Big Idea
In the biological sciences, a dehydration synthesis (condensation reaction) is typically defined as a chemical reaction that involves the loss of water from the reacting molecules. This reaction is used in the formation of carbohydtrates, proteins, triglycerides and phospholipids.

Introduction to Lipids
Biomolecules are molecules unique to living systems and include carbohydrates, proteins, nucleic acids and lipids. Lipids are a diverse group of organic compounds primarily composed of carbon, hydrogen and oxygen. Fatty acids, triglycerides, phospholipids, fat-soluble vitamins and steroids are a few examples of molecules classified as lipids.

The main biological functions of the many varied types of lipids include:
• energy storage
• protection
• insulation
• regulation of physiological processes

Some lipids serve as the structural components of cell membranes.

Model Parts

Color Scheme
- Oxygen (red)
- Nitrogen (blue)
- Phosphorus (yellow)
- Hydrogen (white)
- Carbon (grey)

Note: This kit follows CPK coloring except for phosphorous, which we show in yellow.
Phospholipid Activity 1 Continued

Hydrophobic and Hydrophilic Properties
Understanding the concepts of **hydrophobic** and **hydrophilic** are key to understanding membrane structure. You can divide the words into their two parts to find clues to their meaning. “Hydro” means water and “phobic” means fear of. Hydrophobic regions of molecules don’t interact with water molecules.

1. Separate the word hydrophilic into two parts and record what each of these parts means.  
   *Hydro* means ______________ and *philic* means ______________.

2. What characteristics would a hydrophilic molecule exhibit?  
   *Hydrophilic molecules — or portions of molecules — interact with water molecules.*

You may also see hydrophobic molecules called non-polar and hydrophilic molecules called polar.

What’s a Lipid?
**Fatty acids** are linear chains of carbon and hydrogen atoms with an **organic acid group** (-COOH) at one end. Examine the model of a fatty acid pictured in the box below.

1. Review the image of the phospholipid tail, one of the foam model pieces in the kit.  
   a. Label the carbon, oxygen and hydrogen atoms, and note the hydrophobic and hydrophilic regions of the molecule.  
   b. Draw the molecular formula for this fatty acid.
2. Look at the chemical structures of the common fatty acid stearic acid and the common carbohydrate glucose. Compare the proportion of carbon atoms to oxygen atoms in the table below.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Formula</th>
<th># of C atoms</th>
<th># of O atoms</th>
<th>Ratio of C:O</th>
<th>Ratio of C:H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stearic acid</td>
<td>$CH_3(CH_2)_{17}CO_2H$</td>
<td>18</td>
<td>2</td>
<td>9:1</td>
<td>2:1</td>
</tr>
<tr>
<td>Glucose</td>
<td>$C_6H_{12}O_6$</td>
<td>6</td>
<td>6</td>
<td>1:1</td>
<td>2:1</td>
</tr>
</tbody>
</table>

3a. What do you notice about the amount of oxygen in a fatty acid compared to oxygen in a carbohydrate?

There is less oxygen to carbon in a fatty acid than in a carbohydrate.

3b. What do you observe about the ratio of carbon to hydrogen in a fatty acid compared to a carbohydrate?

They are the same.

Triglycerides are neutral fats. Some triglycerides are considered fats and others oils. When a triglyceride is a solid at room temperature it is a fat. When a triglyceride is a liquid at room temperature it is an oil. The two building blocks that compose triglycerides are fatty acids and glycerol.

4. Label the glycerol and fatty acids in the diagram below.
Forming Triglycerides
In this activity you will model a dehydration synthesis reaction in the formation of a triglyceride and determine the resulting products.

1. Begin with glycerol and three of the straight-chain fatty acids as the reactants in this simulation. A fatty acid is said to be saturated if the carbons comprising the tail are all singly bonded to each other.

2. Remove one of the hydrogen (H) atoms from the glycerol.

3. Remove the hydroxyl group (OH) from one of the fatty acids.

4. Combine the H and the OH.

5. Join the fatty acid to the glycerol.

6. Repeat this process with the two remaining fatty acids.
Phospholipid Activity 1 Continued

a. How many water molecules were formed in this reaction? 3

b. What are the final products of this dehydration synthesis?
   3 water molecules and 1 triglyceride

(c. Predict whether you think this resulting triglyceride would most likely be a fat or an oil? Explain your reasoning.
   The triglyceride will most likely be a fat due to the saturated fatty acid tails. These tails will pack together tightly, forming a solid material.

7. Substitute the third fatty acid tail with the two-part fatty acid tail. The post and hole connection in the two-part tail symbolizes a double bond between the carbons. When one or more double bonds are present between the carbons in the tail of the fatty acid, the molecule is unsaturated.
The double bond in an unsaturated fatty acid may form one of two possible configurations: trans or cis. You may model the trans configuration by attaching the second piece of the tail to the first to produce a straighter chain. The cis configuration may be modeled by producing a kinked configuration. Most naturally-occurring unsaturated fats are in the cis configuration.

If the hydrogens associated with the double bonded carbons are on the same side, the fatty acid is called cis. If the hydrogens associated with the double bonded carbons are on opposite sides, the fatty acid is called trans. (See illustrations below.)

d. Which configuration produces the bigger kink in the structure of the hydrocarbon chain of the triglyceride?

   cis


e. Explain how the cis or trans configurations might contribute to the triglyceride being an oil or a fat?

   An oil would more likely be formed due to the cis kink in the fatty acid tail, which would promote more fluidity.
f. Is the fatty acid in the diagram above in the cis or trans configuration? Explain.

The molecule is in the cis configuration because the hydrogens are located on the same side of the double bonded carbons.

Hydrogenation occurs when hydrogen atoms are added to an unsaturated fatty acid tail, causing double bonds between atoms to become single bonds.

Full hydrogenation occurs when all double bonds convert to single bonds resulting in a saturated fatty acid.

Partial hydrogenation occurs when some of the double bonds are replaced with single ones. Trans fat may be created in partial hydrogenation.
**Introduction to Plasma Membranes**

The plasma membrane is the structural boundary that separates the cell from its surroundings and controls what substances move into and out of the cell. As only some substances are allowed to cross the membrane, the plasma membrane demonstrates the property of **selective permeability**. The plasma membrane is also called a cell membrane.

In particular, the plasma membrane of mammalian red blood cells (erythrocytes) has been the focus of cell membrane study because these cells do not contain nuclei or internal membranes. They represent a source from which a pure plasma membrane may be easily isolated for analysis. In 1925, Dutch scientist Evert Gorter and his research assistant F. Grendel extracted lipids from the membranes of a known number of red blood cells which corresponded to a known surface area of plasma membrane. The surface area occupied by a monolayer of the extracted lipid and the air/water interface was then determined. The results of their experiment showed that the surface area of the lipid monolayer was twice that occupied by the erythrocyte plasma membrane, leading to the conclusion that the plasma membrane consists of two layers called the **lipid bilayers**.

The most abundant lipids in most membranes are **phospholipids**. The ability of phospholipids to spontaneously form membranes is inherent to their **amphipathic** (containing both hydrophilic and hydrophobic regions) nature. The "head" of a phospholipid is composed of the negatively-charged phosphate group and may contain other polar groups. The tail of a phospholipid usually consists of long fatty acid hydrocarbon chains.

Water molecules (shown in the circle in the photo left) can pass in and out of a cell through a plasma membrane, but not easily. **Aquaporin**, a protein embedded in the membrane (shown in the photo right), facilitates passage of water molecules in and out of the cell.

These models are from 3D Molecular Designs' Molecules of Life Collection®. They can be borrowed from the MSOE Lending Library cbm.msoe.edu/teachRes/library/ml.html or purchased from 3D Molecular Designs 3dmoleculardesigns.com/Education-Products/Molecules-of-Life-Collection.htm.
Focus on Phospholipids
The building blocks of a phospholipid include two fatty acid tails, the glycerol backbone and a phosphate head. In this next activity you will model a dehydration synthesis reaction in the formation of a phospholipid.

1. Begin with one of the straight-chain fatty acids (saturated), the kinked-chain fatty acid (unsaturated), glycerol and one of the phospholipid heads as the reactants in this simulation.

2. Remove one of the hydrogen (H) atoms from the glycerol.

3. Remove the hydroxyl group (OH) from one of the straight fatty acids.

4. Combine the H and the OH.
5. Join the fatty acid to the glycerol.

6. Repeat this process with the unsaturated fatty acid.

7. Remove the hydroxyl group from the phospholipid head and the final hydrogen (H) atom from the glycerol.

8. Combine each H with each OH.
Phospholipid Activity 1 Continued

9. Bind the phospholipid head to the glycerol backbone.
   a. What type of reaction was used in the formation of your phospholipid?
      
      Dehydration synthesis - condensation.

   b. Remembering definitions of the terms **hydrophobic** and **hydrophilic**, deconstruct the word *dehydration*.
      
      De: to remove, hydro: water, ation: process.

   c. Define **dehydration synthesis**.
      
      Dehydration is the process of removing water.
      Synthesis is to form something by combining parts.

   d. In the dehydration synthesis reactions you modeled, what parts did you combine to form a triglyceride and phospholipid?
      
      A phospholipid head, glycerol and fatty acid chains.

   e. How many water molecules did you synthesize? 3

   f. Compare and contrast dehydration synthesis of a triglyceride to a phospholipid.
      
      Both reactions yield 3 molecules of water and use glycerol and fatty acid reactants.
      Three fatty acids are needed to form a triglyceride while two fatty acids and a phosphate head are needed to form a phospholipid.
g. Sketch the specific structural formula of the phospholipid model you synthesized in the space provided below. Label the hydrophilic and hydrophobic regions of your structure.

Answers will vary but should include one of the following:

**Hydrophilic**

- Phosphatidylcholine
- Phosphatidylserine
- Phosphatidylinositol
- Phosphatidylethanolamine

**Hydrophobic**

- Sphingomyelin
  (Foam model not provided.)
h. Explain why you labeled the phospholipid parts as you did in your sketch on page 12.

The head contains a lot of oxygen atoms which will interact with polar water molecules. The long carbon chains of the fatty acids do not interact with water and are hydrophobic.

i. Compare your structure to that of the other groups in the room. Record any similarities you observe in these phospholipid structures.

All of the phospholipids have hydrophilic heads that contain a phosphate group and a glycerol. In addition, there are two hydrophobic tails in each phospholipid modeled.

j. Based on these similarities a simplified representation may also be used to indicate phospholipid structure. Sketch a simple model in the space below. Label the hydrophobic and hydrophilic portions of this simplified model.

k. Record any differences in the specific structures you have observed between these phospholipids.

Answers will vary. Potential observations: Each phospholipid contains a phosphate group, but each hydrophilic head is different in its structure and composition of atoms.

With the exception of phosphatidylcholine, the phospholipids have polar atoms on the outer portions of their structures.

• Phosphatidylcholine forms a daisy-like structure with nitrogen in the middle surrounded by carbon atoms.

More answers continued on next page
Phospholipid Activity 1 Continued

More Answers:
- Phosphatidylinositol doesn’t have a nitrogen atom and its 6 carbon atoms form a ring with 6 oxygen bound to the outer portion of the ring.
- Phosphatidylethanolamine is more linear in its shape and has a nitrogen at the top.
- Phosphatidylserine is more irregular in its shape and has an oxygen and nitrogen on the outer edge.

There are four major phospholipids that comprise the plasma membrane. Phosphatidylcholine and sphingomyelin make up the outer leaflet layer of the membrane while phosphatidylethanolamine and phosphatidylserine make up the inner leaflet of the layer membrane. A fifth phospholipid, phosphatidylinositol, is also found in the inner leaflet layer of the plasma membrane. Although phosphatidylinositol is a minor membrane component, it plays a major role in cell signaling.

The general structure of a phospholipid is most often represented by the phosphatidylcholine structure: