# Biochemistry

**Unit 3 · Lesson 1 · Lipids and fatty acids**

The notes for Lesson 1 of Unit 3: chapters 3.1 to 3.2 of the unit book, with their figures, worked examples, exam traps and quizzes, in one file. The full unit book, with every chapter, the exam question bank and the glossary, is linked at the end.

Lesson 1 of 3 | 2 chapters | Chapters 3.1 to 3.2

## About these notes

These are the notes for **Lesson 1 · Lipids and fatty acids** of the University free n easy video lessons on Biochemistry Unit 3, Lipids: Structure and Classification. They are chapters 3.1 to 3.2 of the unit book, unchanged, so a page here is the same page in the full book.

## 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.

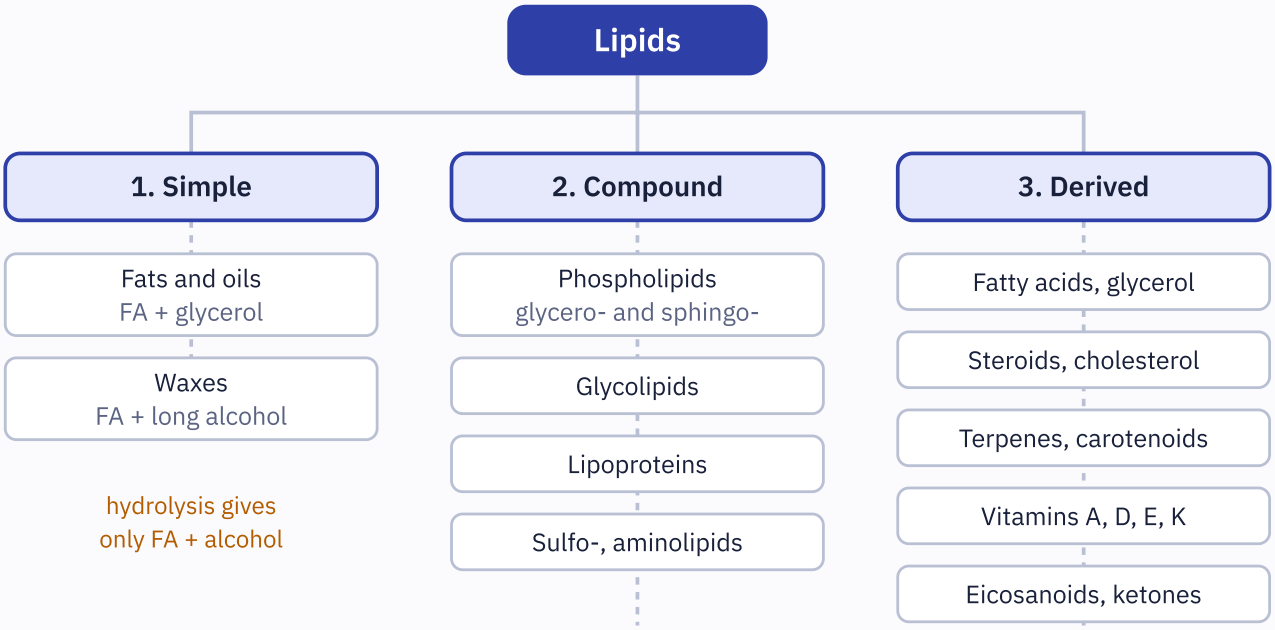



**Figure 3.1.1** The simple–compound–derived tree. Read across: simple lipids are plain esters, compound lipids add one extra group (phosphate, sugar, protein), and derived lipids are what hydrolysis releases plus the lipid-soluble molecules with no ester at all, such as cholesterol. FA = fatty acid.

## 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

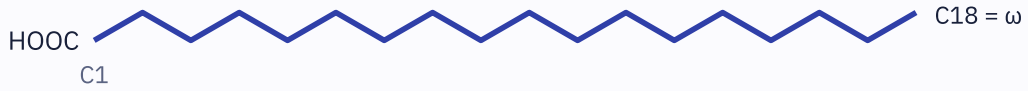
In a **saturated** fatty acid every carbon holds as many hydrogens as it can. The chain is fully extended and flexible, and neighbouring chains lie side by side with many van der Waals contacts. Packing tightly, they need more heat to melt.

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:

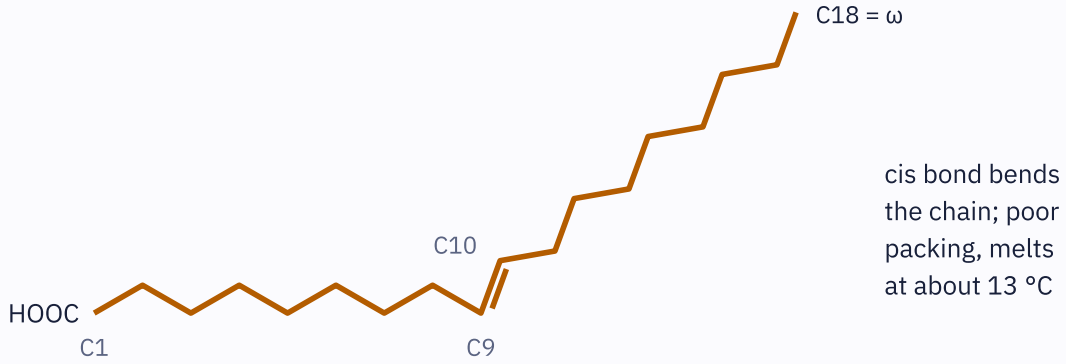
1. Melting point rises with chain length (more contacts per chain).
2. Melting point falls with the number of cis double bonds (poorer packing).

**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.

## Key terms of this lesson

| 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 |

## Glossary (terms used in this lesson)

**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. |
| **Cephalin** | Phosphatidylethanolamine (older use includes phosphatidylserine). |
| **Cerebroside** | Ceramide with one sugar (glucose or galactose). |
| **Cholesteryl ester** | Cholesterol esterified at its 3-OH with a fatty acid. |
| **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. |
| **Lecithin** | Phosphatidylcholine. |
| **Lipoprotein** | Particle of lipid and apolipoprotein that carries lipids in blood. |
| **Sphingosine** | C18 amino alcohol backbone of sphingolipids. |
| **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. |

## The full unit book

Every chapter of Unit 3, the unit summary, the exam question bank with model answers and the full glossary: Biochemistry · Unit 3 · Lipids: Structure and Classification (one file, works offline).

## 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.

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