Lipids and membranes

BIOS 1006

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Objectives

- Know all definitions.
- Describe the roles played by lipids.
  - Structure
  - Energy storage
  - Protection
  - Pigments
  - Coenzymes
  - Signaling
- Describe micelle and bilayer structures.
- Describe the forces that stabilize lipid structures.
- Predict the relative melting points of fatty acids and the lipids in which they are found.
- Draw a fatty acid given a name or designation: (e.g. trans-$18{:}1^{\Delta 9}$ or $18{:}1\omega 9$) and name fatty acids if given a structure. (conformation-carbons:double bonds$^{\Delta \text{ double bond position from COOH}}$ or
- Describe the essential and non-essential designations. (essential = needs to be consumed, non-essential = naturally made by your body)
- Recognize a triacylglycerol or phospholipid given the names, structures or designations of the components.
  - Amide bond? → sphingolipid
  - C5H8 - 5-carbon molecule with 2 double bonds and methyl group? (5-2-1, 5C-2π-1 branch) → isoprenoid
  - Phosphate head and two chains of fatty acid tails? → phospholipid

  - Glycerol backbone (3 carbons bonded to OH) esterified to three fatty acids? → triacylglycerol (triglyceride)
  - Glycerol backbone with two fatty acids and one phosphate group linked to an additional polar head? → glycerophospholipid
  - Multiple isoprene units linked head-to-tail? → terpene or polyisoprenoid
  - Structure with four fused rings? → steroid (e.g., cholesterol)
- Describe the relationship between lipid fluidity and melting point. (more fluidity → lower melting point)
- If given a list of fatty acids or lipids, rank the melting points. From highest to lowest:
  - Saturated fats
  - Trans-unsaturated fats
  - Cis-unsaturated fats
- Describe the biological roles, the chemical reactions and the physical and structural properties of each lipid class.
  - **Triacylglycerols (Triglycerides)**:
    * *Biological role:* Energy storage (very reduced, hydrophobic—no water weight).
    * *Reactions:* Hydrolysis by lipases to release fatty acids.
    * *Structure:* Glycerol backbone + 3 fatty acids via ester linkages.
    * *Physical:* Hydrophobic; melting point depends on saturation of fatty acids.
  - **Phospholipids (Glycerophospholipids)**:
    * *Biological role:* Major component of cell membranes; amphipathic.
    * *Reactions:* Can be cleaved by phospholipases (A_1, A_2, C, D).
    * *Structure:* Glycerol + 2 fatty acids + phosphate + polar head group.
    * *Physical:* Amphipathic; form bilayers and micelles.
  - **Sphingolipids**:
    * *Biological role:* Membrane structure (especially in neurons); signaling.
    * *Reactions:* Formed via amide bond between sphingosine and fatty acid.
    * *Structure:* Sphingosine backbone + 1 fatty acid (amide bond) + head group.
    * *Physical:* Amphipathic; contribute to lipid rafts.
  - **Sterols (e.g., cholesterol)**:
    * *Biological role:* Membrane fluidity regulator; precursor to hormones.

    - *Reactions:* Precursor to steroid hormones, bile acids, and vitamin D.
    - *Structure:* Four fused rings (steroid nucleus) + OH at C3.
    - *Physical:* Amphipathic; fits between phospholipids in membranes.
  - **Isoprenoids (terpenes)**:
    - *Biological role:* Precursors to vitamins (A, E, K), coenzymes (Q), hormones.
    - *Reactions:* Built by linking isoprene units (C_5H_8) head-to-tail.
    - *Structure:* Repeating isoprene (5C) units; various ring or chain forms.
    - *Physical:* Often hydrophobic; may be volatile (like essential oils).
- Determine the class of a lipid if given a structure.
- Determine the class of isoprenoids, and locate isoprene units in molecules.
  - **Isoprene unit:** 5-carbon branched structure (CH_2=C(CH_3)-CH=CH_2). 2 isoprene units = 1 terpene unit
  - **Monoterpene:** 2 isoprene units (C_{10}).
  - **Sesquiterpene:** 3 isoprene units (C_{15}).
  - **Diterpene:** 4 isoprene units (C_{20}).
  - **Triterpene:** 6 isoprene units (C_{30}); e.g., squalene.
  - **Tetraterpene:** 8 isoprene units (C_{40}); e.g., β-carotene.
  - **Look for:** Repeating 5-carbon segments, often in head-to-tail or tail-to-tail arrangements.

Lipids

Are water-insoluble molecules that are highly soluble in organic solvents. They are defined by their solubility (in organic solvents, not water)

Roles of lipids

- Structure (membranes)
- Energy storage (fats, oils)
- Protection (antioxidants, water-proofing)
- Pigments (carotenoids)
- Coenzymes (vitamins, heme)
- Signaling (hormones, growth factors)

Lipids do not form covalent polymers!

Recall:

- proteins are covalent polymers of amino acids
- nucleic acids are covalent polymers of nucleotides
- polysaccharides are covalent polymers of sugars

Lipids also form higher order structures, but the esubunits are not covalently attached. These structures are micelles and bilayers (membranes) that are maintained by IMFs such as LDFs (non-polar parts), hydrogen bonds, dipole-dipole forces, and ion-dipole forces (between lipids and H_2O).

Classes and nomenclature of lipids

- Free fatty acids
- Triacylglycerols
- Phospholipids
- Glycolipids
- Isoprenoids

Fatty acids

Monocarboxylic acids composed of a long hydrocarbon chain with a carboxyl group at the end

- Even number of carbon atoms

- Generally unbranched chain (straight chain)
- Hydrophilic and hydrophobic ends (amphipathic)
- Varying degrees of saturation
- Produced by organisms and synthesized from Acetyl-CoA
- Plants make all the fatty acids they need
- We only produce some fatty acids, the rest must be obtained from our diet (essential fatty acids)
- Essential: in your diet
- Non-essential: can be synthesized by your body (doesn't mean not important!)
- We need to consume **essential fatty acids** (omega-6, omega-3)
- Think of the numbering scheme from the ω-carbon
- Saturated fatty acids are flexible (free rotation aroudn C-C bonds)
- Linear conformation ist he most stable due to steric constraints
- Chains pack tightly against each other and form more rigid, organized aggregates (i.e. membranes)
- London Force Strength is proportional to surface area, depends on length and proximity

saturated fatty acids 0 double bonds

monounsaturated fatty acids 1 double bond

polyunsaturated fatty acids 2 or more double bonds

Double bonds can result in one of two orientations. (cis (favored)/trans)

Saturated fatty acid nomenclature

- 18 carbon saturated fatty acid: 18:0 (carbons:double bonds)
- IUPAC: Octadecanoate (protonated: octadecanoic acid)
- Common: Stearate (protonated: stearic acid)

14:0 **tetra**<u>deca</u>noic acid (tetra = 4, deca = 10)
16:0 hexadecanoic acid
18:0 octadecanoic acid
20:0 **eicosanoic** acid
22:0 **do**<u>cos</u>anoic acid (do = 2, cos = 22)
24:0 tetracosanoic acid
26:0 hexacosanoic acid

Monounsaturated fatty acid nomenclature

18 carbon cis monounsaturated fatty acid with a double bond **starting** at position 11

- Full IUPAC name: cis Δ^{11}-octadecene/-oic acid
- IUPAC shorthand: 18:1$^{\Delta 11}$
- 18:1 ω 7 (counting backwards)

Polyunsaturated fatty acid nomenclature

18 carbon cis monounsaturated fatty acid with 2 double bonds **starting** at positions 9 and 12

- Full IUPAC name: cis-cis- Δ^9, Δ^{12}-octadecadienoic acid (dien = 2 double bonds)
- IUPAC shorthand: 18:1$^{\Delta 9, \Delta 12}$
- 18:2 ω 6 (from the first double bond counting backwards. assuming all are cis and any other double bond is 3 carbons away)

Lipid fluidity

The higher the melting point, the lower the fluidity (this is why butter is solid and olive oil is liquid)

Also depends on chain length. Longer chains have...

- Greater surface area
- Stronger London Forces
- Increased melting point

Lipid fluidity also depends on degree of unsaturation. **More double bonds = lower melting points** (kinks in structure preventing close interactions)

Trans fats (human-introduced by hydrogenation, more solid, higher melting point) are more easily packed together than cis fats (more liquid, lower melting point).

Triacylglycerols

- Glycerol backbone (linear vertical chain of CH-OH)
- Ester linkage containing 3 fatty acid chains and alcohol
- Constituent fatty acid lengths and degrees of unsaturation can vary (fats or oils), depending on number of double bonds/carbons
- Primarily used for energy storage in animal (adipose) and plants
- **Simple** triacylglycerols: All fatty acids are the same
- **Mixed** triacylglycerols: Fatty acids are different

Phospholipids

- Involved in generation of signaling molecules, anchoring proteins, and membrane formation
- An amphipathic derivative of glycerol (3 OH groups) or sphingosine

Phosphoglycerides (phospholipids)

- Composed of glycerol, two fatty acids (R groups), phosphate group, and "X" (amino alcohol or hydrogen)
- Simplest form: phosphatidic acid (X=H) and R = fatty acids
- Others classified according to the amino alcohol attached (X)
- Fatty acids attached can be the smae or different
- Example: **lecithin** (phosphatidylcholine), pH insensitive, a phosphoglyceride with choline
- **Cephalins** (phosphoglycerides with ethanolamine or serine) such as phosphatidylserine and phosphatidylethanolamine

Sphingolipids (includes phospholipids)

- Hydrophobic tail
- Ignored OH group
- Amide with fatty acid
- OH group that can attach a sugar (acetal) or a phosphate-amino alcohol
- Sphingosine + fatty acid = seramide
- General structure: sphingosine (sphingolipid) + fatty acid

Spingophospholipids

Sphingosine + fatty acid + phosphate + amino alcohol (e.g. A sphingomyelin, brain and nervous system tissue)

Find the amide bond!

Sphingoglycolipids

Sphingosine + fatty acid + carbohydrate

Properties of phosphoglycerides and sphingolipids

Hydrophilic head and hydrophobic tails

Isoprenoids

Generated from acetyl-coA, composed of isoprene subunits (CH2-C=CH-CH2-)$_n$

2 classes: **terpenes** and **steroids**

Terpenes

Large and diverse class of strong-smelling organic compounds, mostly produced by plants.

Classified by the number of isoprene or terpene units (**1 terpene unit = 2 isoprene units**)

monoterpenes 2 isoprene units, used in perfumes

sesquiterpenes 3 isoprene units, citronella

tetraterpenes 8 isoprene units, carotenoids

polyterpene 1000s of isoprene units, rubber

Mixed terpenoids - also contain a non-isoprene component (e.g. ubiquinone, vitamin K)

Steroids

Triterpene derivatives (6 isoprene units, 4 fused rings)

Cholesterol:

- Basic structure with multiple rings and alcohol (hydroxyl) group at the end. 4 fused carbon rings, 2 stacked on top of the other 2, mismatched
- Found in all eukaryotes and some bacteria
- A component of plasma membranes
- Precursor for all steroid hormones, Vitamin D and bile salts
- Found as esters with fatty acids and sugars

Micelles and membranes

Structures of lipid assemblies

Conical lipids such as fatty acids form micelles (spherical, fatty acids, detergents)

Cylindrical lipids such as glycerophospholipids form membranes (rectangular, packed closely)

Inverted conical lipids such as triacylglycerols also form membranes

Lipid bilayers

Phospholipids and glycolipids prefer to form bilayer structures in aqueous solutions.

- Structure: Sheet-like

- Thickness: 2 leaflets (outer + inner), 30-40Å
- Stabilized by IMFs (tails: IMFs, heads: with H_2O - ion-dipole, dip-dip, H-bond)
- "Fluid Mosaic Model" (Singer & Nicholson)
- Membranes are dynamic structures composed of proteins and phospholipids
- The bilayer is a fluid matrix (lateral diffusion)
- Lipids and proteins can rotate and freely migrate or diffuse within a leaflet