Biochemistry

Unit 3 · Lipids: Structure and Classification

Lipids are the biomolecules defined by what they dissolve in, not by one shared shape: fats and oils, waxes, phospholipids, sphingolipids, steroids and the short-lived eicosanoids. After this unit you can classify any lipid, name and draw fatty acids, work out saponification and iodine values, explain how membrane lipids differ, and trace cholesterol and arachidonic acid to the hormones and signals made from them.

Taught at 8 of 10 | Usually Sem 3 | 7 chapters

About this unit

This unit is about lipids: what makes a molecule a lipid, how the family is sorted, and what each member does. It starts with the classification that every examiner asks for, then builds upward. Fatty acids (3.2) are the building blocks; joined to glycerol they give fats, oils and waxes (3.3). Swap one fatty acid for a phosphate head group and you get the phospholipids of every membrane (3.4). Replace glycerol with sphingosine and you reach sphingolipids and glycolipids (3.5). Cholesterol and the steroids (3.6) are lipids with no fatty acid at all, and the eicosanoids (3.7) close the unit by turning one membrane fatty acid into fast local signals. How the body makes and burns these molecules is Unit 6.

Chapters

1. Classification of lipids: simple, compound and derived
2. Fatty acids: saturated and unsaturated
3. Triacylglycerols, oils and waxes; saponification
4. Phospholipids: lecithins and cephalins
5. Sphingolipids and glycolipids
6. Cholesterol and steroids
7. Eicosanoids

How to use this book

- Read the lead paragraph and the figure of each chapter first; together they carry the one idea of the chapter.
- Cover the solution of each worked example and do it yourself on paper, with units, before you check.

- Answer every "Check yourself" question in your head or on paper before you open it; the ones you get wrong are your revision list.

3.1 Classification of lipids: simple, compound and derived

Lipids are the biomolecules that do not dissolve in water but dissolve in organic solvents such as chloroform, ether, hexane or benzene. Unlike carbohydrates or proteins, they share no single building block, so they are grouped by what they yield on hydrolysis. The textbook scheme (often called Bloor's classification) gives three groups: simple lipids, which are esters of fatty acids with alcohols; compound lipids, which carry an extra group such as phosphate, sugar or protein; and derived lipids, which are the products of hydrolysing the first two plus other lipid-soluble molecules like cholesterol. This one table of groups is the frame for the whole unit.

What counts as a lipid

A lipid is defined by a property, not a structure. The working definition has three parts. A lipid is insoluble or poorly soluble in water. It is soluble in non-polar organic solvents. It is actually or potentially related to fatty acids, or is used by living cells.

The reason for the solubility is the long hydrocarbon part. A chain of CH_2 groups has no charge and cannot form hydrogen bonds with water, so water pushes these chains together. This is the **hydrophobic effect** (from Unit 1, Water and weak interactions). Many lipids also have a small polar part, such as a carboxyl group or a phosphate head. Such a molecule, with one water-loving end and one water-fearing end, is called **amphipathic**. Amphipathic lipids build membranes; purely non-polar lipids such as triacylglycerols are stored as droplets.

Lipids do four main jobs in the cell: they store energy (fats give about twice the energy per gram of carbohydrate), build membranes (phospholipids, sphingolipids, cholesterol), send signals (steroid hormones, eicosanoids) and insulate and protect (subcutaneous fat, waxes on leaves and feathers). They also carry the fat-soluble vitamins A, D, E and K (Unit 4).

The three groups

1. Simple lipids are esters of fatty acids with an alcohol, and nothing else. Hydrolysis gives only fatty acids and the alcohol.

- **Fats and oils**: esters of fatty acids with glycerol, called triacylglycerols (triglycerides). A fat is solid at room temperature (ghee, butter); an oil is liquid (groundnut oil, sunflower oil).
- **Waxes**: esters of long-chain fatty acids with long-chain monohydric alcohols, such as beeswax.

2. Compound (complex, conjugated) lipids are esters of fatty acids with an alcohol plus one more group.

- **Phospholipids**: contain phosphoric acid and usually a nitrogen base. They split into glycerophospholipids (alcohol is glycerol: lecithin, cephalin) and sphingophospholipids (alcohol is sphingosine: sphingomyelin).
- **Glycolipids**: contain a sugar and sphingosine (cerebrosides, gangliosides) or, in plants, glycerol.
- **Lipoproteins**: lipid packed with protein for transport in blood (chylomicrons, VLDL, LDL, HDL).
- **Others**: sulfolipids (sulfate group), aminolipids.

3. Derived lipids are the hydrolysis products of groups 1 and 2, and other molecules that behave like lipids: fatty acids, glycerol and other alcohols, steroids (cholesterol, bile acids, steroid hormones), terpenes and carotenoids, fat-soluble vitamins, eicosanoids, ketone bodies and lipid aldehydes.

Some books add a fourth group, **neutral lipids**, for uncharged lipids such as triacylglycerols, cholesterol and cholesteryl esters. This is a property-based label that cuts across the three groups; it is not a separate structural class. General Classification of lipids", and its later topics follow the same simple–compound–derived order.

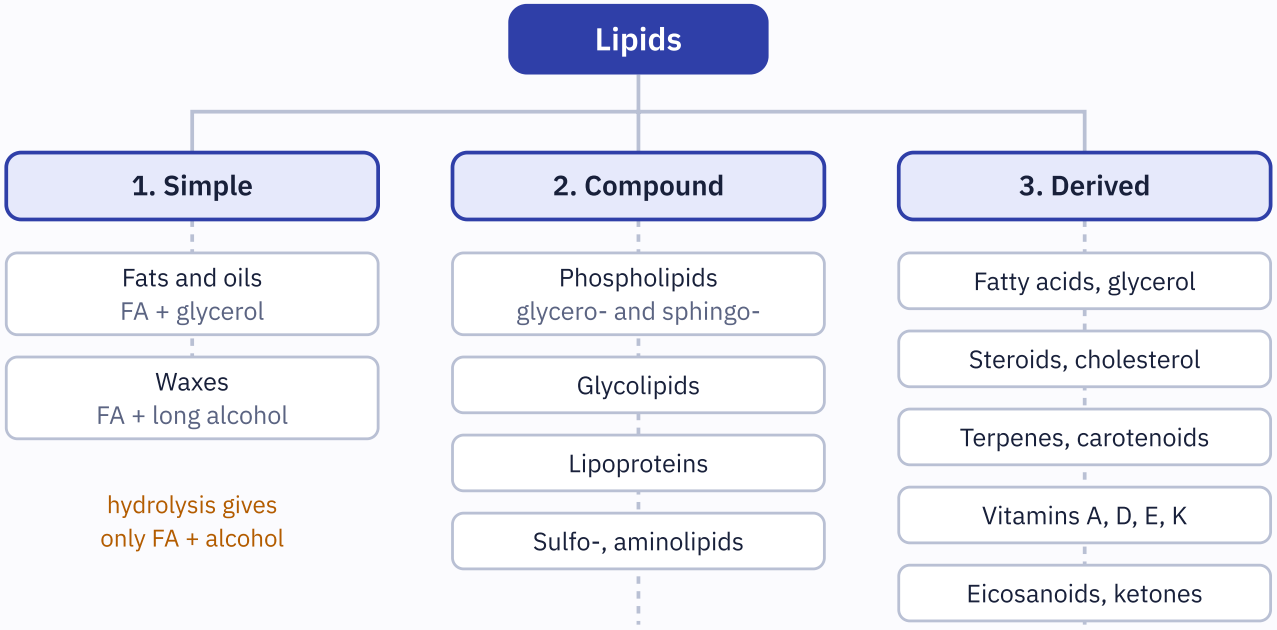


Figure 3.1.1 The simple–compound–derived tree. Read across: simple lipids are plain esters, compound lipids add one extra group (phosphate, sugar, protein), and derived lipids are what hydrolysis releases plus the lipid-soluble molecules with no ester at all, such as cholesterol. FA = fatty acid.

How to place an unknown lipid

1. Ask whether it is an ester. If it has no ester or amide bond to a fatty acid (cholesterol, free fatty acid, vitamin A, a prostaglandin), it is a derived lipid.
2. If it is an ester, list what hydrolysis releases. Only fatty acids plus an alcohol means a simple lipid.
3. Check the alcohol: glycerol gives a fat or oil; a long monohydric alcohol gives a wax.
4. If hydrolysis also releases phosphate, a sugar or protein, it is a compound lipid. Then name the subgroup by the extra part and by the alcohol (glycerol or sphingosine).

Two borderline cases come up often. Cholesteryl ester (cholesterol + fatty acid) is an ester, but most books list it with the derived lipids because the alcohol is a steroid. Sphingomyelin contains both phosphate and sphingosine, so it is a phospholipid and a sphingolipid at the same time; the two labels describe different features.

WORKED EXAMPLE

Question (5 marks). Classify each lipid and give the reason: (a) tripalmitin, (b) beeswax, (c) phosphatidylcholine, (d) galactocerebroside, (e) cholesterol, (f) prostaglandin E_2.

1. (a) Tripalmitin: three palmitic acids esterified to glycerol; hydrolysis gives only fatty acid and glycerol. **Simple lipid, fat.**
2. (b) Beeswax: mainly an ester of palmitic acid with a C_{30} alcohol. Only fatty acid plus a long monohydric alcohol. **Simple lipid, wax.**
3. (c) Phosphatidylcholine (lecithin): glycerol, two fatty acids, phosphate and choline. Extra groups present, alcohol is glycerol. **Compound lipid, glycerophospholipid.**
4. (d) Galactocerebroside: sphingosine, one fatty acid (amide), one galactose, no phosphate. **Compound lipid, glycolipid (glycosphingolipid).**
5. (e) Cholesterol: steroid alcohol, no fatty acid. **Derived lipid, steroid.**
6. (f) Prostaglandin E_2: a C_{20} oxygenated fatty acid made from arachidonic acid. **Derived lipid, eicosanoid.**

EXAM TRAPS

- "Lipids are fats" is wrong. Fats are only one kind of simple lipid; cholesterol and phospholipids are lipids but not fats.
- Glycerol itself is water-soluble, yet it is listed as a derived lipid because it comes from lipid hydrolysis. Say so if asked.
- Waxes are simple lipids, not compound lipids: they have no phosphate, sugar or protein.
- Do not call steroids "simple lipids" because they are small. They have no ester bond to a fatty acid, so they are derived.
- The favourite question: "Classify lipids with one example each" (8–10 marks). Draw the tree in Figure 3.1.1 and add one structure per group.

CHECK YOURSELF

– REMEMBER **Define a lipid.** 2 marks

A biomolecule insoluble in water and soluble in non-polar organic solvents (chloroform, ether), actually or potentially related to fatty acids and used by living cells.

– REMEMBER **Name the three groups of the standard classification.** 1 mark

Simple lipids, compound (complex) lipids and derived lipids.

– UNDERSTAND **Why are lipids grouped by hydrolysis products instead of by one common monomer?** 3 marks

Lipids are a property-based family with no shared repeating unit (unlike amino acids in proteins). What a lipid releases on hydrolysis (fatty acid, alcohol, phosphate, sugar, protein) is the clearest structural difference between members, so it is used to sort them.

– UNDERSTAND **What is an amphipathic lipid? Give two examples.** 2 marks

A lipid with a polar head and a non-polar tail in one molecule, for example phosphatidylcholine and sphingomyelin (also free fatty acids and cholesterol, weakly).

– APPLY **Hydrolysis of a lipid gives sphingosine, a fatty acid, phosphate and choline. Name and classify it.** 3 marks

Sphingomyelin. Phosphate and a base make it a compound lipid (phospholipid); the alcohol sphingosine makes it a sphingophospholipid.

– APPLY **Classify vitamin D_3, ghee and LDL.** 3 marks

Vitamin D_3: derived lipid (sterol derivative). Ghee: simple lipid (fat, mostly triacylglycerols). LDL: compound lipid (lipoprotein).

– ANALYZE **Sphingomyelin appears under "phospholipids" and under "sphingolipids". Is the classification inconsistent?** 4 marks

No. The two labels sort by different features: "phospholipid" by the presence of phosphate, "sphingolipid" by the alcohol backbone. A molecule can carry both features, like a student who is both a Tamilian and an engineer. The classification is a set of overlapping descriptions, not a set of exclusive boxes.

BEYOND THE SYLLABUS

Researchers now use the LIPID MAPS classification, which sorts lipids into eight categories by how they are built: fatty acyls, glycerolipids, glycerophospholipids, sphingolipids, sterol lipids, prenol lipids, saccharolipids and polyketides. It gives every lipid a code and a shorthand name such as PC 16:0/18:1, which mass-spectrometry labels use. The study of all lipids in a cell, **lipidomics**, finds thousands of distinct species and links lipid profiles to diabetes and heart disease. This is not for the exam; search "LIPID MAPS classification" and "lipidomics mass spectrometry" to go further.

3.2 Fatty acids: saturated and unsaturated

A fatty acid is a carboxylic acid with a long hydrocarbon tail, usually 12 to 24 carbons and almost always an even number in plants and animals. It is the basic unit of most lipids: fats, oils, waxes, phospholipids and sphingolipids are all built by attaching fatty acids to an alcohol. A saturated fatty acid has only C–C single bonds; an unsaturated one has one or more C=C double bonds, usually cis. That single difference decides whether a fat is solid ghee or liquid groundnut oil, and how fluid a cell membrane is.

You need: carboxylic acids and cis/trans isomerism from first-year chemistry; the hydrophobic effect from 3.1.

Structure and naming

A fatty acid has a polar carboxyl head (–COOH) and a non-polar tail (CH_3–$(CH_2)_n$–). At pH 7 the head is ionised to $–COO^-$, so in the body fatty acids exist mostly as anions, for example palmitate rather than palmitic acid.

The carboxyl carbon is **C1**. The next carbon is C2 (also called α), then C3 (β), and the last carbon, the methyl carbon, is called **ω** (omega). Two numbering systems follow from this:

- **Δ (delta) numbering** counts from C1. "Δ9" means a double bond between C9 and C10.
- **ω (or n–) numbering** counts from the methyl end. "ω-3" means the first double bond starts at the third carbon from the methyl end.

The shorthand **18:1(Δ9)** reads: 18 carbons, 1 double bond, at position 9. To convert, use ω position = (number of carbons) − (highest Δ position). For oleic acid, 18 − 9 = 9, so oleic acid is an ω-9 fatty acid.

The systematic (IUPAC) name comes from the parent hydrocarbon. Stearic acid (18 C, saturated) is octadecanoic acid; oleic acid is cis-9-octadecenoic acid. Names ending in -anoic are saturated, -enoic unsaturated. The general formula of a saturated fatty acid is $C_nH_{2n}O_2$; each double bond removes two hydrogens.

Saturated and unsaturated

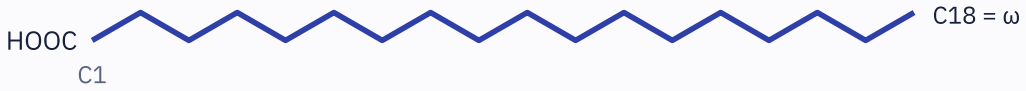
In a **saturated** fatty acid every carbon holds as many hydrogens as it can. The chain is fully extended and flexible, and neighbouring chains lie side by side with many van der Waals contacts. Packing tightly, they need more heat to melt.

An **unsaturated** fatty acid has at least one C=C. **Monounsaturated** (MUFA) acids have one, like oleic acid; **polyunsaturated** (PUFA) acids have two or more, like linoleic acid. In natural fatty acids the double bonds are nearly always **cis**, and in PUFAs they are usually methylene-interrupted: separated by one CH_2 group (Δ9, Δ12, Δ15), not conjugated.

A cis double bond puts a fixed bend in the chain (Figure 3.2.1). Bent chains cannot pack closely, so the van der Waals contacts fall and the melting point drops sharply. Two rules follow, and examiners ask both:

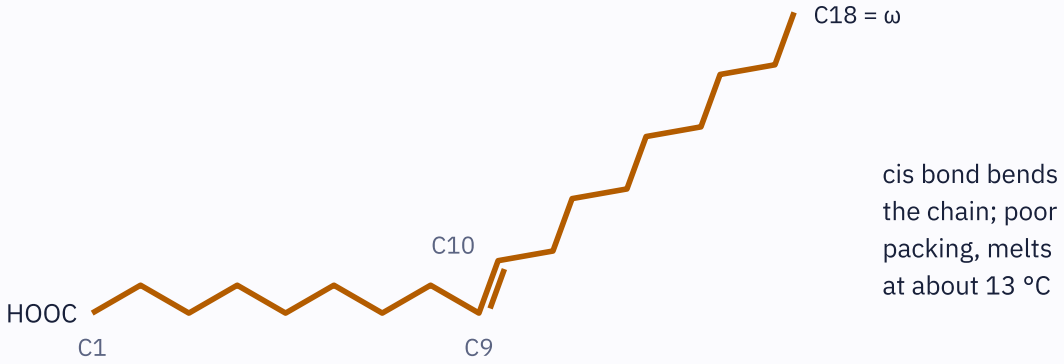
1. Melting point rises with chain length (more contacts per chain).
2. Melting point falls with the number of cis double bonds (poorer packing).

Stearic acid, 18:0 (saturated)



Straight chain, all single bonds: chains pack tightly, melts at about 70 °C.

Oleic acid, 18:1 cis-Δ9 (monounsaturated)



Δ numbers count from C1 (carboxyl); ω numbers count from the methyl end.

Figure 3.2.1 Same length, different shape. Stearic acid is a straight zigzag; oleic acid has one cis double bond between C9 and C10 (the doubled line), which turns the chain. Notice that oleic acid is ω-9 as well as Δ9, because 18 − 9 = 9.

Common fatty acids to know

COMMON NAME	SHORTHAND	SERIES	TYPICAL SOURCE
Butyric	`4:0`	saturated	butter, ghee
Lauric	`12:0`	saturated	coconut oil
Palmitic	`16:0`	saturated	palm oil, animal fat
Stearic	`18:0`	saturated	animal fat, cocoa butter
Oleic	`18:1(Δ9)`	ω-9	olive, groundnut oil
Linoleic	`18:2(Δ9,12)`	ω-6	sunflower, safflower oil
α-Linolenic	`18:3(Δ9,12,15)`	ω-3	flaxseed, mustard oil
Arachidonic	`20:4(Δ5,8,11,14)`	ω-6	membrane phospholipids
Eicosapentaenoic (EPA)	`20:5(Δ5,8,11,14,17)`	ω-3	fish oil
Docosahexaenoic (DHA)	`22:6(Δ4,7,10,13,16,19)`	ω-3	fish oil, brain, retina

Melting points that show the two rules: lauric acid 44 °C, palmitic 63 °C, stearic 70 °C (longer is higher); stearic 70 °C, oleic 13 °C, α-linolenic −11 °C (more double bonds is lower). Coconut oil is rich in lauric acid, which is why it sets solid in a Delhi winter but stays liquid in Kochi.

Essential fatty acids and trans fats

Humans can make saturated fatty acids and can insert a double bond at Δ9, but cannot insert double bonds beyond C9 from the carboxyl end. So **linoleic acid** (ω-6) and **α-linolenic acid** (ω-3) must come from food: they are the **essential fatty acids**. Arachidonic acid can be made from linoleic acid, so it becomes essential only when linoleic acid is lacking. Deficiency causes scaly skin (phrynoderma, "toad skin", in older Indian textbooks) and poor growth.

Trans fatty acids have a trans double bond, which keeps the chain nearly straight, so they behave like saturated fats. They form when vegetable oil is partially hydrogenated to make vanaspati, and they raise LDL cholesterol. FSSAI capped trans fat in oils and fats at 2 percent from January 2022. Elaidic acid (trans-Δ9 18:1) is the trans partner of oleic acid.

How the body builds palmitate and then lengthens and desaturates it is in Unit 6, Fatty acid biosynthesis, elongation and desaturation.

WORKED EXAMPLE

Question (4 marks). (a) Write the ω class of α-linolenic acid 18:3(Δ9,12,15) and arachidonic acid 20:4(Δ5,8,11,14). (b) Give the molecular formula of linoleic acid, 18:2. (c) How many moles of H_2 fully hydrogenate one mole of α-linolenic acid, and what is the product?

1. (a) ω position = carbons − highest Δ. α-Linolenic: 18 − 15 = 3, so **ω-3**. Arachidonic: 20 − 14 = 6, so **ω-6**.
2. (b) Saturated C18 acid: $C_{18}H_{36}O_2$ ($C_nH_{2n}O_2$ with n = 18). Two double bonds remove 4 H: **$C_{18}H_{32}O_2$**.
3. (c) One H_2 saturates one C=C. Three double bonds need **3 mol H_2**, and the product is the saturated C18 acid, **stearic acid**.

EXAM TRAPS

- Δ counts from the carboxyl carbon, ω from the methyl end. Linoleic acid is Δ9,12 and ω-6, not ω-9.
- C2 is the α-carbon; C1 is the carboxyl carbon itself and has no Greek letter.
- "Unsaturated fats are liquid because they are lighter" is wrong. Oleic and stearic acids differ by only 2 H; the cis bend is the reason.
- Trans fats are unsaturated but behave like saturated fats. Do not list them as healthy because they have a double bond.
- Essential means "needed from the diet", not "most important". Arachidonic acid is only conditionally essential.

CHECK YOURSELF

– REMEMBER **Name the two essential fatty acids and give their shorthand.** 2 marks

Linoleic acid 18:2(Δ9,12), ω-6; α-linolenic acid 18:3(Δ9,12,15), ω-3.

– REMEMBER **What is the systematic name of oleic acid?** 1 mark

cis-9-Octadecenoic acid.

– UNDERSTAND **Why does a cis double bond lower the melting point?** 3 marks

The cis bond fixes a bend in the chain. Bent chains cannot lie close together, so there are fewer van der Waals contacts between neighbours and less heat is needed to separate them.

– UNDERSTAND **Why are linoleic and α-linolenic acids essential for humans?** 2 marks

Human desaturases cannot insert a double bond beyond C9 (counting from the carboxyl end), so the Δ12 and Δ15 bonds these acids need cannot be made in the body; they must come from food.

– APPLY **Write the Δ shorthand and ω class of EPA, which has 20 carbons and double bonds starting at C5, C8, C11, C14 and C17.** 2 marks

20:5(Δ5,8,11,14,17). ω = 20 − 17 = 3, so ω-3.

– APPLY **Arrange in order of increasing melting point: stearic, oleic, palmitic, α-linolenic.** 2 marks

α-Linolenic (18:3) < oleic (18:1) < palmitic (16:0) < stearic (18:0).

– ANALYZE **Vanaspati and groundnut oil come from vegetable oils, yet one is solid and one is liquid. Explain, and say which is worse for the heart.** 4 marks

Vanaspati is partially hydrogenated: many cis double bonds are saturated and some are converted to trans. Saturated and trans chains are straight and pack well, so it is solid. Groundnut oil keeps its cis MUFA and PUFA and stays liquid. Vanaspati is worse because trans fats raise LDL cholesterol.

BEYOND THE SYLLABUS

Plants and microbes can make ω-3 fatty acids that humans cannot, and fish obtain EPA and DHA from marine algae. Biotechnology companies now grow microalgae such as *Schizochytrium* to produce DHA for infant formula, and oilseed crops have been engineered to make fish-type ω-3 oils. Bacteria change their membrane fatty acids with temperature, a process called homeoviscous adaptation. This is not for the exam; search "microalgal DHA production" and "homeoviscous adaptation" to go further.

3.3 Triacylglycerols, oils and waxes; saponification

Triacylglycerols (TAGs, also called triglycerides) are glycerol with three fatty acids attached by ester bonds. They are the body's main energy store and the main component of every cooking fat and oil. Waxes are the other simple lipids: one long fatty acid joined to one long alcohol, made for waterproofing rather than fuel. Boiling a fat with alkali breaks its ester bonds and gives glycerol and soap; this reaction, saponification, is also the basis of the number that labs use to judge a fat, the saponification value.

You need: fatty acid names from 3.2; ester hydrolysis from first-year chemistry.

Triacylglycerols

Glycerol (propane-1,2,3-triol) has three –OH groups. Each can form an ester with the –COOH of a fatty acid, losing one water molecule. One fatty acid gives a monoacylglycerol, two a diacylglycerol, three a triacylglycerol. The carbons of glycerol are numbered sn-1, sn-2 and sn-3 (sn = stereospecific numbering), because the middle carbon becomes chiral when the outer two fatty acids differ.

- A **simple TAG** has three identical fatty acids, such as tripalmitin or triolein.
- A **mixed TAG** has two or three different fatty acids. Almost all natural fats are mixtures of mixed TAGs.

TAGs have no charge and no polar head left, so they are **neutral lipids**, completely insoluble in water. That is why they are ideal for storage: they pack into anhydrous droplets in fat cells (adipocytes) without carrying water. They are also more reduced than sugars, so they give about 9 kcal per gram against about 4 kcal per gram for carbohydrate. Fat under the skin also insulates the body, which is why seals and penguins carry thick blubber.

A **fat** is a TAG mixture that is solid at room temperature; it is rich in saturated fatty acids (ghee, butter, lard). An **oil** is liquid at room temperature; it is rich in unsaturated fatty acids (sunflower, groundnut, mustard oil). Palm and coconut oil are exceptions: they are plant oils high in saturated fat.

Saponification and other reactions of fats

Heating a TAG with sodium or potassium hydroxide hydrolyses all three ester bonds. The products are glycerol and three salts of fatty acids, which are **soaps**:



Sodium soaps are hard (bar soap); potassium soaps are soft (liquid soap, shaving cream). A soap anion is amphipathic: its tail dissolves in grease and its $-COO^-$ head faces water, so soap forms micelles that carry oil away. In hard water, Ca^{2+} and Mg^{2+} form insoluble salts with the soap, which is the grey scum in a bucket.

The reactions to know are:

1. **Hydrolysis** by lipases or acid: TAG → glycerol + free fatty acids. In digestion, pancreatic lipase cuts at sn-1 and sn-3 and leaves 2-monoacylglycerol.
2. **Saponification** by alkali, as above.
3. **Hydrogenation**: H_2 with a nickel catalyst adds across C=C, turning oil into a solid fat (vanaspati); partial hydrogenation forms trans fats.
4. **Halogenation**: iodine or iodine monochloride adds across each C=C. The amount taken up measures unsaturation.
5. **Oxidation**: oxygen attacks PUFAs and gives peroxides, then aldehydes and ketones with a bad smell. This is **oxidative rancidity**. **Hydrolytic rancidity** is lipase action releasing free fatty acids; butyric acid makes stale butter smell. Antioxidants such as vitamin E, BHA and BHT slow oxidation.

6. **Acrolein test**: heating fat with potassium bisulfate dehydrates the glycerol to acrolein, which has a sharp, irritating smell. It detects glycerol, so it is positive for fats and negative for waxes.

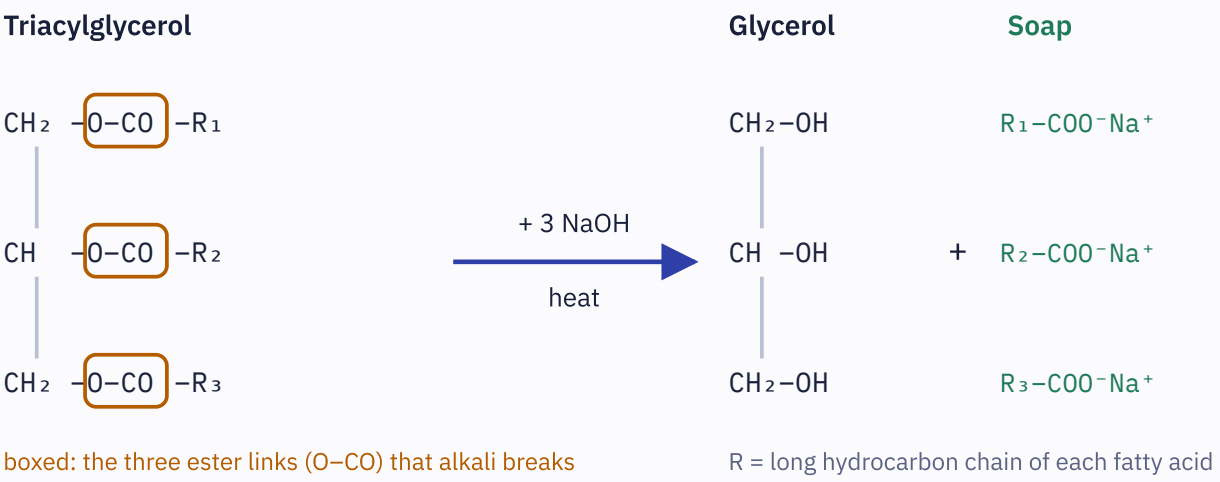


Figure 3.3.1 Saponification. Alkali cuts each of the three ester bonds (boxed), releasing glycerol and one soap anion per fatty acid. Notice the ratio: one mole of TAG uses three moles of hydroxide, which is the 3 in the saponification value formula below.

Saponification value and the other fat constants

The **saponification value (SV)** is the number of milligrams of KOH needed to saponify 1 g of fat. Because each TAG uses three KOH whatever its size, a fat of short chains has more molecules per gram and a higher SV. So SV tells you the **average chain length**: SV = 3 × 56.1 × 1000 / M, where 56.1 g/mol is the molar mass of KOH and M is the average molar mass of the TAG in g/mol. Most cooking oils have SV near 190; butterfat is higher (about 220–230) and coconut oil higher still (about 250), because both contain short- and medium-chain fatty acids.

1. Weigh W grams of fat into a flask; add a measured excess of 0.5 N alcoholic KOH.
2. Reflux on a water bath for about 30–60 minutes until saponification is complete. Set up a blank with the same KOH and no fat.
3. Titrate the unused KOH in both flasks with 0.5 N HCl, using phenolphthalein, until the pink colour just disappears.
4. SV = (B − S) × N × 56.1 / W, where B and S are the mL of HCl for blank and sample and N is the normality of the HCl.

The other constants, each measuring one property:

- **Iodine value (IV)**: grams of iodine absorbed by 100 g of fat. It measures unsaturation. Coconut oil is low (below 10), olive and groundnut oils are in the 80s and 90s, sunflower oil is higher and linseed oil is highest.
- **Acid value**: milligrams of KOH to neutralise the free fatty acids in 1 g of fat. It rises as a fat turns rancid.
- **Peroxide value**: peroxides per kilogram of fat, a direct measure of oxidative rancidity.
- **Reichert–Meissl (RM) number**: millilitres of 0.1 N alkali needed to neutralise the volatile, water-soluble fatty acids distilled from 5 g of fat. Butterfat is high because of butyric acid; most vegetable oils are very low. It is used to detect vanaspati in ghee.

Books put the boundaries at slightly different values, roughly 100 and 130 to 150.

Waxes

A wax is an ester of a long-chain fatty acid (about C14 to C36) with a long-chain monohydric alcohol (about C16 to C30). Both halves are long and saturated, so waxes are solid, water-repellent and melt above body temperature. Beeswax is mainly triacontanyl palmitate (C_{30} alcohol + palmitic acid). Other waxes: carnauba from palm leaves (car polish), lanolin from wool (creams), and the waxy cuticle that keeps leaves from drying out. Waxes waterproof feathers and insect bodies. Humans cannot digest them. They saponify only with difficulty, and give a negative acrolein test because they contain no glycerol.

WORKED EXAMPLE

Question (6 marks). (a) 2.0 g of an oil was refluxed with alcoholic KOH. The blank needed 25.0 mL and the sample 11.0 mL of 0.5 N HCl. Find the saponification value and the average molar mass of its TAG. (b) Find the theoretical iodine value of triolein (M = 885.4 g/mol; I_2 = 253.8 g/mol).

1. KOH used by the oil = B − S = 25.0 − 11.0 = 14.0 mL of 0.5 N, that is 14.0 × 0.5 = 7.0 milliequivalents.
2. Mass of KOH = 7.0 meq × 56.1 mg/meq = 392.7 mg, for 2.0 g of oil. SV = 392.7 / 2.0 = **196 mg KOH/g**.
3. Average M = 3 × 56.1 × 1000 / SV = 168 300 / 196.4 ≈ **857 g/mol**, a typical long-chain vegetable oil.
4. (b) Triolein has three C=C (one per oleic acid); each takes up one I_2. Iodine per mole = 3 × 253.8 = 761.4 g.
5. IV = 761.4 × 100 / 885.4 = **86 g I_2 per 100 g**, in the non-drying range.

EXAM TRAPS

- High saponification value means **short** chains (low molar mass), not "more fat".
- Iodine value measures unsaturation, not chain length. Mixing up SV and IV is the commonest slip.
- Forgetting the blank: the formula uses (B − S), the KOH that the fat used, not the HCl in the sample flask.
- Waxes give a negative acrolein test; fats and oils give a positive one.
- Favourite question: "Define saponification value, iodine value, acid value and RM number and state their significance."

CHECK YOURSELF

– REMEMBER **Define saponification value.** 1 mark

Milligrams of KOH needed to completely saponify 1 g of fat or oil.

– REMEMBER **What is the main component of beeswax?** 1 mark

Triacontanyl palmitate: an ester of palmitic acid with a C_{30} alcohol.

– UNDERSTAND **Why are TAGs better than glycogen for long-term energy storage?** 3 marks

They are more reduced (about 9 against 4 kcal/g) and, being non-polar, are stored without water, whereas glycogen carries about twice its weight of bound water. So the same energy weighs far less as fat.

– UNDERSTAND **Distinguish hydrolytic and oxidative rancidity.** 3 marks

Hydrolytic: lipases (with water) split TAGs into free fatty acids; short ones like butyric smell bad. Oxidative: oxygen attacks double bonds of PUFAs, giving peroxides, aldehydes and ketones. The first raises acid value, the second peroxide value.

– APPLY **Calculate the saponification value of tripalmitin (M = 807.3 g/mol).** 3 marks

SV = 3 × 56.1 × 1000 / 807.3 = 168 300 / 807.3 = **208.5 mg KOH/g**.

– APPLY **A ghee sample has a much lower RM number than pure ghee. What do you conclude?** 2 marks

It is probably adulterated with vanaspati or another vegetable fat, which has very few volatile short-chain fatty acids.

– ANALYZE **Coconut oil has a high SV but a low IV; sunflower oil has a normal SV and a high IV. What does each tell you about their fatty acids?** 4 marks

Coconut oil: high SV means many short and medium chains (lauric, myristic); low IV means few double bonds, so it is mostly saturated. Sunflower oil: normal SV means mainly C18 chains; high IV means many double bonds, mainly linoleic acid.

BEYOND THE SYLLABUS

Transesterification of TAGs with methanol gives fatty acid methyl esters, which is biodiesel, with glycerol as the by-product; it is the same ester chemistry as saponification. Lipases are used industrially to make cocoa butter substitutes by swapping fatty acids at sn-1 and sn-3. Oleaginous yeasts and microalgae are being developed to make TAGs for fuel. This is not for the exam; search "enzymatic interesterification" and "oleaginous yeast" to go further.

3.4 Phospholipids: lecithins and cephalins

Phospholipids are compound lipids that carry a phosphate group. The commonest ones, glycerophospholipids, are built like a triacylglycerol with the third fatty acid replaced by phosphate plus a small polar alcohol. That swap turns a neutral storage fat into an amphipathic molecule with a charged head and two oily tails, the molecule that forms the bilayer of every cell membrane. Lecithin (head group choline) and cephalin (head group ethanolamine) are the two that examiners name; the same plan, with other heads, gives the signalling lipids and the lipids of mitochondria.

You need: TAG structure and sn numbering from 3.3; amphipathic molecules from 3.1.

The common plan: phosphatidic acid plus a head

Start with glycerol 3-phosphate. Esterify sn-1 and sn-2 with fatty acids and you have **phosphatidic acid**, the parent of all glycerophospholipids. Then join a polar alcohol (X) to the phosphate by a second ester bond. The phosphate now links two alcohols, so it is a **phosphodiester**.

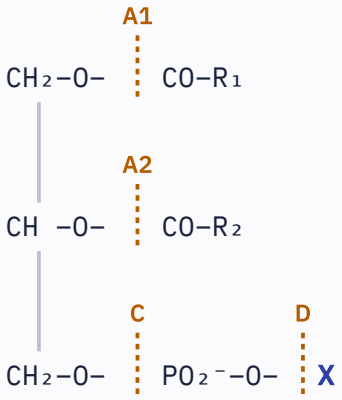
The fatty acid at sn-1 is usually saturated (palmitic, stearic) and the one at sn-2 usually unsaturated (oleic, linoleic, arachidonic). The sn-2 position is where the body stores arachidonic

acid, which becomes the eicosanoids of 3.7.

The head group X names the phospholipid:

- **X = choline**: phosphatidylcholine (PC), called **lecithin**. Net charge 0 at pH 7 (phosphate −, choline +).
- **X = ethanolamine**: phosphatidylethanolamine (PE), called **cephalin**. Net charge 0.
- **X = serine**: phosphatidylserine (PS). Net charge −1. Older books group it with the cephalins.
- **X = inositol**: phosphatidylinositol (PI). Net charge −1. Its phosphorylated form PIP_2 is split in cell signalling to IP_3 and diacylglycerol.
- **X = phosphatidylglycerol**: diphosphatidylglycerol, called **cardiolipin**, found in the inner mitochondrial membrane and in bacteria.

Glycerophospholipid



HEAD GROUP X	LIPID	COMMON NAME
choline	**PC**	lecithin
ethanolamine	**PE**	cephalin
serine	**PS**	cephalin group
inositol	**PI**	signalling
H (no head)	**PA**	phosphatidic acid

sn-1: R_1 usually saturated · sn-2: R_2 usually unsaturated
dashed lines: bonds cut by phospholipases A1, A2, C, D

Figure 3.4.1 One plan, many heads. Two fatty acids sit on sn-1 and sn-2 of glycerol, and sn-3 carries a phosphodiester to the head group X. The dashed lines mark where each phospholipase cuts: A1 and A2 release a fatty acid, C releases the phosphorylated head, D releases the free head.

Lecithins and cephalins

Lecithins (PC) are the most abundant phospholipids of animal cell membranes, concentrated in the outer leaflet. Egg yolk and soybean are rich sources; commercial soy lecithin is used as an emulsifier in chocolate, ice cream and medicines. Lecithin is also:

- **Lung surfactant.** Dipalmitoyl-phosphatidylcholine (DPPC, both chains palmitic) lines the alveoli and lowers surface tension, so the alveoli do not collapse on breathing out. Premature babies may lack it and develop respiratory distress syndrome. A lecithin-to-sphingomyelin (L/S) ratio of 2 or more in amniotic fluid indicates mature lungs.

- **A source of choline** for acetylcholine and for methyl groups.
- **A fatty acid donor** in blood: the enzyme LCAT (lecithin–cholesterol acyltransferase) moves the sn-2 fatty acid of lecithin onto cholesterol in HDL.

Cephalins (PE, and PS in the older grouping) take their name from the Greek for "head", because they were first found in brain. They sit mostly in the inner leaflet of the plasma membrane. When a platelet is activated, PS flips to the outer face and gives clotting factors a surface to assemble on. PS on the outside of a cell is also an "eat me" signal for cells dying by apoptosis.

Properties and phospholipases

Because each phospholipid has two tails, its shape is roughly cylindrical. Cylinders pack side by side into a **bilayer**, heads facing water on both sides and tails meeting in the middle. (A single-tailed fatty acid or soap is cone-shaped and forms micelles instead.) Phospholipids are also good emulsifiers, and they are part of the surface coat of lipoproteins and bile micelles.

Plasmalogens are glycerophospholipids whose sn-1 chain is joined by an ether (vinyl ether) bond instead of an ester. They are common in heart and nerve tissue. Platelet-activating factor is a related ether lipid.

The **phospholipases** each cut one bond (Figure 3.4.1):

1. **Phospholipase A1** removes the sn-1 fatty acid.
2. **Phospholipase A2** removes the sn-2 fatty acid, leaving a **lysophospholipid** (lysolecithin from lecithin). Lysolecithin is a detergent that breaks red cell membranes, which is why snake and bee venoms rich in PLA2 cause haemolysis. Cellular PLA2 releases arachidonic acid for eicosanoids.
3. **Phospholipase C** cuts between glycerol and phosphate, giving diacylglycerol plus phosphocholine (or IP_3 from PIP_2). The α-toxin of *Clostridium perfringens* in gas gangrene is a phospholipase C.
4. **Phospholipase D** cuts between phosphate and the head, giving phosphatidic acid plus free choline.

How cells make these lipids (via CDP-diacylglycerol or CDP-choline) is in Unit 6, Synthesis of triacylglycerols, phospholipids and cholesterol.

WORKED EXAMPLE

Question (6 marks). (a) 1-Palmitoyl-2-arachidonoyl-phosphatidylcholine is treated separately with phospholipases A2, C and D. Give the products of each. (b) Amniotic fluid from a pregnancy at 33 weeks contains lecithin 4.2 mg/dL and sphingomyelin 1.5 mg/dL. Should the doctors expect the baby's lungs to be mature?

1. PLA2 cuts the sn-2 ester: **arachidonic acid + 1-palmitoyl-lysophosphatidylcholine** (lysolecithin).
2. PLC cuts the glycerol–phosphate bond: **1-palmitoyl-2-arachidonoyl-glycerol (a diacylglycerol) + phosphocholine**.
3. PLD cuts the phosphate–choline bond: **phosphatidic acid (same two chains) + choline**.
4. (b) L/S = 4.2 / 1.5 = **2.8**. This is above 2, so the lungs are likely mature and enough surfactant is being made.

EXAM TRAPS

- Lecithin's head is choline, cephalin's is ethanolamine. Swapping them is the classic slip.
- PLA2 releases a fatty acid, not the head group; PLD releases the head group; PLC releases the phosphorylated head.
- Phosphatidic acid is the parent molecule, not a breakdown "acid" of lecithin by hydrolysis of fatty acids.
- Sphingomyelin is a phospholipid but not a glycerophospholipid; it is covered in 3.5.
- Favourite question: "Draw the structure of lecithin and give its functions", often with "action of phospholipases".

CHECK YOURSELF

– REMEMBER **What are the hydrolysis products of lecithin?** 2 marks

Glycerol, two fatty acids, phosphoric acid and choline.

– REMEMBER **Which phospholipid is the main component of lung surfactant?** 1 mark

Dipalmitoyl-phosphatidylcholine (DPPC), a lecithin.

– UNDERSTAND **Why do phospholipids form bilayers while soaps form micelles?** 3 marks

A phospholipid has two tails of similar width to its head, so it is cylindrical and packs flat into a sheet. A soap has one tail and a wide head, so it is cone-shaped and packs into a sphere, a micelle.

– UNDERSTAND **Why does phosphatidylserine on the outer surface of a cell matter?** 2 marks

PS is normally kept in the inner leaflet. On the outer face it provides the negatively charged surface for clotting factors on activated platelets, and it marks apoptotic cells for removal by macrophages.

– APPLY **Give the net charge at pH 7 of PC, PE and PS.** 3 marks

PC 0 (phosphate – and quaternary N^+); PE 0 (phosphate – and NH_3^+); PS –1 (phosphate –, carboxyl –, NH_3^+).

– APPLY **A snakebite victim's urine turns red. Link this to a phospholipid.** 3 marks

Venom phospholipase A2 converts membrane lecithin to lysolecithin, a detergent that lyses red cells. Released haemoglobin appears in urine (haemoglobinuria).

– ANALYZE **Compare a TAG and a lecithin with the same two fatty acids at sn-1 and sn-2. Why is one a fuel and the other a membrane builder?** 4 marks

The TAG has a third fatty acid at sn-3, so it has no polar head: it is neutral, insoluble and packs into droplets for storage. Lecithin has phosphocholine at sn-3, a charged head that faces water, making it amphipathic and cylindrical, so it assembles into bilayers. One change at sn-3 switches function.

BEYOND THE SYLLABUS

Liposomes, vesicles made of lecithin and cholesterol, carry drugs into cells, and the lipid nanoparticles of the mRNA vaccines used in COVID-19 contain a phosphatidylcholine (DSPC) as a helper lipid. Synthetic lung surfactants are given to premature babies. Lipid flippases and scramblases, which control membrane asymmetry, are an active research area. This is not for the exam; search "lipid nanoparticle composition" and "phospholipid scramblase" to go further.

3.5 Sphingolipids and glycolipids

Sphingolipids are membrane lipids built on sphingosine, a long amino alcohol, instead of glycerol. Add one fatty acid to sphingosine and you get ceramide, the parent of the whole family; add phosphocholine to ceramide and you get sphingomyelin, the lipid of the myelin sheath; add sugars and you get the glycosphingolipids: cerebrosides, globosides and gangliosides. Their sugar heads face outwards from the cell and act as labels for recognition, blood groups and toxin binding.

You need: phospholipid structure from 3.4; glycosidic bonds and glycoconjugates from Unit 1.

Sphingosine and ceramide

Sphingosine is an 18-carbon amino alcohol. It has an –OH on C1, an $–NH_2$ on C2, an –OH on C3 and a trans double bond between C4 and C5. Carbons 1 to 3 form a polar region much like the glycerol of a phospholipid, and the long hydrocarbon from C4 onwards acts as the first tail. The cell makes it from palmitoyl-CoA and serine (see Unit 6).

When a fatty acid is joined to the C2 $–NH_2$ by an **amide bond** (not an ester bond), the product is **ceramide**. Ceramide has two tails, like a diacylglycerol, and a free C1 –OH where a head group can attach. Every sphingolipid is ceramide plus a head on C1. Ceramide is also important in its own right: it is a main lipid of the skin barrier in the outer layer of the epidermis, and it acts as a signal for cell stress and apoptosis.

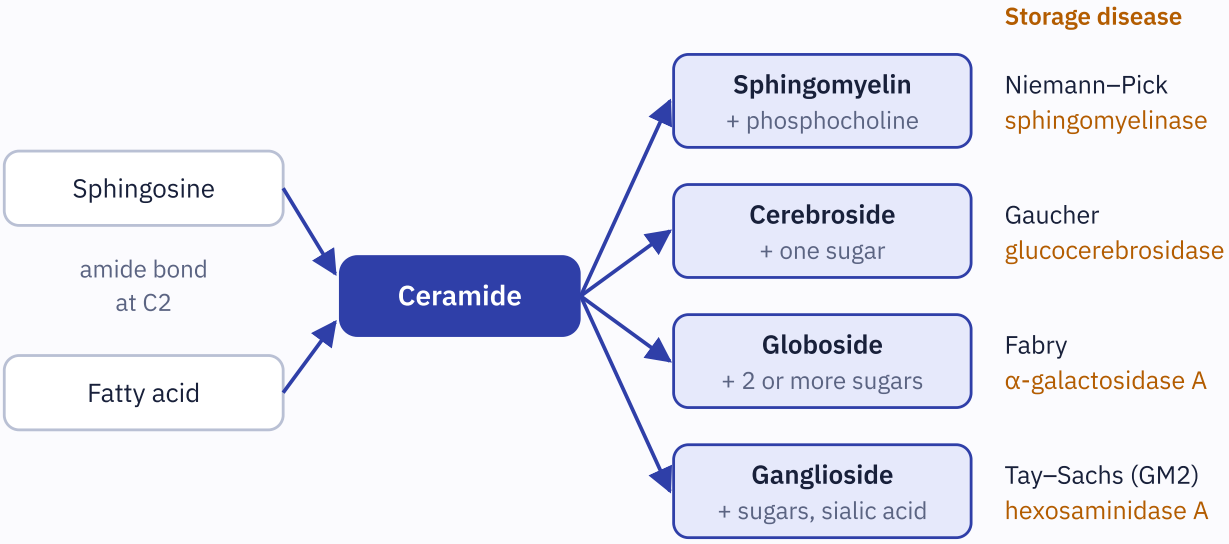
The sphingolipid family

1. **Sphingomyelin** = ceramide + phosphocholine (or phosphoethanolamine) on C1. It contains phosphate, so it is a **phospholipid**, the only sphingolipid that is one in humans. It is rich in the myelin sheath that insulates nerve axons and is found in the outer leaflet of the plasma membrane, where it gathers with cholesterol into ordered patches called lipid rafts.
2. **Cerebrosides** = ceramide + one sugar on C1, through a glycosidic bond, and no phosphate. Galactocerebroside is typical of nerve cell membranes; glucocerebroside occurs in other tissues. A sulfated galactocerebroside is a **sulfatide**.
3. **Globosides** = ceramide + two or more neutral sugars (glucose, galactose, N-acetylgalactosamine). Lactosylceramide is the simplest. Cerebrosides and globosides together are called neutral glycolipids.
4. **Gangliosides** = ceramide + an oligosaccharide carrying one or more **sialic acid** residues (N-acetylneuraminic acid, NeuAc). Sialic acid carries a negative charge, so gangliosides are

acidic glycolipids. They are most abundant in the membranes of nerve cells in the grey matter of the brain.

Ganglioside names follow a code: **G** for ganglioside, then **M**, **D** or **T** for one, two or three sialic acids, then a number that rises as the neutral sugar chain gets shorter. So GM1 has the longest sugar chain of the mono-sialo series and GM3 the shortest. GM2 is the one that accumulates in Tay–Sachs disease.

Terpenes are not sphingolipids; they are isoprene-based derived lipids and are taught with the steroids in 3.6.



Each disease: the lysosomal enzyme (orange) is missing, so the lipid in that row piles up.

Figure 3.5.1 Ceramide is the hub. Every sphingolipid is ceramide with a head on C1; the head decides the class. Read each row to the right for the disease caused when the lysosomal enzyme that removes that head (or, for Tay–Sachs, the terminal sugar of GM2) is missing.

Glycolipids and what they do

A **glycolipid** is any lipid with a sugar attached by a glycosidic bond. In animals almost all glycolipids are glycosphingolipids (cerebrosides, globosides, gangliosides). In plants the main ones are **glyceroglycolipids**: monogalactosyl- and digalactosyl-diacylglycerol (MGDG and DGDG) are the most abundant lipids of chloroplast thylakoid membranes.

Glycolipid sugar heads always face the outside of the cell. They work as:

- **Recognition labels.** The ABO blood group antigens are oligosaccharides carried on glycosphingolipids (and glycoproteins) of red cells; group A and B differ by one terminal sugar.
- **Receptors for toxins and microbes.** Cholera toxin binds ganglioside GM1 on intestinal cells before it enters them.

- **Insulation and stability** of myelin (galactocerebroside, sulfatide, sphingomyelin).

Sphingolipid storage diseases

Sphingolipids are broken down step by step in lysosomes, one sugar or head group at a time, each step by its own enzyme. If one enzyme is missing, its substrate cannot be degraded and accumulates in the lysosomes; these are the **sphingolipidoses**, a kind of lysosomal storage disease. Most are autosomal recessive; Fabry disease is X-linked.

DISEASE	ENZYME MISSING	LIPID STORED	MAIN FEATURES
Tay–Sachs	Hexosaminidase A	Ganglioside GM2	neurodegeneration in infancy, cherry-red spot in the retina
Niemann–Pick (A, B)	Sphingomyelinase	Sphingomyelin	enlarged liver and spleen; type A also nerve damage
Gaucher	Glucocerebrosidase (β-glucosidase)	Glucocerebroside	enlarged liver and spleen, bone damage; treated by enzyme replacement
Fabry	α-Galactosidase A	Globotriaosylceramide	pain in hands and feet, kidney and heart damage
Krabbe	Galactocerebrosidase	Galactocerebroside	loss of myelin in infancy

WORKED EXAMPLE

Question (5 marks). A six-month-old child is losing motor skills and the eye doctor sees a cherry-red spot in the macula. A brain biopsy shows lysosomes packed with a ganglioside carrying one sialic acid and three neutral sugars. (a) Name the lipid and the disease. (b) Which enzyme is deficient and which bond does it cut? (c) Why is the brain hit hardest?

1. (a) One sialic acid: the "M" series. The sugar chain is one shorter than GM1's, so it is **GM2**. GM2 storage with a cherry-red spot is **Tay–Sachs disease**.
2. (b) The enzyme is **β-hexosaminidase A**. It removes the terminal N-acetylgalactosamine from GM2, turning it into GM3. Without it, GM2 cannot move down the degradation path.
3. (c) Gangliosides are most concentrated in neurons of the grey matter, so the stored lipid builds up there first and swells and kills nerve cells.

EXAM TRAPS

- The fatty acid in a sphingolipid is joined by an **amide** bond, not an ester bond.
- Sphingomyelin is a phospholipid; cerebrosides and gangliosides are not (no phosphate).
- Glycerol is absent from all sphingolipids. A "sphingolipid with glycerol" is a contradiction.
- Cerebroside = one sugar; ganglioside = sugars plus sialic acid. "Ganglioside without sialic acid" is a globoside.
- Tay–Sachs stores GM2, not GM1. Gaucher stores glucocerebroside, Niemann–Pick stores sphingomyelin; the pairing is asked every year.

CHECK YOURSELF

– REMEMBER **What is ceramide?** 1 mark

Sphingosine with a fatty acid joined by an amide bond to its C2 amino group; the parent of all sphingolipids.

– REMEMBER **Name the enzyme missing in Gaucher disease and the lipid stored.** 2 marks

Glucocerebrosidase (β-glucosidase); glucocerebroside accumulates.

– UNDERSTAND **Why are gangliosides negatively charged at pH 7?** 2 marks

They contain sialic acid (N-acetylneuraminic acid), whose carboxyl group is ionised to $-COO^-$ at pH 7.

– UNDERSTAND **How do glycolipids help a cell to be recognised?** 3 marks

Their oligosaccharide heads stick out from the outer leaflet, and the exact sugar sequence differs between cell types and individuals. Antibodies, lectins, toxins and other cells bind specific sequences, as with ABO blood group antigens and cholera toxin binding GM1.

– APPLY **Hydrolysis of a lipid gives sphingosine, a fatty acid and galactose only. Name and classify it.** 2 marks

Galactocerebroside: a neutral glycosphingolipid (cerebroside), a compound lipid with no phosphate.

– APPLY **Give one difference and one similarity between sphingomyelin and lecithin.** 2 marks

Difference: sphingomyelin has sphingosine and an amide-linked fatty acid; lecithin has glycerol and two ester-linked fatty acids. Similarity: both carry phosphocholine as head group and both are amphipathic membrane phospholipids.

– ANALYZE **Gaucher disease can be treated by giving the enzyme intravenously, but Tay–Sachs cannot be treated this way. Suggest why.** 4 marks

Gaucher mainly affects macrophages of liver, spleen and bone marrow, which take up infused enzyme from blood. Tay–Sachs damage is in neurons of the brain, and the large enzyme protein cannot cross the blood–brain barrier, so infused enzyme does not reach the stored GM2.

BEYOND THE SYLLABUS

Substrate reduction therapy treats some sphingolipidoses by blocking the enzyme that makes glucosylceramide, so less lipid needs breaking down. Gene therapy and brain-penetrating enzymes are being tested for the neurological forms. Sphingosine-1-phosphate is a signalling lipid, and fingolimod, a drug for multiple sclerosis, acts on its receptors. This is not for the exam; search "substrate reduction therapy Gaucher" and "sphingosine-1-phosphate signalling" to go further.

3.6 Cholesterol and steroids

Steroids are lipids built on a rigid frame of four fused rings, the steroid nucleus. Cholesterol is the main steroid of animal cells: it stiffens and seals membranes, and it is the raw material for bile acids, the steroid hormones and vitamin D. It has no fatty acid and no ester bond in its free form, which is why it is classed as a derived lipid. Because it is insoluble in blood, it travels inside lipoproteins, and the balance between LDL and HDL cholesterol is one of the strongest predictors of heart disease.

You need: classification of derived lipids from 3.1; amphipathic membrane lipids from 3.4.

The steroid nucleus and cholesterol

The steroid nucleus is **cyclopentanoperhydrophenanthrene**: three six-membered rings (A, B, C) fused like phenanthrene, fully saturated ("perhydro"), with a five-membered ring D attached. It has 17 carbons, numbered in a fixed order that every steroid uses. Any molecule with this nucleus is a steroid; a steroid with an –OH at C3 is a **sterol**.

Cholesterol ($C_{27}H_{46}O$) adds four features to the nucleus (Figure 3.6.1):

- a **3β-hydroxyl** group on ring A, its only polar group;

- a **double bond between C5 and C6** in ring B;
- two **methyl groups**, C19 on C10 and C18 on C13;
- an **eight-carbon branched side chain** on C17 (carbons 20 to 27).

The –OH is a tiny head on a large flat hydrophobic body, so cholesterol is only weakly amphipathic. In membranes it sits between phospholipids with its –OH near their head groups. When the –OH is esterified with a fatty acid, the product, **cholesteryl ester**, is even more hydrophobic; this is the form stored in cells and carried in the core of lipoproteins.

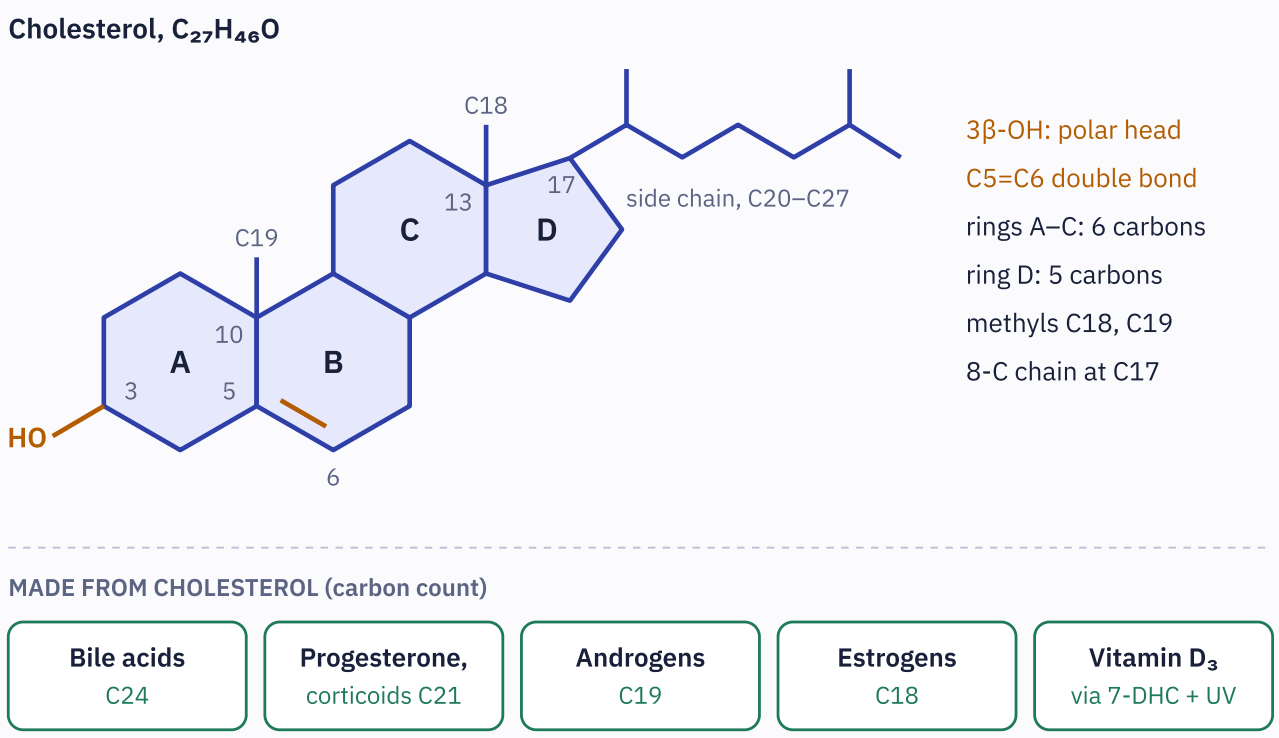


Figure 3.6.1 The steroid nucleus as it appears in cholesterol. Rings A, B and C have six carbons, ring D five. Orange marks the two features examiners ask about most, the 3β-OH and the C5=C6 double bond. The bottom row shows the steroid families the body makes from cholesterol, each with its carbon count, which falls as the side chain is cut away.

What cholesterol does

1. **Membrane fluidity buffer.** Its rigid rings restrict the movement of nearby fatty acid chains, so membranes are less fluid at body temperature; it also keeps chains from packing into a solid gel when cold. Animal plasma membranes contain a large share of cholesterol; plants use phytosterols such as β-sitosterol and stigmasterol, and fungi use **ergosterol**, which is the target of antifungal drugs such as amphotericin B and the azoles. Most bacteria have no sterols.
2. **Bile acids.** The liver converts cholesterol to the C24 **primary bile acids**, cholic acid and chenodeoxycholic acid; the first step is 7α-hydroxylation. They are joined (conjugated) to

glycine or taurine, giving **bile salts** such as glycocholate and taurocholate. Bile salts are strong amphipathic detergents that emulsify dietary fat and form micelles for its absorption. Gut bacteria convert some to **secondary bile acids** (deoxycholic and lithocholic acid). About 95 percent of bile salts are reabsorbed and returned to the liver (enterohepatic circulation); the rest is lost in faeces, and this is the body's main way of getting rid of cholesterol.

3. **Steroid hormones.** In mitochondria of the adrenal cortex and gonads, the side chain is cut to give **pregnenolone** (C21), the common parent. From it come progesterone (C21), the **glucocorticoids** (cortisol, C21), the **mineralocorticoids** (aldosterone, C21), the androgens (testosterone, C19) and the estrogens (estradiol, C18, with an aromatic ring A).
4. **Vitamin D.** In the skin, ultraviolet B light opens ring B of 7-dehydrocholesterol, an intermediate of cholesterol synthesis, giving vitamin D_3 (cholecalciferol). Its activation and functions are in Unit 4.

Cortisol is made in the zona fasciculata of the adrenal cortex; it raises blood glucose by promoting gluconeogenesis, breaks down muscle protein and suppresses inflammation and immunity, which is why synthetic glucocorticoids (prednisolone, dexamethasone) are used against inflammation. **Aldosterone** is made in the zona glomerulosa; it acts on the kidney to retain Na^+ (and with it water) and excrete K^+, so it controls blood volume and pressure.

Terpenes: the isoprene family

Terpenes (isoprenoids) are derived lipids built from five-carbon **isoprene** units (2-methyl-1,3-butadiene). They are classed by how many units they contain:

CLASS	ISOPRENE UNITS	CARBONS	EXAMPLES
Monoterpenes	2	C10	menthol, limonene, geraniol
Sesquiterpenes	3	C15	farnesol
Diterpenes	4	C20	phytol (side chain of chlorophyll), retinol, gibberellins
Triterpenes	6	C30	squalene, the precursor of cholesterol
Tetraterpenes	8	C40	carotenoids: β-carotene, lycopene
Polyterpenes	many	—	natural rubber

Steroids are modified triterpenes: the cell builds squalene from six isoprene units and folds it into the four rings, losing three carbons on the way to cholesterol (C27). The pathway from acetyl-CoA through HMG-CoA and the action of statins are in Unit 6, Synthesis of triacylglycerols, phospholipids and cholesterol.

Lipoproteins and heart disease

A **lipoprotein** is a particle with a core of TAG and cholesteryl ester and a shell of phospholipid, free cholesterol and proteins called apolipoproteins. The classes, from largest and least dense to smallest and densest, are:

- **Chylomicrons**: carry dietary TAG from the intestine.
- **VLDL**: carry TAG made in the liver to tissues; as they lose TAG they become IDL and then LDL.
- **LDL**: carry most of the blood's cholesterol to tissues, taken up through the LDL receptor. Called "bad cholesterol" because excess LDL enters artery walls, is oxidised and taken up by macrophages, which become foam cells and build **atherosclerotic plaque**.
- **HDL**: collect excess cholesterol from tissues and return it to the liver (reverse cholesterol transport), helped by LCAT. Called "good cholesterol" because higher HDL goes with lower risk.

Commonly used adult targets (US NCEP ATP III, also used in Indian labs) are total cholesterol below 200 mg/dL, LDL below 100 mg/dL as optimal, HDL of 60 mg/dL or more as protective (below 40 is low), and fasting TAG below 150 mg/dL. In familial hypercholesterolaemia, a faulty LDL receptor keeps LDL high from birth and causes early heart attacks.

Two colour tests detect cholesterol in the lab. In the **Liebermann–Burchard test**, cholesterol in chloroform with acetic anhydride and concentrated sulfuric acid turns green. In the **Salkowski test**, chloroform and concentrated sulfuric acid give a red colour in the chloroform layer.

WORKED EXAMPLE

Question (5 marks). A 45-year-old's fasting lipid profile reads: total cholesterol 230 mg/dL, HDL 38 mg/dL, triacylglycerol 160 mg/dL. (a) Estimate LDL cholesterol with the Friedewald formula. (b) Find the total cholesterol/HDL ratio. (c) Comment on the risk.

1. Friedewald formula (all values in mg/dL, valid when TAG is below 400 mg/dL): LDL = TC − HDL − TAG/5. Here TAG/5 = 160/5 = 32 mg/dL estimates VLDL cholesterol.
2. LDL = 230 − 38 − 32 = **160 mg/dL**.
3. TC/HDL = 230 / 38 = **6.1**.
4. Comment: total cholesterol is above 200, LDL is well above the optimal 100, HDL is below 40 and TAG is just above 150. With a high TC/HDL ratio as well, this person has raised cardiovascular risk and needs diet, exercise and possibly a statin, as a doctor decides.

EXAM TRAPS

- Cholesterol is a derived lipid (steroid alcohol), not a fat. It gives no energy; the body cannot break the ring system down to CO_2.
- The double bond is between C5 and C6, in ring B, not in ring A.
- "Good" and "bad" cholesterol are the same molecule; the labels describe the carrier, HDL or LDL.
- Bile acids are C24 and come from cholesterol; bile pigments (bilirubin) come from haem. Do not mix them up.
- Steroids are made from squalene, a triterpene; carotenoids are tetraterpenes. Count isoprene units carefully.

CHECK YOURSELF

– REMEMBER **What is the parent ring system of all steroids called?** 1 mark

Cyclopentanoperhydrophenanthrene (the steroid nucleus): three six-membered rings and one five-membered ring.

– REMEMBER **Name two primary bile acids and the amino acids they are conjugated with.** 2 marks

Cholic acid and chenodeoxycholic acid; conjugated with glycine or taurine.

– UNDERSTAND **How does cholesterol keep membrane fluidity steady?** 3 marks

Its rigid rings reduce the motion of nearby fatty acid chains, lowering fluidity at high temperature; at low temperature it gets between chains and stops them packing into a gel. So it buffers fluidity against temperature change.

– UNDERSTAND **Why is LDL called "bad" and HDL "good" cholesterol?** 3 marks

LDL delivers cholesterol to tissues; excess LDL enters artery walls, is oxidised and forms foam cells and plaque. HDL removes cholesterol from tissues back to the liver. High LDL raises, and high HDL lowers, the risk of atherosclerosis.

– APPLY **Total cholesterol 190 mg/dL, HDL 50 mg/dL, TAG 100 mg/dL. Estimate LDL.** 2 marks

LDL = 190 − 50 − 100/5 = 190 − 50 − 20 = **120 mg/dL** (near optimal, above 100).

– APPLY **Classify by isoprene units: β-carotene, menthol, squalene.** 3 marks

β-Carotene: tetraterpene (8 units, C40). Menthol: monoterpene (2 units, C10). Squalene: triterpene (6 units, C30).

– ANALYZE **Bile acid sequestrant drugs bind bile salts in the gut and stop their reabsorption. Why does this lower blood cholesterol?** 4 marks

Bile salts lost in faeces are not returned to the liver, so the liver must make new bile acids from cholesterol. It takes more LDL from blood (more LDL receptors) to supply this, and blood LDL cholesterol falls. It uses the main excretion route of cholesterol on purpose.

BEYOND THE SYLLABUS

Newer cholesterol-lowering drugs block PCSK9, a protein that destroys LDL receptors, using monoclonal antibodies or small interfering RNA. Lipoprotein(a), a modified LDL particle, is now measured as an inherited risk factor. Bacteria use hopanoids, sterol-like molecules, to stiffen their membranes, and their fossils are used as molecular markers of ancient life. This is not for the exam; search "PCSK9 inhibitors" and "lipoprotein(a) risk" to go further.

3.7 Eicosanoids

Eicosanoids are signalling molecules made from 20-carbon polyunsaturated fatty acids, mainly arachidonic acid ("eicosa" is Greek for twenty). They include the prostaglandins, prostacyclin, the thromboxanes and the leukotrienes. Unlike classical hormones they are not stored and do not travel far: a cell makes them within seconds when stimulated, they act on the same cell or its neighbours, and they are destroyed quickly. They control pain, fever, inflammation, blood clotting, labour and airway tone, which makes them the targets of some of the most used drugs in the world, from aspirin to asthma tablets.

You need: arachidonic acid and ω-numbering from 3.2; phospholipase A2 from 3.4.

Precursors and the three families

Arachidonic acid, 20:4(Δ5,8,11,14), is an ω-6 fatty acid stored at sn-2 of membrane phospholipids. When a cell receives a signal (injury, a hormone, an immune trigger), **phospholipase A2** cuts it free. This release is the controlling step: no free arachidonic acid, no eicosanoids. Then two main enzyme routes act on it:

1. **Cyclooxygenase (COX) pathway**, the "cyclic" route. The enzyme, also called prostaglandin H synthase, adds two O_2 and closes a ring, giving PGG_2 and then **PGH_2**. Tissue-specific

enzymes turn PGH_2 into the **prostanoids**: prostaglandins (PGE_2, $PGF_2\alpha$, PGD_2), **prostacyclin** (PGI_2, mainly in vessel walls) and **thromboxane A_2** (TXA_2, mainly in platelets). There are two forms of the enzyme: **COX-1**, made all the time in most tissues (stomach, platelets, kidney), and **COX-2**, switched on at sites of inflammation.

2. **Lipoxygenase (LOX) pathway**, the "linear" route. **5-Lipoxygenase**, mainly in white blood cells, gives LTA_4 and then the **leukotrienes** LTB_4, LTC_4, LTD_4 and LTE_4. Other lipoxygenases give lipoxins and hydroxy acids.
3. A third, smaller route uses **cytochrome P450** enzymes to make epoxy acids that act on blood vessels.

The precursor sets the "series". Arachidonic acid gives series-2 prostanoids (two double bonds, the subscript in PGE_2) and series-4 leukotrienes. The ω-3 fatty acid EPA, 20:5, gives series-3 prostanoids and series-5 leukotrienes, which are generally weaker promoters of inflammation and clotting. This is one reason fish oil is studied for heart health.

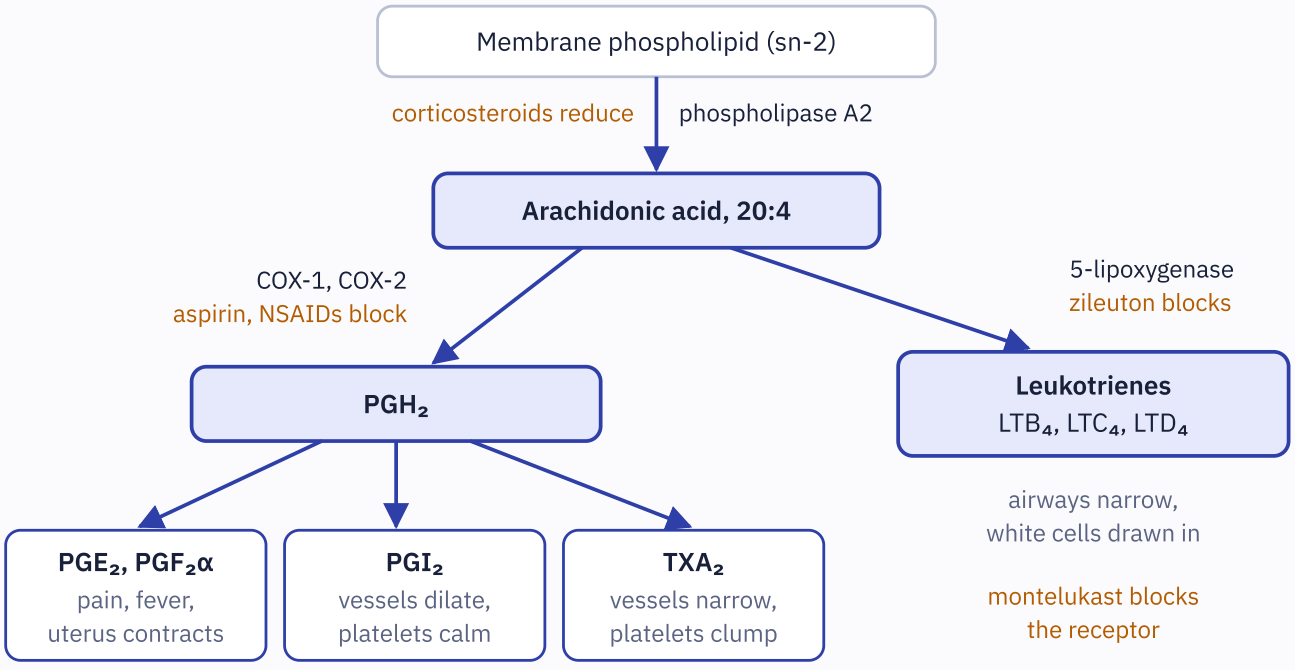


Figure 3.7.1 One fatty acid, two routes. Phospholipase A2 releases arachidonic acid; cyclooxygenase sends it to PGH_2 and the prostanoids (left), 5-lipoxygenase to the leukotrienes (right). Orange shows where common drugs act. Notice that PGI_2 and TXA_2 come from the same PGH_2 yet have opposite effects on vessels and platelets.

Structures and actions

Prostaglandins are built on prostanoic acid, a C20 acid with a five-membered (cyclopentane) ring formed between C8 and C12. The letter after PG (A to I) tells the groups on the ring; the

subscript tells the number of C=C double bonds in the side chains. They were named in the 1930s by Ulf von Euler, who found them in seminal fluid and believed they came from the prostate gland. Sune Bergström, Bengt Samuelsson and John Vane shared the 1982 Nobel Prize in Physiology or Medicine for this field.

Thromboxanes have a six-membered ring that contains an oxygen atom. **Leukotrienes** have no ring; they have three conjugated double bonds (a "triene") and were first found in leukocytes, hence the name. LTC_4, LTD_4 and LTE_4 carry cysteine-containing groups and together were once called the slow-reacting substance of anaphylaxis.

The actions to remember:

- **PGE_2**: causes fever (acts on the hypothalamus), pain and the redness and swelling of inflammation; protects the stomach lining by reducing acid and increasing mucus; keeps the ductus arteriosus open before birth.
- **$PGF_2\alpha$**: contracts the uterus (labour, menstrual cramps) and constricts bronchi.
- **PGI_2 (prostacyclin)**: made by the endothelium; dilates vessels and prevents platelets from clumping.
- **TXA_2**: made by platelets; constricts vessels and makes platelets clump, starting a clot.
- **Leukotrienes**: LTB_4 attracts neutrophils; LTC_4 and LTD_4 constrict airways strongly and make vessels leaky, as in asthma and allergy.

Eicosanoids act through cell-surface G-protein-coupled receptors, which change cAMP or Ca^{2+} inside the cell.

Drugs that act on the pathway

1. **Aspirin** transfers an acetyl group to a serine in the active site of COX, blocking it permanently. **Ibuprofen** and other NSAIDs block it reversibly. Both reduce PGE_2, so they lower fever, pain and inflammation, but by also blocking COX-1 in the stomach they reduce its protection and can cause ulcers.
2. **COX-2 selective inhibitors** (coxibs such as celecoxib) were made to spare the stomach. Some raised the risk of heart attacks, and rofecoxib was withdrawn in 2004, because blocking endothelial PGI_2 while platelet TXA_2 continues tips the balance toward clotting.
3. **Corticosteroids** reduce PLA2 activity and the production of COX-2, so they cut both branches; this is part of their strong anti-inflammatory effect.
4. **Leukotrienes** are targeted in asthma: montelukast blocks their receptor and zileuton inhibits 5-lipoxygenase.
5. Prostaglandin analogues are used as drugs: misoprostol (a PGE_1 analogue) protects the stomach and is used in obstetrics; latanoprost (a $PGF_2\alpha$ analogue) treats glaucoma.

WORKED EXAMPLE

Question (6 marks). A doctor prescribes 75 mg of aspirin daily to a patient after a heart attack. Explain, using the eicosanoid pathway, how such a low dose prevents clots in arteries without stopping prostacyclin production for long.

1. Clotting in arteries starts when platelets clump, driven by TXA_2 made in platelets by COX-1. Prostacyclin (PGI_2) from the endothelium opposes this.
2. Aspirin acetylates COX **irreversibly**. A blocked enzyme stays blocked until the cell makes new enzyme.
3. Platelets have **no nucleus**, so they cannot make new COX. Each exposed platelet stays unable to make TXA_2 for its whole life of about 7 to 10 days.
4. Endothelial cells have a nucleus and make fresh COX within hours, so PGI_2 production recovers between doses.
5. Result: a daily low dose keeps TXA_2 low and lets PGI_2 recover, shifting the balance away from clotting. A higher dose would block more endothelial COX and stomach COX-1 with no extra benefit and more side effects.

EXAM TRAPS

- Aspirin blocks cyclooxygenase, not lipoxygenase. It does not lower leukotrienes, and in some people it can even worsen asthma.
- Prostacyclin (PGI_2) and thromboxane (TXA_2) have opposite effects; do not list both as "pro-clotting".
- The subscript in PGE_2 is the number of double bonds in the side chains, not a type number. Series 2 comes from arachidonic acid.
- Eicosanoids are local (autocrine and paracrine) mediators made on demand, not stored hormones carried in blood.
- Favourite question: "Write the biosynthesis and functions of prostaglandins" or "Explain the action of aspirin".

CHECK YOURSELF

– REMEMBER **Name the precursor of series-2 prostaglandins and the enzyme that releases it.** 2 marks

Arachidonic acid, 20:4(Δ5,8,11,14); released from membrane phospholipids by phospholipase A2.

– REMEMBER **List the main classes of eicosanoids.** 2 marks

Prostaglandins, prostacyclin, thromboxanes (together the prostanoids) and leukotrienes; also lipoxins.

– UNDERSTAND **Why are eicosanoids called local hormones?** 2 marks

They are made on demand by many cell types and act on the same or neighbouring cells within seconds to minutes before being inactivated, instead of travelling in blood from one gland to distant targets.

– UNDERSTAND **Why can long-term NSAID use cause stomach ulcers?** 3 marks

COX-1 in the stomach makes PGE_2 and PGI_2, which reduce acid secretion and increase mucus and blood flow. NSAIDs block COX-1, so this protection is lost and acid damages the lining.

– APPLY **A diet rich in fish oil raises EPA in membranes. Which prostanoid and leukotriene series would increase?** 2 marks

EPA (20:5) gives series-3 prostanoids (such as TXA_3, PGI_3) and series-5 leukotrienes (such as LTB_5).

– APPLY **Choose a drug to block (a) fever, (b) asthma attacks driven by leukotrienes, (c) all branches of the pathway.** 3 marks

(a) Aspirin, ibuprofen or another NSAID (COX inhibition). (b) Montelukast (receptor blocker) or zileuton (5-LOX inhibitor). (c) A corticosteroid, which reduces PLA2 activity and COX-2 production.

– ANALYZE **Explain how selective COX-2 inhibitors can protect the stomach yet raise the risk of heart attack.** 4 marks

They spare COX-1, so gastric prostaglandins and platelet TXA_2 continue. They block COX-2, which contributes much of the endothelial PGI_2. With PGI_2 lowered and TXA_2 unchanged, the balance shifts toward vasoconstriction and platelet clumping, increasing clot risk in coronary arteries.

BEYOND THE SYLLABUS

Inflammation does not just fade; it is actively switched off by specialised pro-resolving mediators such as lipoxins, resolvins and protectins, many made from ω-3 fatty acids. Drug research is moving from blocking eicosanoids to boosting this resolution phase. Lipidomic mass spectrometry now measures dozens of eicosanoids in a drop of blood. This is not for the exam; search "resolvins inflammation resolution" and "eicosanoid lipidomics" to go further.

Unit summary

TERM	MEANING OR FORMULA	CHAPTER
Lipid	water-insoluble, organic-solvent-soluble biomolecule related to fatty acids	3.1
Simple / compound / derived	ester of FA + alcohol / ester + extra group (phosphate, sugar, protein) / hydrolysis products and steroids	3.1
Shorthand 18:2(Δ9,12)	18 carbons, 2 double bonds, starting at C9 and C12 from the carboxyl end	3.2
ω class	ω = number of carbons − highest Δ position	3.2
Essential fatty acids	linoleic (ω-6) and α-linolenic (ω-3)	3.2
Saponification value	mg KOH per g fat; SV = 3 × 56.1 × 1000 / M; lab: (B − S) × N × 56.1 / W	3.3
Iodine value	g I_2 per 100 g fat; measures unsaturation	3.3
Acid value, RM number	free fatty acids (rancidity); volatile soluble fatty acids (ghee purity)	3.3
Lecithin / cephalin	phosphatidylcholine / phosphatidylethanolamine	3.4
Phospholipases	A1, A2 remove fatty acids; C gives DAG + phospho-head; D gives PA + head	3.4
Ceramide	sphingosine + amide-linked fatty acid; parent of sphingolipids	3.5
Ganglioside	ceramide + oligosaccharide with sialic acid; GM2 stored in Tay–Sachs	3.5
Cholesterol	$C_{27}H_{46}O$; steroid nucleus, 3β-OH, C5=C6, side chain at C17	3.6
Friedewald formula	LDL = TC − HDL − TAG/5 (mg/dL, TAG below 400)	3.6
Isoprene unit	C5 building block of terpenes; squalene (C30) → steroids	3.6
COX / 5-LOX	arachidonic acid → PGH_2 → prostanoids / → leukotrienes	3.7

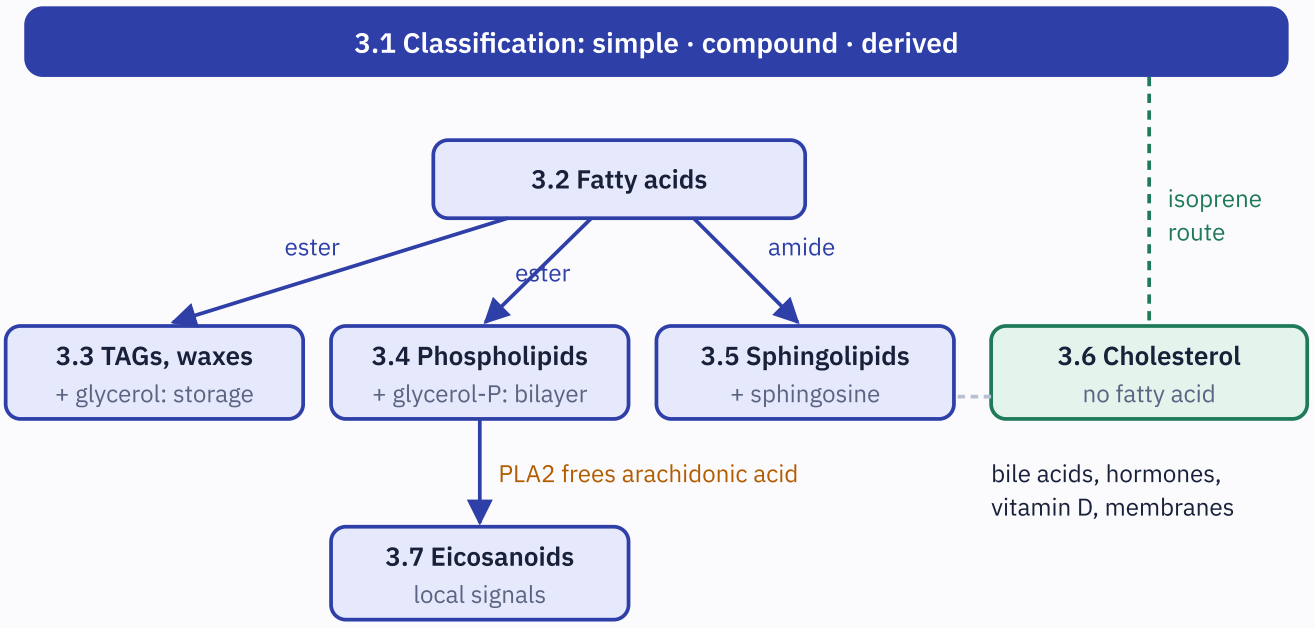


Figure 3.S.1 How the chapters connect. Fatty acids are the shared part of TAGs, phospholipids and sphingolipids (joined by ester or amide bonds); one fatty acid stored in phospholipids becomes the eicosanoids. Cholesterol comes by a separate isoprene route and works beside phospholipids and sphingolipids in membranes.

Takeaways

1. Lipids are grouped by solubility, then sorted by hydrolysis products into simple, compound and derived lipids.
2. Fatty acids are named by chain length and double bond positions; Δ counts from the carboxyl end, ω from the methyl end.
3. Longer chains raise the melting point; cis double bonds lower it. Linoleic and α-linolenic acids are essential.
4. TAGs store energy; saponification value tells average chain length, iodine value tells unsaturation.
5. Waxes are esters of long fatty acids with long alcohols and serve as waterproof coats.
6. Glycerophospholipids are phosphatidic acid plus a head: choline makes lecithin, ethanolamine makes cephalin.
7. Sphingolipids are ceramide plus a head; missing lysosomal enzymes cause Tay–Sachs, Niemann–Pick and Gaucher disease.
8. Cholesterol stiffens membranes and is the parent of bile acids, steroid hormones and vitamin D; LDL and HDL carry it.
9. Eicosanoids come from arachidonic acid by the COX and LOX routes, and aspirin, NSAIDs, steroids and montelukast act on them.

Exam question bank

Remember and understand

- **1. Classify lipids with suitable examples and one structure for each class. (10 marks)**

  Definition of lipid; simple (fats and oils with TAG structure, waxes with beeswax); compound (glycerophospholipids such as lecithin, sphingophospholipids such as sphingomyelin, glycolipids, lipoproteins, sulfolipids); derived (fatty acids, glycerol, steroids, terpenes, fat-soluble vitamins, eicosanoids); a neat tree diagram; note on borderline cases.

- **2. Explain the classification, nomenclature and properties of fatty acids. (10 marks)**

  Saturated and unsaturated (MUFA, PUFA) with examples; Δ and ω numbering and shorthand; cis and trans; effect of chain length and unsaturation on melting point with values; essential fatty acids and why; trans fats and vanaspati.

- **3. Describe the structure and functions of phospholipids, with lecithin and cephalin as examples. (10 marks)**

  Phosphatidic acid plan; head groups and names; structures of lecithin and cephalin; charges; amphipathic nature and bilayer; lung surfactant and L/S ratio; PS in clotting and apoptosis; plasmalogens and cardiolipin; phospholipase sites.

- **4. Write the structure of cholesterol and list its biological importance. (8 marks)**

  Steroid nucleus with numbering; 3β-OH, C5=C6, C18, C19 methyls, side chain at C17; cholesteryl ester; membrane fluidity; bile acids and bile salts; steroid hormones from pregnenolone; vitamin D_3; colour tests.

- **5. What are sphingolipids? Describe sphingomyelin, cerebrosides and gangliosides with their functions. (10 marks)**

  Sphingosine and ceramide (amide bond); sphingomyelin as phospholipid and myelin lipid; cerebrosides (galacto-, gluco-) and sulfatides; globosides; gangliosides with sialic acid and GM naming; roles in recognition, blood groups, toxin receptors; mention of plant glyceroglycolipids.

Apply

- **6. Define saponification value and describe its determination. 1.5 g of fat used 13.2 mL less 0.5 N HCl than the blank; find its SV and average molar mass. (12 marks)**

  Definition and significance; reaction; procedure with reflux, blank, phenolphthalein; formula. Calculation: KOH = 13.2 × 0.5 × 56.1 = 370.3 mg; SV = 370.3 / 1.5 = 246.9 mg KOH/g; M = 168 300 / 246.9 ≈ 682 g/mol, a fat rich in short and medium chains (like coconut oil).

- **7. Define iodine value, acid value, peroxide value and Reichert–Meissl number. Calculate the theoretical iodine value of trilinolein (M = 879.4 g/mol). (10 marks)**

  Definitions and what each measures; drying, semi-drying and non-drying oils; use in detecting rancidity and adulteration. Trilinolein has 6 C=C: 6 × 253.8 × 100 / 879.4 = 173 g I_2/100 g.

- **8. Explain the action of phospholipases A1, A2, C and D on lecithin, with the products, and give one biological example of each type where known. (8 marks)**

  Sites on the structure; products (lysolecithin + FA; DAG + phosphocholine; PA + choline); PLA2 in venom haemolysis and arachidonic acid release; PLC in PIP_2 signalling and *C. perfringens* α-toxin; PLD giving phosphatidic acid.

- **9. Write the biosynthesis of prostaglandins, thromboxanes and leukotrienes from arachidonic acid and state their functions. (12 marks)**

  PLA2 release; COX-1 and COX-2 to PGG_2 and PGH_2; PGE_2, $PGF_2\alpha$, PGI_2, TXA_2; 5-LOX to LTA_4 and LTB_4, LTC_4, LTD_4; flow diagram; functions of each; series from different precursors.

- **10. A lipid profile shows TC 250, HDL 35 and TAG 200 mg/dL. Calculate LDL, explain the roles of the lipoproteins and relate the result to atherosclerosis. (10 marks)**

  LDL = 250 − 35 − 40 = 175 mg/dL; all values outside targets; lipoprotein classes and their cargo; LDL oxidation, foam cells and plaque; HDL and reverse transport; familial hypercholesterolaemia.

Analyze and evaluate

- **11. Compare triacylglycerols, glycerophospholipids and sphingolipids in structure, bonds and function. (12 marks, spans 3.3–3.5)**

  Backbone (glycerol, glycerol-3-phosphate, sphingosine); fatty acid links (ester vs amide); polarity (neutral vs amphipathic); assembly (droplets vs bilayers); functions (storage vs membranes and signalling vs recognition); a comparison table and one structure each.

- **12. "Membrane fluidity depends on both fatty acids and sterols." Discuss. (10 marks, spans 3.2, 3.4, 3.6)**

  Chain length and cis double bonds; tails of phospholipids; cholesterol's buffering at high and low temperature; sphingomyelin and cholesterol in rafts; homeoviscous adaptation in bacteria as an example.

- **13. Explain the biochemical basis of sphingolipid storage diseases, with Tay–Sachs, Niemann–Pick and Gaucher diseases as examples, and evaluate treatment options. (12 marks)**

  Stepwise lysosomal degradation; enzyme missing and lipid stored for each; clinical features; inheritance; enzyme replacement for Gaucher and why it fails for brain disease; substrate reduction.

- **14. Evaluate why aspirin, selective COX-2 inhibitors and corticosteroids have different benefits and side effects, using the eicosanoid pathway. (12 marks, spans 3.4 and 3.7)**

  Sites of action (COX irreversible, COX-2 selective, PLA2 and COX-2 expression); effects on PGE_2, PGI_2, TXA_2, leukotrienes; gastric ulcer, antiplatelet effect, heart risk of coxibs; broad anti-inflammatory action of steroids.

Glossary

Amphipathic	Having a polar and a non-polar part in one molecule.
Arachidonic acid	20:4(Δ5,8,11,14), ω-6; precursor of series-2 prostanoids.
Bile salt	Bile acid conjugated to glycine or taurine; emulsifies fat.
Cephalin	Phosphatidylethanolamine (older use includes phosphatidylserine).
Ceramide	Sphingosine with an amide-linked fatty acid; parent of sphingolipids.
Cerebroside	Ceramide with one sugar (glucose or galactose).
Cholesteryl ester	Cholesterol esterified at its 3-OH with a fatty acid.
Cyclooxygenase (COX)	Enzyme converting arachidonic acid to PGH_2; target of aspirin.
Eicosanoid	Signalling molecule made from a C20 polyunsaturated fatty acid.
Essential fatty acid	Fatty acid needed in the diet: linoleic and α-linolenic acids.
Ganglioside	Ceramide with an oligosaccharide containing sialic acid.
Iodine value	Grams of iodine taken up by 100 g of fat; measures unsaturation.
Isoprene	Five-carbon unit from which terpenes and steroids are built.

Lecithin	Phosphatidylcholine.
Leukotriene	Linear eicosanoid from 5-lipoxygenase; constricts airways.
Lipoprotein	Particle of lipid and apolipoprotein that carries lipids in blood.
Lysophospholipid	Phospholipid that has lost one fatty acid, for example lysolecithin.
Phosphatidic acid	Glycerol-3-phosphate with two fatty acids; parent of glycerophospholipids.
Prostacyclin	PGI_2; vasodilator that prevents platelet clumping.
Rancidity	Spoilage of fat by hydrolysis or oxidation.
Saponification	Alkaline hydrolysis of a fat into glycerol and soap.
Saponification value	mg KOH needed to saponify 1 g of fat.
Sphingosine	C18 amino alcohol backbone of sphingolipids.
Steroid nucleus	Cyclopentanoperhydrophenanthrene: four fused rings A–D.
Thromboxane A_2	Platelet eicosanoid that constricts vessels and aggregates platelets.
Trans fat	Unsaturated fat with trans double bonds, formed in partial hydrogenation.
Triacylglycerol	Glycerol esterified with three fatty acids; storage fat.
Wax	Ester of a long-chain fatty acid with a long-chain alcohol.

Sources and further reading

Textbooks

- D. L. Nelson and M. M. Cox, *Lehninger Principles of Biochemistry*, W. H. Freeman; the chapter on lipids and the chapter on lipid biosynthesis (from memory; check).
- J. M. Berg, J. L. Tymoczko, G. J. Gatto and L. Stryer, *Biochemistry*, W. H. Freeman; chapters on membrane lipids and lipid metabolism (from memory; check).
- D. Voet and J. G. Voet, *Biochemistry*, Wiley (from memory; check).
- U. Satyanarayana and U. Chakrapani, *Biochemistry*, a widely used Indian textbook; the chapter on lipids (from memory; check).
- V. W. Rodwell and others, *Harper's Illustrated Biochemistry*, McGraw-Hill, for lipoproteins and clinical aspects (from memory; check).

Open web resources

- LIPID MAPS, Lipid Classification System: lipidmaps.org/resources/education/classification (the eight lipid categories).

- FSSAI, news compilation on the trans fat regulation of December 2020: fssai.gov.in (PDF) (limit of 2 percent in oils and fats from January 2022).

Syllabus: the University free n easy universal syllabus, built from top universities' syllabi.

Built for the University free n easy YouTube channel from the universal syllabus of Biochemistry (Oct 2026). Written with top universities' syllabi and standard textbooks; check a formula against your prescribed book before an exam, and report mistakes on the channel.