4.2: Lipids

Lipids are a diverse group of hydrophobic compounds that include molecules like fats, oils, waxes, phospholipids, and steroids. Most lipids are at their core hydrocarbons, molecules that include many nonpolar carbon-carbon or carbon-hydrogen bonds. The abundance of nonpolar functional groups give lipids a degree of hydrophobic (“water fearing”) character and most lipids have low solubility in water. Depending on their physical properties (encoded by their chemical structure), lipids can serve many functions in biological systems including energy storage, insulation, barrier formation, cellular signaling. The diversity of lipid molecules and their range of biological activities are perhaps surprisingly large to most new students of biology. Let's start by developing a core understanding of this class of biomolecules.

Fats and oils

A common fat molecule or triglyceride. These types of molecules are generally hydrophobic and, while they have numerous functions, are probably best known for their roles in body fat and plant oils. A triglyceride molecule derived from two types of molecular components—a polar "head" group and a nonpolar "tail" group. The "head" group of a triglyceride is derived from a single glycerol molecule. Glycerol, a carbohydrate, is composed of three carbons, five hydrogens, and three hydroxyl (-OH) functional groups. The nonpolar fatty acid "tail" group consists of three hydrocarbons (a functional group composed of C-H bonds) that also have a polar carboxyl functional group (hence the term "fatty acid"—the carboxyl group is acidic at most biologically relevant pHs). The number of carbons in the fatty acid may range from 4–36; most common are those containing 12–18 carbons.
Figure
1.

Triacylglycerol is formed by the joining of three fatty acids to a glycerol backbone in a dehydration reaction. Three molecules of water are released in the process.

Attribution: Marc T. Facciotti (own work)

Note: possible discussion

The models of the triglycerides shown above depict the relative positions of the atoms in the molecule. If you Google for images of triglycerides you will find some models that show the phospholipid tails in different positions from those depicted above. Using your intuition, give an opinion for which model you think is a more correct representation of real life. Why?
Natural fats like butter, canola oil, etc., are composed mostly of triglycerides. The physical properties of these different fats vary depending on two factors:

1. The number of carbons in the hydrocarbon chains;
2. The number of desaturations, or double bonds, in the hydrocarbon chains.

The first factor influences how these molecules interact with each other and with water, while the second factor dramatically influences their shape. The introduction of a double bond causes a "kink" in the otherwise relatively "straight" hydrocarbon, depicted in a slightly exaggerated way in Figure 3.

Based on what you can understand from this brief description, propose a rationale—in your own words—to explain why butter is solid at room temperature while vegetable oil is liquid.

Here is an important piece of information that could help you with the question: butter has a greater percentage of longer and saturated hydrocarbons in its triglycerides than does vegetable oil.
Figure 3.
The straight saturated fatty acid versus the "bent"/"kinked" unsaturated fatty acid.
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Sterols

Steroids are lipids with a fused ring structure. Although they do not resemble the other lipids discussed here, they are designated as lipids because they are also largely composed of carbons and hydrogens, are hydrophobic, and are insoluble in water. All steroids have four linked carbon rings. Many steroids also have the -OH functional group which puts them in the alcohol classification of sterols. Several steroids, like cholesterol, have a short tail. Cholesterol is the most common steroid. It is mainly synthesized in the liver and is the precursor to many steroid hormones such as testosterone. It is also the precursor to Vitamin D and of bile salts which help in the emulsification of fats and their subsequent absorption by cells. Although cholesterol is often spoken of in negative terms, it is necessary for the proper functioning of many animal cells, particularly in its role as a component of the plasma membrane where it is known to modulate membrane structure, organization, and fluidity.
Figure 4.
Cholesterol is a modified lipid molecule that is synthesized by animal cells and is a key structural element in cellular membranes. Cortisol is a hormone (signaling molecule) that is often released in response to stress. Attribution: Marc T. Facciotti (own work)

Note: possible discussion

In the molecule of cortisol above, what parts of the molecule would you classify as functional groups? Is there any disagreement over what should and should not be included as a functional group?

Phospholipids

Phospholipids are major constituents of the cell membrane, the outermost layer of cells. Like fats, they are composed
of fatty acid chains attached to glycerol molecule. Unlike the triacylglycerols, phospholipids have two fatty acid tails and a phosphate group attached to the sugar. Phospholipid are therefore **amphipathic** molecules, meaning it they have a hydrophobic part and a hydrophilic part. The two fatty acid chains extending from the glycerol are hydrophobic and cannot interact with water, whereas the phosphate-containing head group is hydrophilic and interacts with water. Can you identify the functional groups on the phospholipid below that give each part of the phospholipid its properties?

**Note**

Make sure to note in Figure 5 that the phosphate group has an R group linked to one of the oxygen atoms. R is a variable commonly used in these types of diagrams to indicate that some other atom or molecule is bound at that position. That part of the molecule can be different in different phospholipids—and will impart some different chemistry to the whole molecule. At the moment, however, you are responsible for being able to recognize this type of molecule (no matter what the R group is) because of the common core elements—the glycerol backbone, the phosphate group, and the two hydrocarbon tails.
Figure 5.

A phospholipid is a molecule with two fatty acids and a modified phosphate group attached to a glycerol backbone. The phosphate may be modified by the addition of charged or polar chemical groups. Several chemical R groups may modify the
phosphate. Choline, serine, and ethanolamine are shown here. These attach to the phosphate group at the position labeled R via their hydroxyl groups. Attribution: Marc T. Facciotti (own work)

In the presence of water, some phospholipids will spontaneously arrange themselves into a micelle (Figure 6). The lipids will be arranged such that their polar groups will be on the outside of the micelle, and the nonpolar tails will be on the inside. Under other conditions, a lipid bilayer can also form. This structure, only a few nanometers thick, is composed of two opposing layers of phospholipids such that all the hydrophobic tails align face-to-face in the center of the bilayer and are surrounded by the hydrophilic head groups. A phospholipid bilayer forms as the basic structure of most cell membranes and are responsible for the dynamic nature of the plasma membrane.
In the presence of water, some phospholipids will spontaneously arrange themselves into a micelle.

Source: Created by Erin Easlon (own work)

Note: possible discussion

As mentioned above, if you were to take some pure phospholipids and drop them into water that some of the phospholipid would spontaneously form into micelles. This sounds like a process that could be described by an Energy Story.

Go back to the Energy Story rubric and try to create an Energy Story for this process — I expect that the steps involving the description of energy might be difficult at this point (we'll come back to that later) but you should be able to do at least the first three steps. You can also constructively critique each other's work to create an optimized story.

The phospholipid membrane is discussed in detail in a later module. It will be important to remember the chemical properties associated with the functional groups in the phospholipid in order to understand the function of the cell membrane.