ANSC (NUTR) 618
LIPIDS & LIPID METABOLISM
Membrane Lipids and Sphingolipidsd

I. Classes of membrane lipids

A. Glycerolipids (quantitatively the most important of the three membrane lipids)

B. Shingolipids

C. Cholesterol/sterols

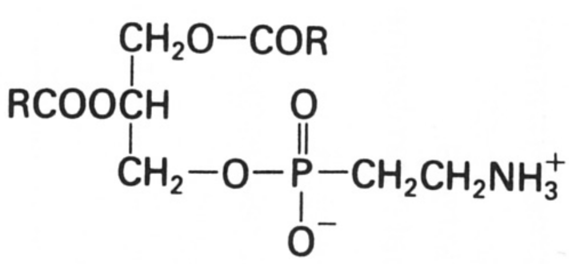
II. Glycerolipids

A. Definition

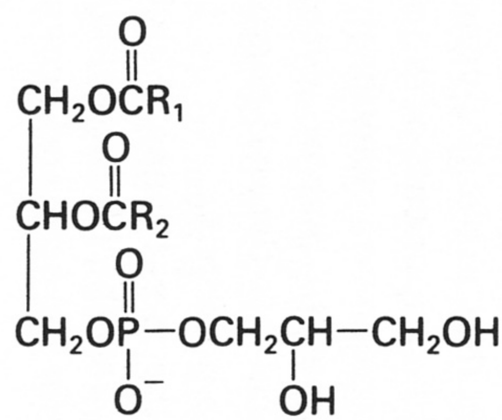
1. Glycerolipids are amphiphilic molecules (i.e., contain polar and nonpolar portions).
2. Glycerol comprises the backbone.
3. Polar molecules are restricted to the *sn*-3 position.

B. Types

1. Phosphoglycerides (i.e., phospholipids), the most abundant glycerolipids ***in animals***.
   a. Phosphatidylcholine (lecithin), most abundant animal phospholipid
   b. Phosphatidylethanolamine
   c. Phosphatidylserine
   d. Phosphatidylinositols
   e. Phosphatidylglycerols (containing a second glycerol at *sn*-3) are the most abundant **phospholipids *in nature***.



Phosphatidylethanolamine



Phosphatidylglycerol

2. Synthesis of phospholipids

a. Phosphatidic acid (PA) is formed from glycerol-3-phosphate and two fatty acyl-coenzyme A.

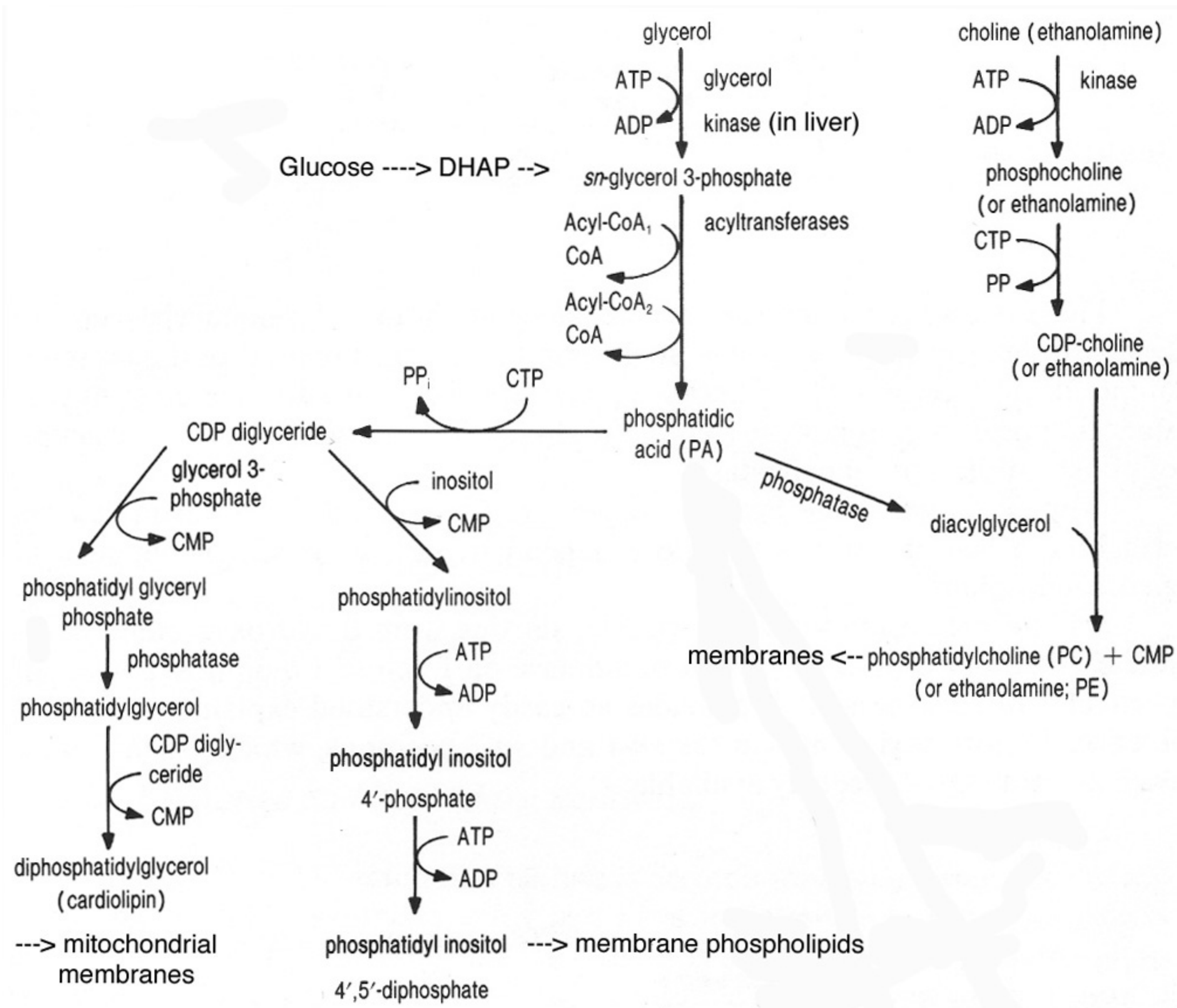
b. PA can be dephosphorylated by phosphatidate phosphohydrolase to form 1,2-DAG (which also can be converted to TAG).

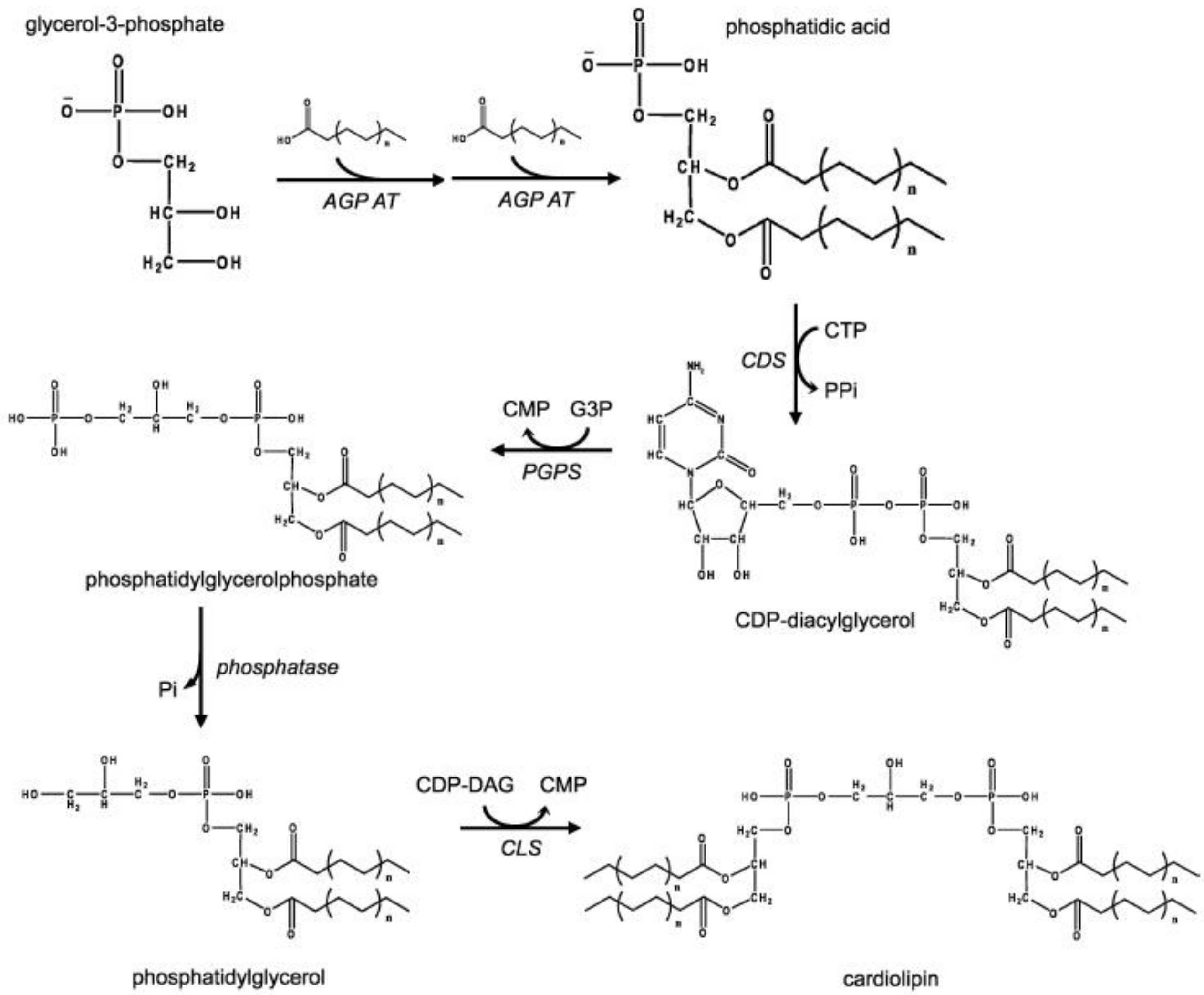
c. PA can react with cytosine triphosphate (CTP) to form CDP-glyceride.

1) CDP-glyceride can react with inositol to ultimately form phosphatidyl inositol.

2) CDP-glyceride can react with glycerol-3-phosphate to ultimately form phosphatidylglycerol and then cardiolipin (abundant in inner mitochondrial membranes).

d. 1,2-Diacylglycerol can react with CDP-choline to form phosphatidyl choline.





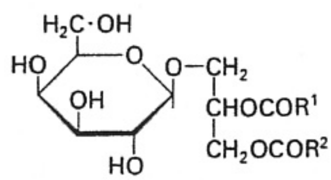
3. Glycoglycerides (i.e., **glycolipids**) are the most abundant **glycerolipids** ***in nature***.
   a. *sn*-3 carbon contains galactose in most plants.
   b. Especially abundant in plant leaves and algae (chloroplasts; this is why they are the most abundant in nature).
   c. "16:3-plants" are enriched with $16:3\Delta^{6,9,12}$, but also high in $18:3\Delta^{9,12,15}$.
   d. "18:3-plants" are enriched with $18:3\Delta^{9,12,15}$, with no $16:3\Delta^{6,9,12}$.

Fatty acid compositions of glycosylglycerides in two plants

Plant leaf		(% total fatty acids) 16:0	16:3	18:1	18:2	18:3
Spinach ('16:3-plant')	MGDG	trace	25	1	2	72
	DGDG	3	5	2	2	87
	SQDG	39	–	1	7	53
Pea ('18:3-plant')	MGDG	4	–	1	3	90
	DGDG	9	–	3	7	78
	SQDG	32	–	2	5	58

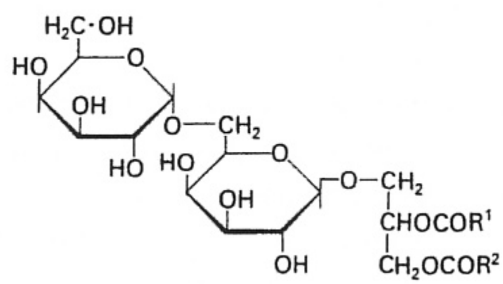
'16:3-plants' contain hexadecatrienoate in their monogalactosyldiacylglycerol while '18:3-plants' contain α-linolenate instead. The reason for this is provided by the differences in fatty acid metabolism between these two types of plants.

Monogalactosyl-diacylglycerol (MGDG)



1,2-diacyl-[β-D-galactopyranosyl-(1′→3)-*sn*-glycerol

Digalactosyl-diacylglycerol (DGDG)



1,2-diacyl-[α-D-galactopyranosyl-(1′→6′)-β-D-galactopyranosyl-(1′→3)]-*sn*-glycerol

C. Composition of membranes

1. Animal membranes are enriched with phospholipids, but contain some glycolipid.
2. Plant membranes are enriched with glycolipids, but contain some phospholipid (especially phosphatidylglycerol).
3. Chloroplasts usually contain large amounts of 18:3n-3 (sn-1) and 16:0 (sn-2).

Table 6.2 Lipid composition of different membranes

	Membrane (% total lipid)				
	Chloroplast (spinach)	Protoplast (*B. megaterium*)	Mitochondrion (rat)	Erythrocyte (rat)	Myelin (rat)
Lipid:protein (wt/wt)	1:1	1:3	1:3	1:3	3:1
Phospholipid	12	48	90	61	41
PC	tr	0	40	34	12
PE+PI+PS	tr	19	41	11	26
PG	12	26	–	–	–
DPG	–	3	7	–	–
SPH	–	–	2	16	3
Glycolipid	80	52	–	11	42
MGDG	41	–			
DGDG	23	–			
SQDG	16	–			
Sterol, sterol ester	tr	0	tr	28	17
Acylglycerols	–	–	10	–	–
Pigments	8	–	–	–	–

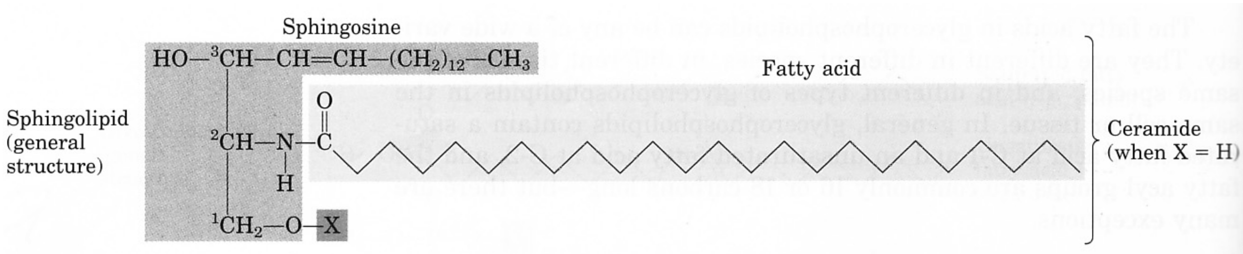
PC = phosphatidylcholine; PE = phosphatidylethanolamine; PS = phosphatidylserine; PG = phosphatidylglycerol; SPH = sphingomyelin; MGDG = monogalactosyldiacylglycerol; DGDG = digalactosyldiacylglycerol; SQDG = sulpholipid; DPG = diphosphatidylglycerol; tr = trace. The glycolipids in rat membranes are sphingolipids.

III. Sphingolipids

A. Definition

1. Base = sphingosine (long-chain amino alcohol), **synthesized from palmitic acid and serine**
   a. Sphingosine is similar to glycerol, but contains a long-chain fatty acid at carbon #3.
   b. The fatty acid at carbon #3 is a C—C linkage.
2. Contain one molecule of a fatty acid at carbon #2 in an amide linkage (alkali-stable, from serine).
3. Have a polar head group at the #1 carbon
   a. Ceramide = sphingosine with an alcohol group at carbon #1 and a fatty acid in amide linkage at carbon #2
   b. Sphingomyelins contain phosphocholine or phosphoethanolamine at carbon #1 in addition to the fatty acid at carbon #2
   c. Galactosylcerebrosides = sphingosine with galactose residues in 1→ 4 linkage at carbon #1, classified as **glycolipids**. There can be multiple saccharides of differing structures.

d. Gangliosides contain sialic acid at the #1 carbon.



B. Location

1. Sphingolipids are concentrated in neuronal tissues.

2. Small amounts of sphingolipids are located in all membranes.

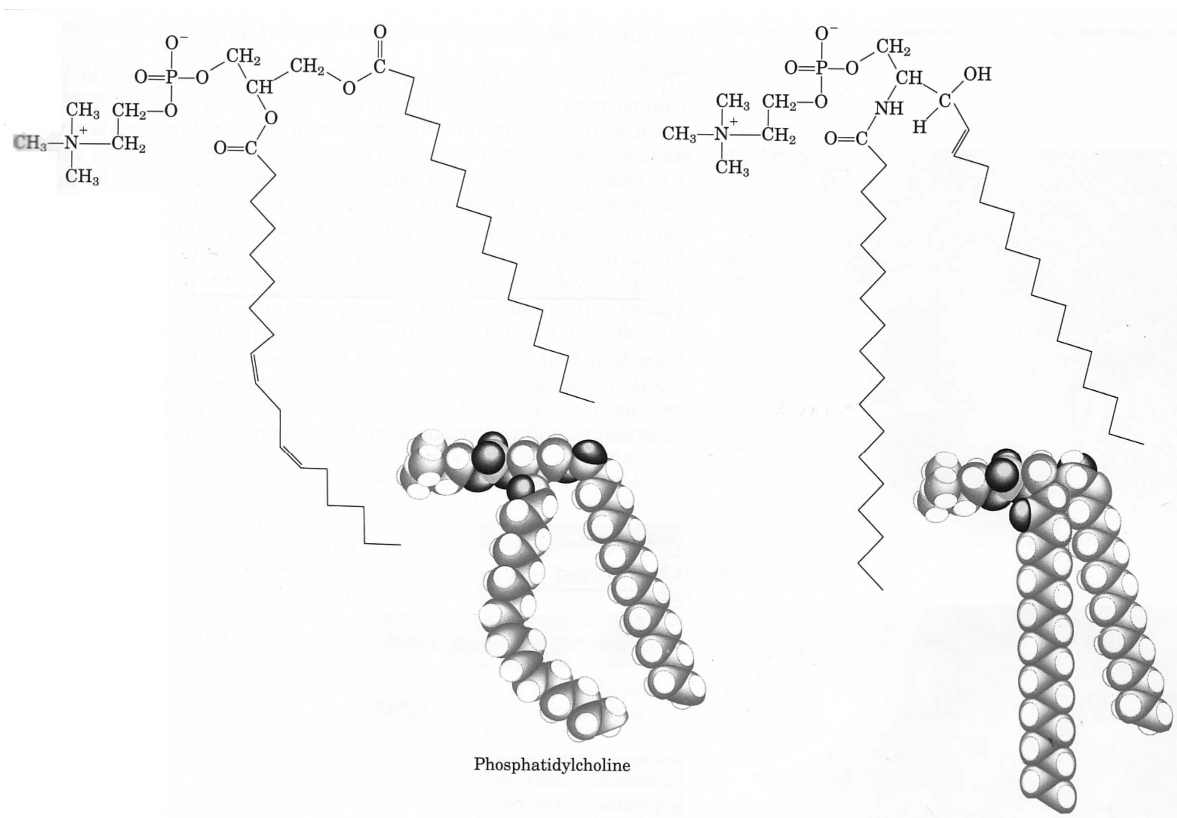


Figure 9–10 The similarities in shape and in molecular structure of phosphatidylcholine (a glycerophospholipid) and sphingomyelin (a sphingolipid) are clear when their space-filling and structural formulas are drawn as here.

IV. Sterols in membranes (all have cholesterol-like structures)

A. Cholesterol (animals)

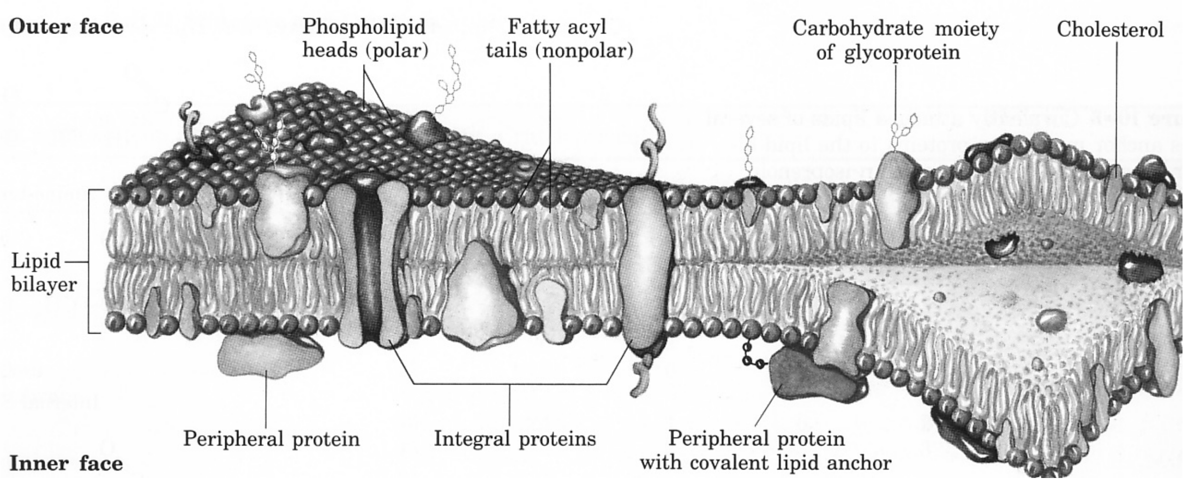
B. Egosterol (yeast)

C. Stigmasterol and sitosterol (plants)

IV. Membrane structure

A. Fluid mosaic model for membrane structure

1. Membranes are lipid bilayers, which polar heads of phospholipids oriented toward the aqueous environment.
2. Integral and peripheral proteins and cholesterol stud the surface of the membrane.



B. Asymmetry of the lipid bilayer

1. Phosphatidylcholine and sphingomyelin (which contains phosphocholine) are located in the outer surface.
2. Phosphatidylethanolamine, phosphatidylserine, and phosphatidylinositol line the inner surface.

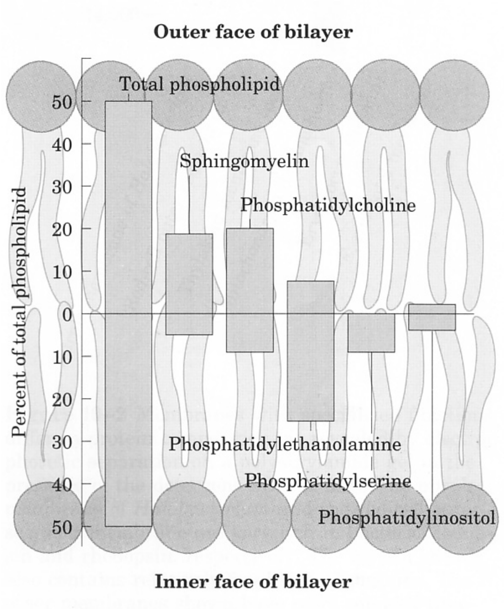
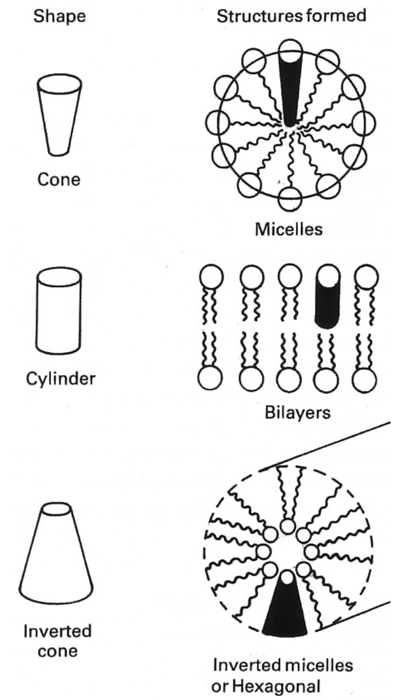
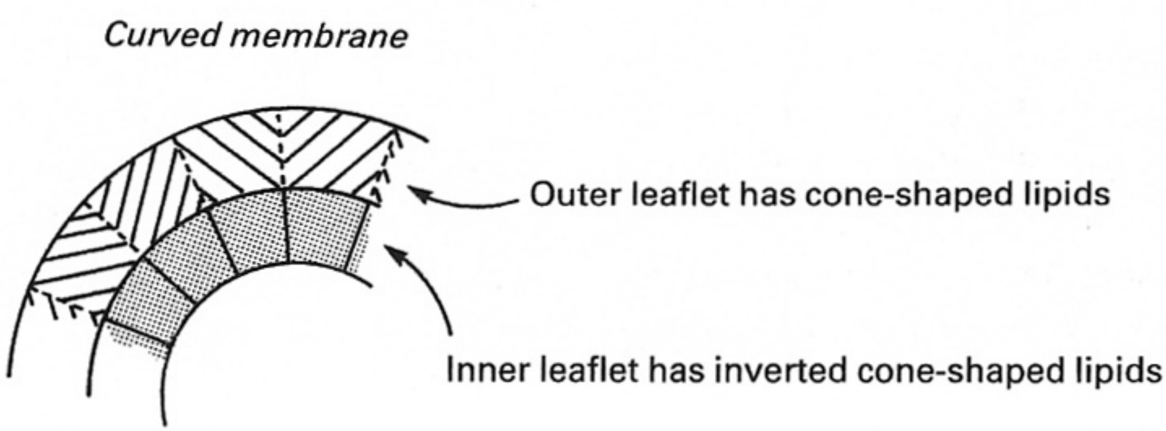


Figure 10–5 The distribution of specific erythrocyte membrane lipids between the inner and outer face is asymmetric.



3. Saturated fatty acids promote cone structures.
   -- An excess of saturated fatty acids in the outside membrane causes pinching of the membrane.
4. Polyunsaturated fatty acids promote inverted cones.
   -- An excess of polyunsaturated fatty acids in the outside membrane causes concavity of the membrane.



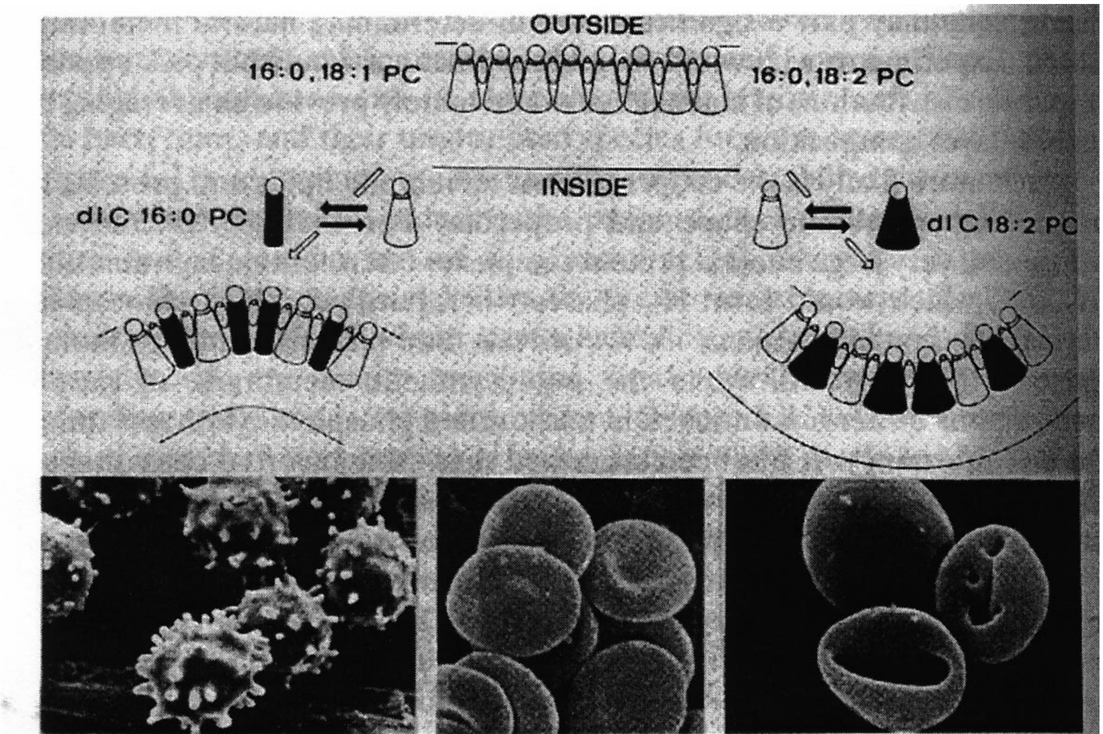


Figure 8.4 The relationship between lipid composition and erythrocyte shape. Reproduced with kind permission of Professor L.L.M. van Deenen and Elsevier Trends Journals, from *Trends in Biochemical Sciences* (1985), p. 322, Figure 3.

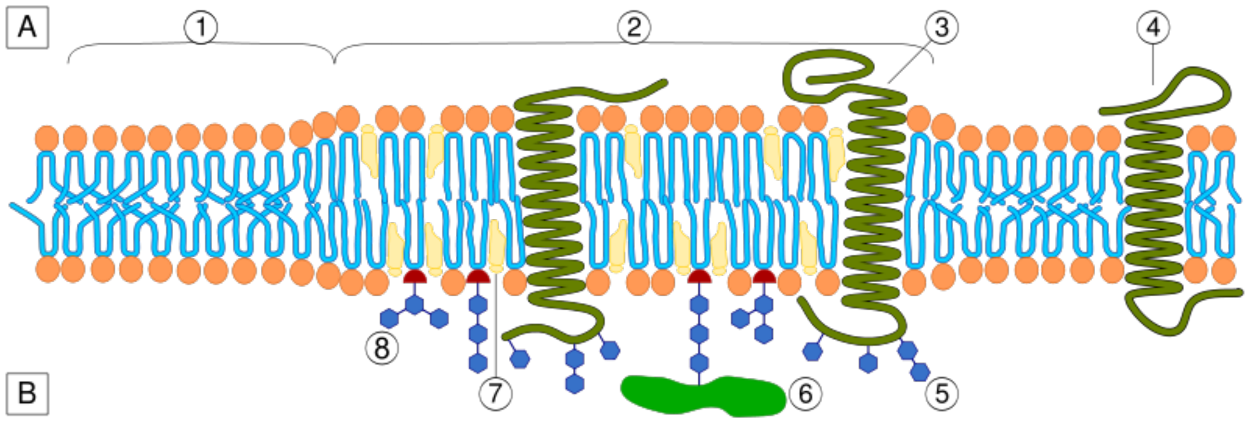
V. Membrane (lipid) rafts in cell membranes

A. Membrane rafts are small (10–200 nm), heterogeneous, highly dynamic, sterol- and sphingolipid-enriched domains that compartmentalize cellular processes.

B. Small rafts can sometimes be stabilized to form larger platforms through protein-protein and protein-lipid interactions

C. Lipid rafts are enriched in glycosphingolipids (ie cerebrosides and gangliosides) and sphingomyelin, mostly consisting of saturated acyl chains resulting in ordering of these domains.

D. Many raft-associated proteins are linked with saturated acyl chains through GPI-anchor (GPI = glycosylphosphatidylinositol) or acylation (palmitoylation or myristoylation).



A = Extracellular domain

B = Intracellulare domain

1 = Non-raft domain

2 = Lipid raft

3 = Lipid raft-associated transmembrane protein

4 = Non-raft membrane protein

5 = Glycosylation modifications on glycoproteins and glycolipids

6 = GPI-anchored protein

7 = cholesterol

8 = Glycolipid

Distribution of fatty acids and cholesterol in membrane lipids and neutral lipids

Muscle	Membrane lipids	Neutral lipids
16:0	24.0	30.1
18:0	11.7	11.4
18:1n-9	32.1	42.3
18:2n-6	12.8	5.0
18:3n-3	1.6	0.1
Cholesterol, mg/100 g	76	23
Adipose tissue		
16:0	23.1	27.3
18:0	12.8	10.9
18:1n-9	34.9	41.9

18:2n-6	0.4	3.3
18:3n-3	5.2	0.1
Cholesterol, mg/100 g	10	90