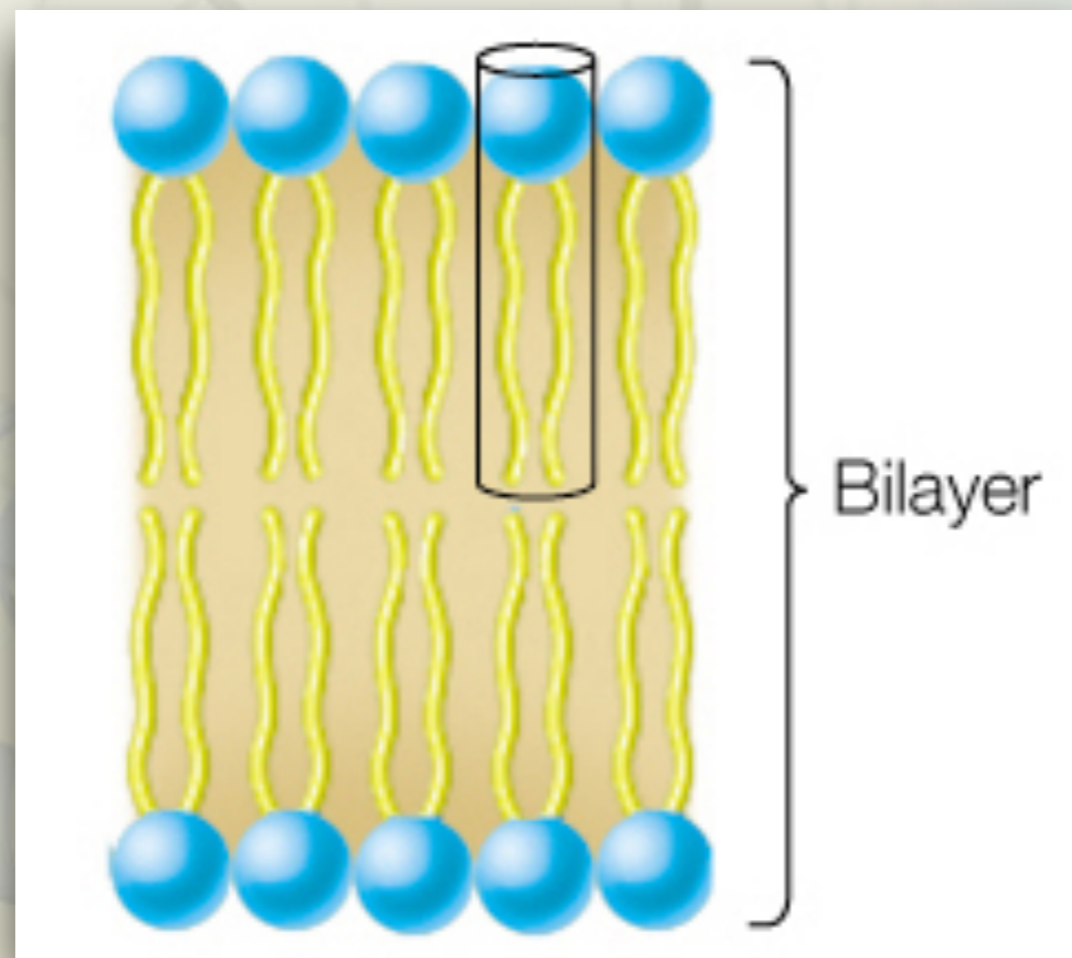
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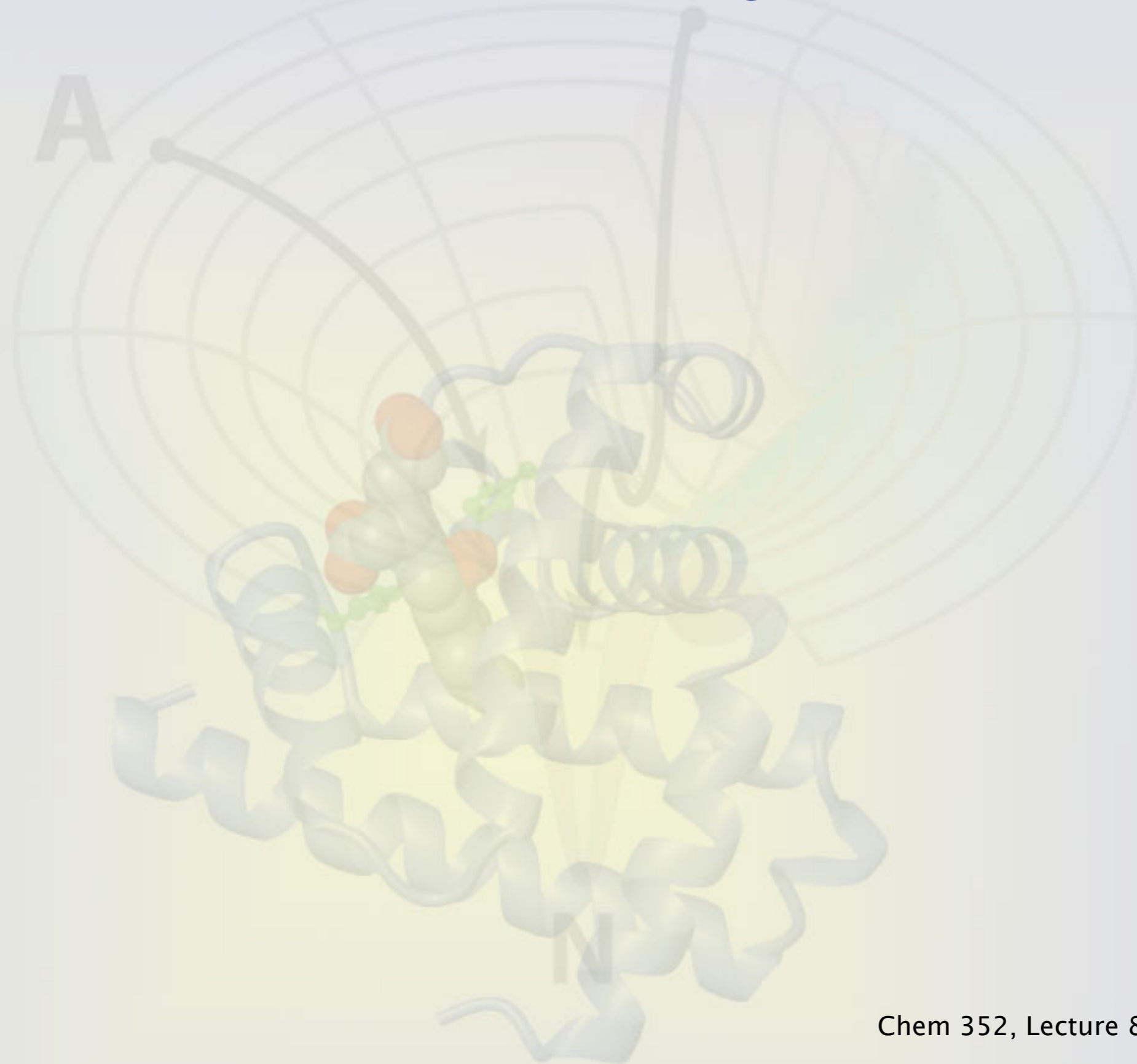


Lipid Constituents of Biological Membranes

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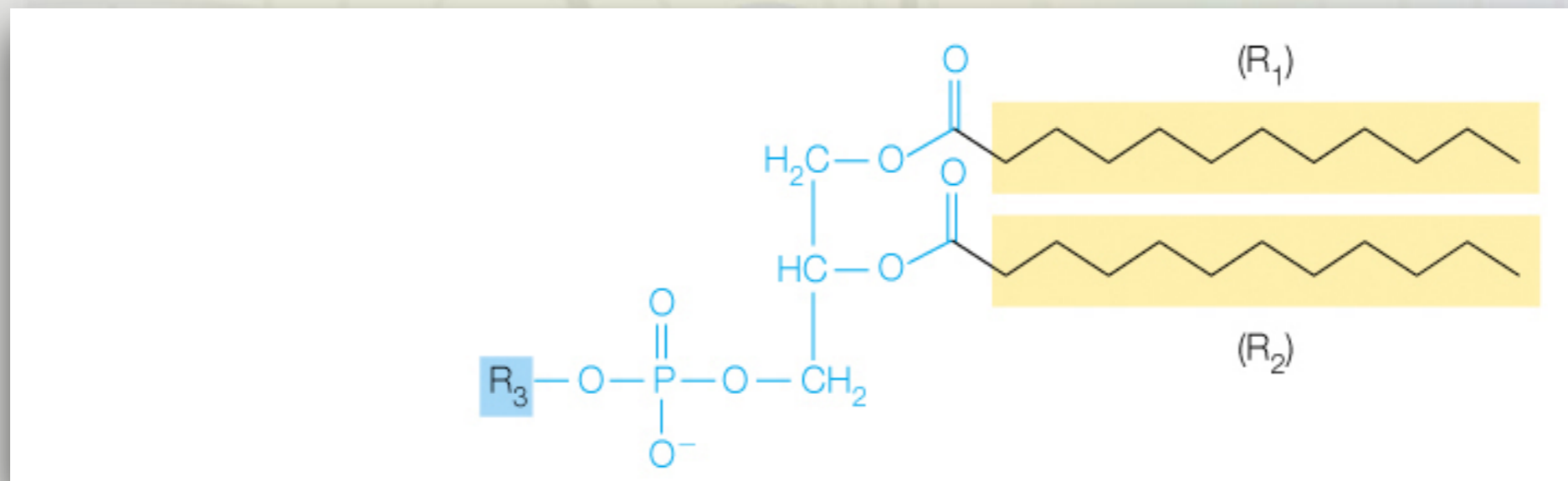


Lipid Constituents of Biological Membranes



Lipid Constituents of Biological Membranes

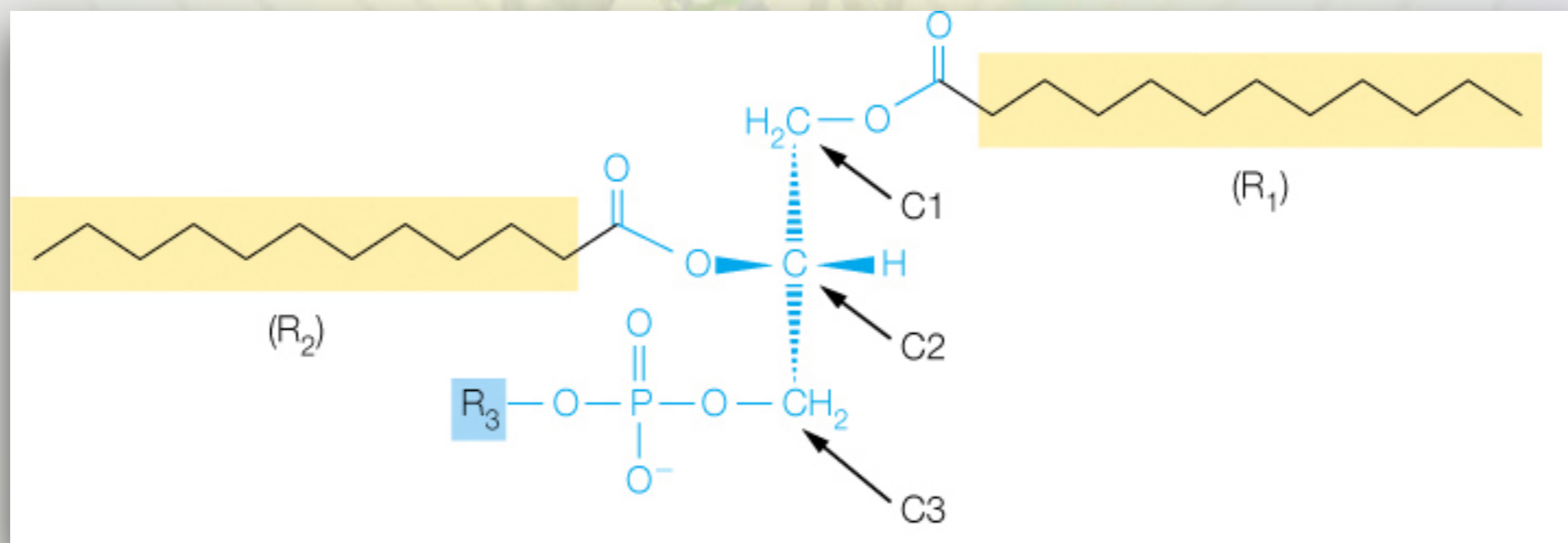
One type of membrane-forming lipid are the *phospholipids*, in which one of the fatty acid esters in a triacylglycerol has been substituted with a phosphate ester.



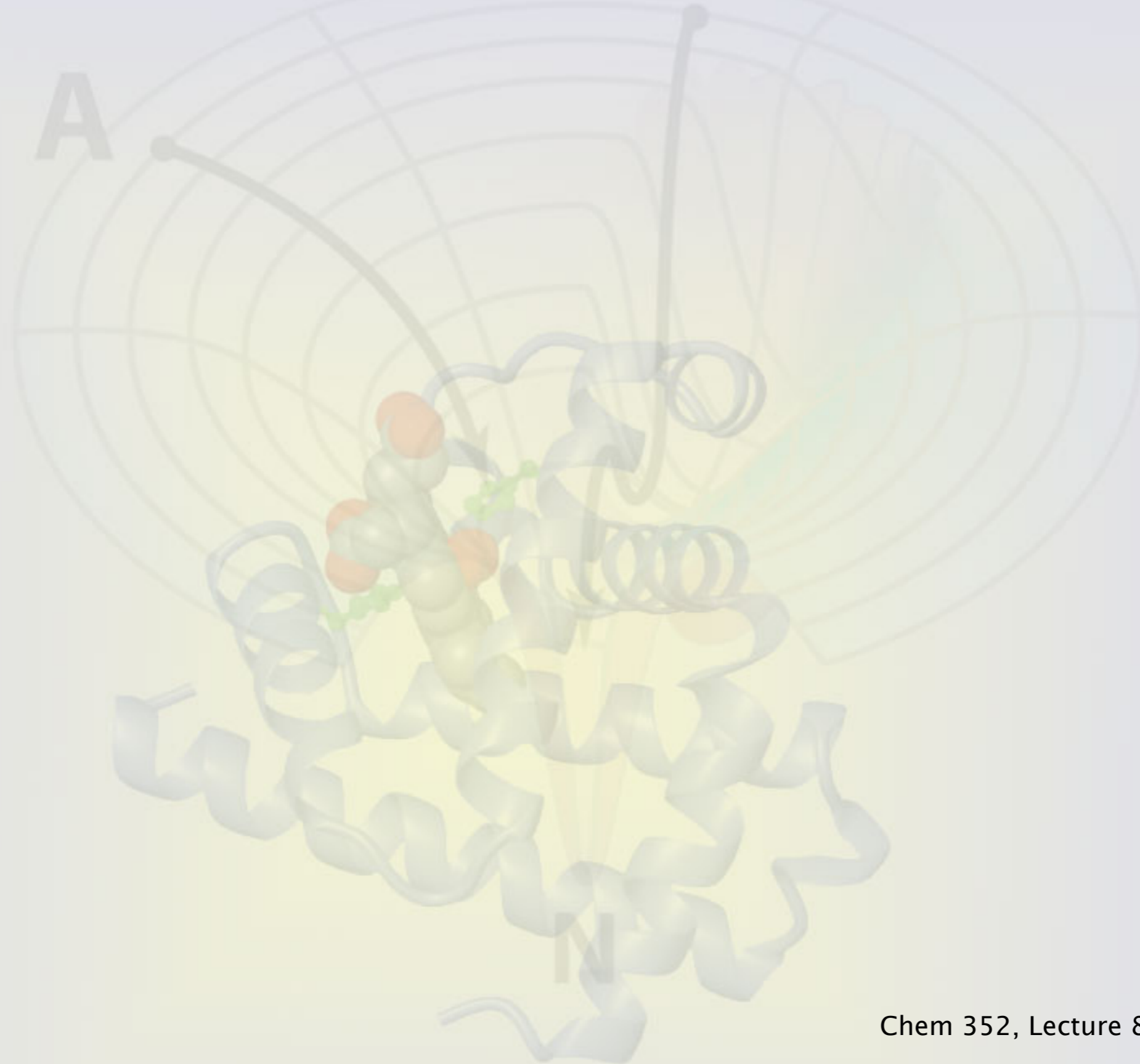
Lipid Constituents of Biological Membranes

One type of membrane-forming lipid are the *phospholipids*, in which one of the fatty acid esters in a triacylglycerol has been substituted with a phosphate ester.

- ✦ This substitution produces a chiral carbon.



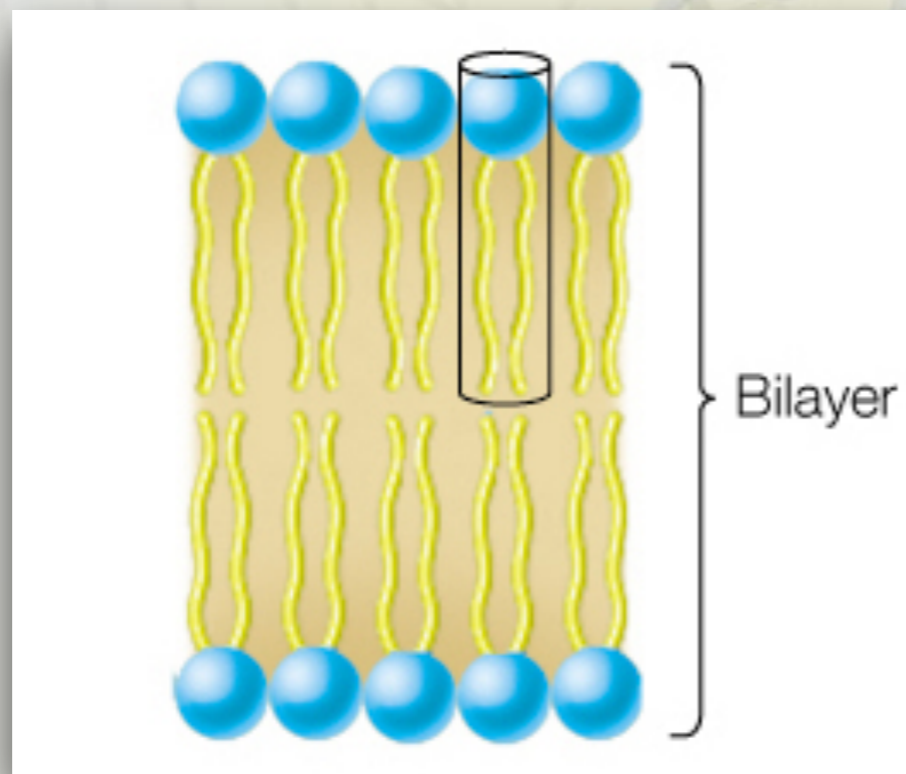
Lipid Constituents of Biological Membranes



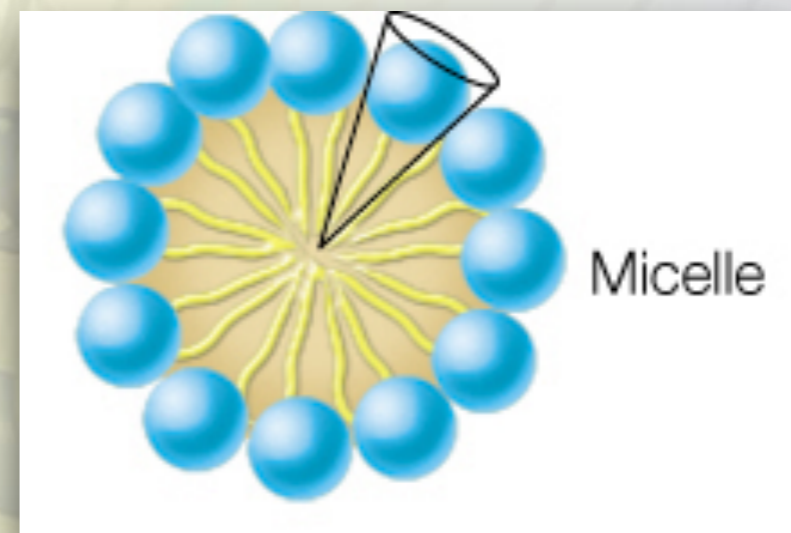
Lipid Constituents of Biological Membranes

Phospholipids have a more cylindrical shape than single fatty acids, which are more wedged-shaped.

- ✦ This is why, when placed in water, they produce lipid bilayers instead of micelles as soaps do.

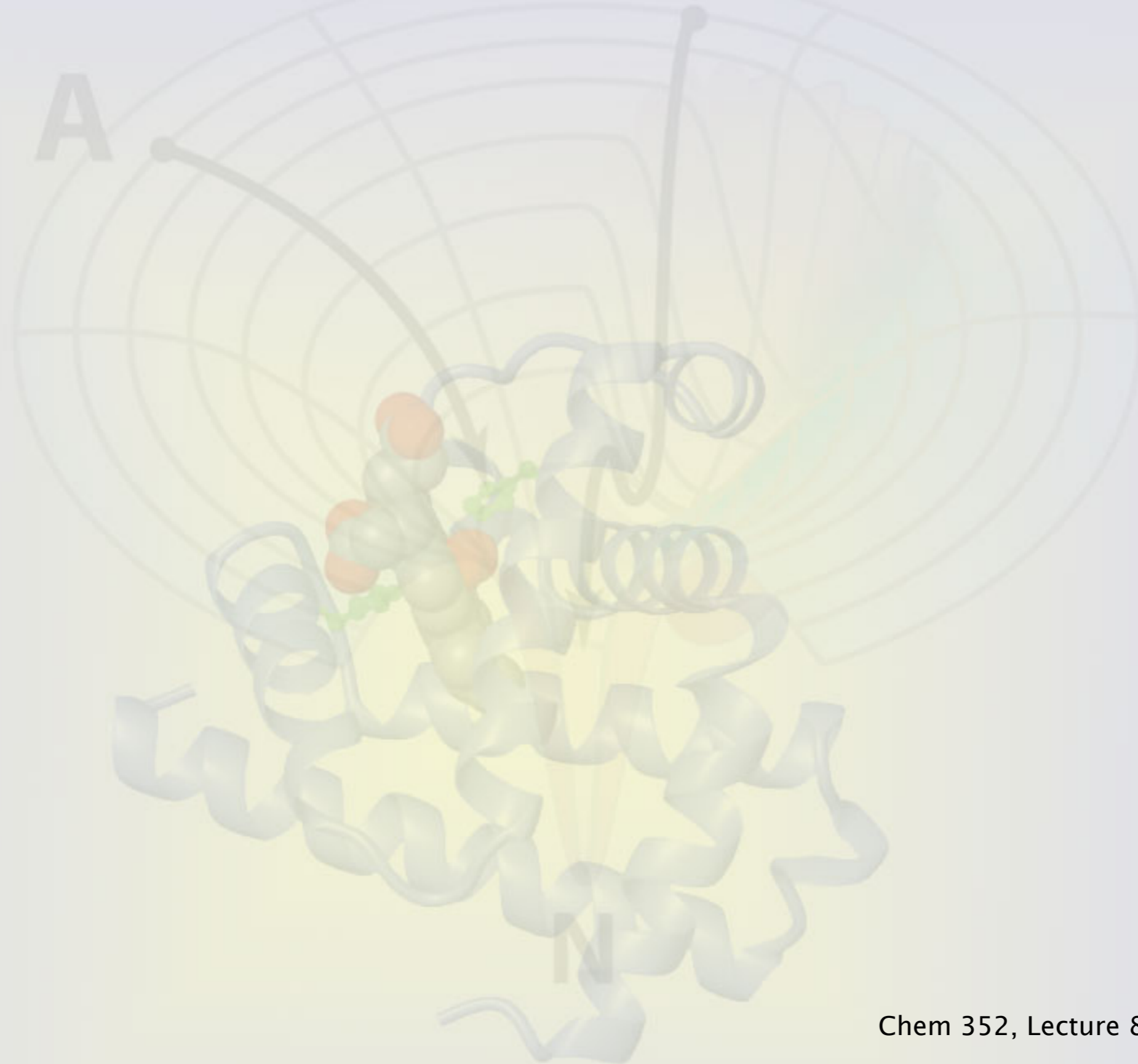


Phospholipids form bilayers



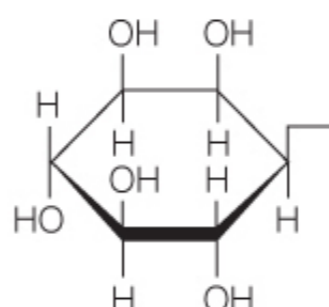
Whereas, soaps form micelles

Lipid Constituents of Biological Membranes



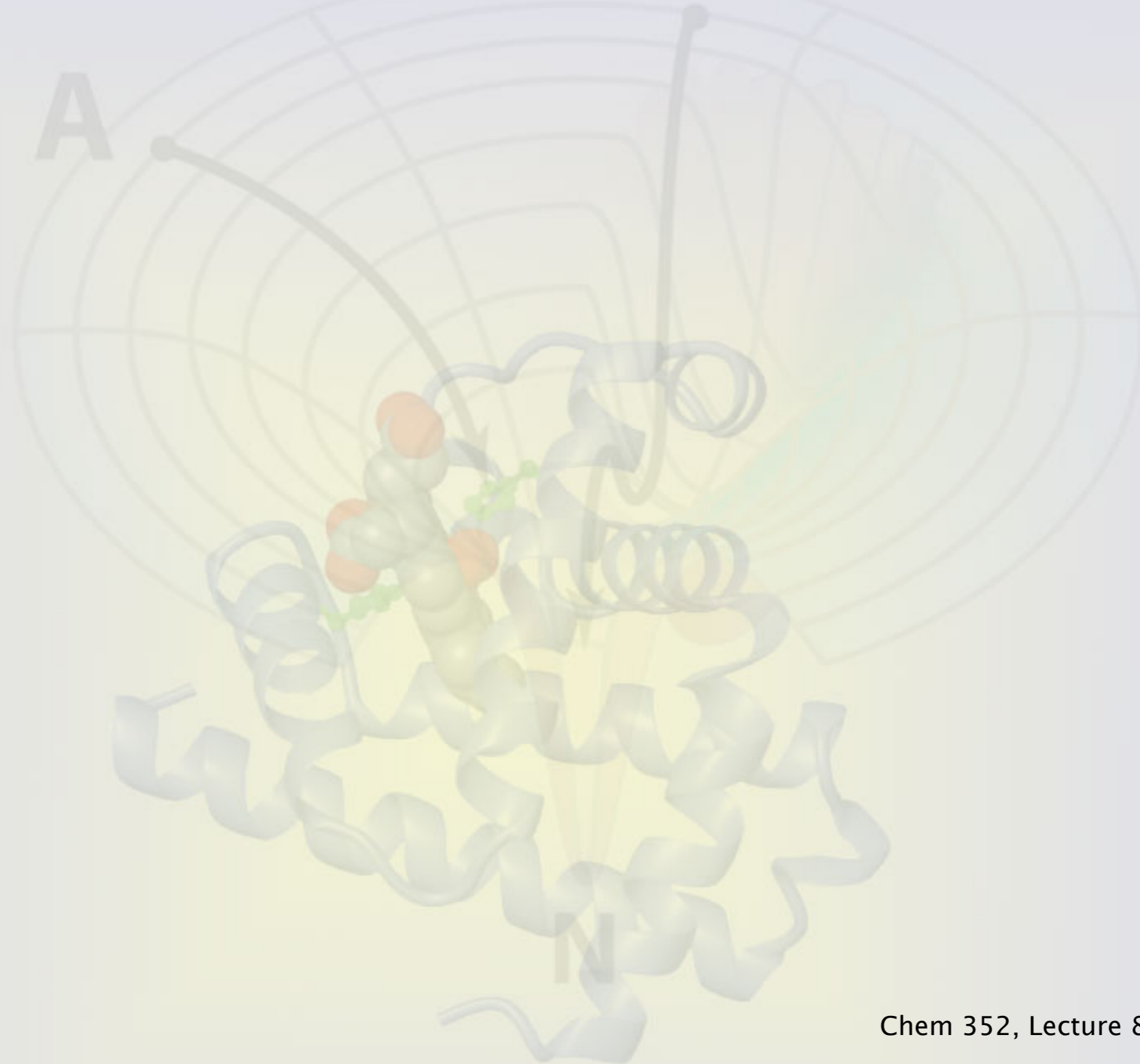
Lipid Constituents of Biological Membranes

The phosphate in phospholipids can form a phosphodiester link to a number of hydrophilic substituents.

TABLE 10.3 The hydrophilic groups ^a that distinguish common glycerophospholipids	
Name of Glycerophospholipid	R ₃ (in Figure 10.6)
Phosphatidic acid	H— (ionized at neutral pH)
Phosphatidylethanolamine (PE)	H ₃ N ⁺ —CH ₂ —CH ₂ —
Phosphatidylcholine (PC)	(CH ₃) ₃ N ⁺ —CH ₂ —CH ₂ —
Phosphatidylserine (PS)	$\begin{array}{c} \text{H} \\ \\ \text{H}_3\text{N}^+ - \text{C} - \text{CH}_2 - \\ \\ \text{COO}^- \end{array}$
Phosphatidyl inositol (PI)	

^a These are the R₃ groups in Figure 10.6. In addition to this variation, there is also a great deal of variation in the hydrocarbon tails (R₁ and R₂ groups).

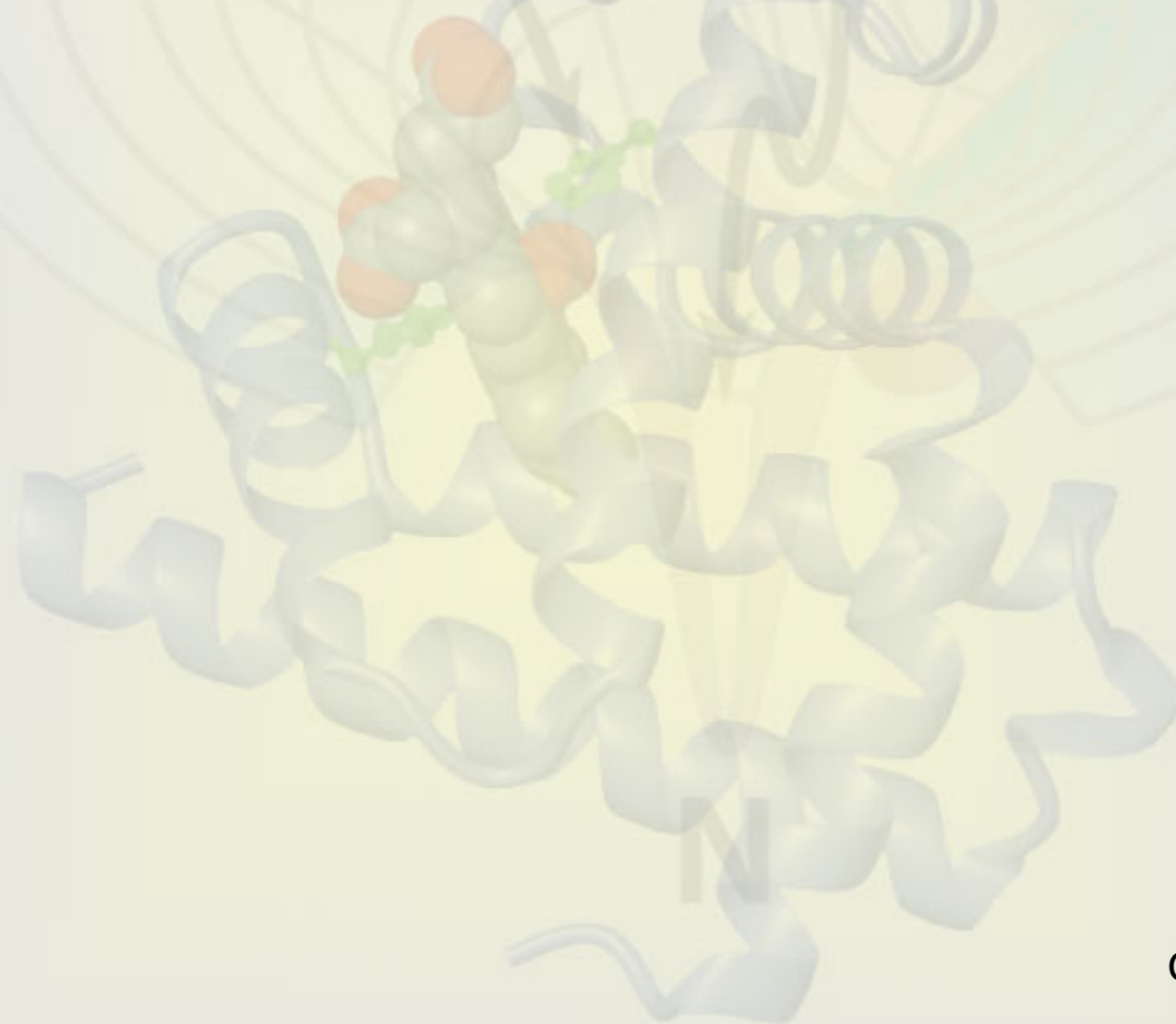
Lipid Constituents of Biological Membranes



Lipid Constituents of Biological Membranes

Other types of membrane lipids include the *sphingolipids* and *glycosphingolipids*.

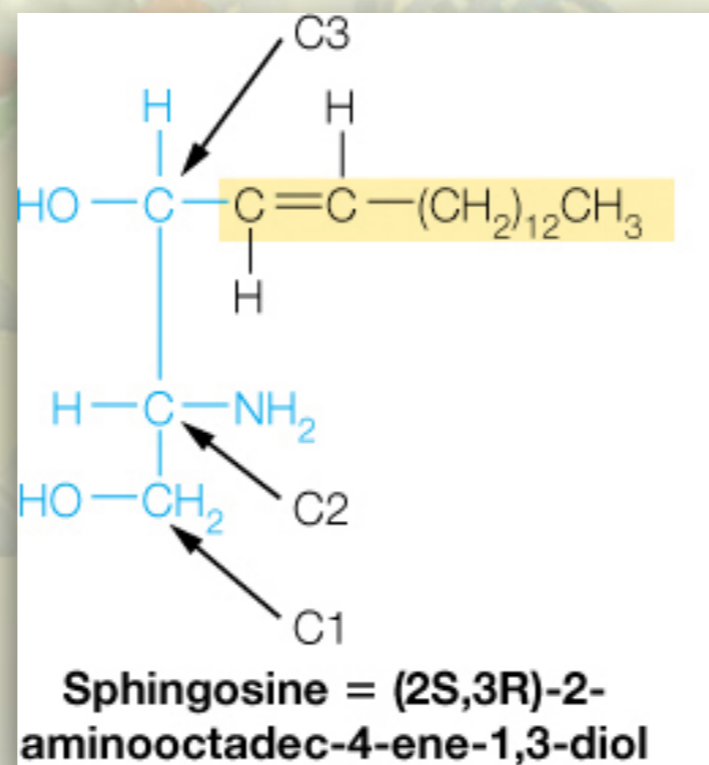
- ✦ While having different chemical structures than the phospholipids, they share similar shapes and physical properties in the presence of water.



Lipid Constituents of Biological Membranes

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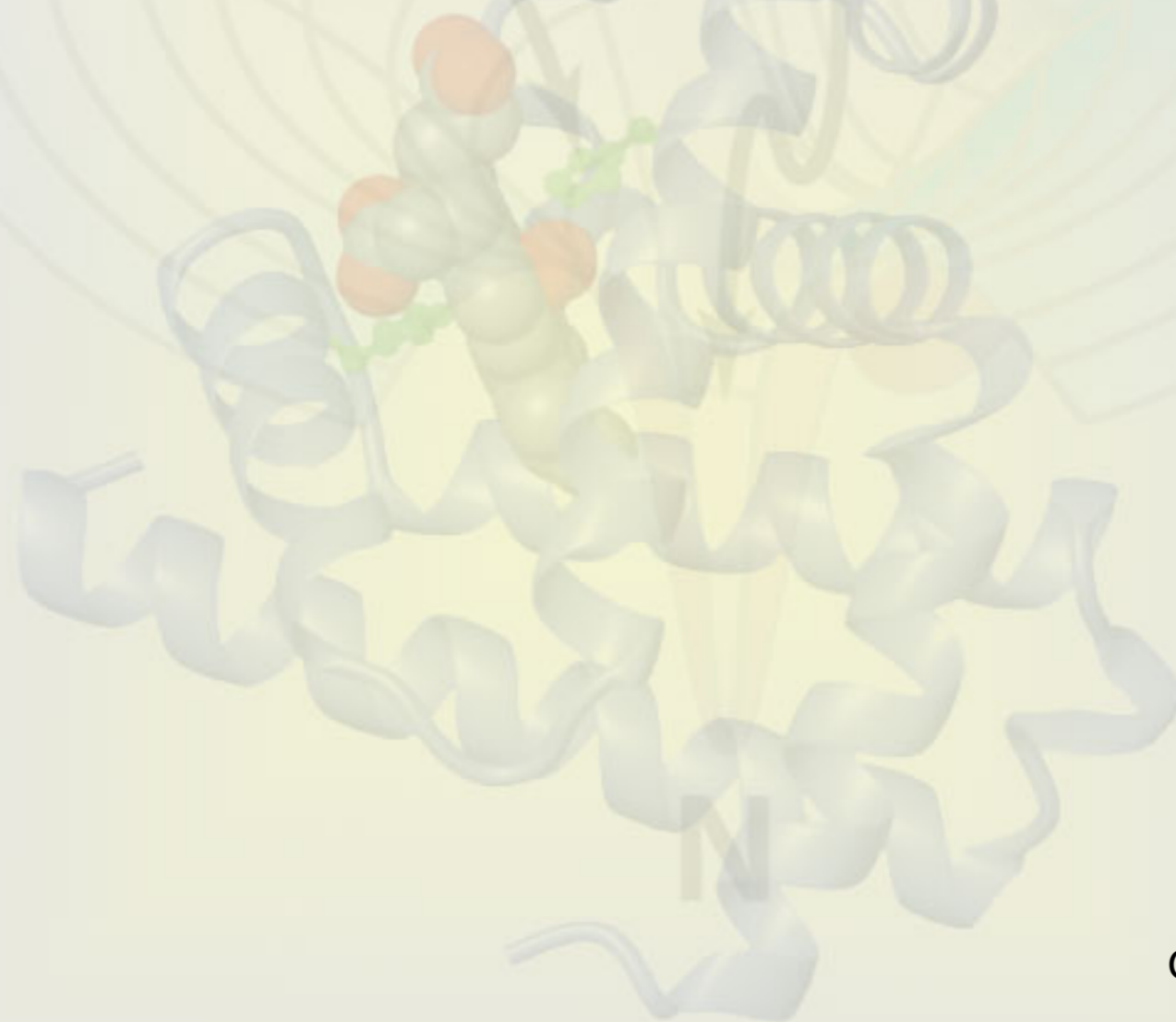
- ✦ While having different chemical structures than the phospholipids, they share similar shapes and physical properties in the presence of water.
- ✦ The core component of sphingolipids is *sphingosine*



Lipid Constituents of Biological Membranes

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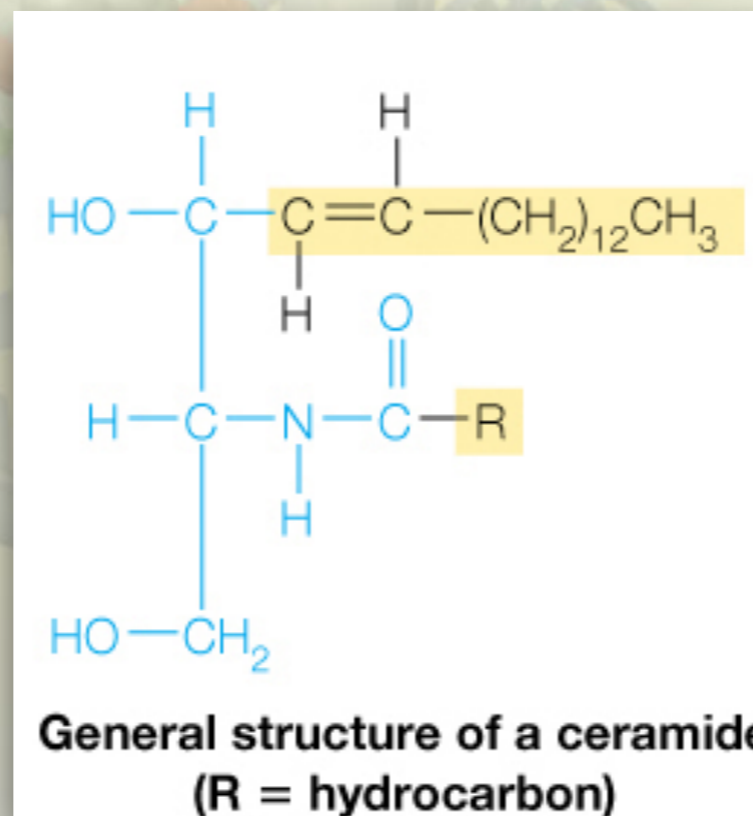
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Lipid Constituents of Biological Membranes

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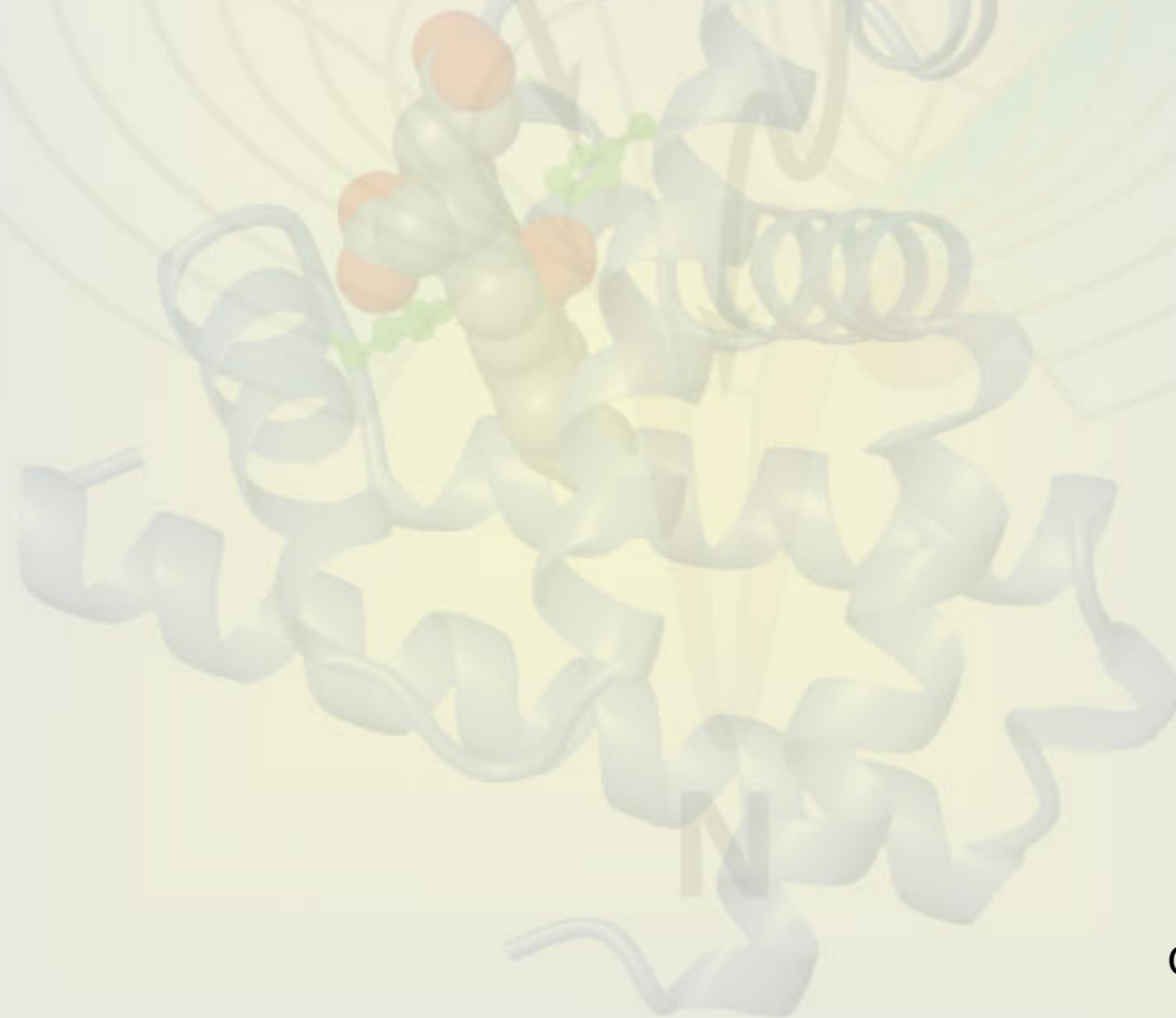
- ✦ While having different chemical structures than the phospholipids, they share similar shapes and physical properties in the presence of water.
- ✦ The addition of a fatty acid ester to sphingosine produces a ceramide.



Lipid Constituents of Biological Membranes

Other types of membrane lipids include the *sphingolipids* and *glycosphingolipids*.

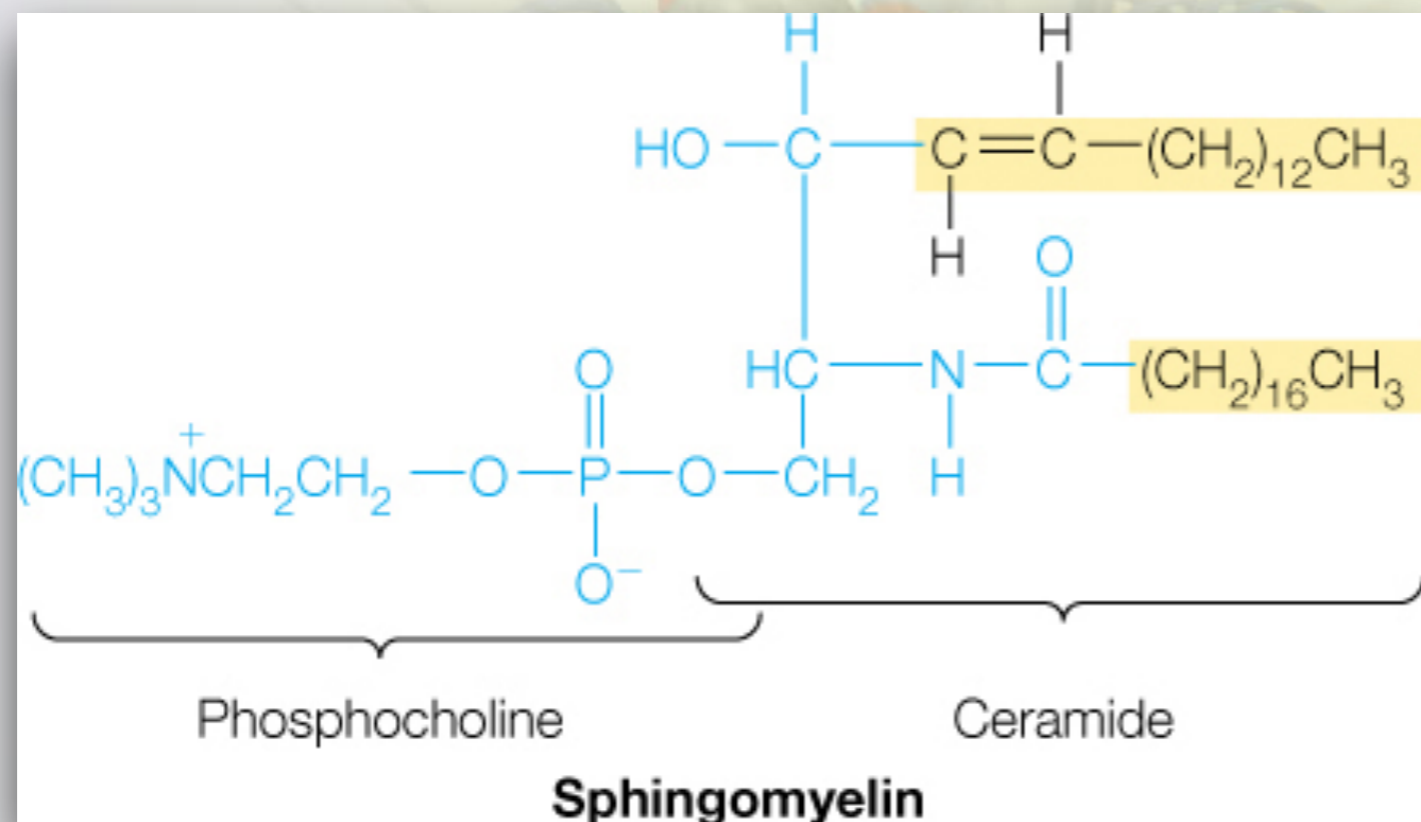
- ✦ While having different chemical structures than the phospholipids, they share similar shapes and physical properties in the presence of water.



Lipid Constituents of Biological Membranes

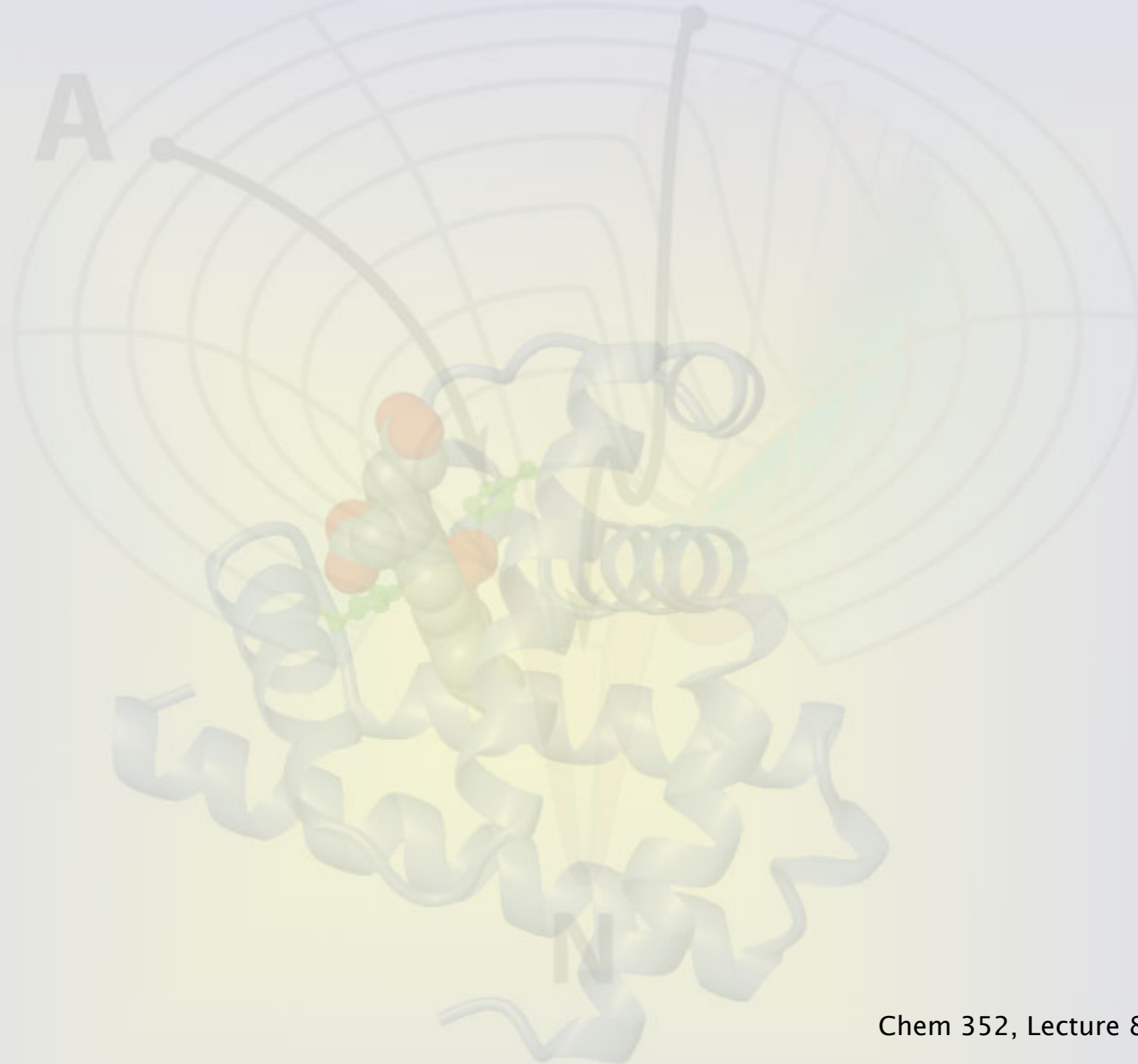
Other types of membrane lipids include the *sphingolipids* and *glycosphingolipids*.

- ✦ While having different chemical structures than the phospholipids, they share similar shapes and physical properties in the presence of water.
- ✦ Additional substituents can be added to the free hydroxyl group.



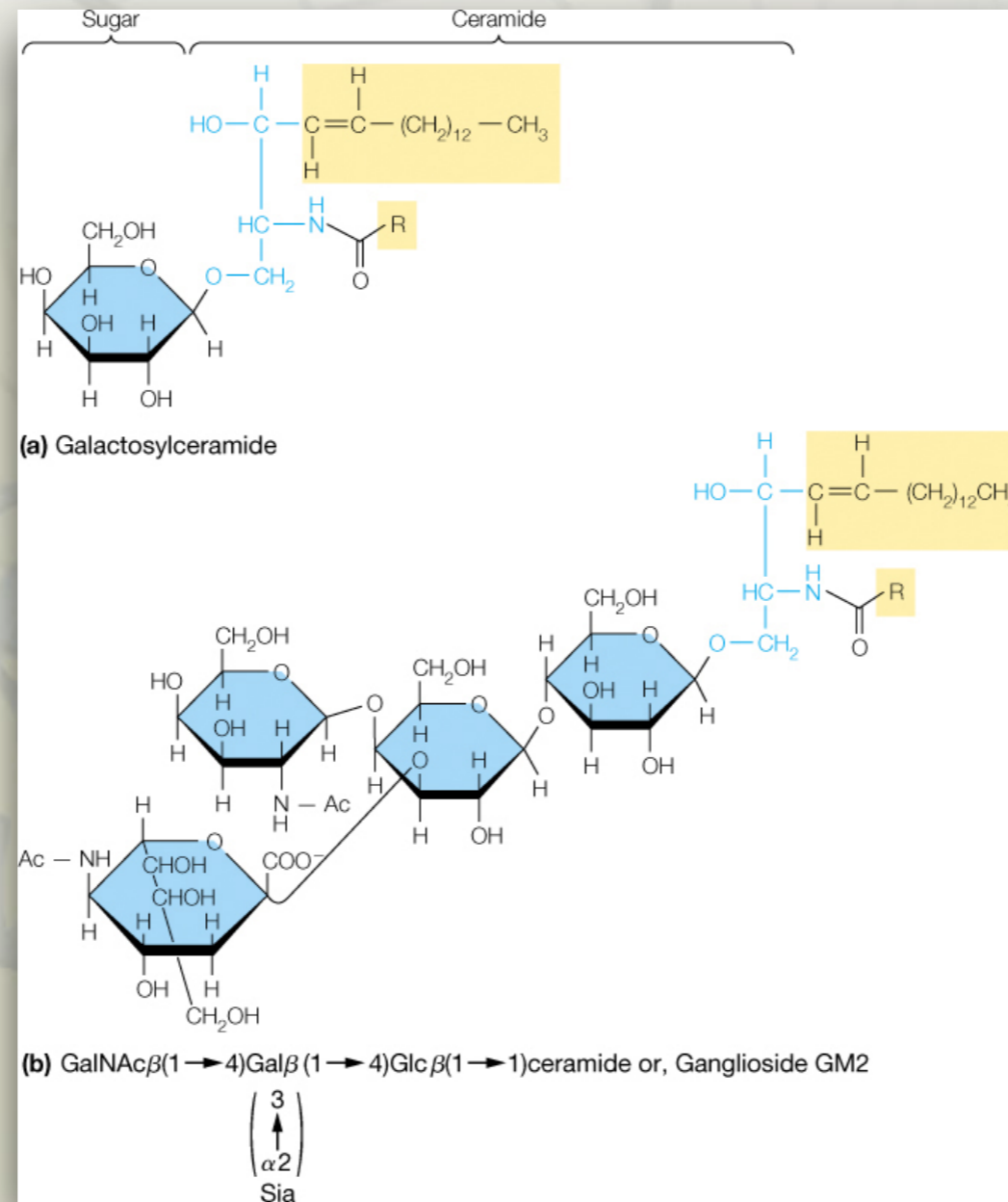
For example, the addition of a phosphocholine group produces sphingomyelin

Lipid Constituents of Biological Membranes

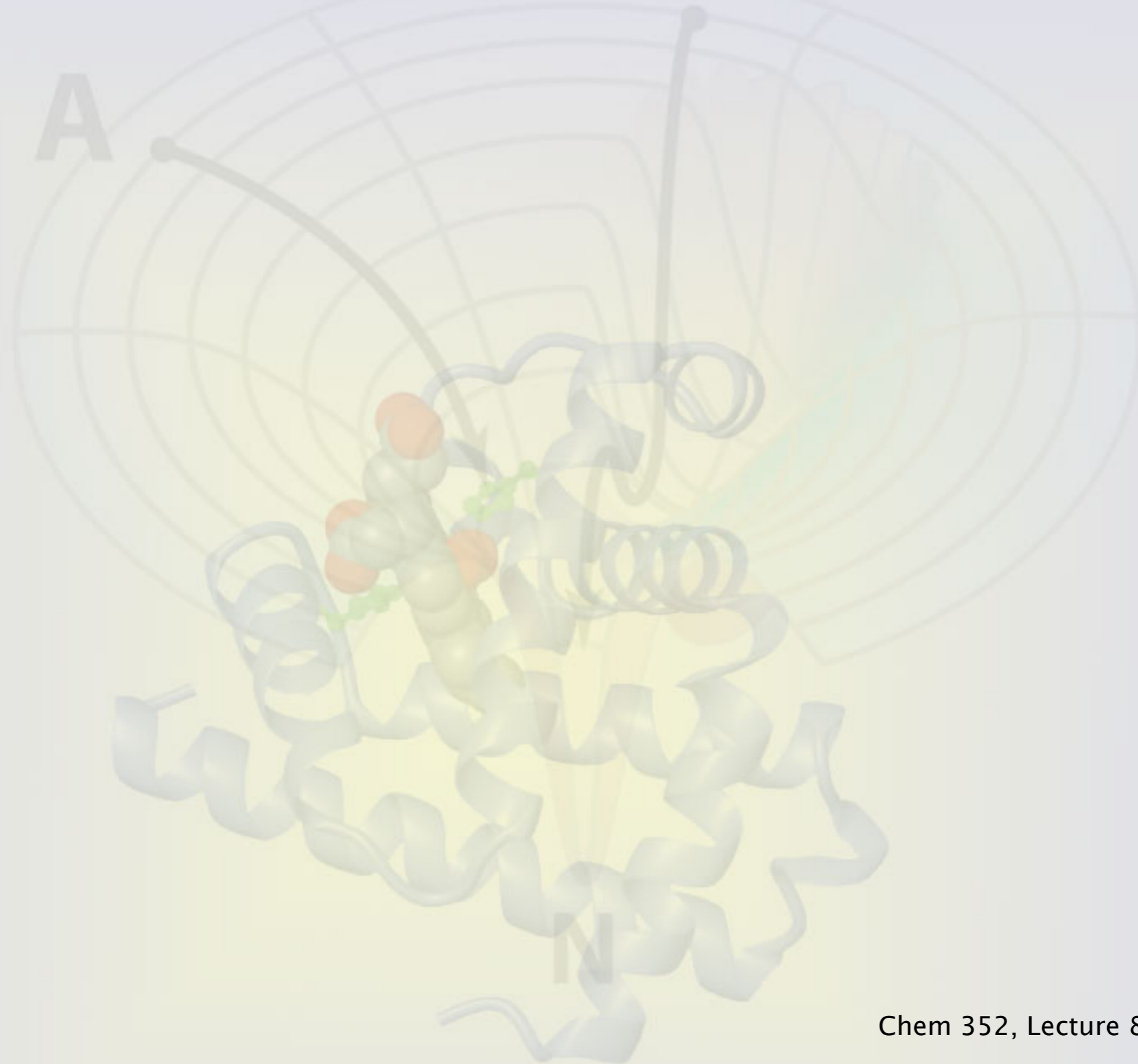


Lipid Constituents of Biological Membranes

The addition of mono- and oligo saccharides to ceramide produces glycosphingolipids.

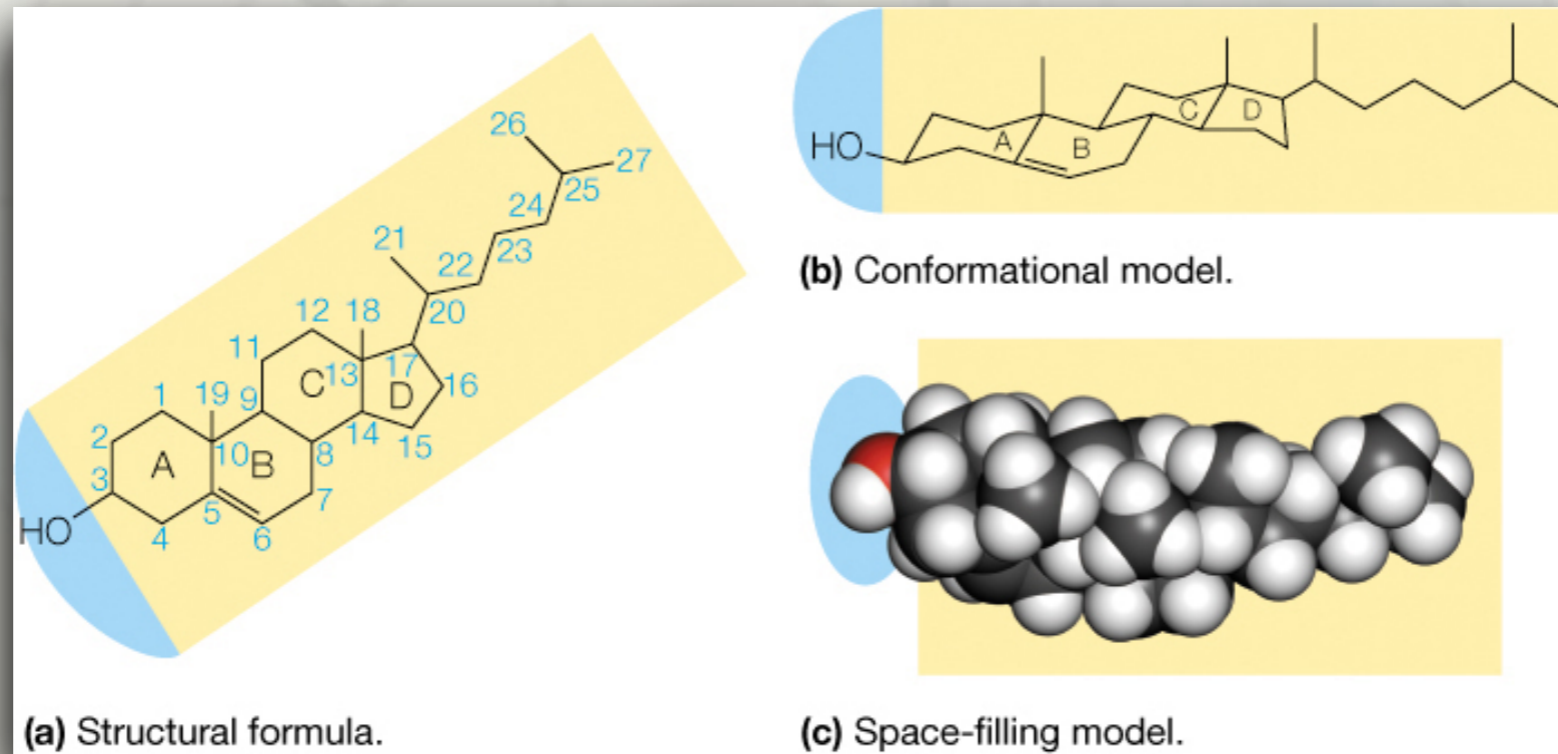


Lipid Constituents of Biological Membranes



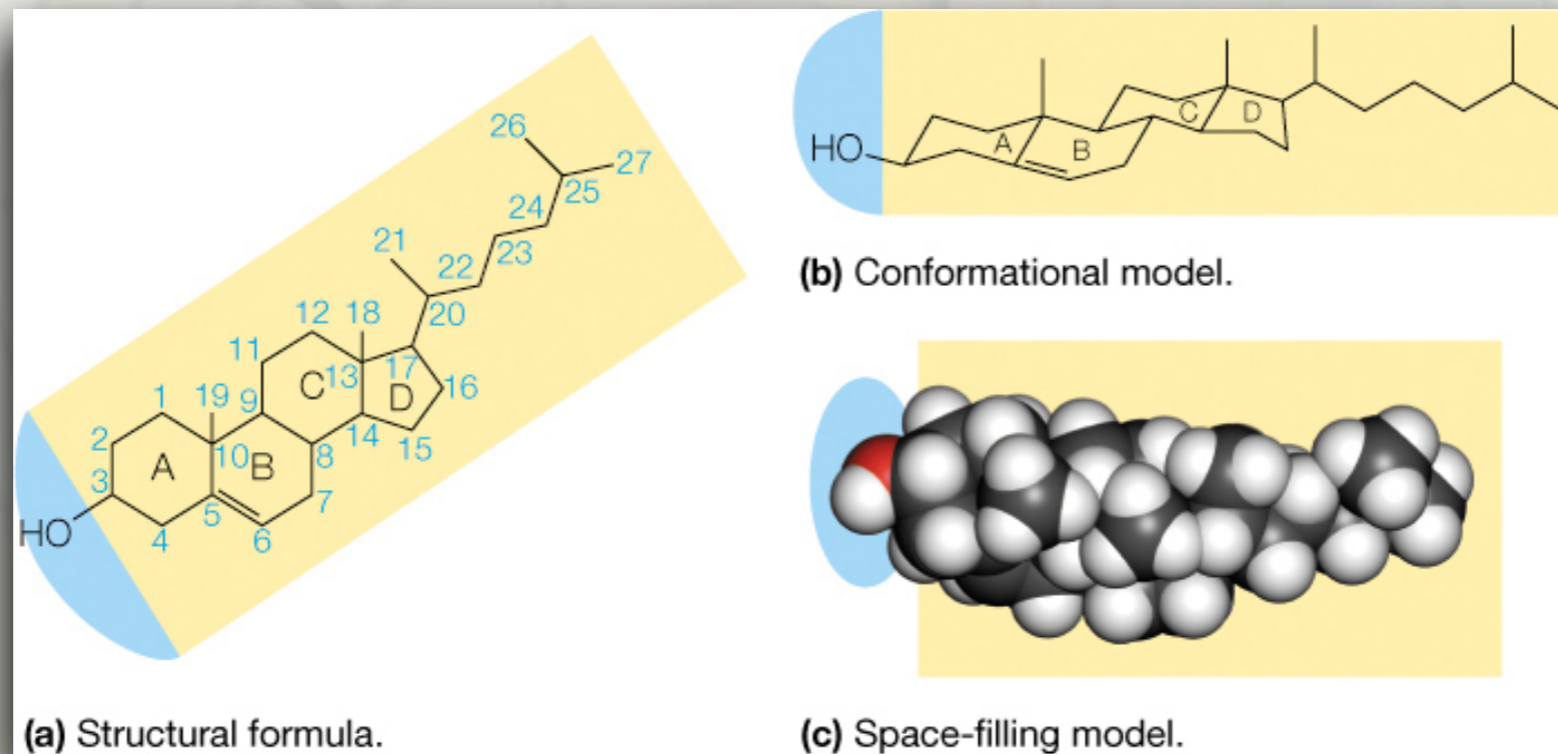
Lipid Constituents of Biological Membranes

Another important membrane component in animal membranes is cholesterol.



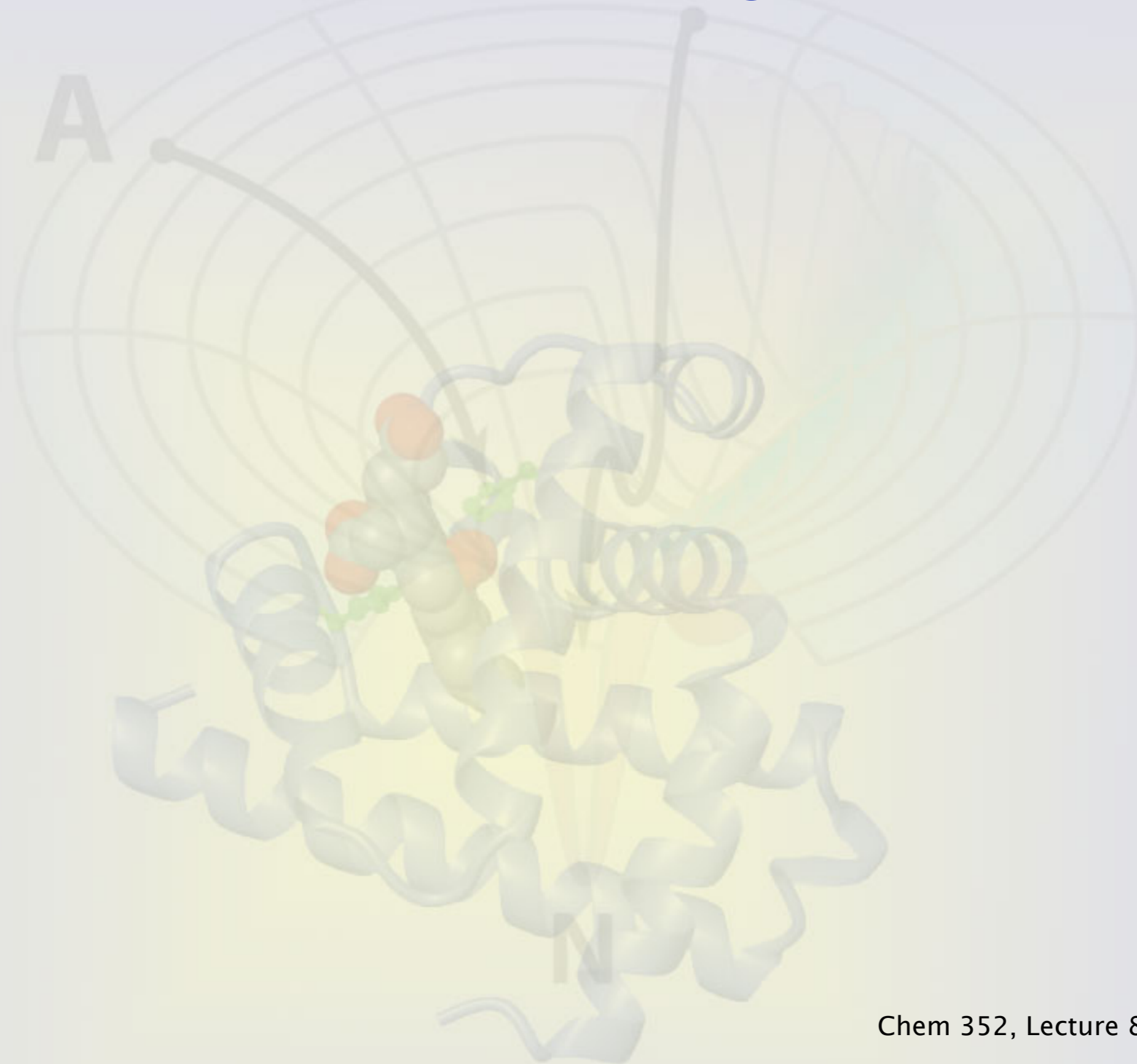
Lipid Constituents of Biological Membranes

Another important membrane component in animal membranes is cholesterol.



- ✦ Cholesterol helps to maintain the fluidity of animal membranes in the same way the unsaturated fatty acids do in plant membranes

Lipid Constituents of Biological Membranes



Lipid Constituents of Biological Membranes

The lipid composition of biological membranes is a complex mixture of all of these components.

TABLE 10.4 Lipid composition of some biological membranes

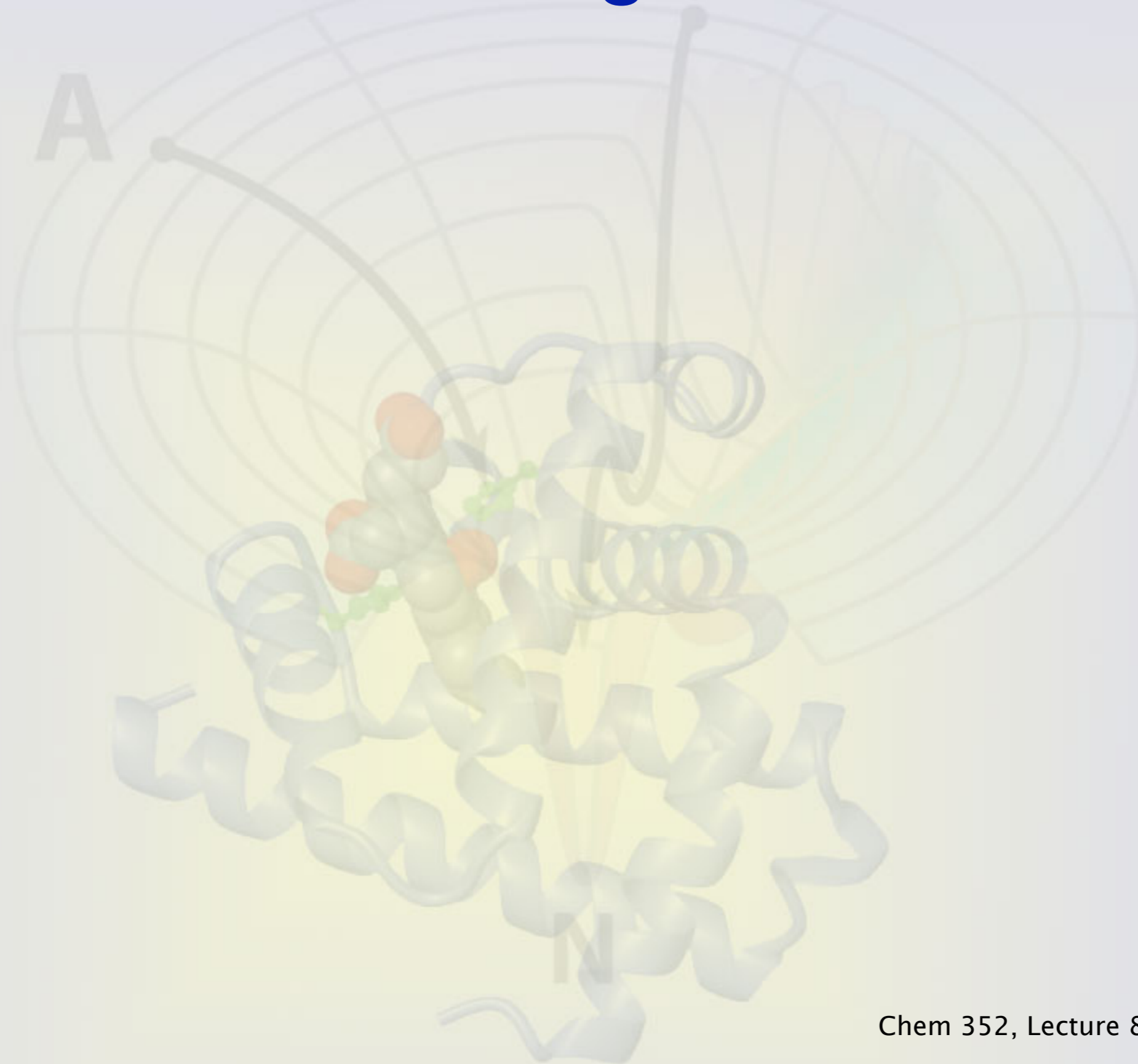
Lipid	Percentage of Total Composition in			
	Human Erythrocyte Plasma Membrane	Human Myelin	Bovine Heart Mitochondria	<i>E. coli</i> Cell Membrane
Phosphatidic acid	1.5	0.5	0	0
Phosphatidylcholine	19	10	39	0
Phosphatidylethanolamine	18	20	27	65
Phosphatidylglycerol	0	0	0	18
Phosphatidylinositol	1	1	7	0
Phosphatidylserine	8.0	8.0	0.5	0
Sphingomyelin	17.5	8.5	0	0
Glycolipids	10	26	0	0
Cholesterol	25	26	3	0
Others	0	0	23.5	17

Data from C. Tanford (1973) *The Hydrophobic Effect*. Wiley, New York.



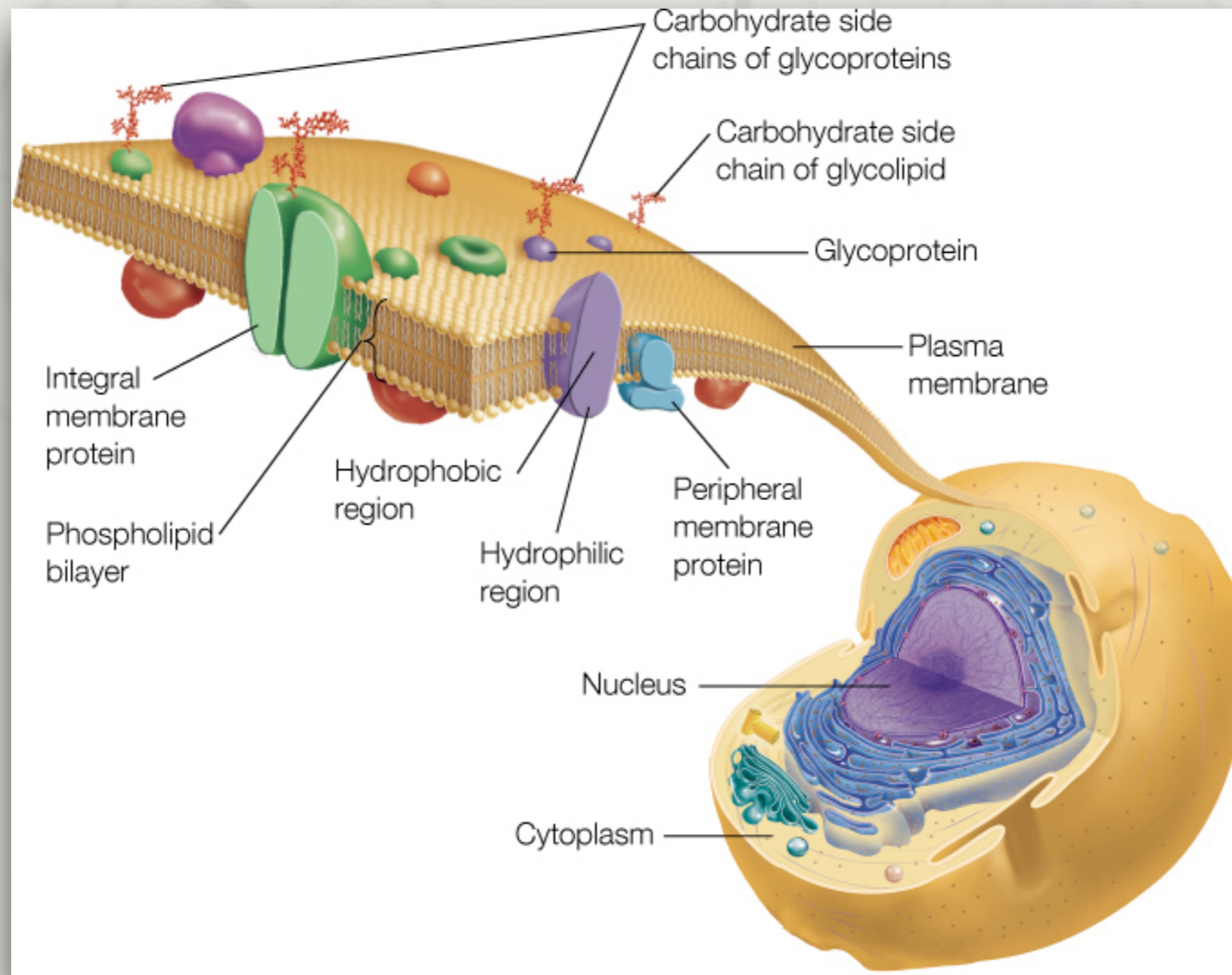
10.3 - The Structure and Properties of Membranes and Membrane Proteins

Structure of Biological Membranes

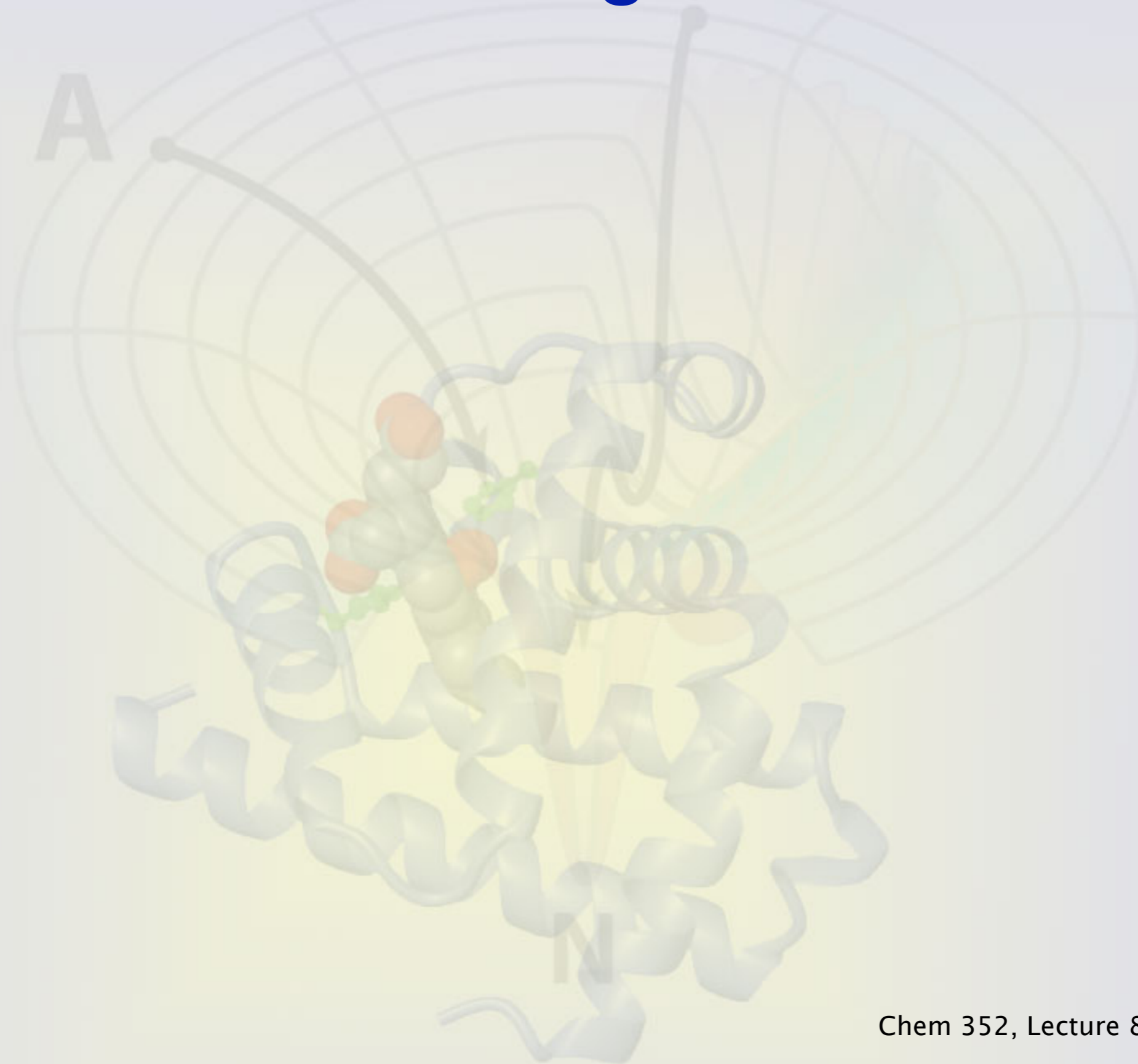


Structure of Biological Membranes

Biological membranes comprise, on average, 40% lipid and 60% protein.



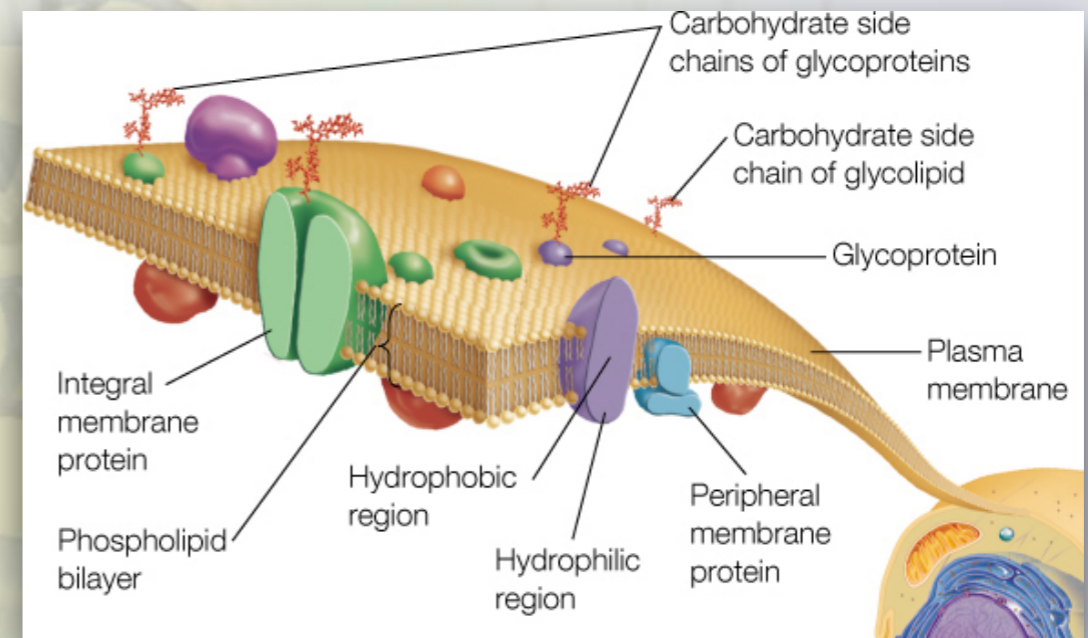
Structure of Biological Membranes



Structure of Biological Membranes

In the early 1970's S.J. Singer and G.L. Nicolson proposed their *fluid mosaic model* for biological membranes.

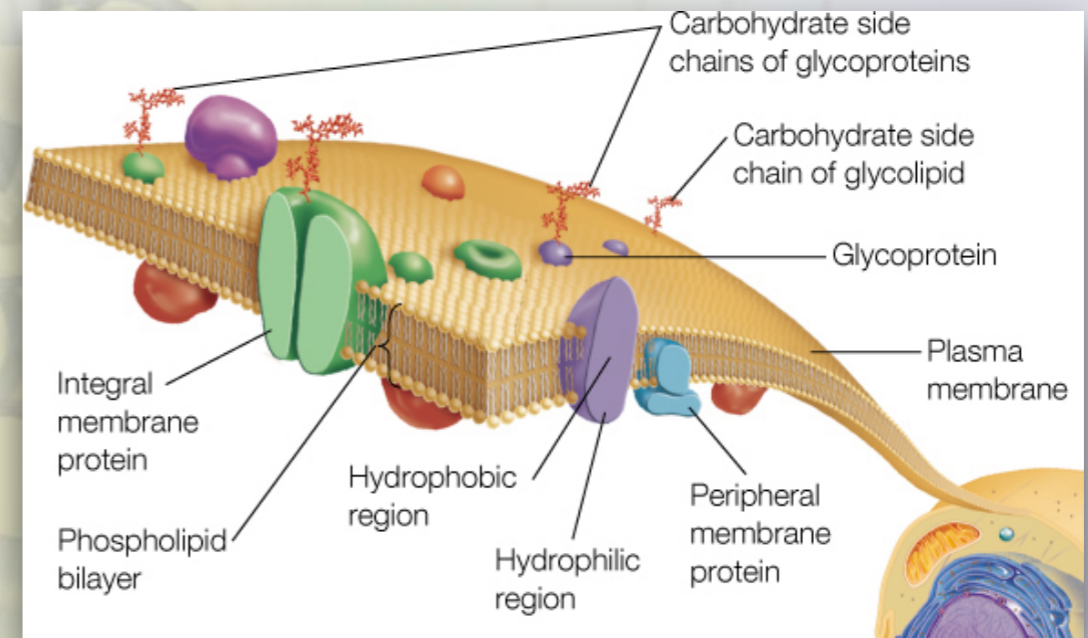
- ♦ The membrane lipids form a fluid framework in which proteins are associated.



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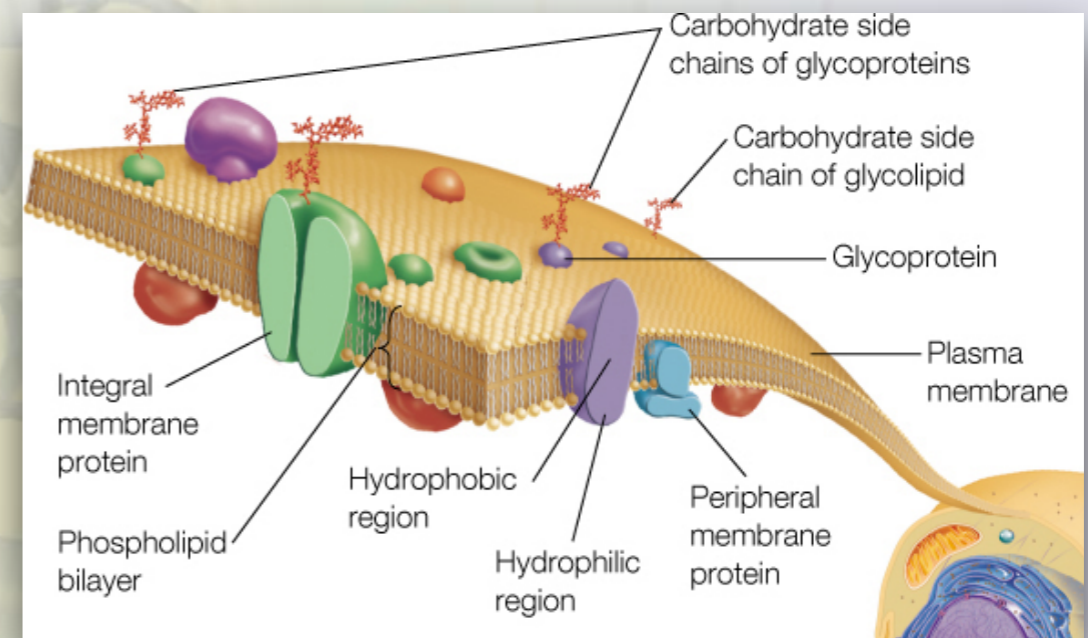
- ♦ The membrane lipids form a fluid framework in which proteins are associated.
- ♦ These proteins can be
 - Peripheral and attached to either side of the membrane
 - Integral and spanning the membrane.



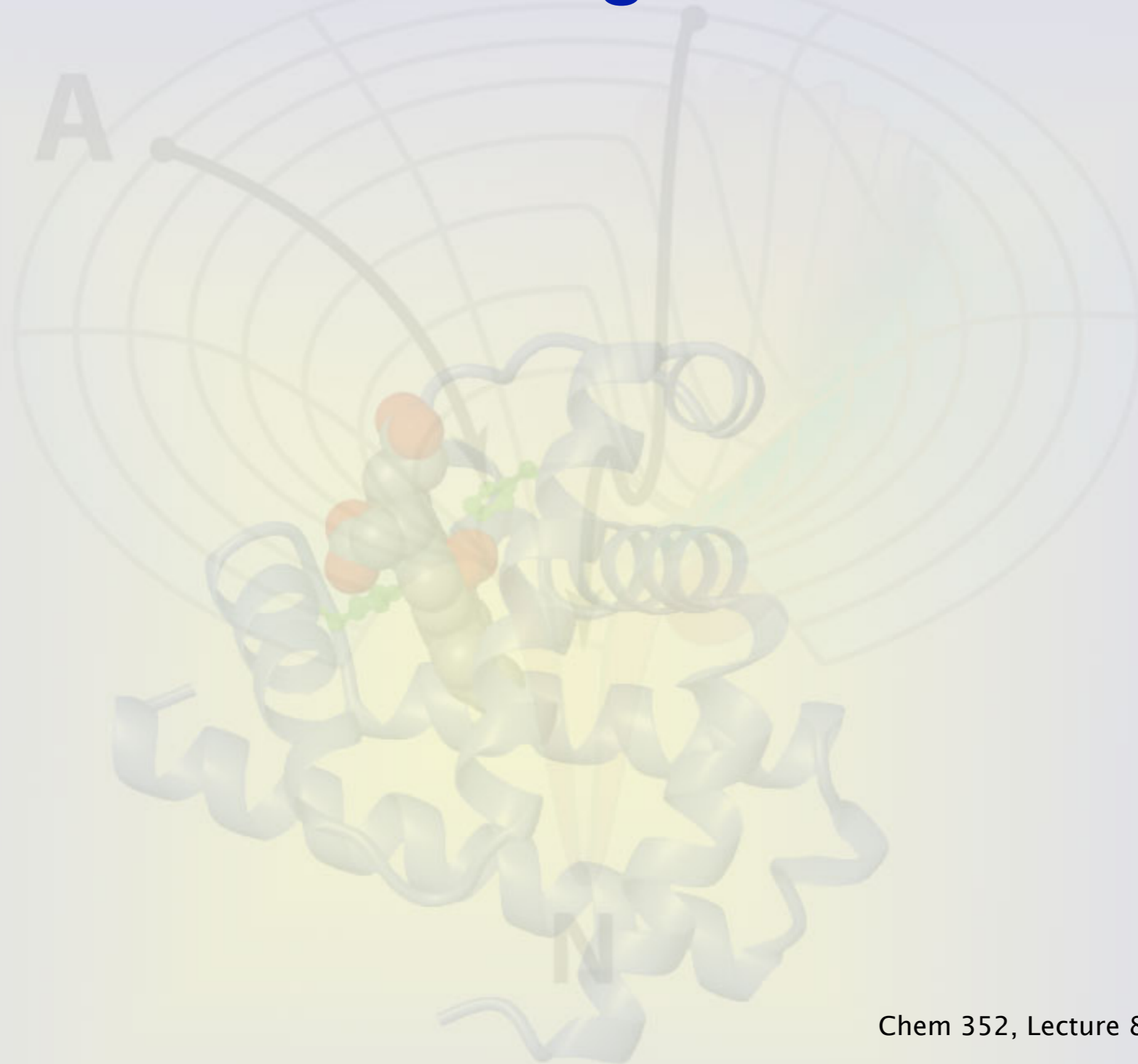
Structure of Biological Membranes

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- ✦ The membrane lipids form a fluid framework in which proteins are associated.
- ✦ These proteins can be
 - Peripheral and attached to either side of the membrane
 - Integral and spanning the membrane.
- ✦ The membranes are typically asymmetrical with respect to both the lipid and protein compositions on either side of the membrane.



Structure of Biological Membranes



Structure of Biological Membranes

The compositions of membranes for different cell and organelle types can vary considerably.

TABLE 10.5 Protein, lipid, and carbohydrate content of some membranes			
Membrane	Percent by Weight		
	Protein	Lipid	Carbohydrate
Myelin	18	79	3
Human erythrocyte (plasma membrane)	49	43	8
Mitochondria (outer membrane)	52	48	0
Sarcoplasmic reticulum (muscle cells)	67	33	0
Chloroplast lamellae	70	30	0
Gram-positive bacteria	75	25	0
Mitochondria (inner membrane)	76	24	0

Adapted from *Annual Review of Biochemistry* 41:731, G. Guidotti, Membrane proteins.
© 1972 Annual Reviews.

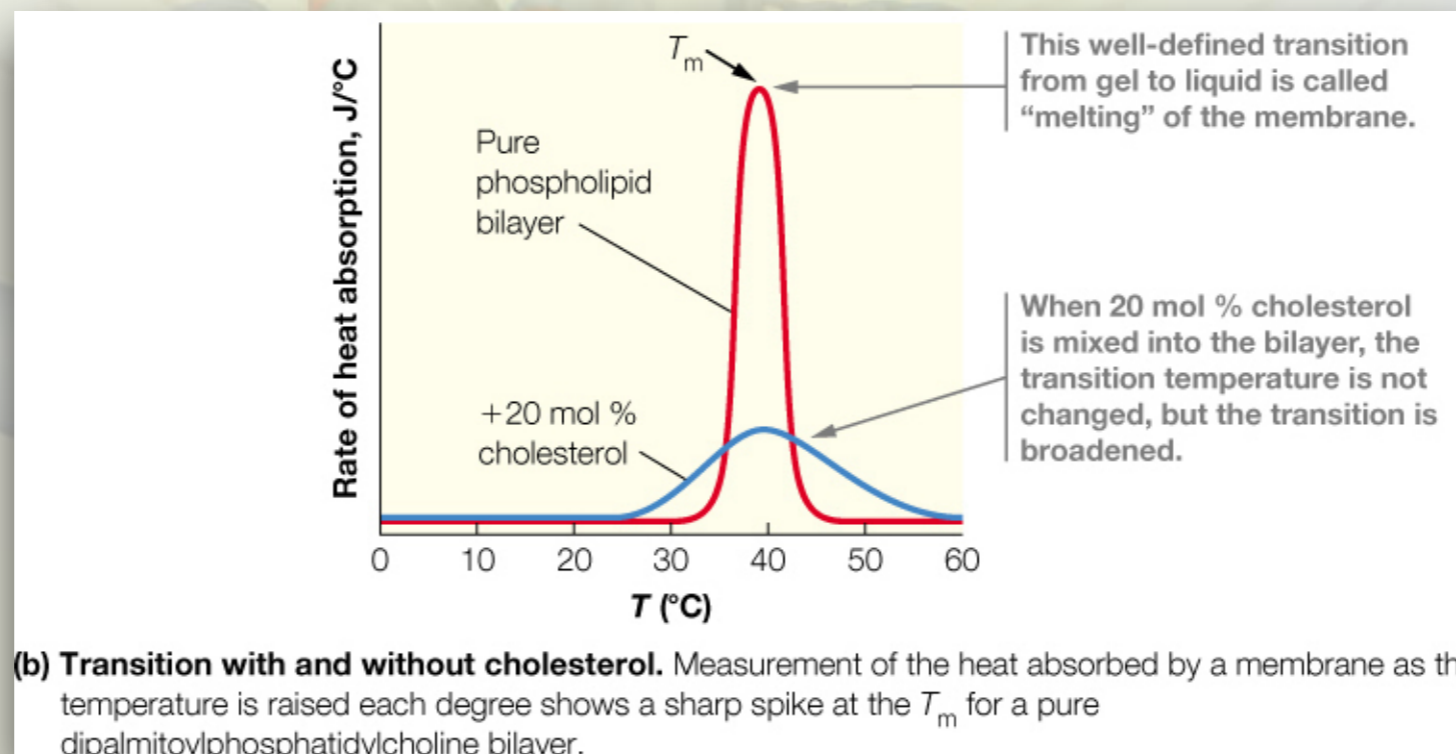
Fluidity of Biological Membranes



Fluidity of Biological Membranes

Biological membranes must remain in a fluid state to be functional.

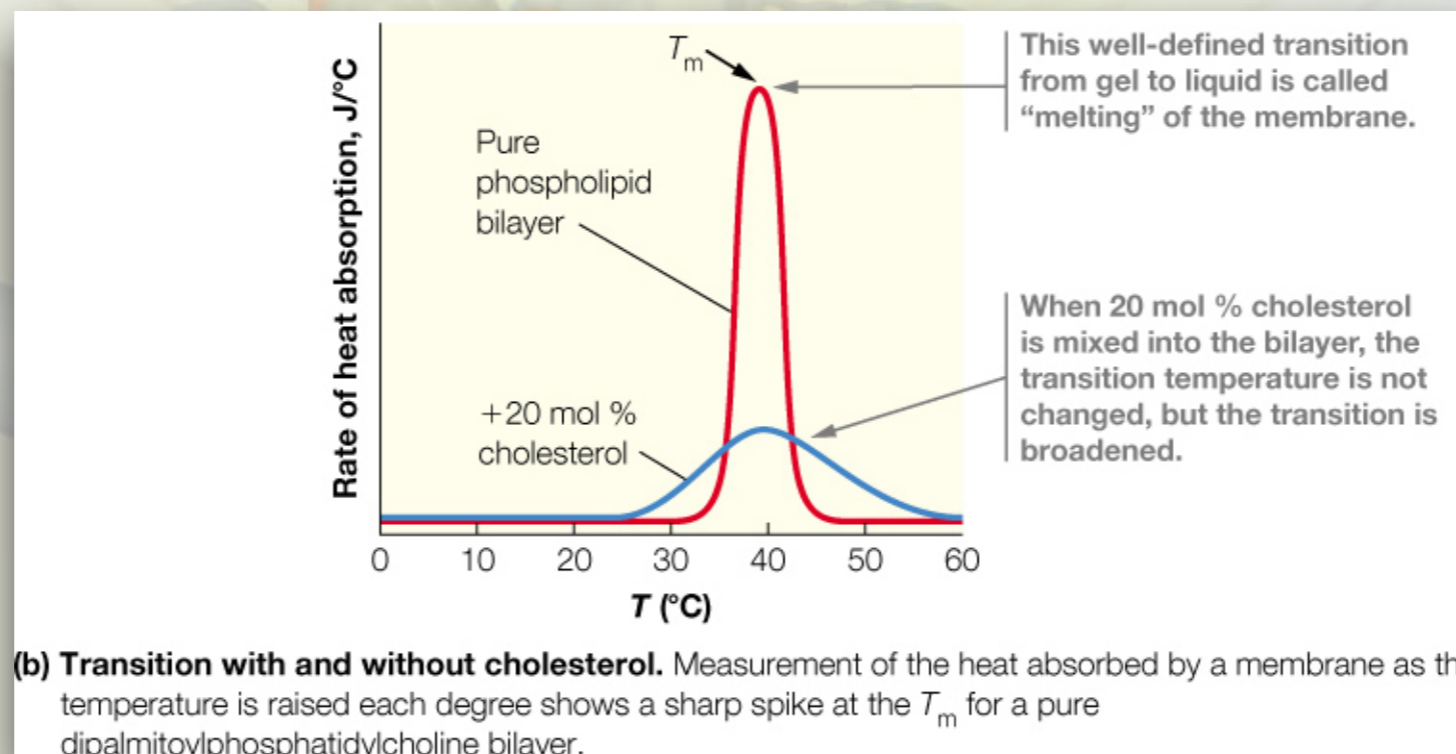
- ♦ The length of the fatty acid tails and the presence of *cis* double bonds influences the transition temperature (T_m) from a gel state to a fluid state.



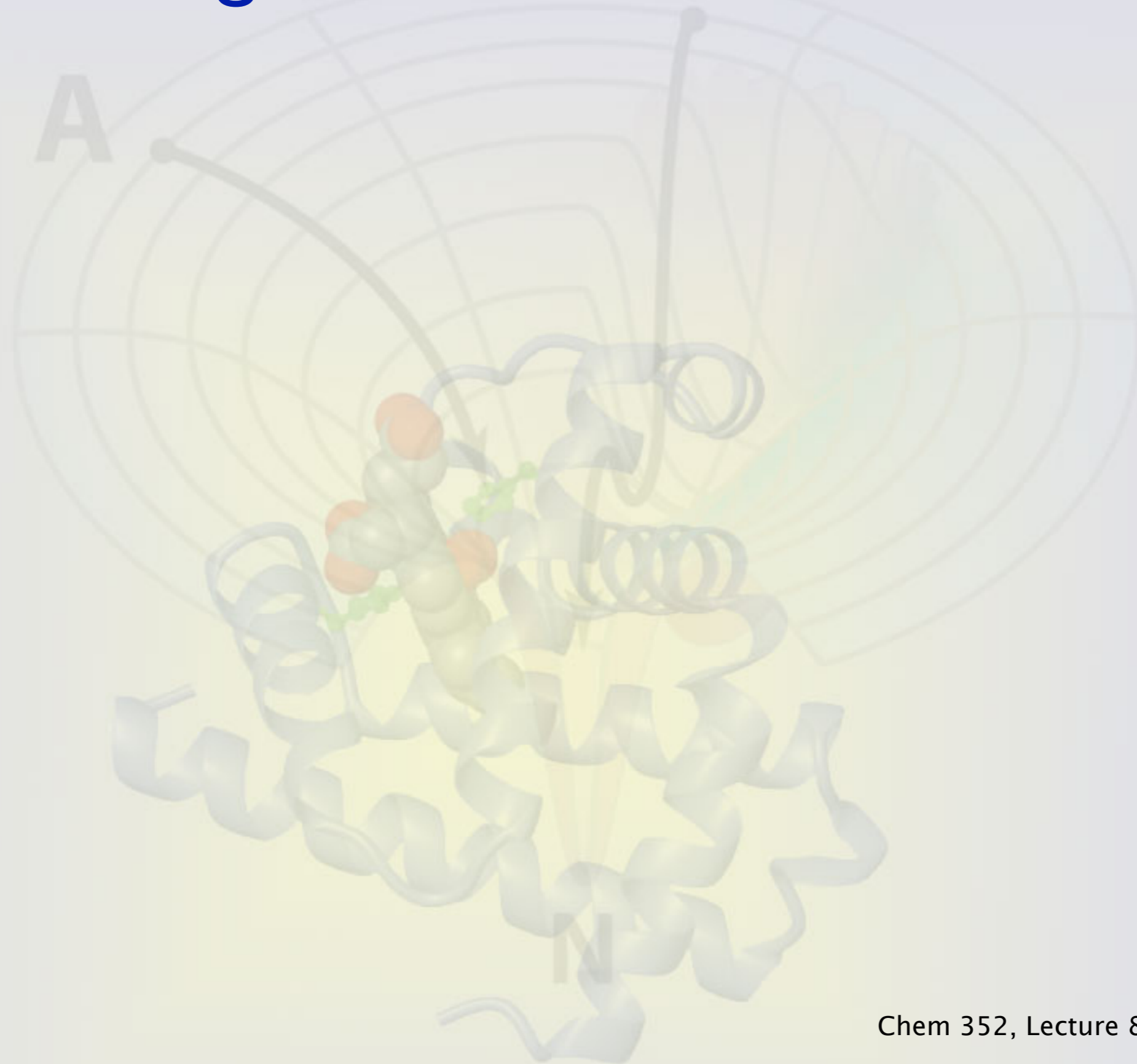
Fluidity of Biological Membranes

Biological membranes must remain in a fluid state to be functional.

- ✦ The length of the fatty acid tails and the presence of *cis* double bonds influences the transition temperature (T_m) from a gel state to a fluid state.
- The presence of cholesterol can influence how broad the transition is.



Integral Membrane Proteins

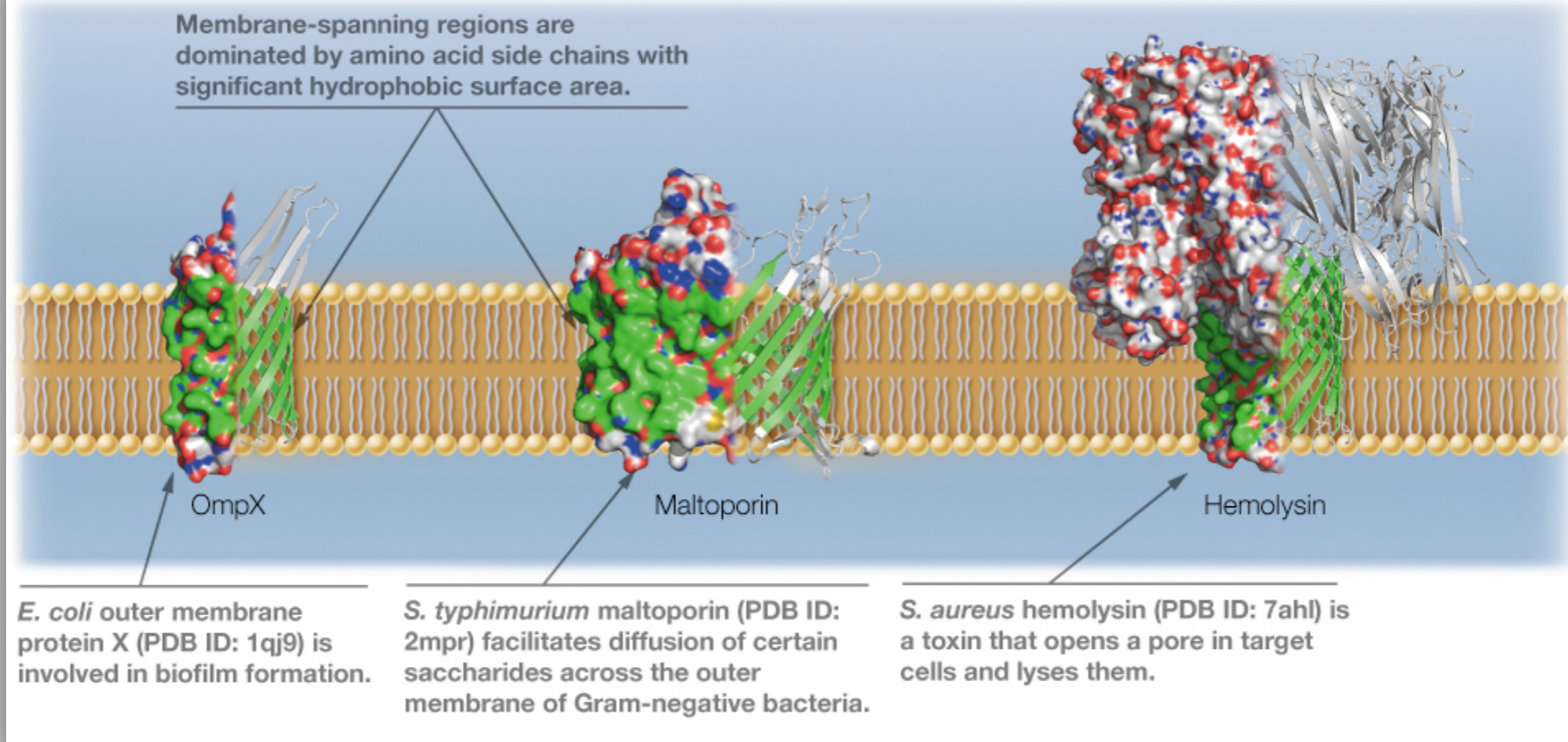


Integral Membrane Proteins

Integral membrane proteins span the membrane using either

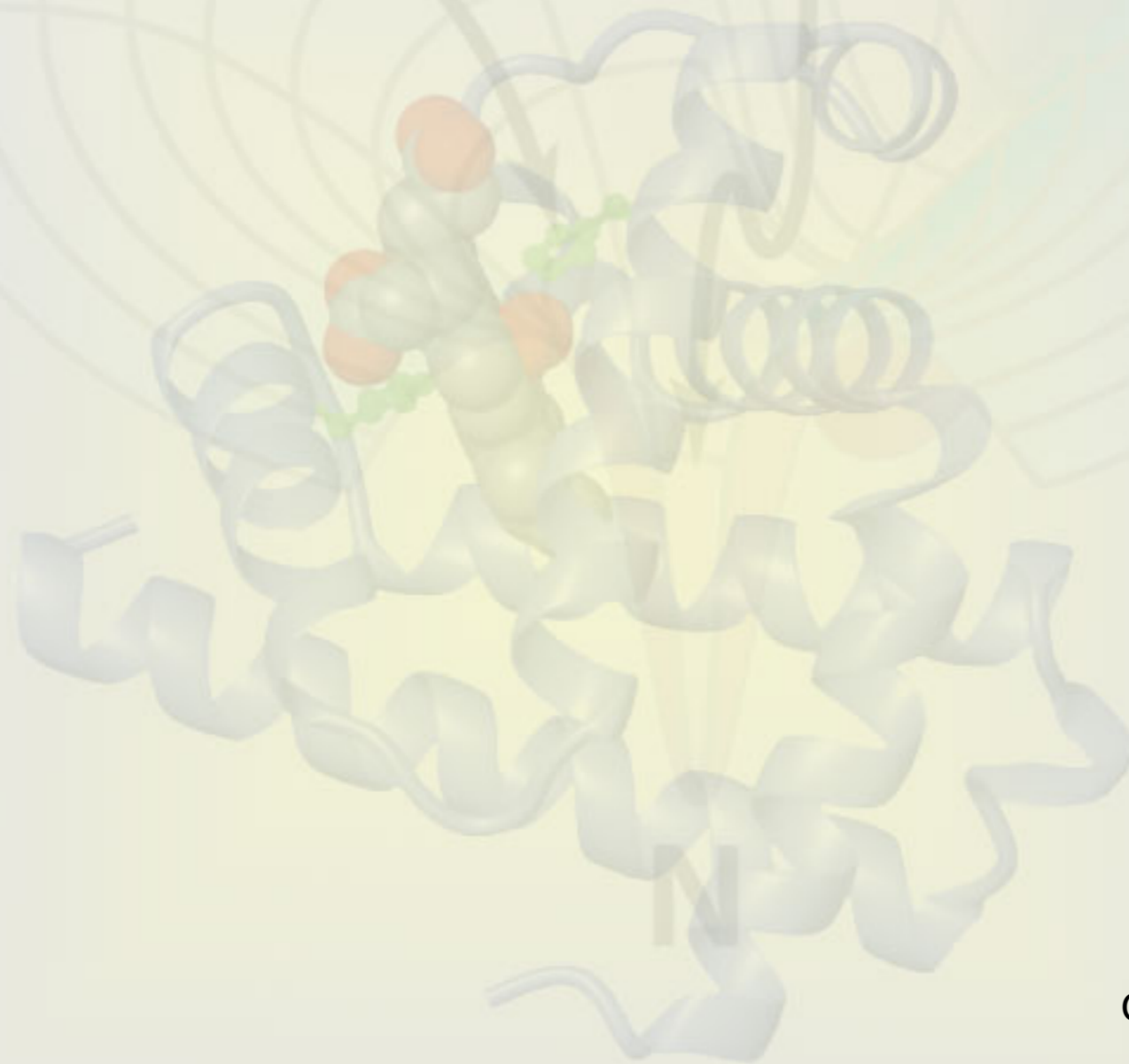
- ♦ hydrophobic β -barrels,

Examples of β -barrel transmembrane structures.



Integral Membrane Proteins

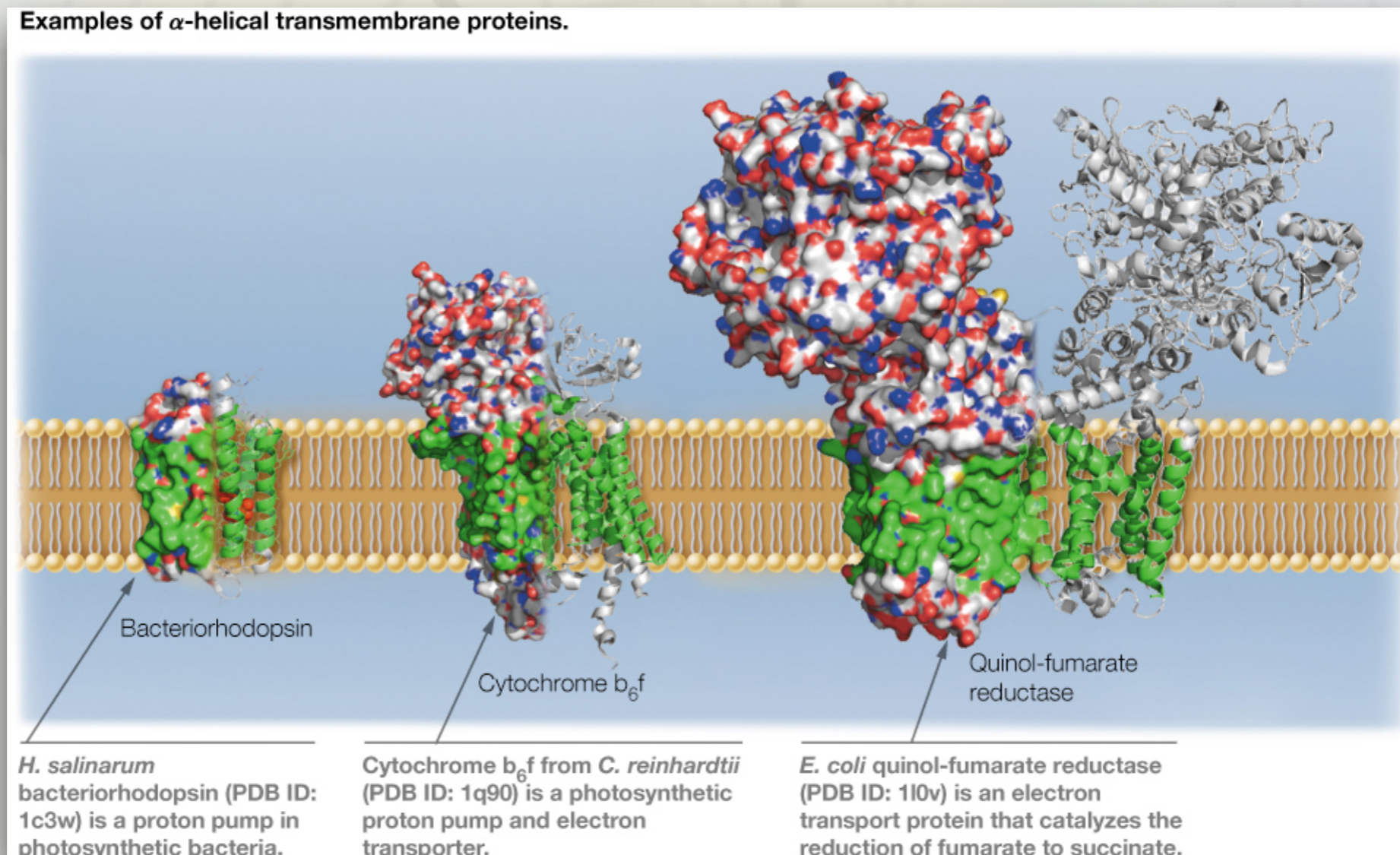
Integral membrane proteins span the membrane using either



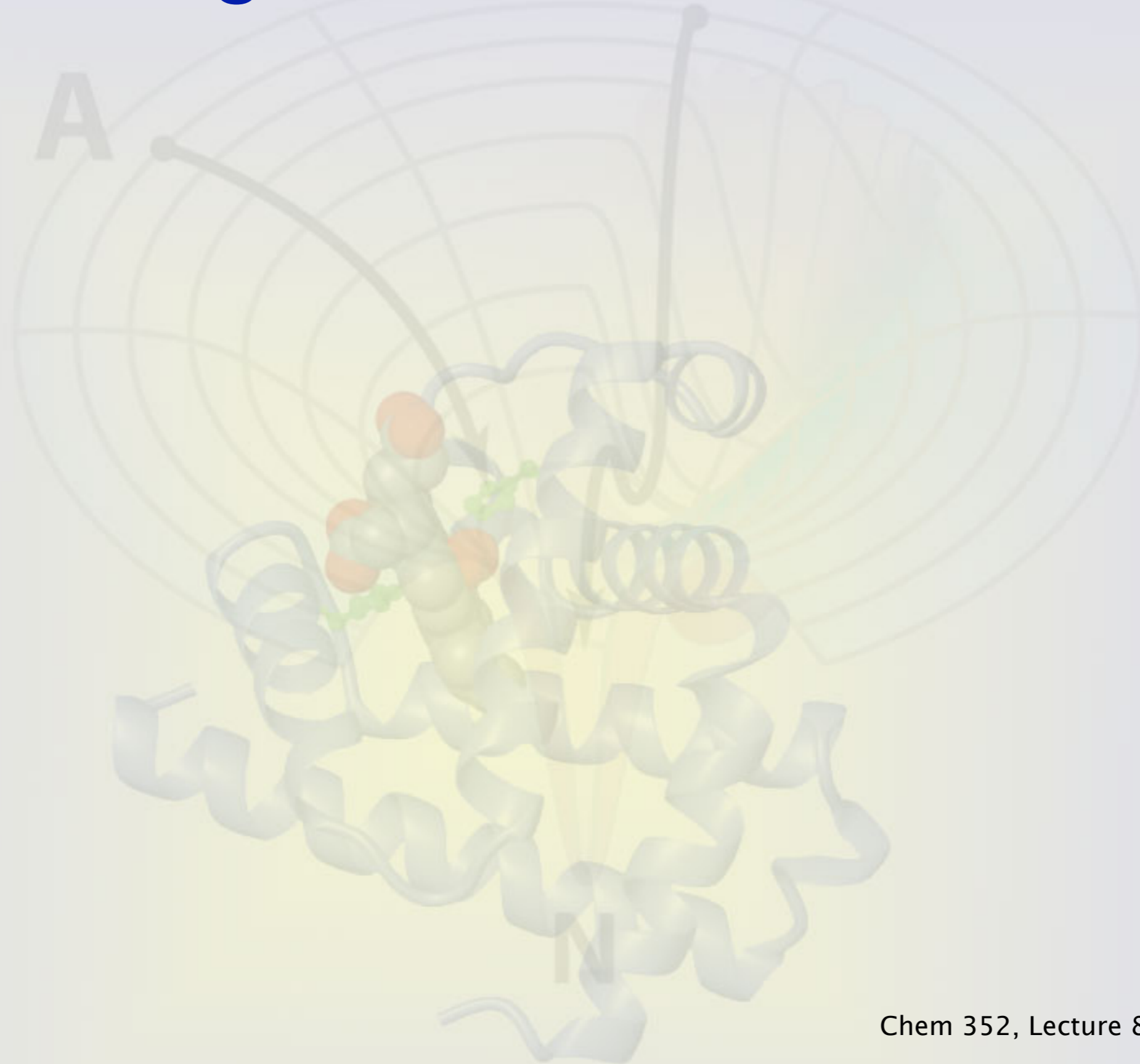
Integral Membrane Proteins

Integral membrane proteins span the membrane using either

- ♦ hydrophobic α -helices,

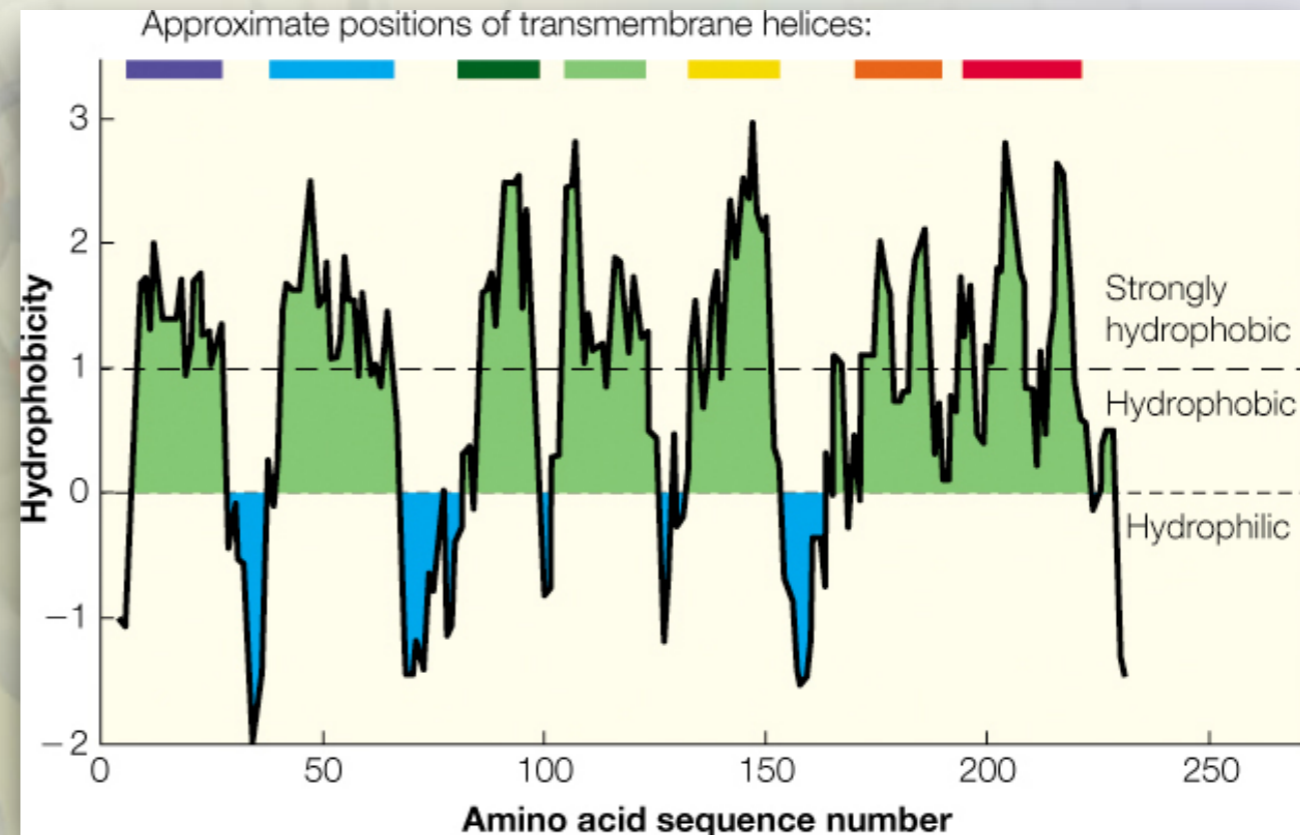
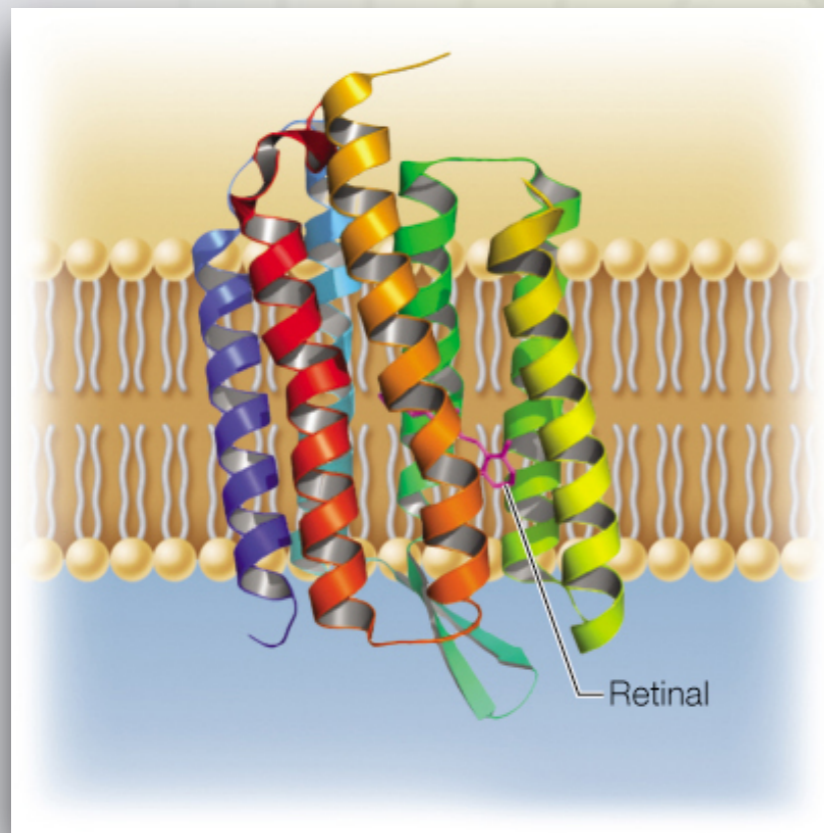


Integral Membrane Proteins



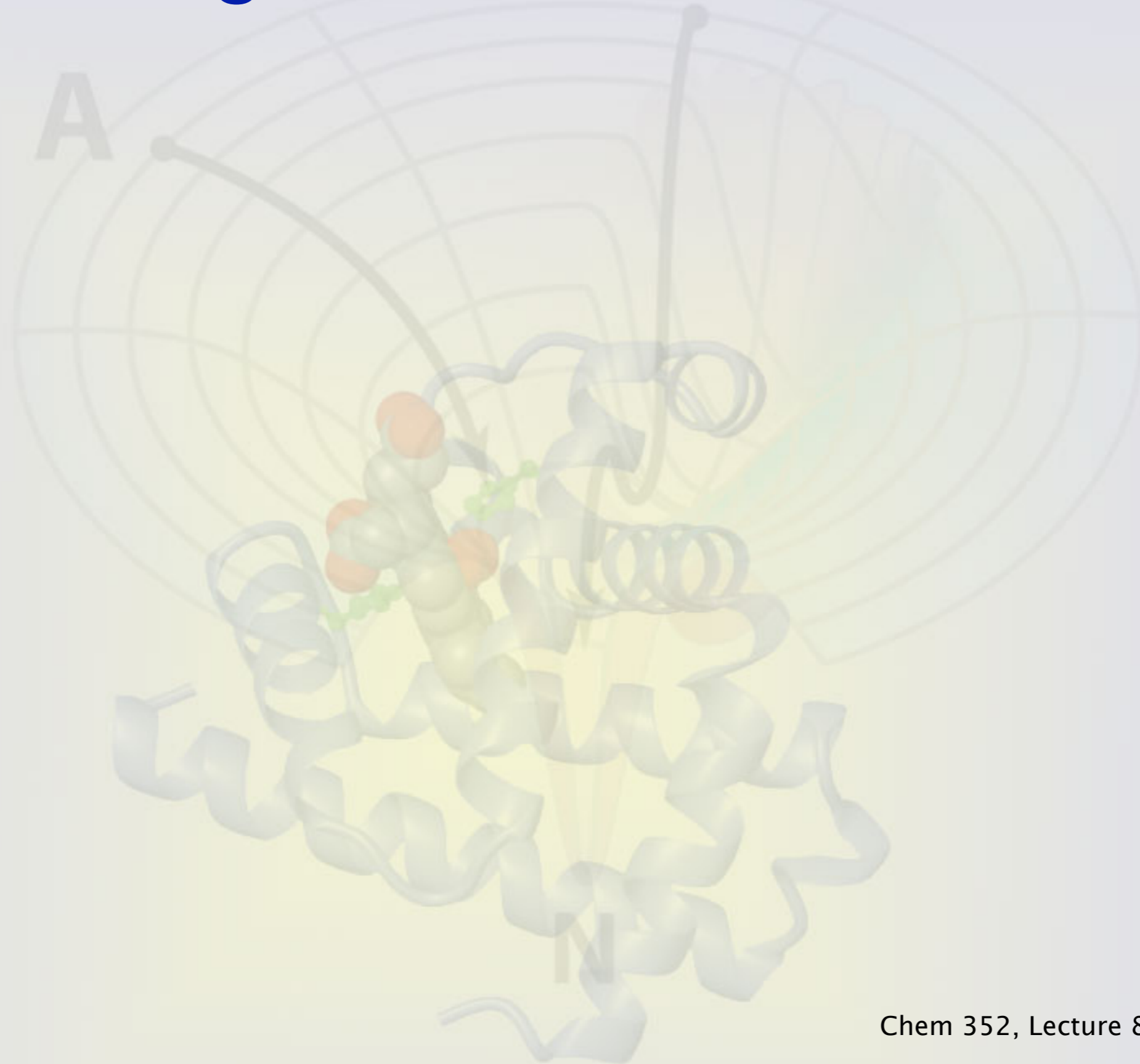
Integral Membrane Proteins

Analyzing an integral membrane protein's amino acid sequence using a hydrophobicity plot can reveal the segments that span the membrane.



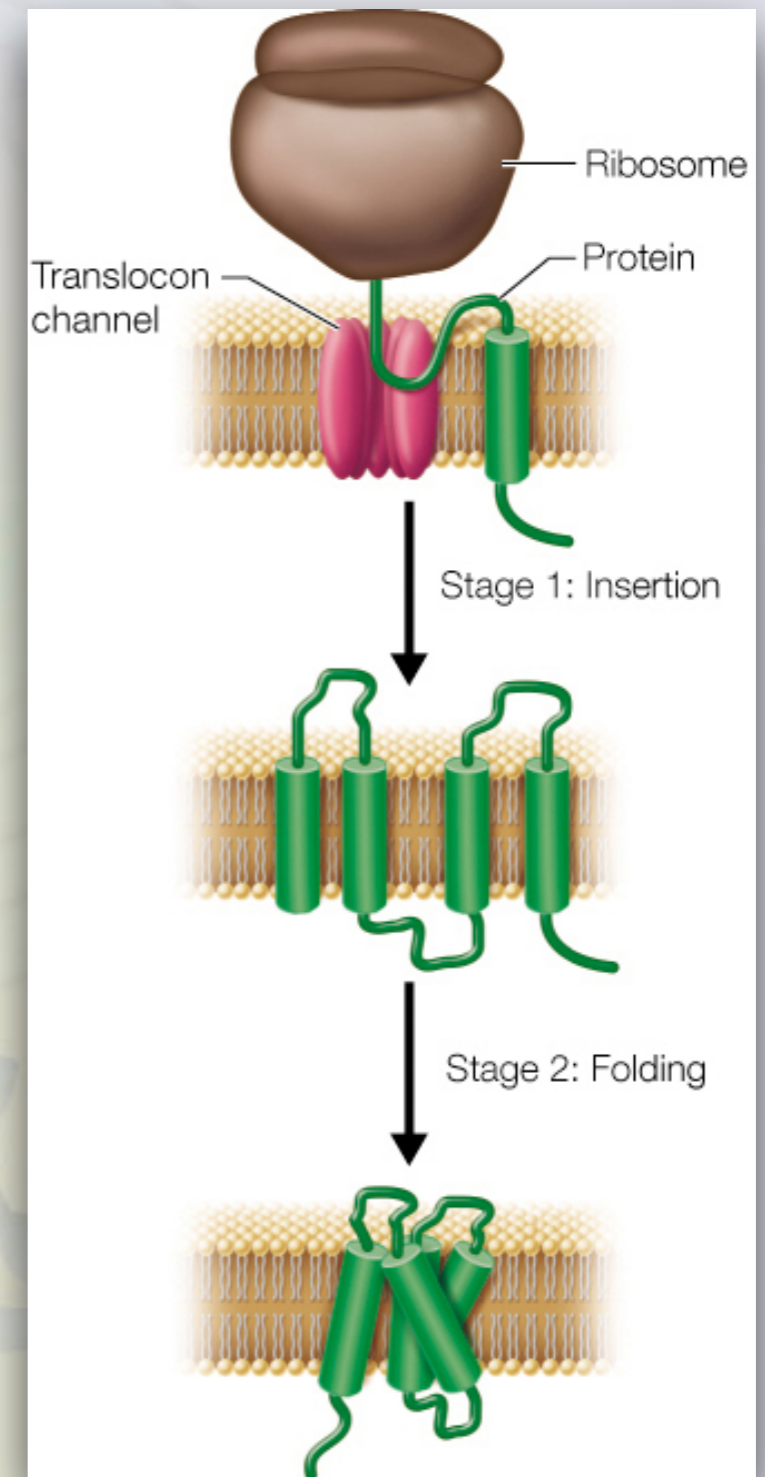
Bacteriorhodopsin

Integral Membrane Proteins

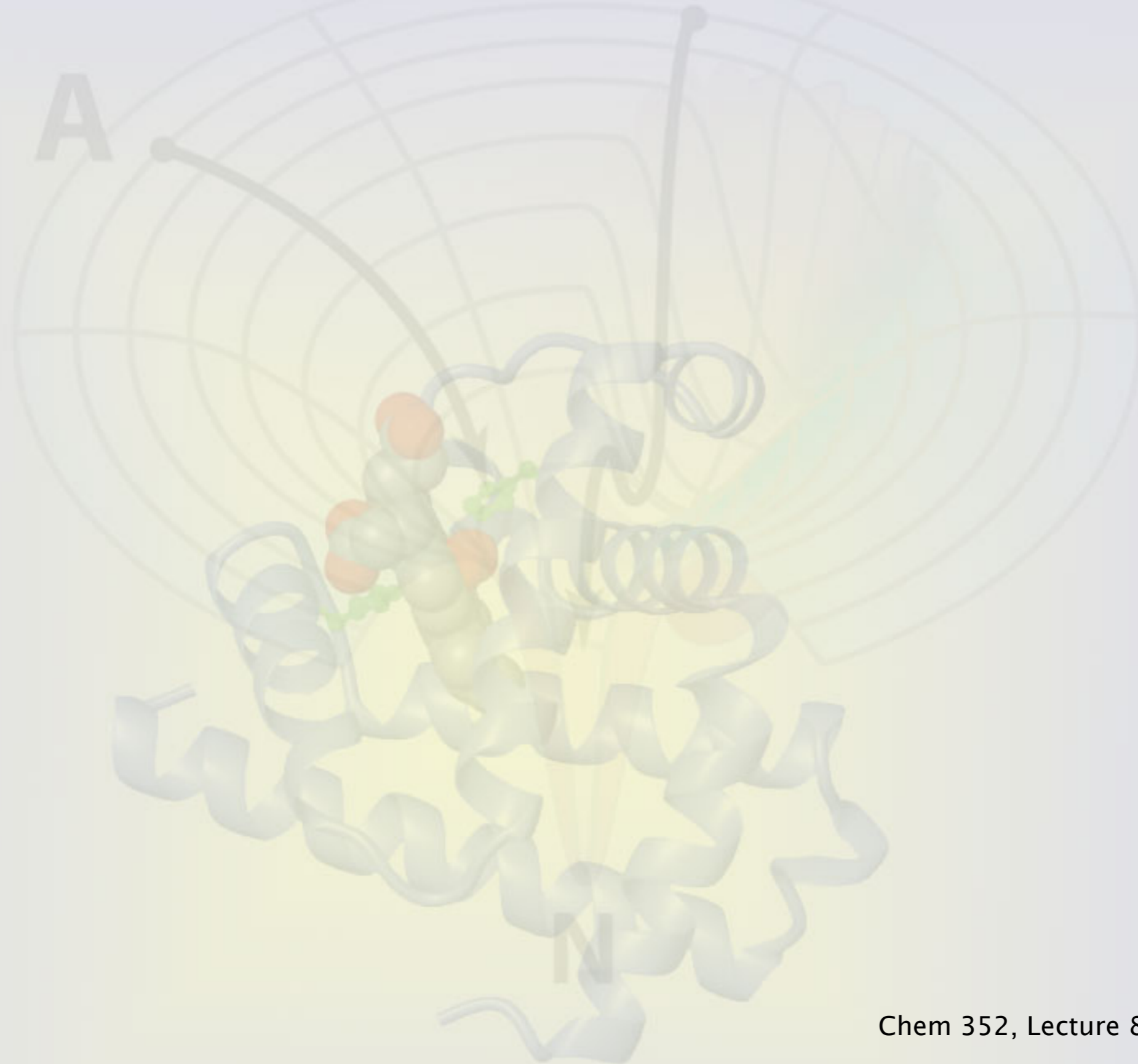


Integral Membrane Proteins

A protein channel called a “translocon” can facilitate the insertion of integral membrane proteins into the membrane bilayer.

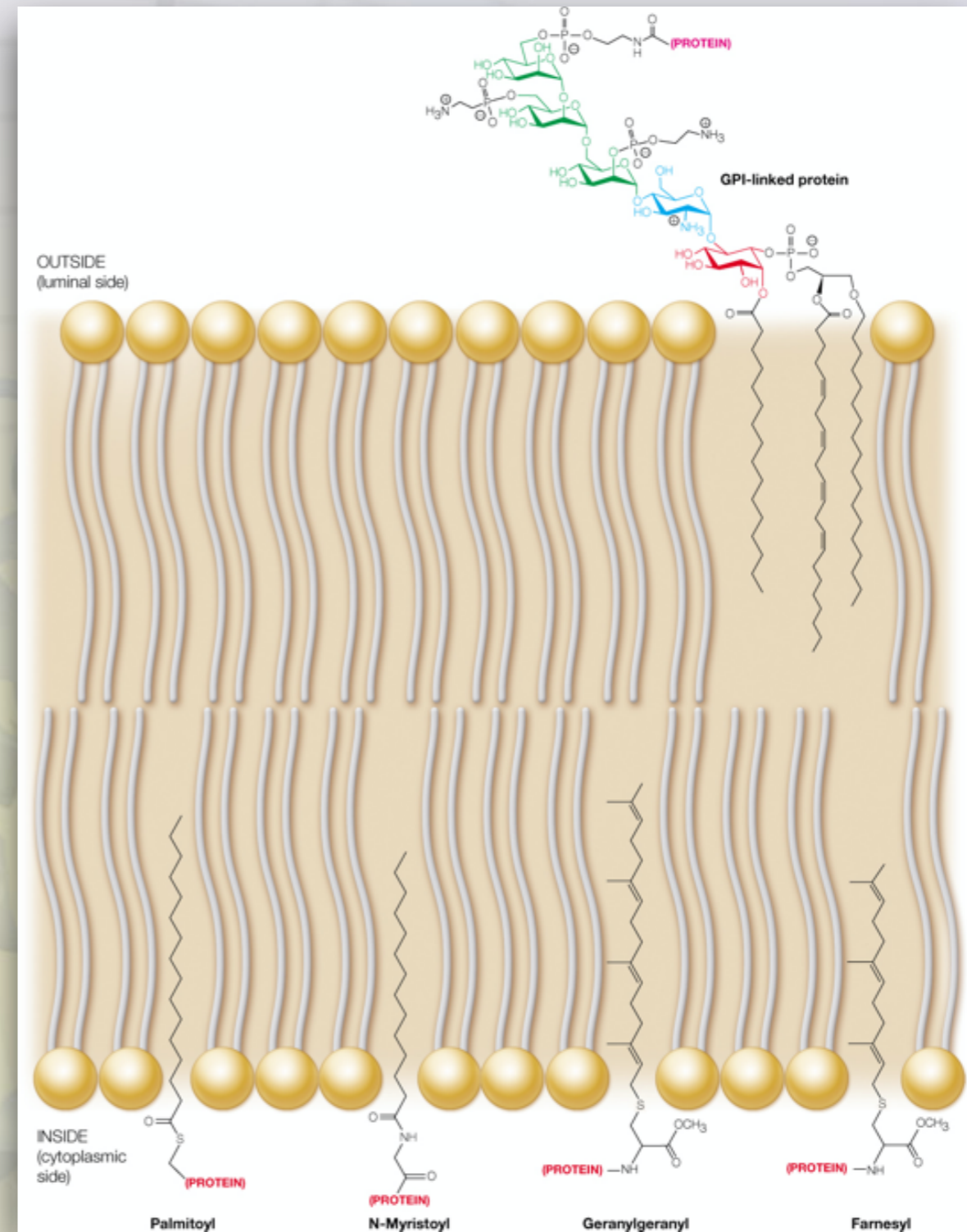


Peripheral Membrane Proteins

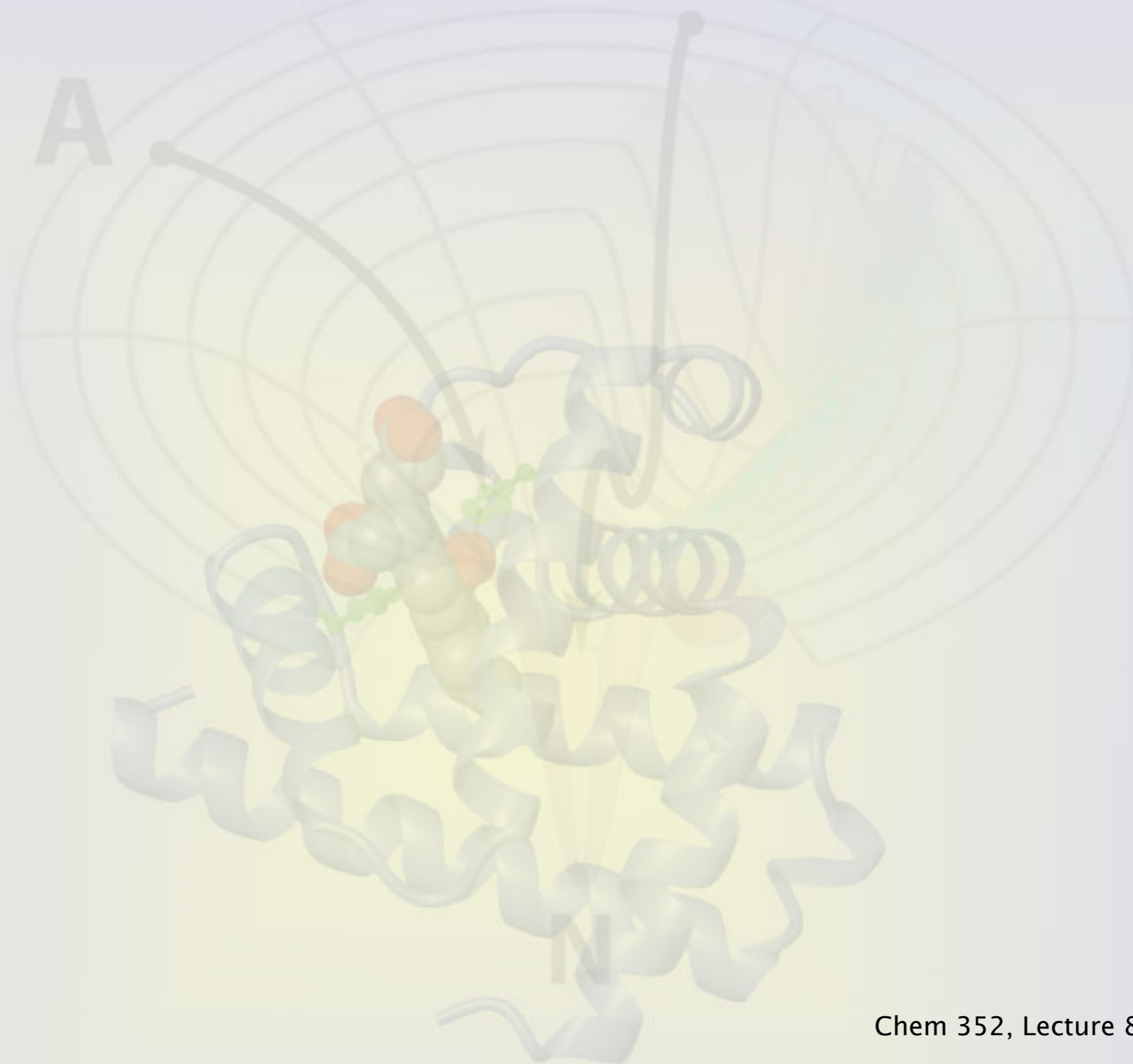


Peripheral Membrane Proteins

Peripheral membrane proteins are often attached to a membrane using covalently-linked lipids.

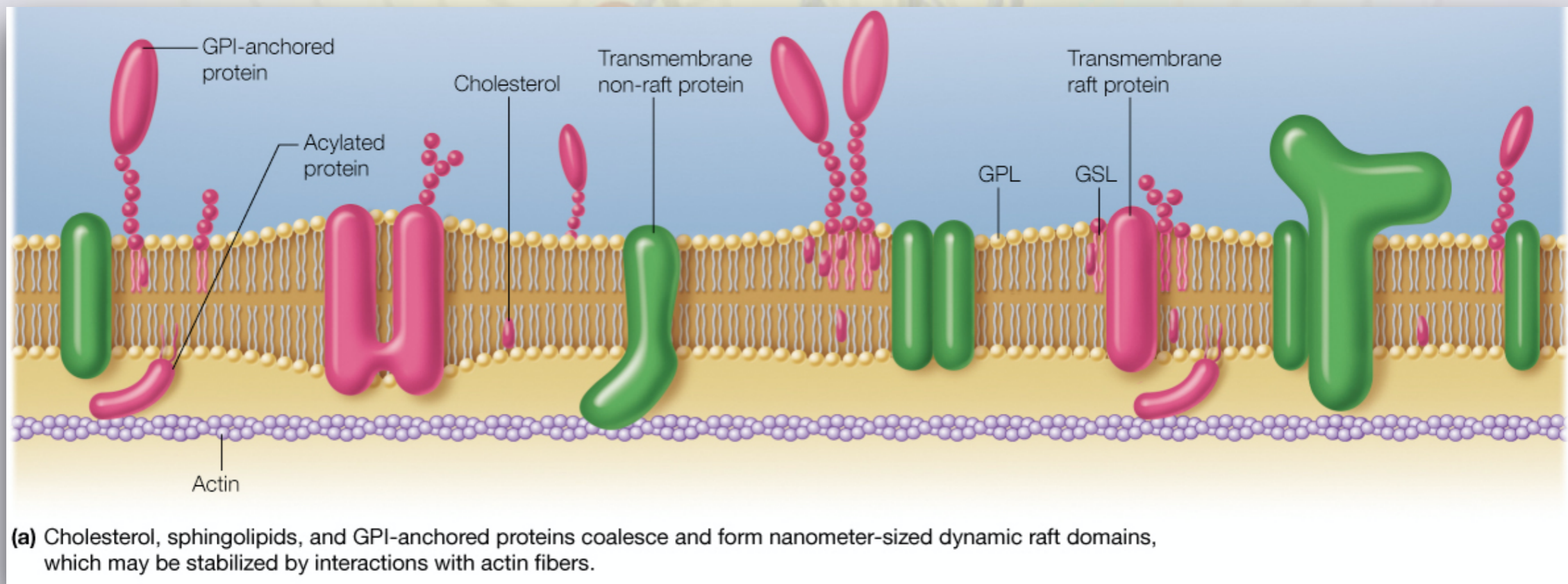


The Fluid Mosaic Model



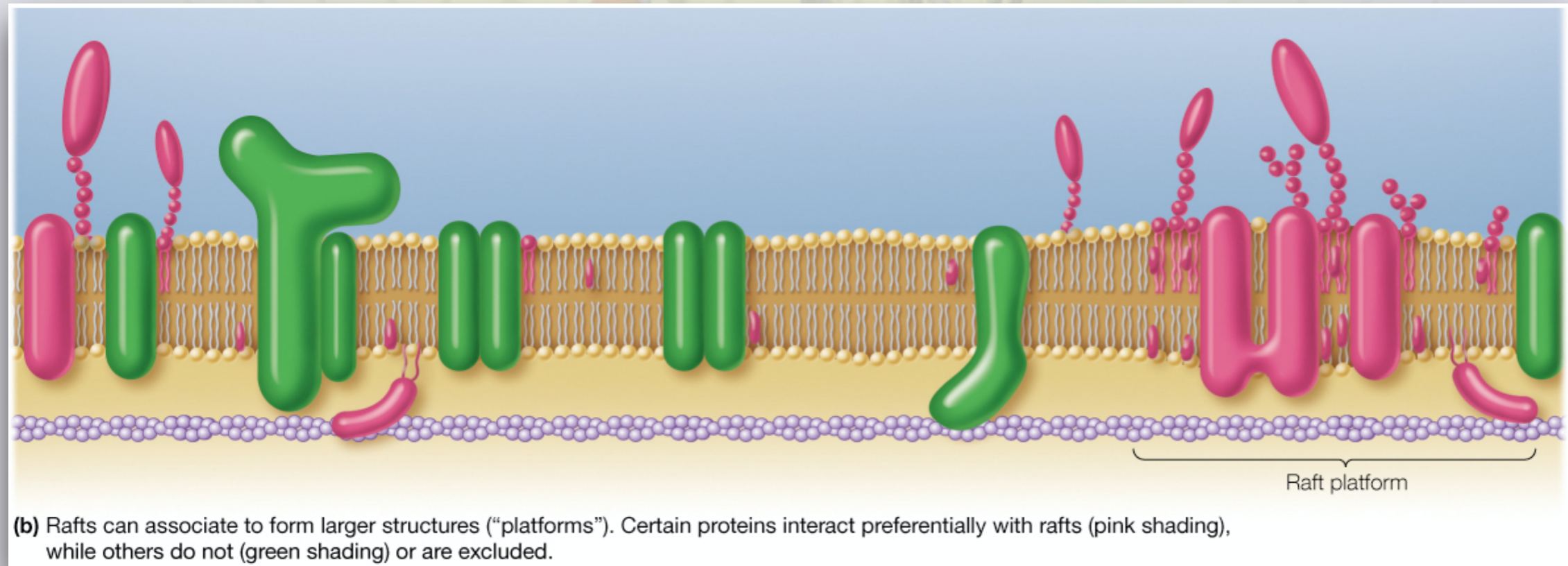
The Fluid Mosaic Model

After being proposed nearly fifty years ago, Singer and Nicolson's fluid mosaic model of biological membranes persists, but many new details have been added over the years.



The Fluid Mosaic Model

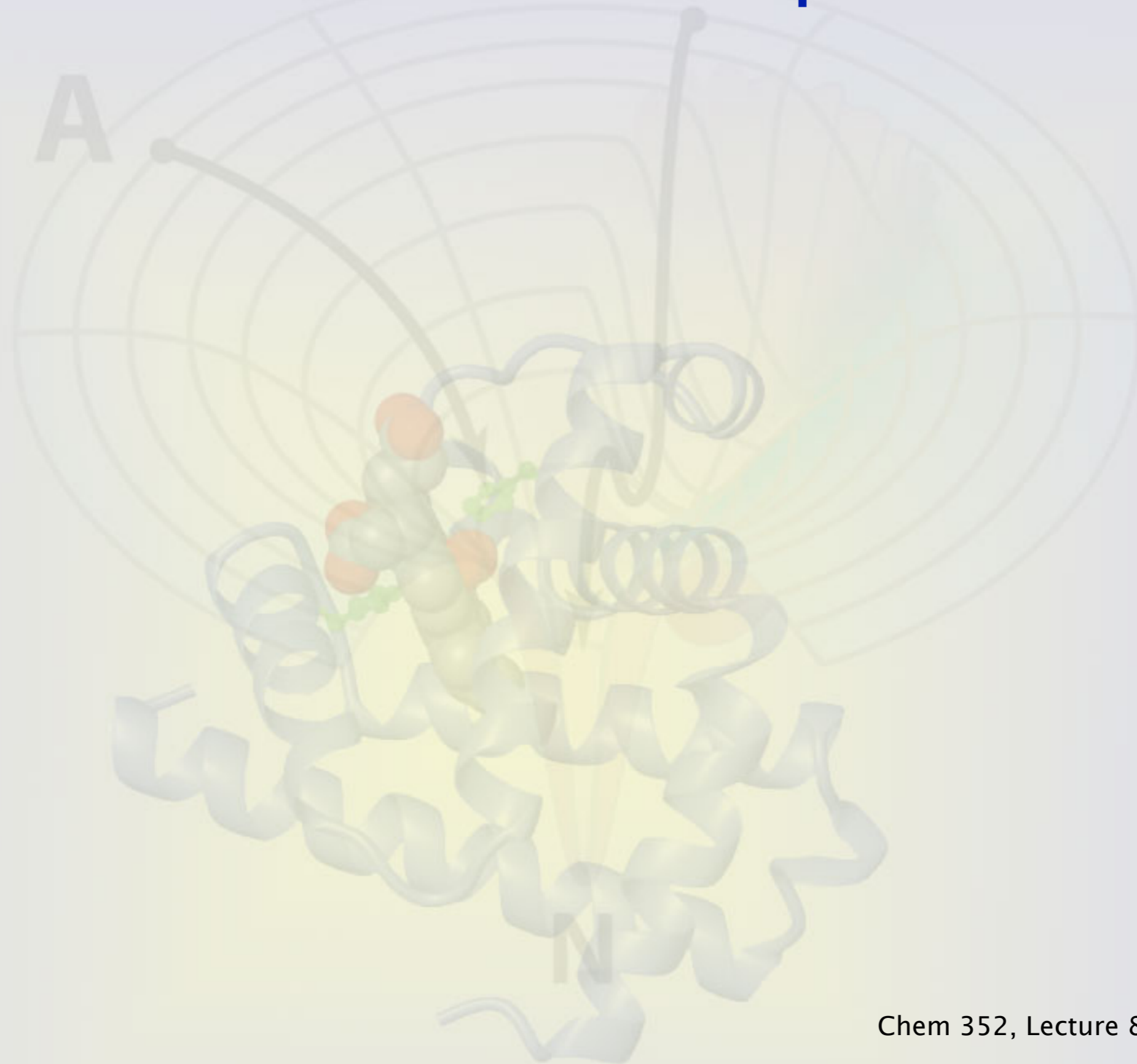
After being proposed nearly fifty years ago, Singer and Nicolson's fluid mosaic model of biological membranes persists, but many new details have been added over the years.



10.4 - Transport Across Membranes

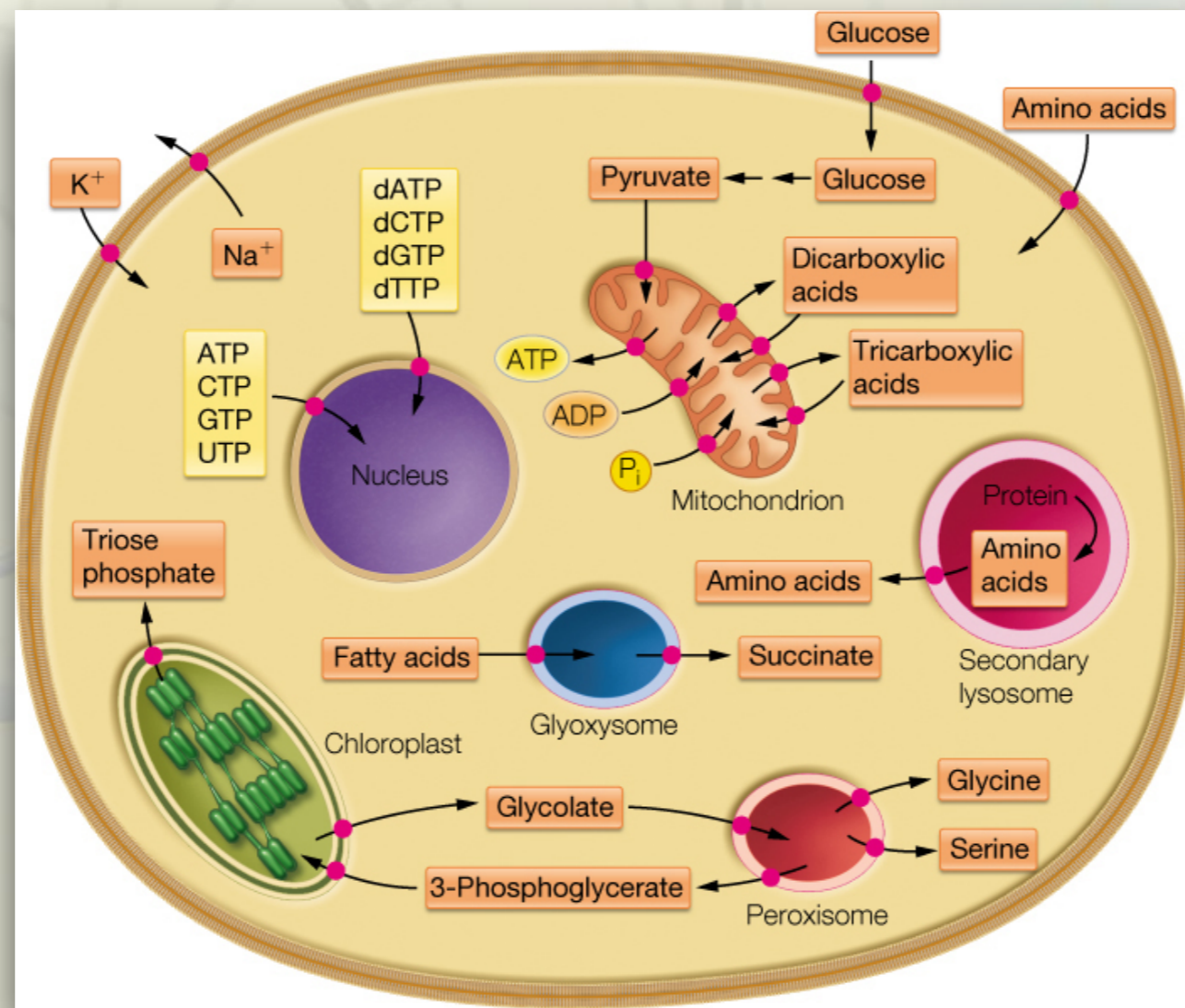


Membrane Transport



Membrane Transport

While biological membranes represent boundaries, they must also provide means for selective transport of materials and information between the regions separated by membranes.



The Thermodynamics of Transport

The Thermodynamics of Transport

The free energy change for transporting a substance across a membrane, will depend on the relative concentrations of that substance on either side of the membrane.

$$\begin{aligned}\Delta G &= \Delta G^{\circ'} + RT \ln Q \\ &= RT \ln K_{eq} + RT \ln \frac{[C_2]}{[C_1]}\end{aligned}$$

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$$\begin{aligned}\Delta G &= \Delta G^{\circ'} + RT \ln Q \\ &= RT \ln K_{eq} + RT \ln \frac{[C_2]}{[C_1]}\end{aligned}$$

♦ At equilibrium, $C_2 = C_1$

$$\Delta G^{\circ'} = -RT \ln K_{eq} = -RT \ln \left(\frac{[C_2]}{[C_1]} \right)_{eq} = -RT \ln(1) = 0$$

$$\Delta G = RT \ln \frac{[C_2]}{[C_1]}$$

The Thermodynamics of Transport

The Thermodynamics of Transport

Membranes often have an electrical potential across them due to differences in the concentration ions on either side of the membrane

- ✦ This membrane potential is represented as

$$\Delta\psi = \psi_{in} - \psi_{out}$$

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- ✦ This membrane potential is represented as

$$\Delta\psi = \psi_{in} - \psi_{out}$$

- ✦ This adds an additional work term to the free energy of transport.

$$\Delta G = RT \ln \frac{[C_2]}{[C_1]} + Z\mathcal{F} \Delta\psi$$

- ✦ where,
 - Z is the charge on the ion being transported
 - \mathcal{F} is Faraday's constant

The Thermodynamics of Transport

The Thermodynamics of Transport

When transport is unfavorable, it needs to be coupled to a reaction or process that is favorable.

- ✦ This is referred to as *active transport*

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- ✦ For the favorable reaction or process

$$\Delta G = \Delta G^{\circ'} + RT \ln Q$$

The Thermodynamics of Transport

When transport is unfavorable, it needs to be coupled to a reaction or process that is favorable.

- ✦ This is referred to as *active transport*
- ✦ For the favorable reaction or process

$$\Delta G = \Delta G^{\circ'} + RT \ln Q$$

- ✦ When this is coupled to the unfavorable transport, the expression becomes

$$\Delta G = \Delta G^{\circ'} + RT \ln \frac{Q[C_2]}{[C_1]} + Z\mathcal{F} \Delta\psi$$

Nonmediated or Simple Transport

Nonmediated or Simple Transport

This is when a substance moves across a membrane due to simple diffusion.

- ✦ The rate of transport, J , will depend on the concentration difference and the permeability coefficient, P , for the substance.

$$J = -P(C_2 - C_1)$$

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- ✦ The rate of transport, J , will depend on the concentration difference and the permeability coefficient, P , for the substance.

$$J = -P(C_2 - C_1)$$

TABLE 10.6 Permeability coefficients (cm/s) for some ions and molecules through membranes

Ion/molecule	Synthetic Membrane (Phosphatidylserine)	Biological Membrane (Human Erythrocyte)
K ⁺	$< 9 \times 10^{-13}$	2.4×10^{-10}
Na ⁺	$< 1.6 \times 10^{-13}$	10^{-10}
Cl ⁻	1.5×10^{-11}	$1.4 \times 10^{-4*}$
Glucose	4×10^{-10}	$2 \times 10^{-5*}$
Water	5×10^{-3}	5×10^{-3}

Data from M. K. Jain and R. C. Wagner (1980) *Introduction to Biological Membranes*. Wiley, New York.

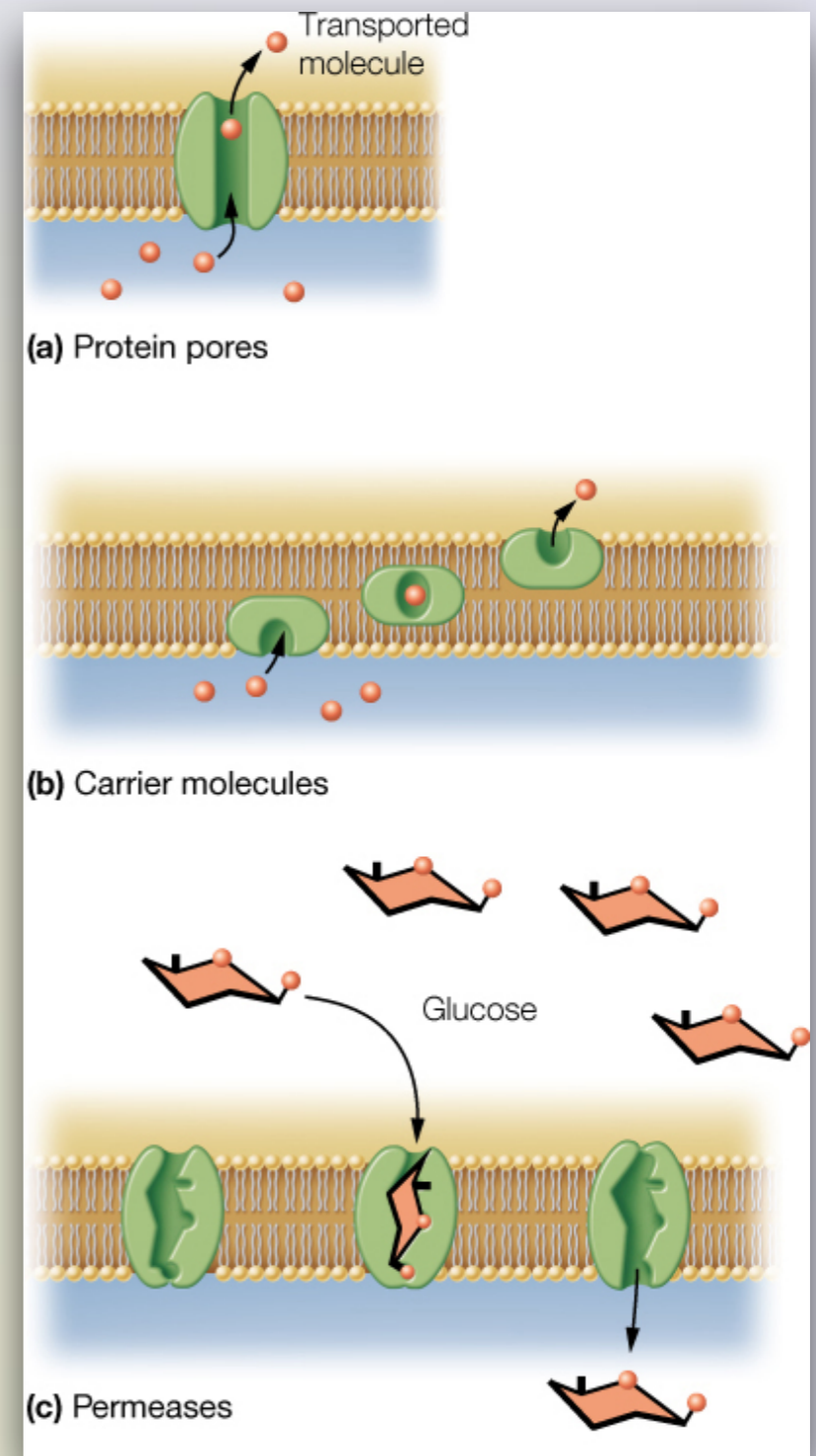
*Facilitated transport. Note that whenever facilitated transport is encountered, the permeability coefficient rises dramatically.

Facilitated Transport

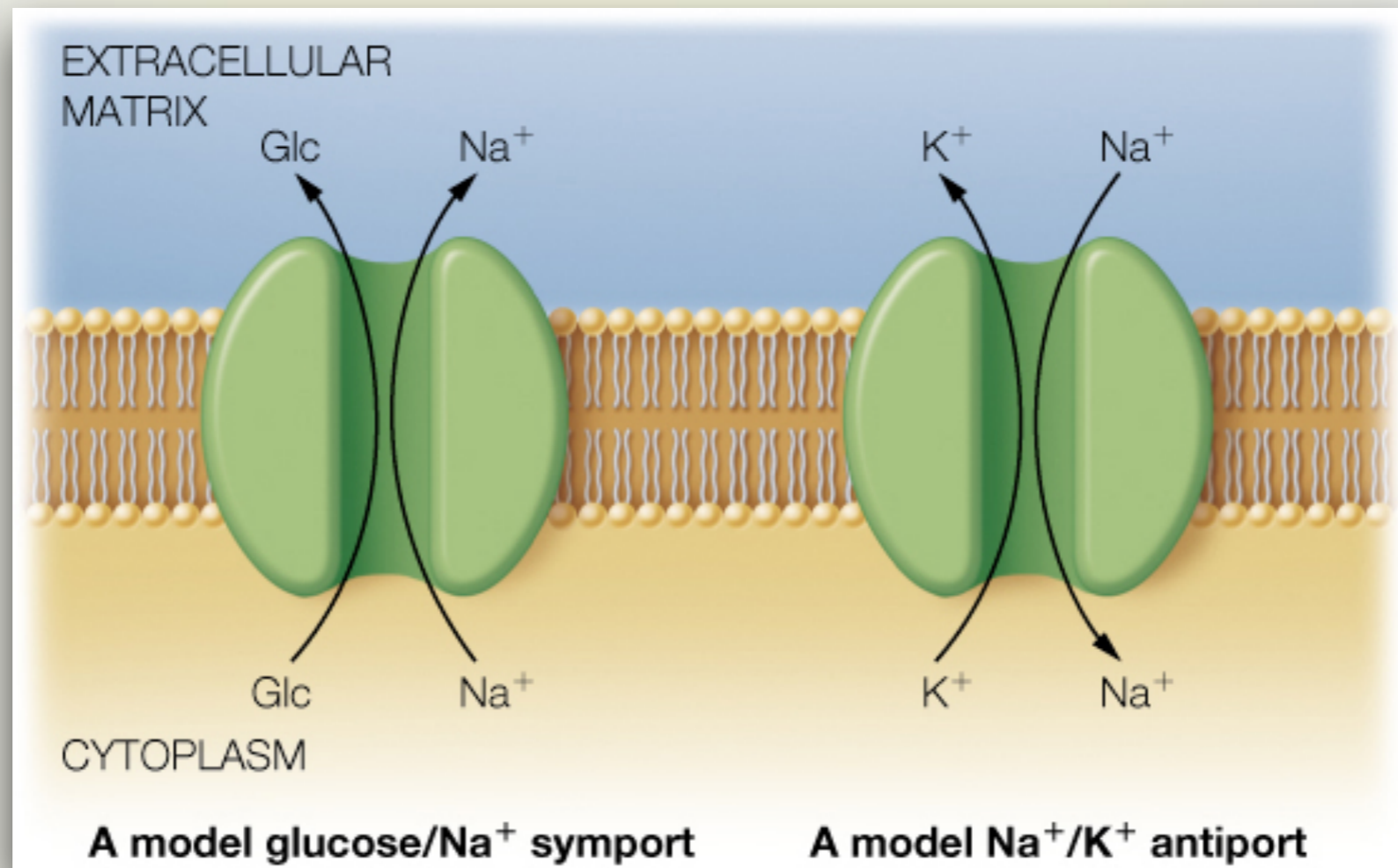
Facilitated Transport

The flow of a substance down a concentration gradient across a membrane can be facilitated.

- ✦ The process is called *passive transport*, because it does not require and additional source of energy.

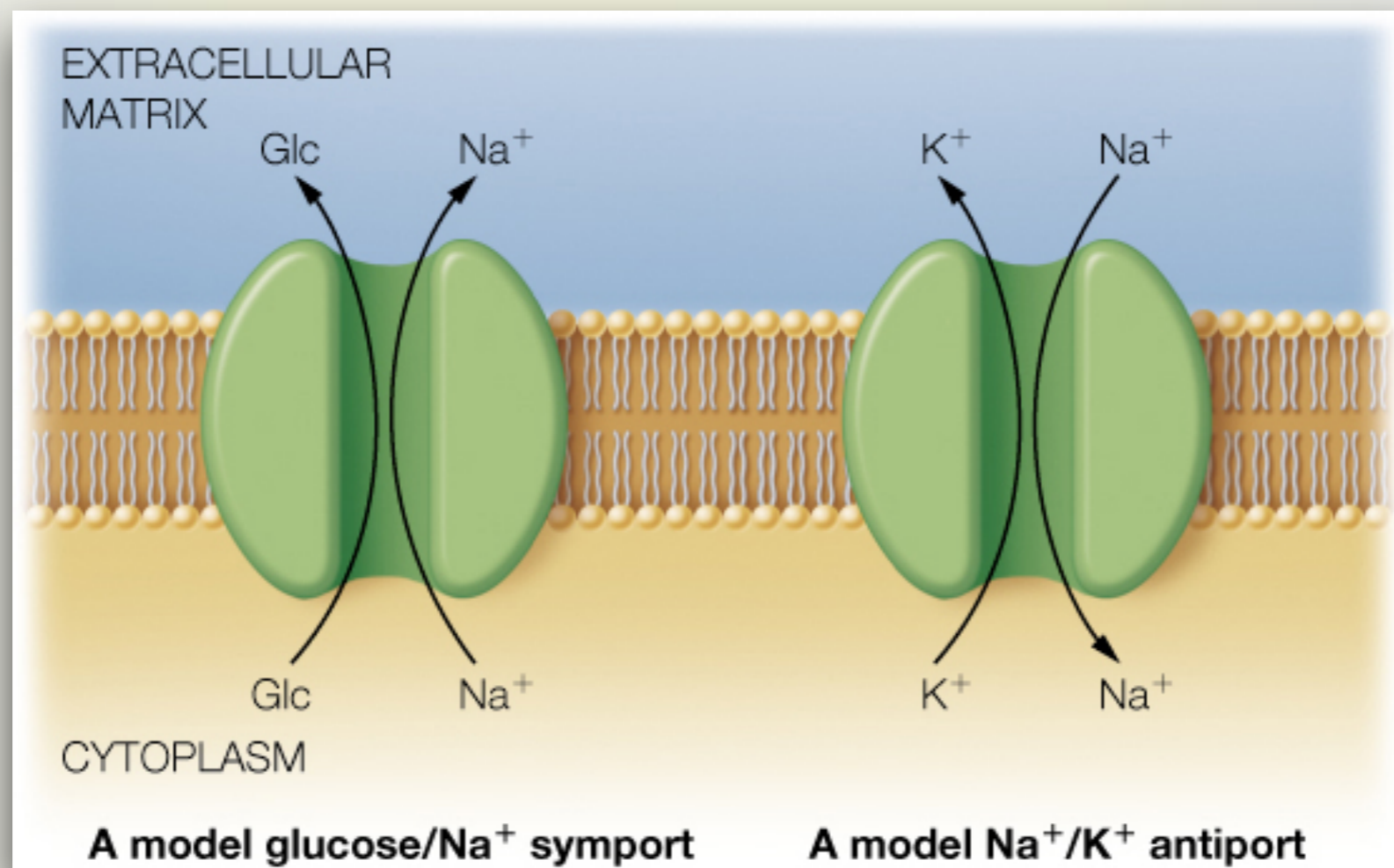


Cotransport



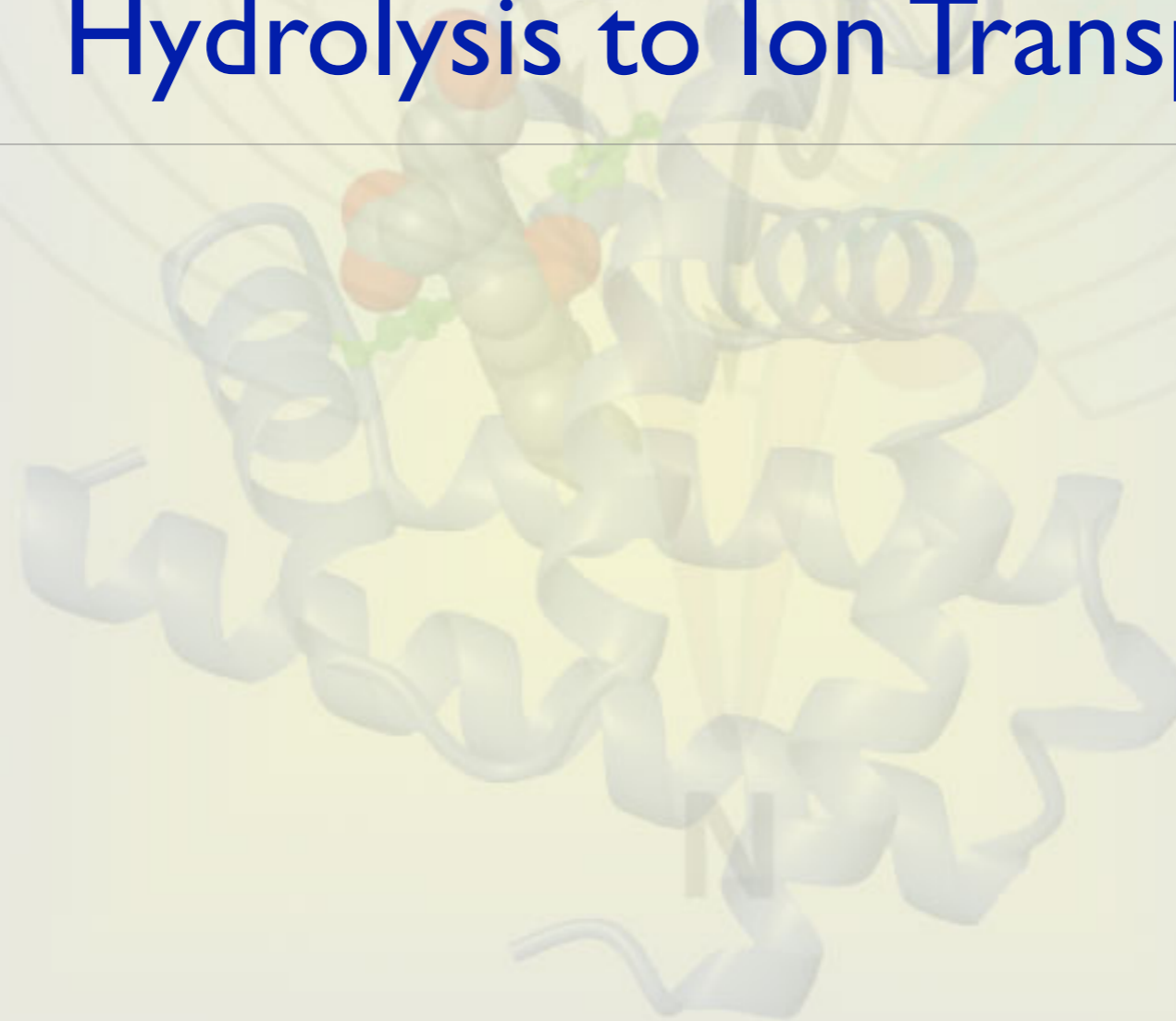
Cotransport

It is possible to transport one substance up a concentration gradient by coupling its transport to another substance that is flowing down a concentration gradient.

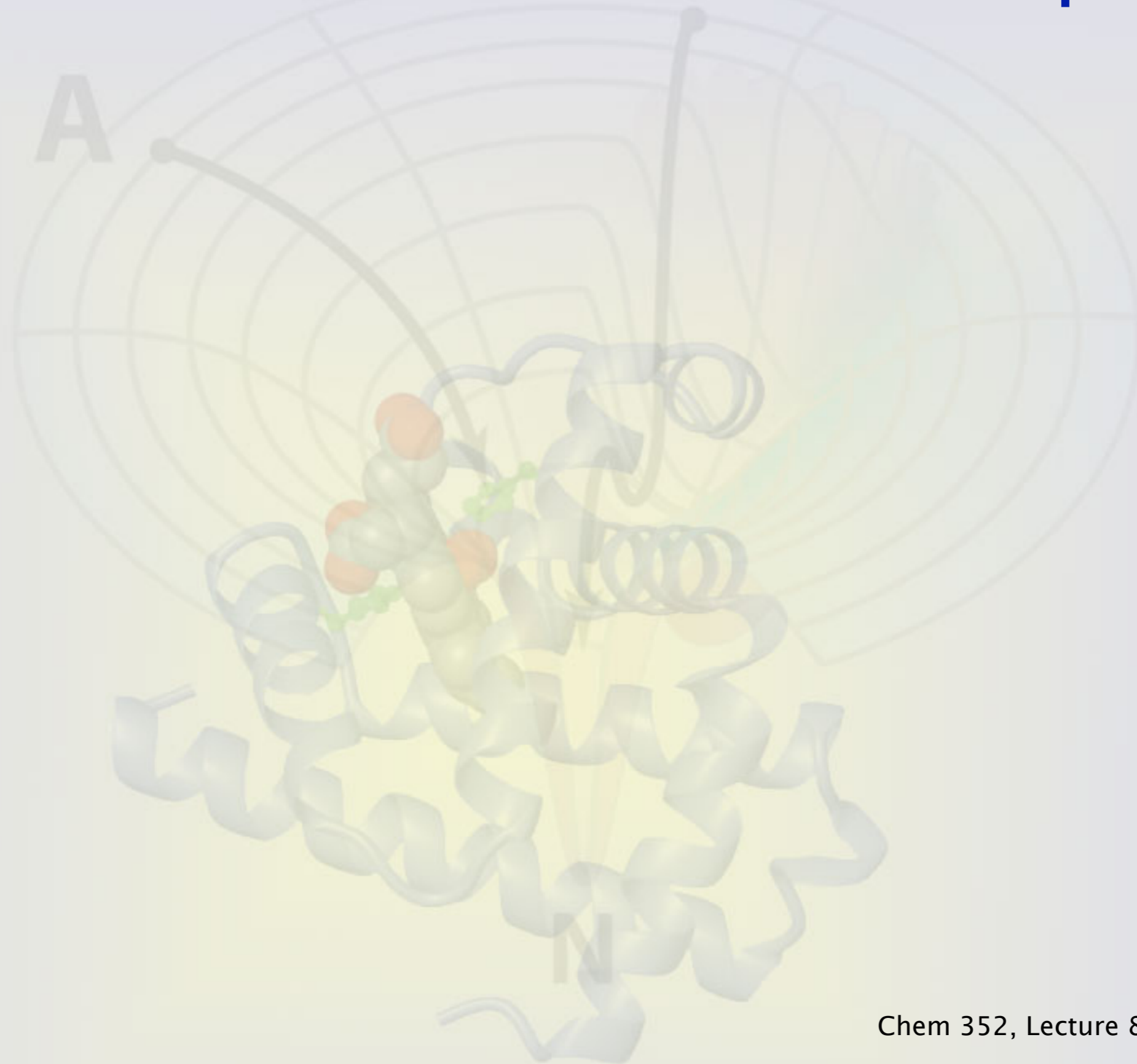


The background features a schematic diagram of an ion pump, likely a Na⁺ pump, embedded in a lipid bilayer. The pump is shown as a grey ribbon structure with a central vertical axis. Two points, 'A' and 'B', are marked on this axis with lines extending to the membrane surface. Point 'A' is on the left side, and point 'B' is on the right side. The diagram illustrates the conformational changes of the pump as it moves ions across the membrane. The text '10.5 - Ion Pumps: Direct Coupling of ATP Hydrolysis to Ion Transport' is overlaid in blue on the left side of the diagram.

10.5 - Ion Pumps: Direct Coupling of ATP Hydrolysis to Ion Transport

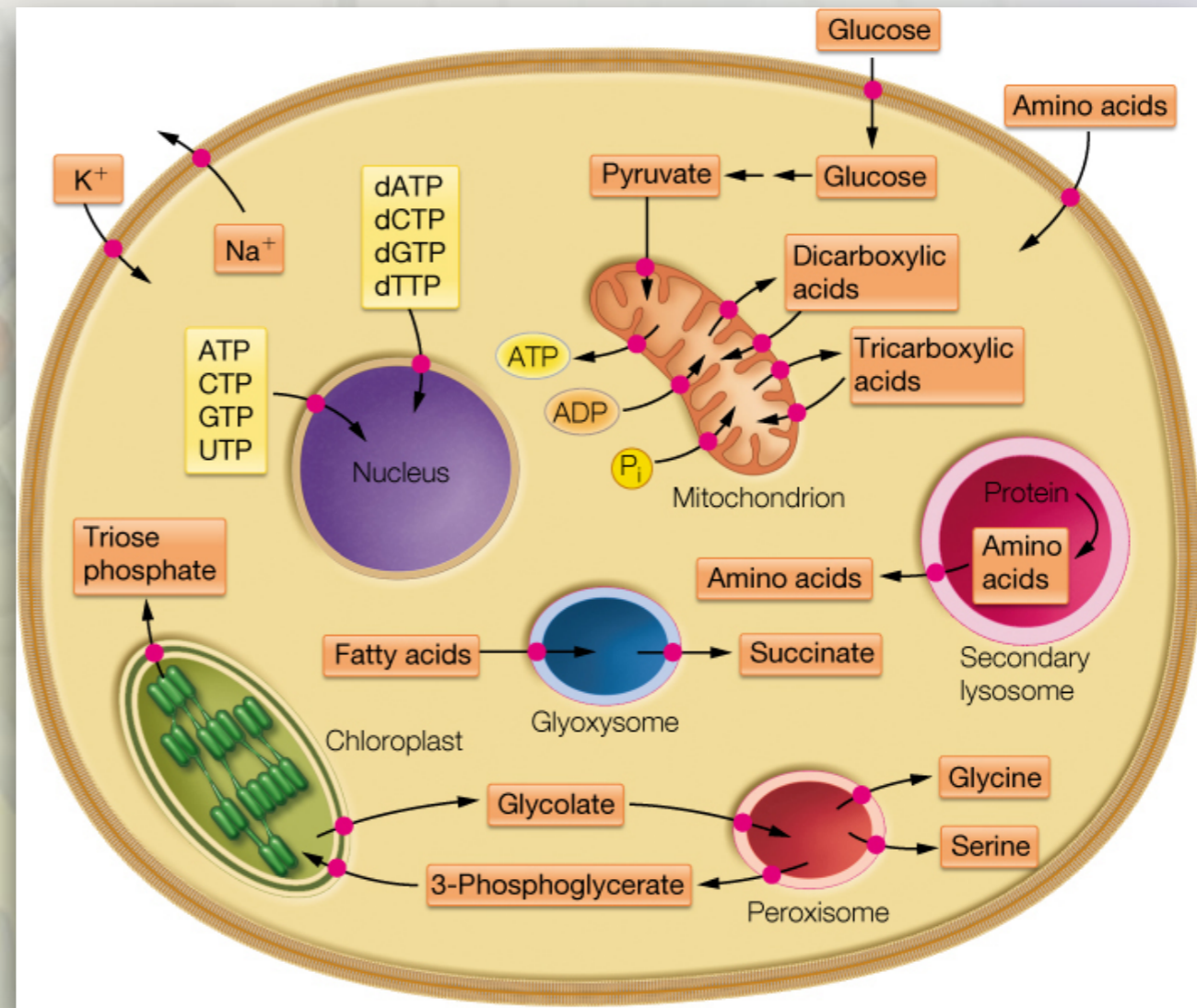


The Sodium-Potassium Pump



The Sodium-Potassium Pump

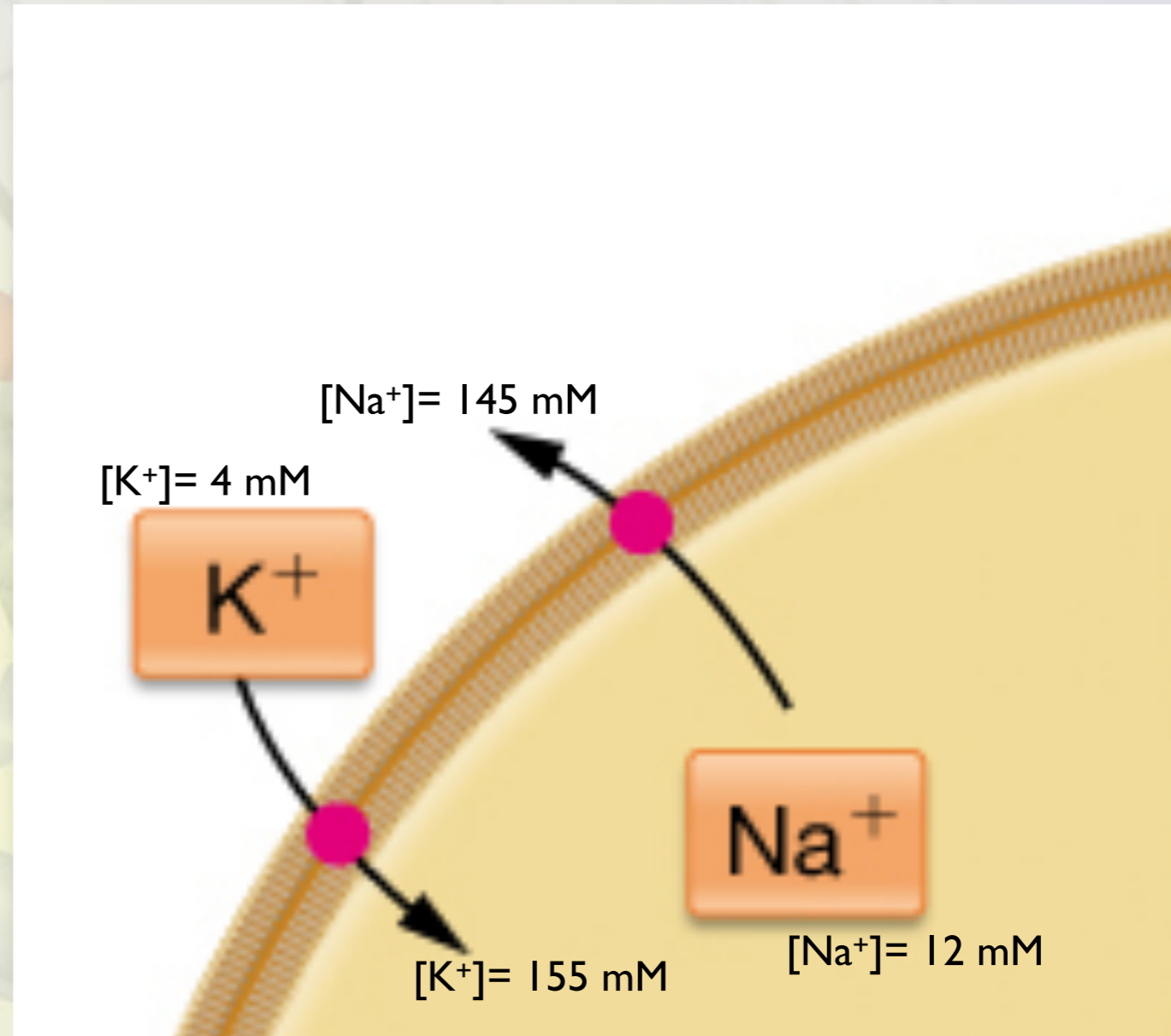
Animal cells maintain a concentration gradient for both Na^+ and K^+ across their cell membranes.



The Sodium-Potassium Pump

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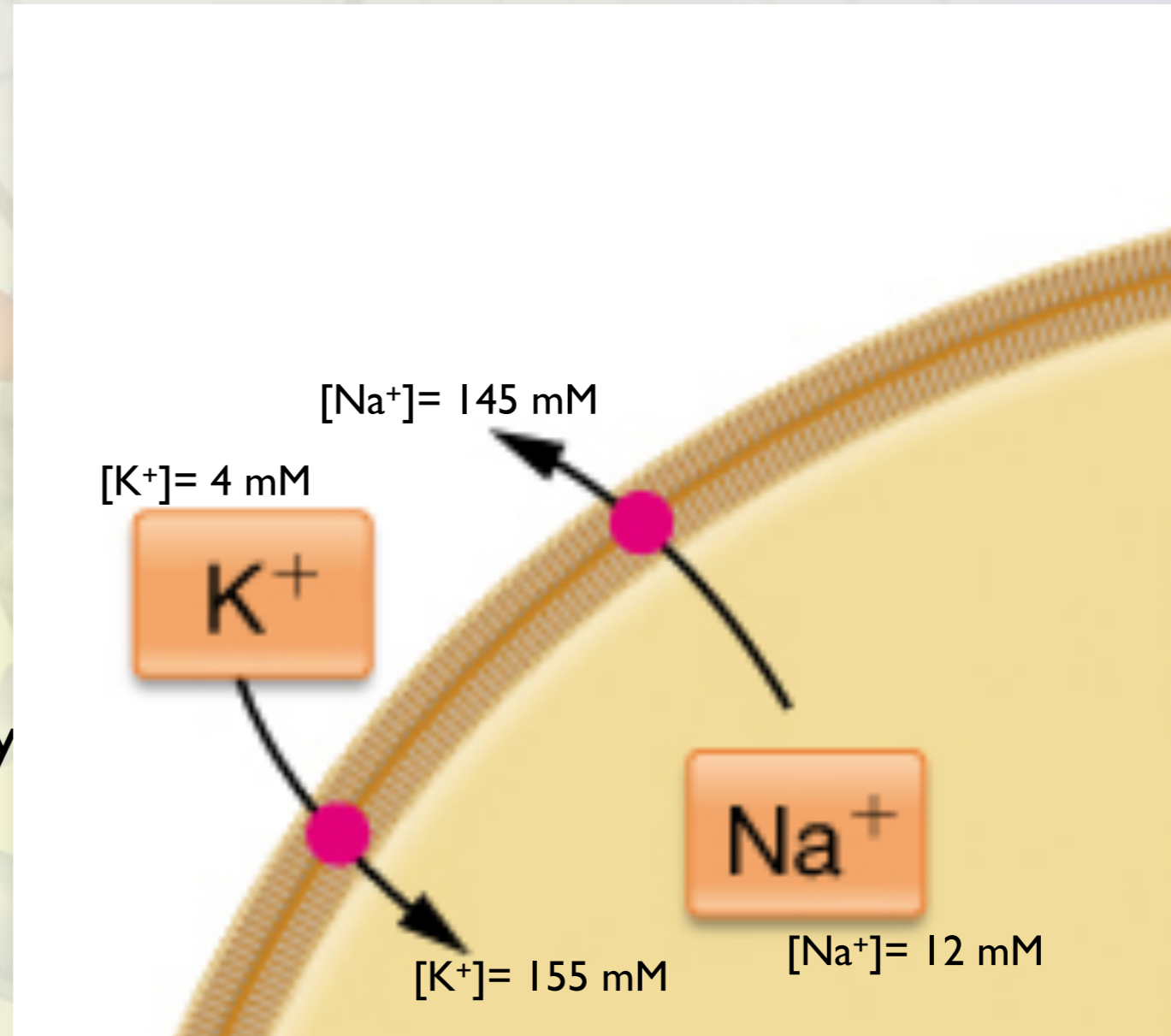
- ✦ Since both ions need to be transported up these gradients, a source of energy is needed to facilitate this *active transport*.



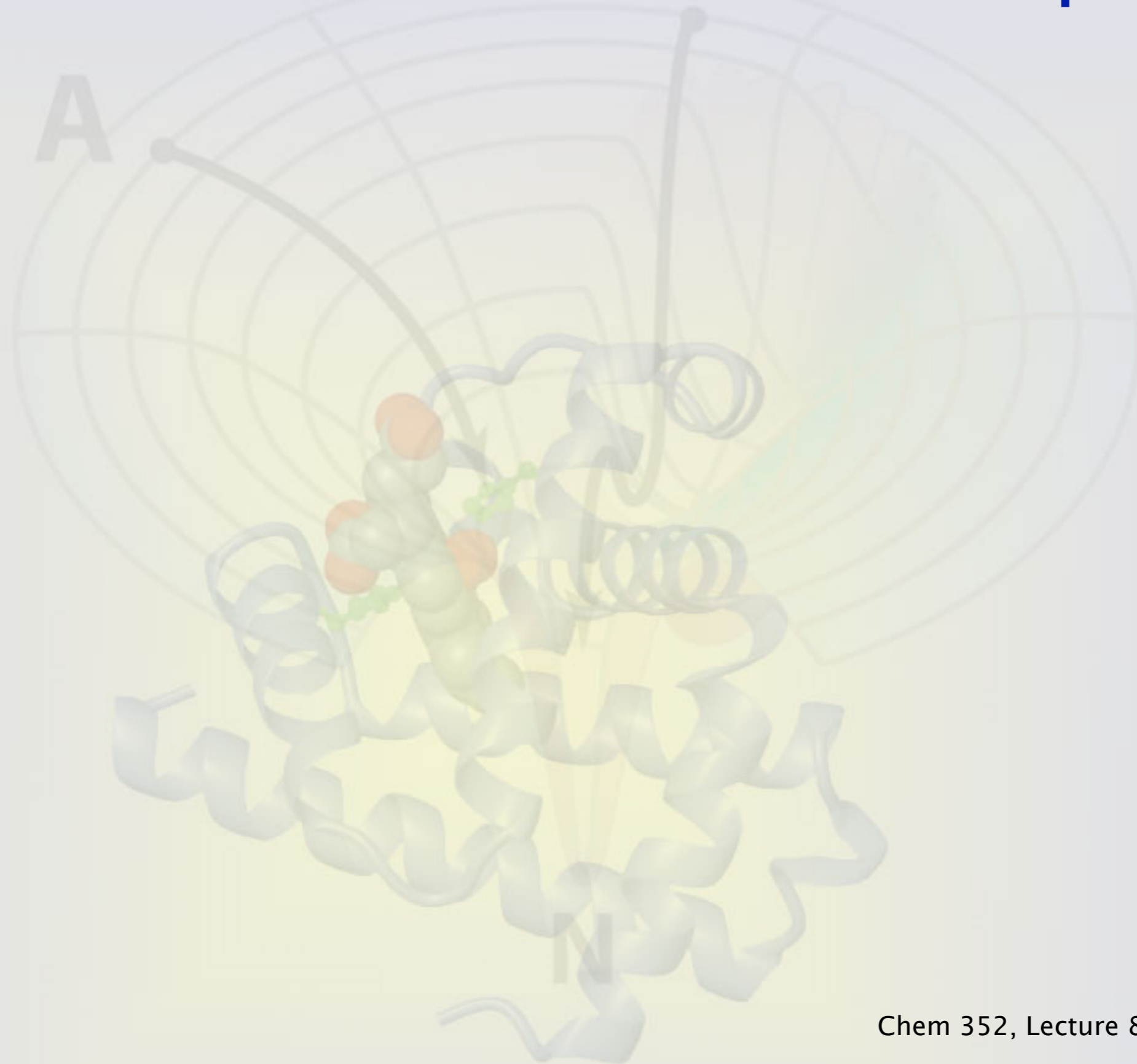
The Sodium-Potassium Pump

Animal cells maintain a concentration gradient for both Na^+ and K^+ across their cell membranes.

- ✦ Since both ions need to be transported up these gradients, a source of energy is needed to facilitate this *active transport*.
- ✦ The source of energy is the hydrolysis of ATP



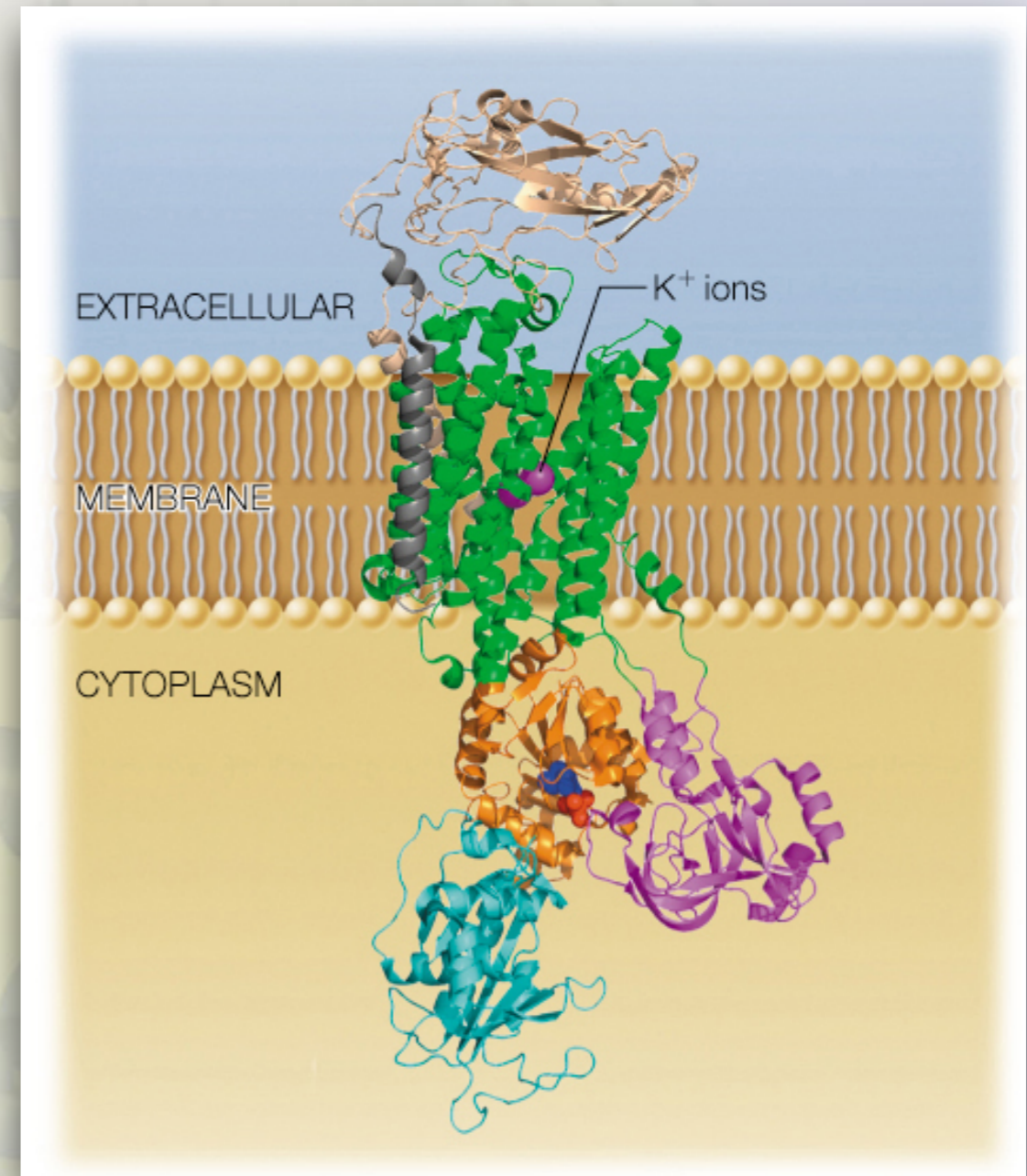
The Sodium-Potassium Pump



The Sodium-Potassium Pump

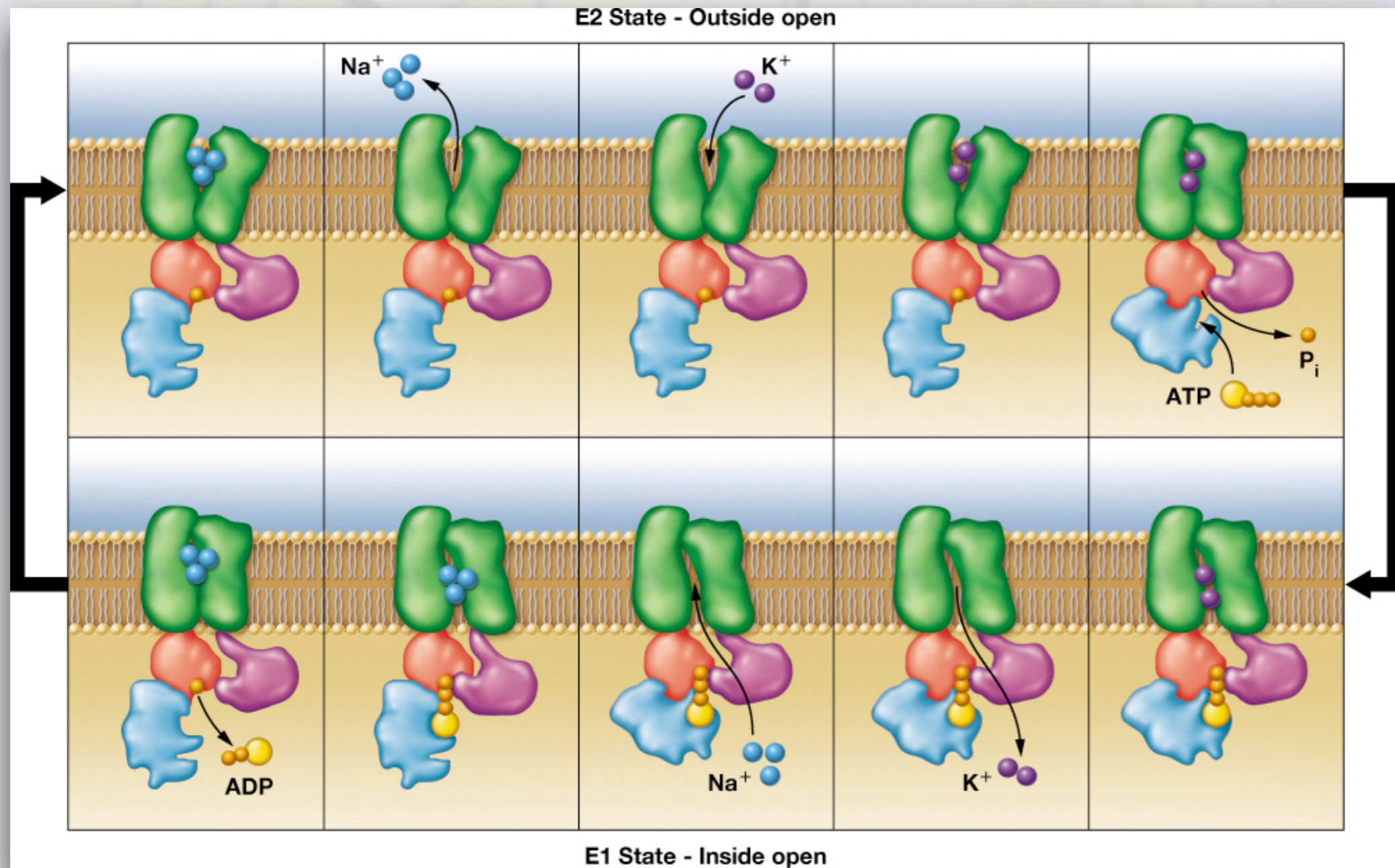
Animal cells maintain a concentration gradient for both Na^+ and K^+ across their cell membranes.

- ✦ The $\text{Na}^+\text{-K}^+$ ATPase pump couples the transport of 3 Na^+ ions out of the cell and 2 K^+ ions into the cell to the hydrolysis of ATP to ADP and P_i .



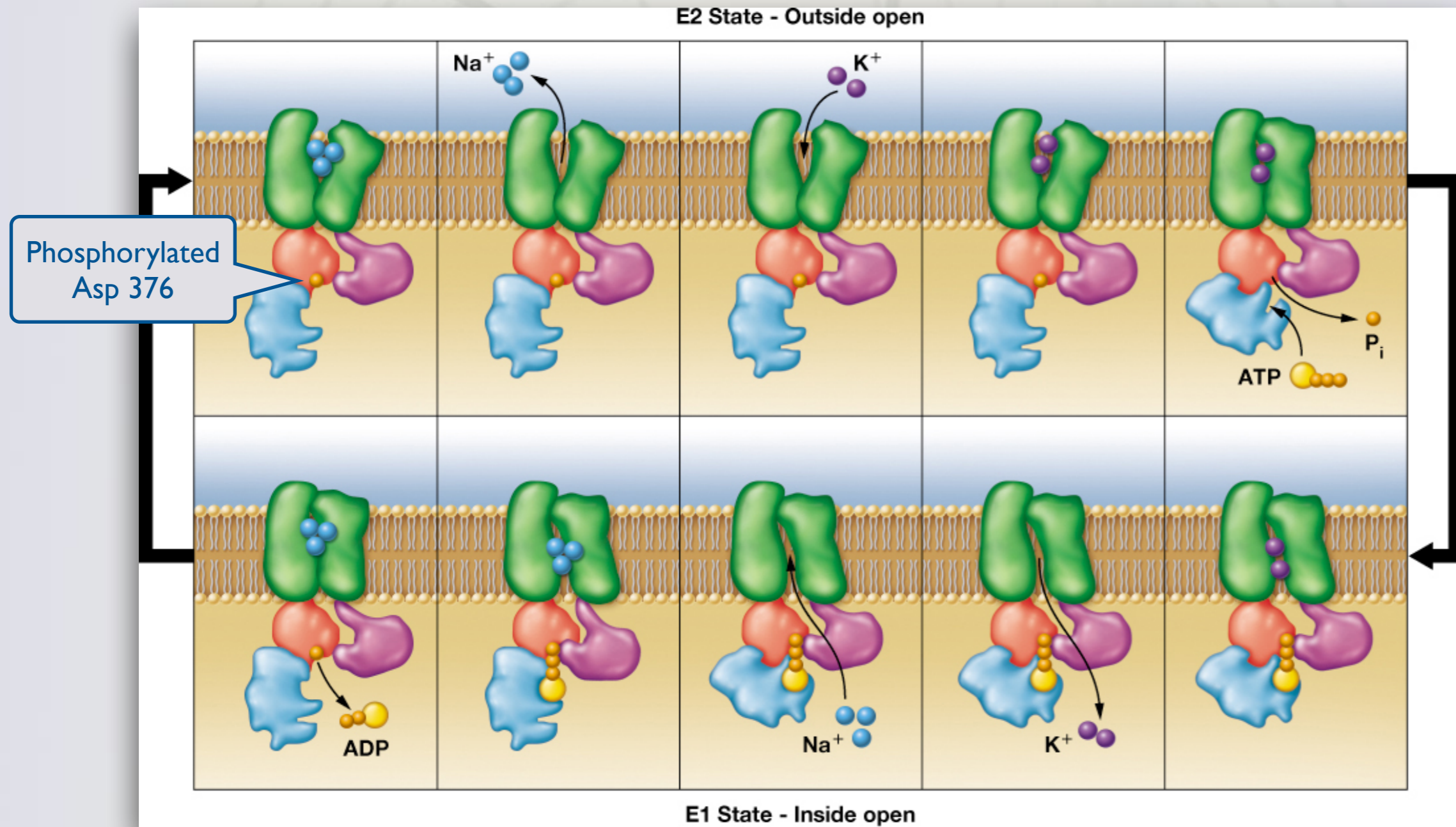
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The Sodium-Potassium Pump

The Sodium-Potassium Pump

Calculating the free energy required to

- ♦ Pump 3 Na⁺ ions up a gradient from 12 mM to 145 mM
- ♦ Pump 2 K⁺ ions up a gradient from 4 mM to 155 mM
- ♦ With a membrane potential of $\Delta\psi_{in \rightarrow out} = \psi_{out} - \psi_{in} = +60 \text{ mV}$

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Per Na⁺ (in→out)

$$\Delta G = RT \ln \frac{[C_{\text{Na}^+}]_{out}}{[C_{\text{Na}^+}]_{in}} + Z_{\text{Na}^+} \mathcal{F} \Delta\psi_{in\rightarrow out}$$

$$\Delta G = \left(0.008314 \frac{\text{kJ}}{\text{mol K}}\right) (310 \text{ K}) \left(\ln \frac{0.145}{0.012}\right) + (+1) \left(96.48 \frac{\text{kJ}}{\text{mol V}}\right) (+0.060 \text{ V}) = +12.2 \frac{\text{kJ}}{\text{mol Na}^+}$$

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Per K⁺ (out→in)

$$\Delta G = RT \ln \frac{[C_{\text{K}^+}]_{in}}{[C_{\text{K}^+}]_{out}} + Z_{\text{K}^+} \mathcal{F} \Delta\psi_{out\rightarrow in}$$

$$\Delta G = \left(0.008314 \frac{\text{kJ}}{\text{mol K}}\right) (310 \text{ K}) \left(\ln \frac{0.155}{0.004}\right) + (+1) \left(96.48 \frac{\text{kJ}}{\text{mol V}}\right) (-0.060 \text{ V}) = +3.6 \frac{\text{kJ}}{\text{mol K}^+}$$

The Sodium-Potassium Pump

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Per 3 mol Na⁺ (in→out) + 2 mol K⁺ (out→in)

$$\Delta G_{total} = (3 \text{ mol Na}^+) \left(+12.2 \frac{\text{kJ}}{\text{mol Na}^+} \right) + (2 \text{ mol K}^+) \left(+12.2 \frac{\text{kJ}}{\text{mol Na}^+} \right) = +43.8 \text{ kJ}$$

The Sodium-Potassium Pump

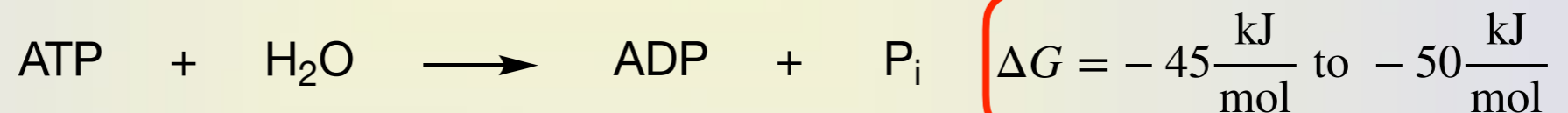
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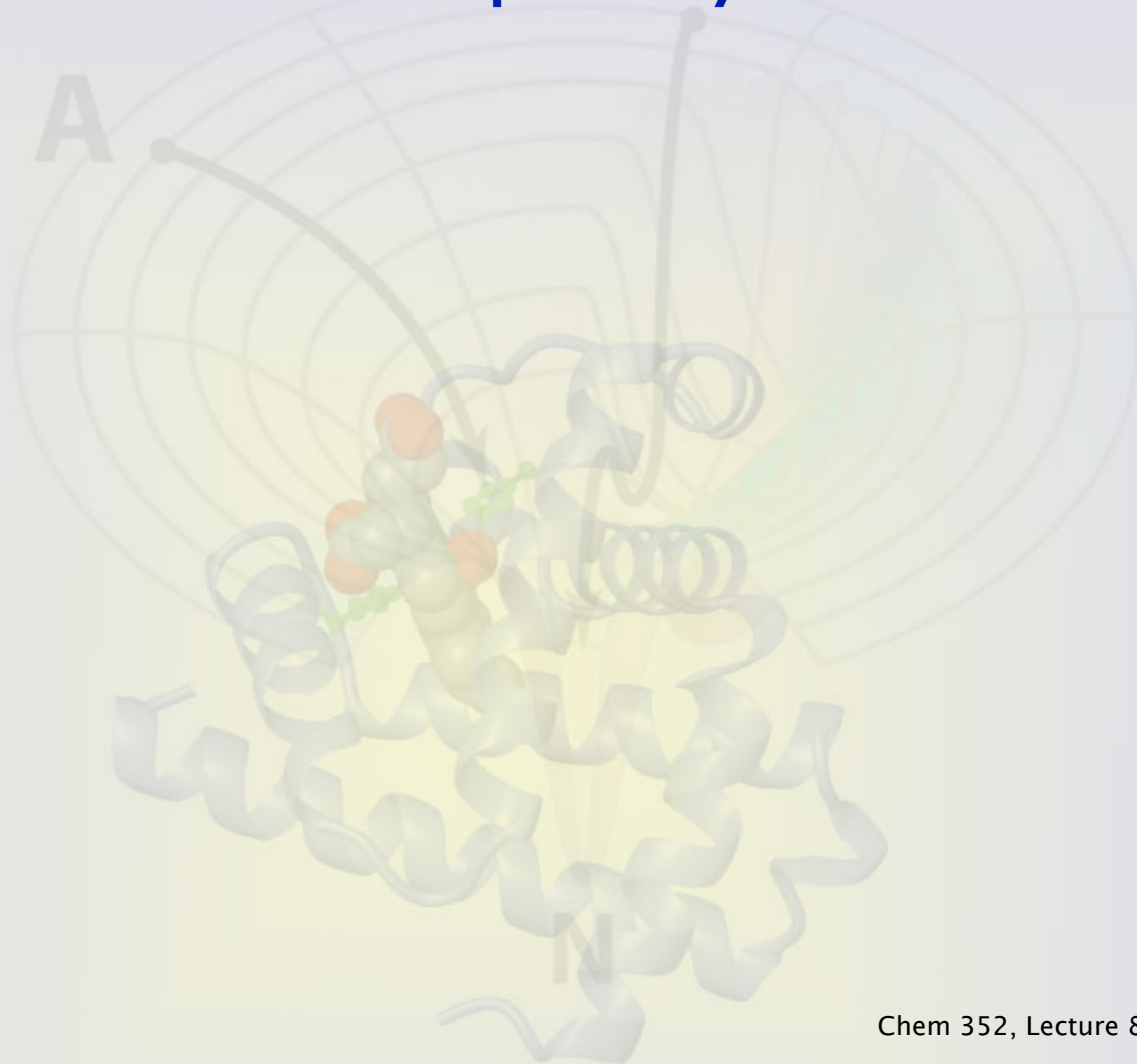
Under cellular conditions, the hydrolysis of 1 mol of ATP to ADP + P_i releases -45 to -50 kJ of free energy



10.5 - Cotransport Systems



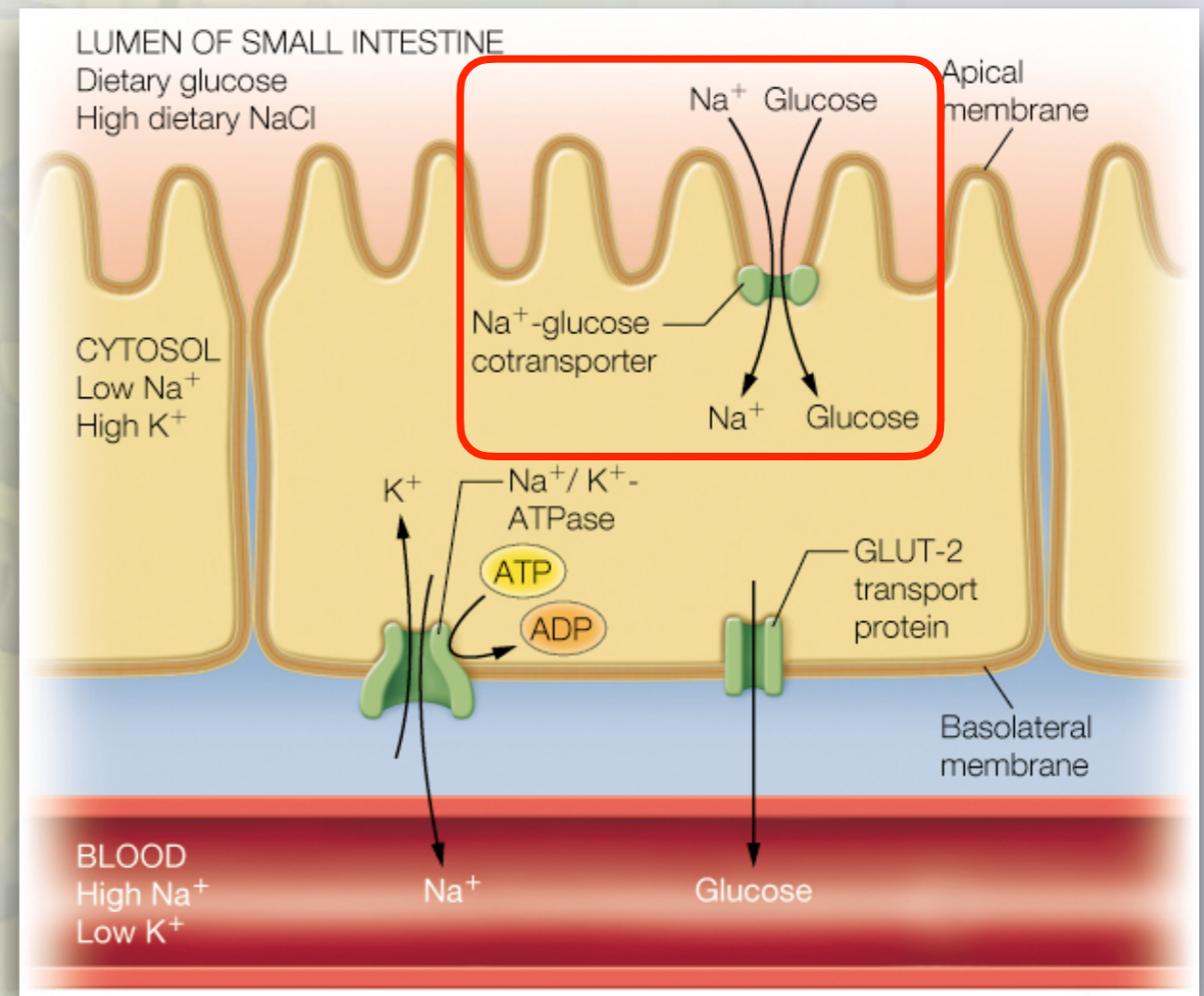
Cotransport Systems



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Another strategy for *active transport* is to couple the transport one substance up a concentration gradient by coupling that transport to the movement of another substance down a concentration gradient.

- ♦ The sodium-glucose cotransport system of the small intestine provides an example.



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Another strategy for *active transport* is to couple the transport one substance up a concentration gradient by coupling that transport to the movement of another substance down a concentration gradient.

- ♦ The sodium-glucose cotransport system of the small intestine provides an example.
- ♦ A low concentration of Na^+ is maintained in the epithelia cells by the Na^+ - K^+ -ATPase pump

