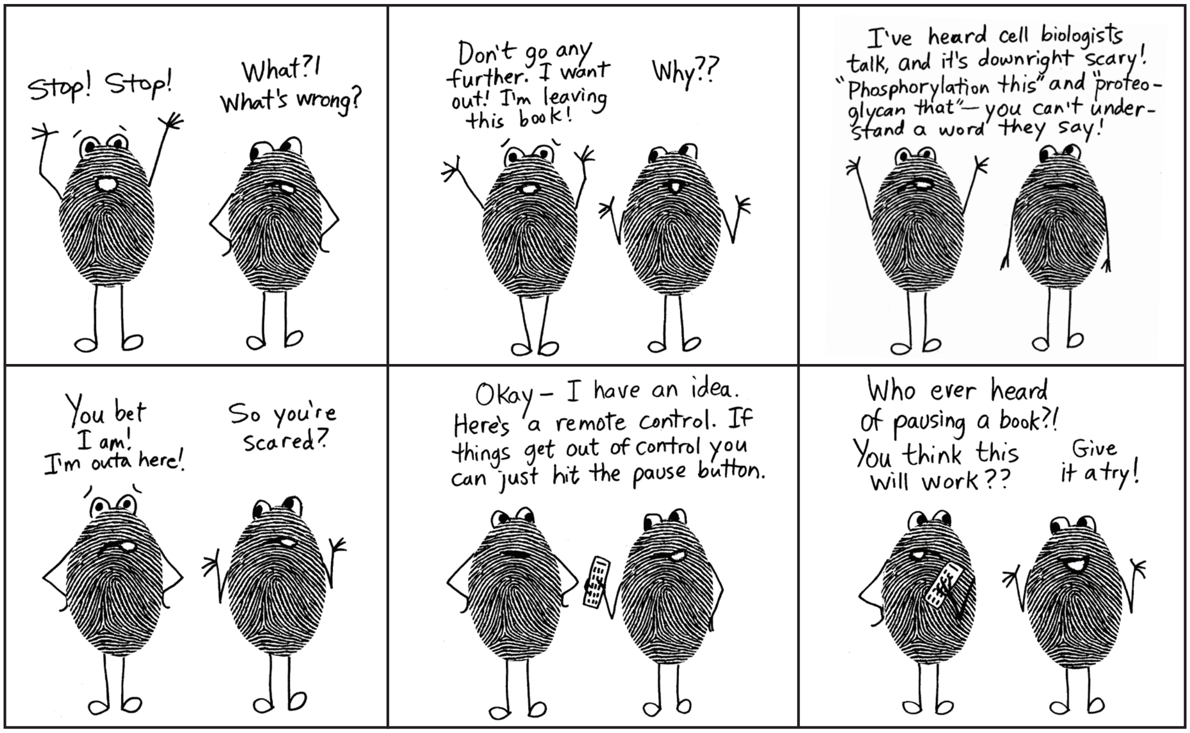
CHAPTER 2: THE CELL MEMBRANE

So now that we know a little bit about how cells were discovered, let's start learning about what cells are made of and how their insides work. We'll start with the outer surface, the ***plasma membrane***.

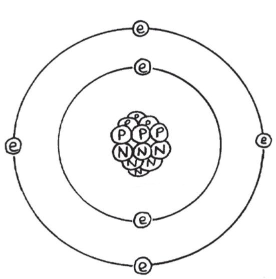


Okay, we're ready now?

Let's look at the outside of the cell first. The outer layer of a cell is called the ***membrane***, or, to be more precise, the ***plasma membrane***. (Don't worry about the word "plasma." We'll get to that later.) In plant cells there is an extra layer outside the membrane—a thick coating made of tough ***cellulose***. Bacteria, also, sometimes have thick outer walls. However, underneath those thick walls there is still a thin membrane. The membrane is so thin that it would take 10,000 of them stacked on top of each other to be as thick as a sheet of paper. It's barely visible even with one of those high-power electron microscopes, because it's only two molecules thick! The molecules that form a cell membrane are called ***phospholipids***.

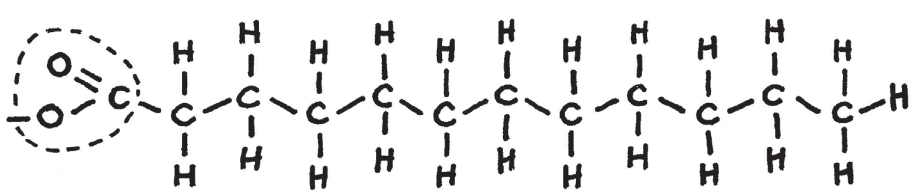
WAIT! DON'T PAUSE THE BOOK!

Let's look at this word and figure out what it means. The second part of the word, ***lipid***, means "fat." You know what fats are—those white streaks in your meat, the vegetable oil you use to fry your potatoes, the cream on top of fresh milk, even the grease that builds up on your scalp if you don't shampoo your hair for a few days. Lipids are greasy and oily and don't mix with water. If we look at one molecule of grease or fat, we'll see that it is made of a chain of carbon atoms with hydrogen atoms attached.



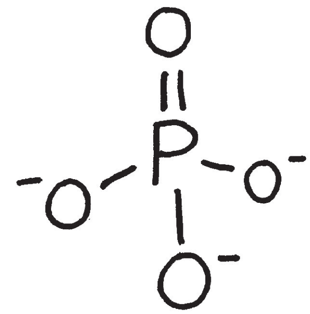
A single carbon atom is often drawn like this. Atoms have layers of electrons orbiting a nucleus made of protons and neutrons.

This circled part of the molecule is the "acid."



The simplest lipid molecule is called a ***fatty acid***.
The "fatty" part is the string of carbon atoms.

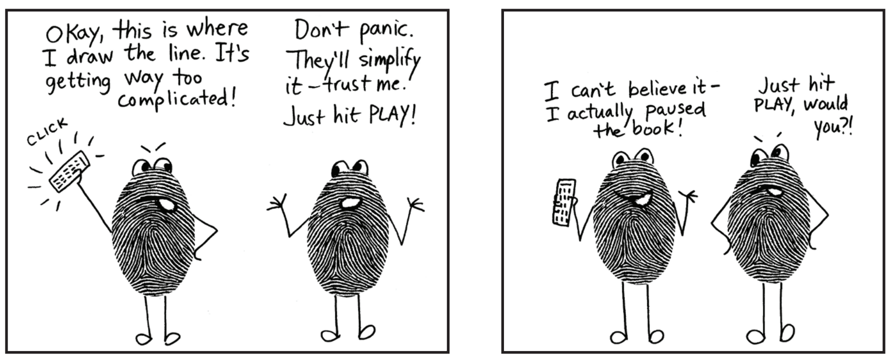
Drawing entire atoms is too difficult. In this book, we are going to simply use a letter to represent an atom. C is carbon, H is hydrogen, O is oxygen. If you want to know more about atoms and how they join together to make molecules, check out "The Elements" book by Ellen McHenry.



Phospho is short for “phosphate.” A phosphate molecule is made of four oxygen atoms attached to an atom of phosphorus, P. (Phosphorus is a fascinating element that can glow in the dark and is found in matches and fluorescent light bulbs, but it is also found in many biological molecules, including phospholipids. We’ll be meeting phosphorus again in future chapters.)

Phosphorus atoms can make five bonds. Imagine phosphorus has having five arms so that it can shake or clasp hands with five people all at once. Oxygen atoms can make only two bonds. They are more like you, having two arms. In phosphate, one oxygen atoms does a double handshake and uses two of phosphorus’s five bonds. The three other oxygen atoms make one bond with phosphorus, but have their other “arm” unattached to anything. This is indicated by that minus sign next to them. (The minus sign represents a free electron that can make a bond.) Phosphate is written like this: PO_4^{3-}. The “4” tells you how many oxygen atoms there are. The “3-” tells you how many dangling, unattached arms there are.

PAUSE



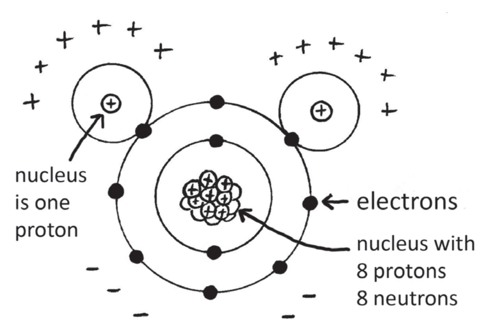
PLAY

For our study of cell membranes, the most important difference between the phosphates and lipids is their reaction to water molecules. Phosphates are said to love water. Yes, scientists really do use the term “love,” but they say it in Greek. They combine the Greek word for water, “hydro,” with the Greek word for love, “philia” to make the word “hydrophilic,” meaning water-loving.

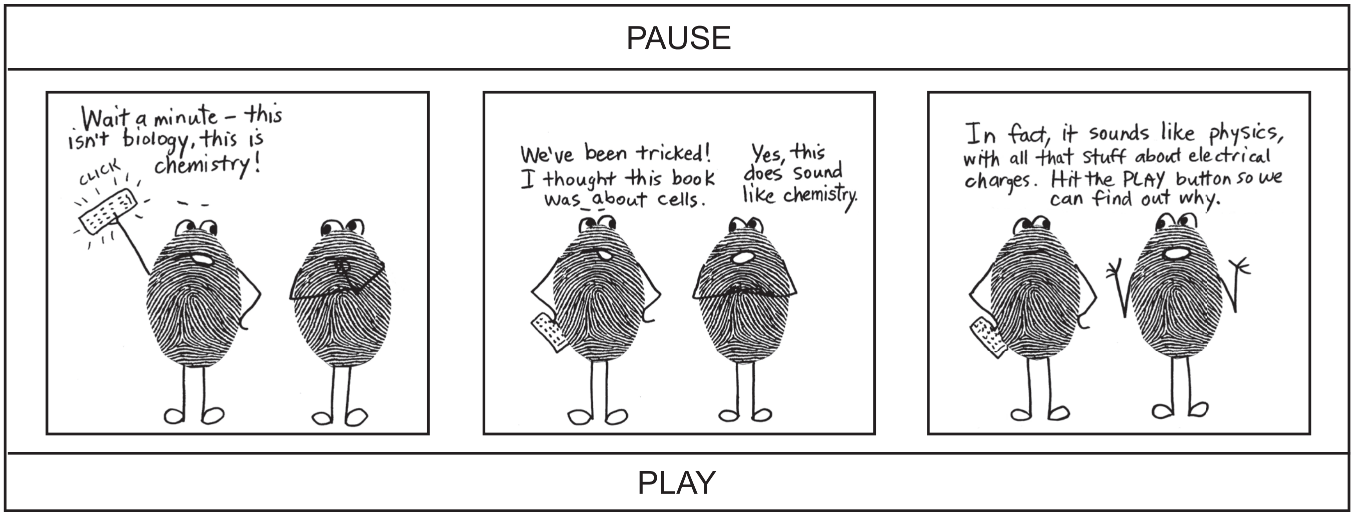
Lipids, on the other hand, “hate” water molecules. They are said to be “hydrophobic.” The Greek word “phobia” means “fear,” so perhaps they feel more fear than hatred? It is silly, of course, to say that molecules can love or hate or fear or have any other emotion. So, if molecules aren’t actually loving or hating, what makes them react the way they do to water molecules? Let’s look at a water molecule to find out.

A water molecule consists of an oxygen atom holding on to two hydrogen atoms. Remember, oxygen has two “arms” and can hold on to two atoms. Hydrogen atoms are very small and have only one “arm” with which to make a bond. The water molecule is a pretty happy molecule, since each atom is making the number of bonds that it wants to make. However, it does have one issue. The oxygen atom is much larger, with a nucleus that is 16 times larger than a hydrogen’s nucleus. The eight protons in the oxygen’s nucleus have a very strong pull on the eight electrons that are being shared between the oxygen and the hydrogens. The result is that the electrons spend more time going around the oxygen than they do the hydrogens. The presence of the negatively charged electrons around the oxygen atom makes the molecule electrically lopsided. The side without the hydrogen atoms is slightly negative, and side where the hydrogens attach is slightly positive.

WATER MOLECULE

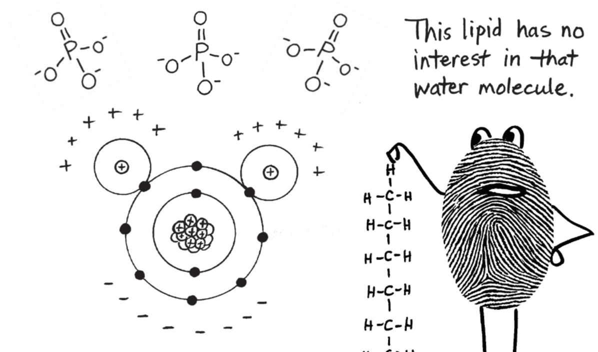


All molecules that are electrically lopsided are called ***polar*** molecules. “Polar” means that something has two ends, or sides, that are different. (Sometimes we think of the world “polar”as meaning “cold,” because the north and south poles of the earth are located where it is cold, but the real meaning of “polar” is “opposite.”)



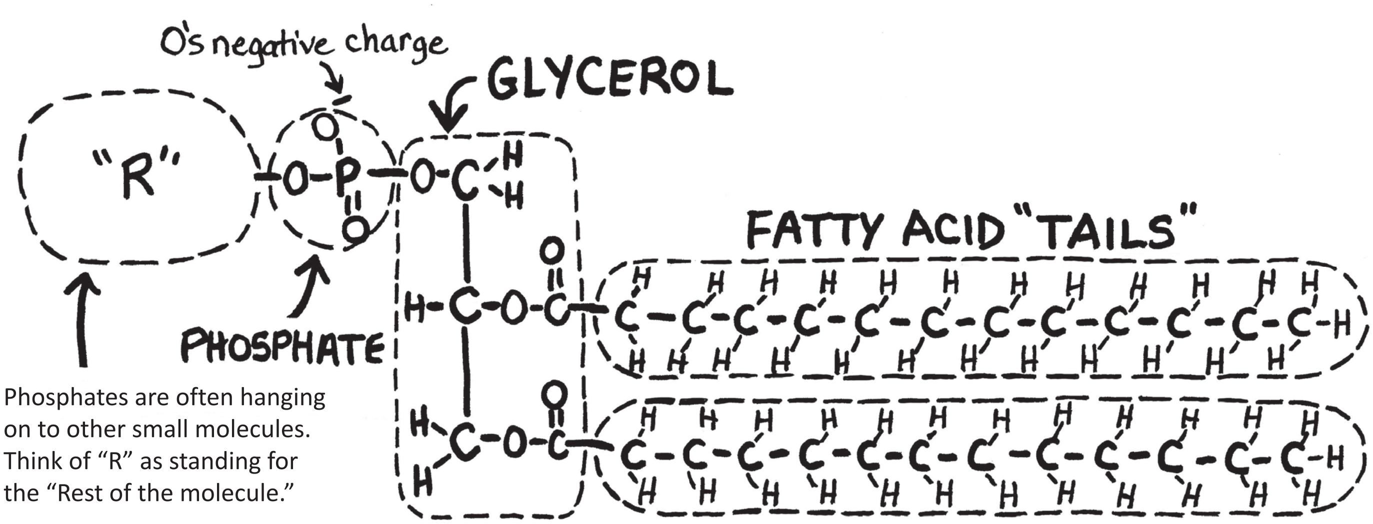
Chemistry is the foundation on which biology rests. The answers to many biology questions involve chemistry. And yes, chemistry is largely about the electrical interactions between atoms. So, in a way, biology boils down to physics. Let's continue on and see what role polarity plays in a membrane.

You may have heard the phrase, "Opposites attract." The context in which you heard the phrase might not have been physics, but the origin of this saying is rooted in physics. Positive and negative charges attract. The reason why this is true can only be explained by studying quantum physics, which is far beyond the scope of this book. All we need to know is that those dangling minus signs on molecules will want to be close to a molecule, or a part of a molecule, that has a positive charge. Those minus signs on the phosphate will be attracted to the positive side of a water molecule. But what about lipid molecules? If you look at the fatty acid that our friend is holding, you can see that there aren't any minus or plus signs around it. Therefore it doesn't interact with water molecules.

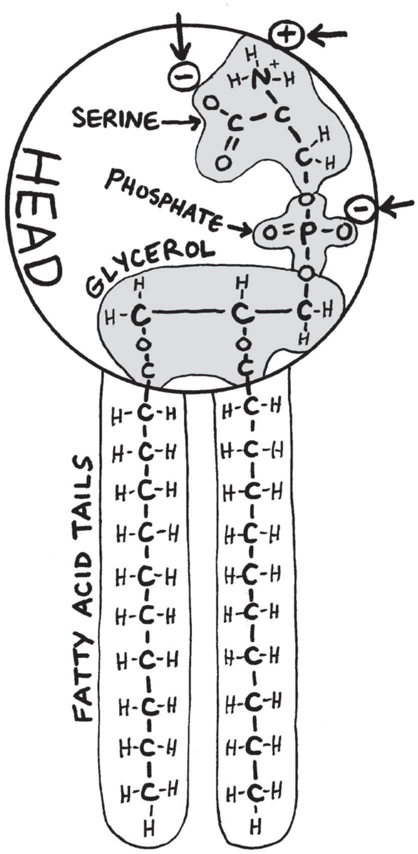


The black dots are electrons. Most of them are around the oxygen atom.

And, now, finally, we are ready to look at a phospholipid molecule. The name tells us that it is a phosphate connected to a lipid (a fatty acid carbon chain). A little clump of atoms called ***glycerol*** *(GLISS-er-ol)* holds them together. Glycerol is like a 2-sided clip that can hold on to both a phosphate and two carbon chains.

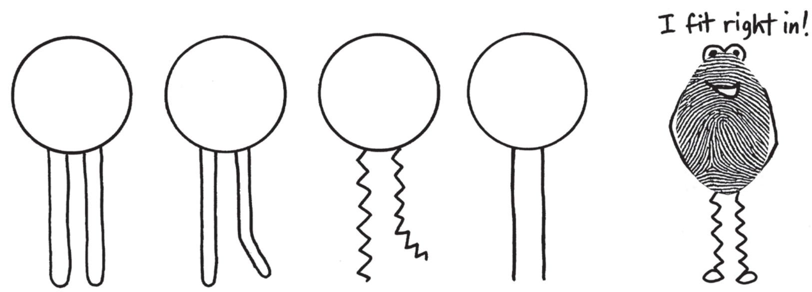


Phosphates are often hanging on to other small molecules. Think of "R" as standing for the "Rest of the molecule."



This is the most complicated phospholipid diagram you will see in this book. It shows that the "head" area is made of a glycerol, a phosphate, and another small molecule (here we see a simple protein called "serine"). The head isn't really round, but we can imagine that these odd-shaped molecules are contained in a circular area. The arrows are pointing to the electrical charges of the head area. We see two negative charges, and one positive charge, so the negative charges win by one. The overall charge of this head is (-1). This negative charge will be attracted to a water molecule's positive side. Some phospholipid heads have one positive and one negative charge, which makes them electrically neutral. They are still considered "hydrophilic" molecules, though, even without a negative charge.

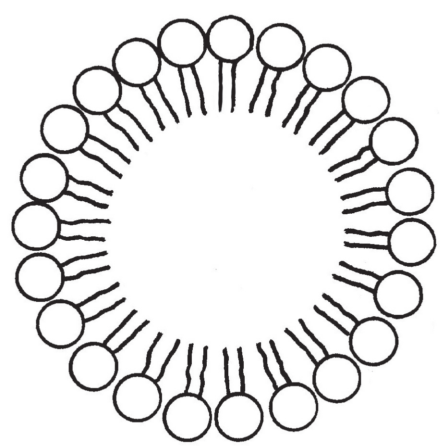
Now that we've seen the complete structure of a phospholipid molecule, we are going to learn a helpful shortcut. We'll need to draw lots of these molecules to make a cell membrane, and it's obvious that this molecule is far too complicated to draw repeatedly. Scientists use a simple diagram that is easily recognizable as a phospholipid. The tails can be thick or thin, and are sometimes zig-zaggy or slightly bent.

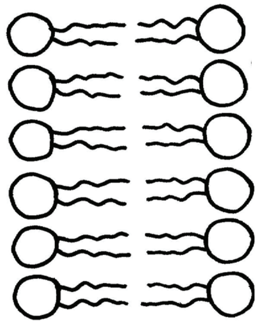


Now that we can easily draw a lot of phospholipids, we are ready to see how they behave as a group. What would happen if you took a bunch of these phospholipids and tossed them into a bucket of water? The heads would feel quite at home among the water molecules because they are hydrophilic, loving water. The hydrophobic tails, however, would be freaking out. It would be a nightmare for them to be surrounded by water molecules. They would need to cooperate to create a "NO WATER" zone where they can feel comfortable and safe. This is accomplished by having the phospholipids create a sphere where the tails are all pointing to the inside.

This shape is called a ***micelle*** (mie-SELL). (Though shown as a circle in this diagram, a micelle is actually a sphere.)

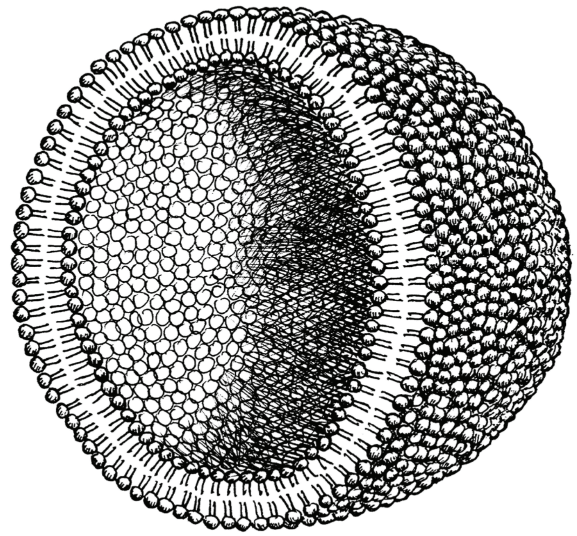
BONUS INFO: Micelles are found throughout your body, especially in your blood. They allow hydrophobic molecules (such as digested fats and some vitamins) to be transported in the bloodstream. Since blood is 90% water, the bloodstream is a very uncomfortable place for a molecule that hates water! The hydrophobic molecule hide inside the micelle.





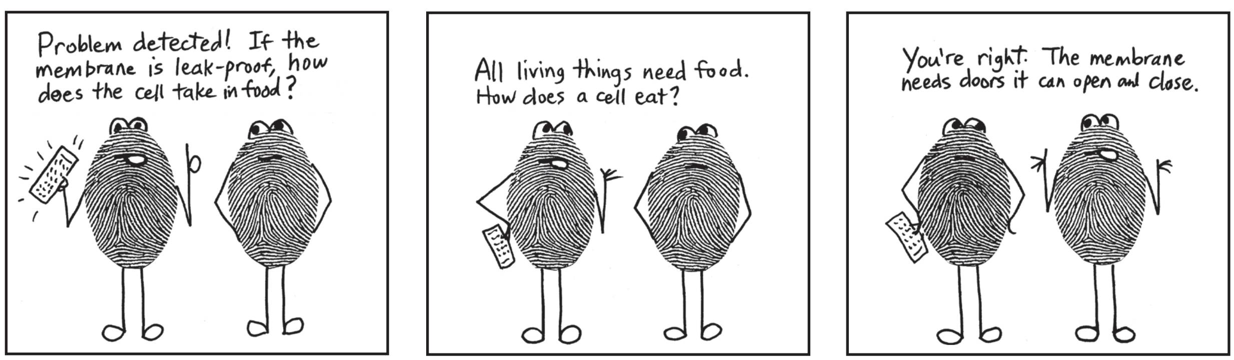
Another arrangement that phospholipids can make is called a ***bi-layer.*** ("Bi" means "two.") This shape is sort of what you would get if you took a micelle and flattened it. The diagram here on the left shows the phospholipids lined up perfectly, with the tails of one molecule exactly opposite the tails of another. In reality, they don't always line up so perfectly. (Notice the optical illusion: a white line down the middle.) If we had a large, three-dimensional sheet of bi-layer we might be able to fold it in such as way that it formed a hollow sphere.

If we use hundreds, or perhaps even thousands, of phospholipid molecules, we can make a sizable sphere. Look at the cut-away edge. Can you see all the individual phospholipid molecules lined up tail to tail, forming a bi-layer? If we had not cut the sphere in half, you would not be able to see the tails. The surface of the sphere would look like a "sea" of balls.



Now we have a nice, tight, almost leak-proof ball. Very small molecules, such as oxygen or carbon dioxide, might sneak through the cracks, but large molecules don't stand a chance of getting through. This is what the outer layer, or ***plasma membrane,*** of a cell is made of. Most of the organelles inside a cell are also wrapped in a bi-layer membrane. Additionally, the cell makes and uses spheres like this for storing things, almost as if they were plastic bags.

PAUSE

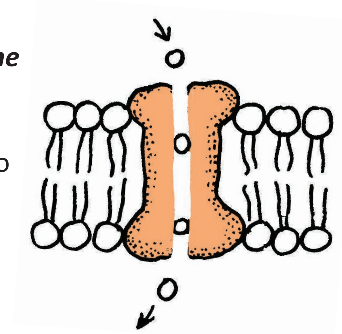


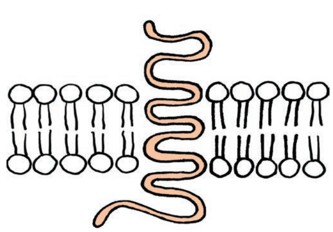
PLAY

Yes, the membrane needs doors and portals that it can control. Now that we understand the structure of the membrane itself, we can look at the microscopic "gadgets" that are in it.

Many of the structures that are embedded in a cell's membrane are made of ***protein***. They are called (no surprise here) ***membrane-bound proteins***. In future chapters we'll learn what proteins are made of and see how the cell manufactures them. For now, we are just going to take a brief survey of the general types of proteins we find and the jobs they do. Membrane-bound proteins can be found on the outside, on the inside, or going all the way through membrane.

Proteins that go all the way through the membrane are called ***transmembrane proteins***. ("Trans" is Latin for "across.") They act as **tunnels**, or **portals**, letting some types of molecules pass through and keeping others out. A cell wants to take in food molecules (sugars, fats, proteins) and get rid of waste molecules. It might also want to take in a chemical message sent by another cell. Some transmembrane proteins act like **pumps**, pushing water or salt molecules in or out of the cell.

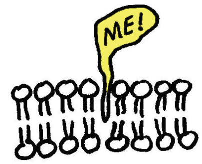




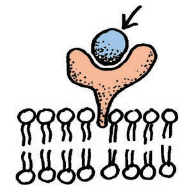
Another type of transmembrane protein acts like a **switch**. When you flip a light switch, it moves internal parts that are hidden in the wall, and the result is that electricity flows into a light bulb. A cell has biological switches with an external part that can be triggered by something in the cell's environment, and an internal part that reacts to the stimulus and makes a change inside the cell.

Proteins attached to the outer surface of the cell are properly called ***peripheral membrane proteins.*** (Peripheral means "on the outside.") Here are some examples of jobs they might do:

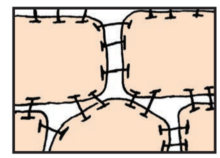
1) Act as a **flag**, identifying the cell as belonging to the organism it is part of, so that it doesn't get attacked by immune system cells who are out looking for foreign invaders. Cells don't have eyes and can't see; they rely on their sense of touch to identify things around them. Immune system cells feel the surface of any cell that crosses their path. If they feel this ID flag, they know not to attack the cell. If this flag isn't there, the battle is on!



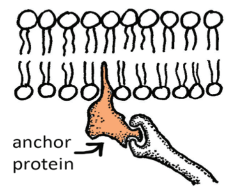
2) Act as a **mailbox**, receiving messages from other cells. Cells are usually part of a larger organism and they must all work together to keep themselves alive. They communicate by sending chemical messages to each other. These messenger molecules have a particular shape that will only fit into a receptor that has a complimentary shape, like a key into a lock.



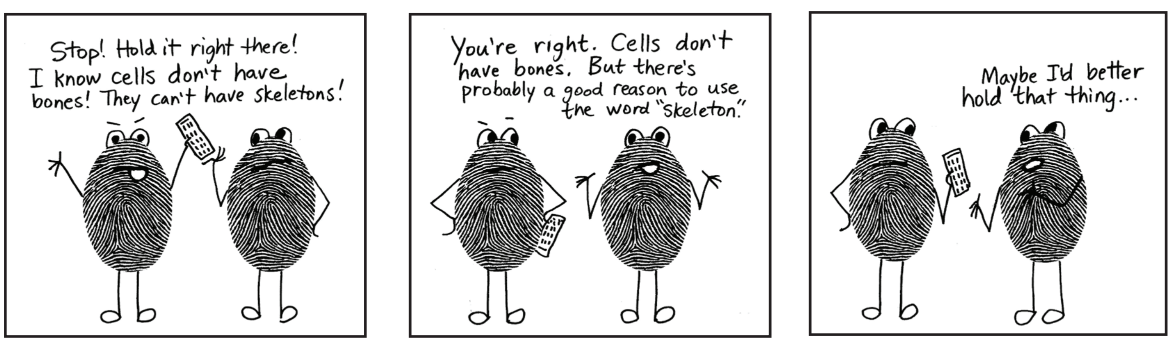
3) Act as an **anchoring hook**, allowing the cell to stick to other cells. These proteins can grab and hold on to the corresponding anchor proteins of other cells. Some anchoring mechanisms are designed to hold the cells tightly together. Other mechanisms allow for a looser, more flexible attachment. The anchoring hooks between skin cells (shown here) are called ***desmosomes***. Desmosomes allow your skin to be very strong yet very flexible.



The proteins on the inner side of the membrane most often function as a place to attach things to, sort of like a hook or clip stuck into a wall. The most common cell part that needs to be anchored to the membrane is the cell's skeleton.



PAUSE

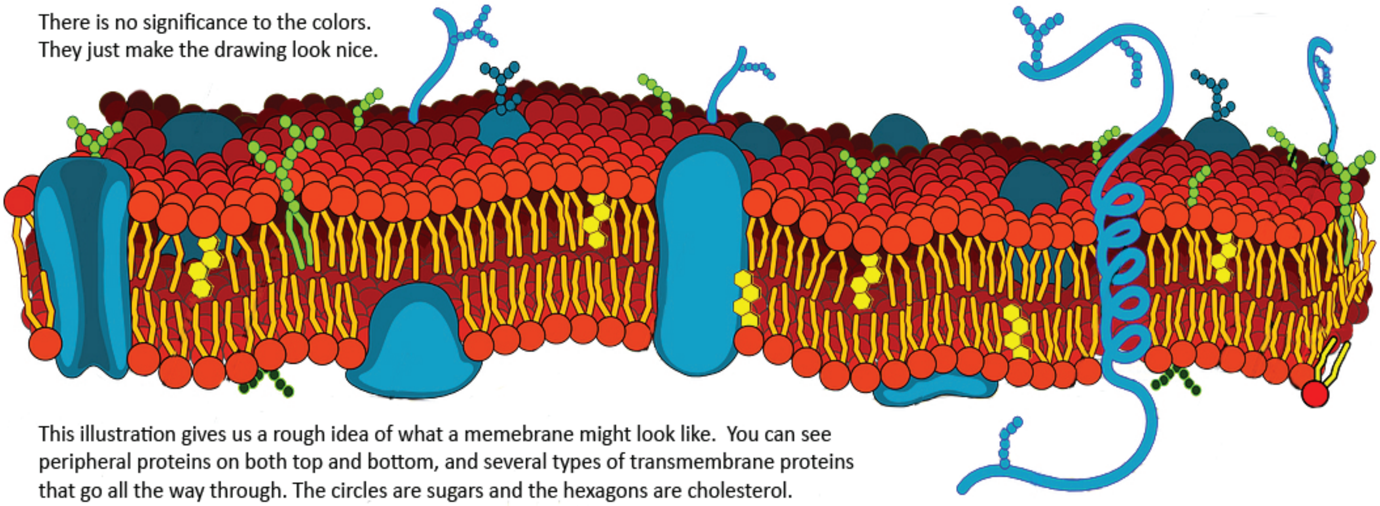


PLAY

We'll learn about the cell's skeleton in the next chapter. No, cells don't have bones; but they do have rafts...

Some cell processes require more than one of the protein structures that are embedded in the membrane. Think of how many tools a carpenter needs to build something. All the tools and materials must be right there within reach so that he can do his job. Imagine if the carpenter's tools kept wandering off all the time because the floor was in constant motion. He turns around to grab the saw and it's not there. He must go and search for it, and by the time he gets back his lumber is missing. And when he is ready to nail something, his hammer is gone. He spends all his time trying to keep his tools in one place and never actually gets the job done. Fortunately, this would never happen because we live in a world where gravity and friction keep objects (on flat surfaces) firmly in place.

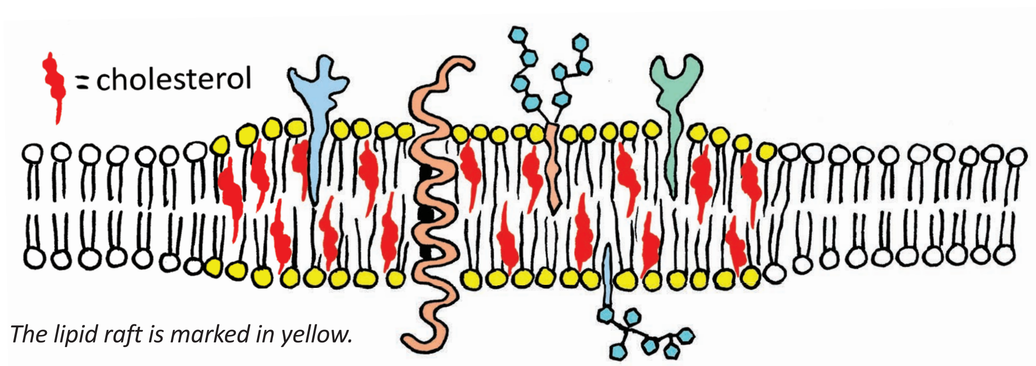
The surface of a membrane, however, is quite unlike the firm floors on which we place our furniture and our tools. The phospholipids are not tied together and are probably in constant motion. How much they move is still being researched, but most scientists think that the membrane forms what they call a ***fluid mosaic***. The word "mosaic" is used by artists to describe a picture or pattern that is formed by many small objects such as colored pebbles or pieces of colored glass. The word "fluid" means "in motion." (Imagine a small pond completely covered by floating ping-pong balls. A ball would not be able to travel across the pond but would still be able to shift its position quite a bit.)



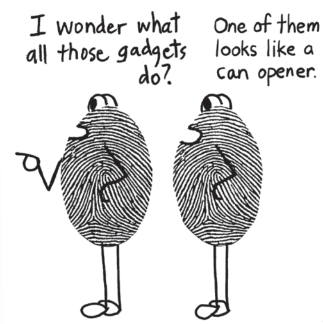
There is no significance to the colors. They just make the drawing look nice.

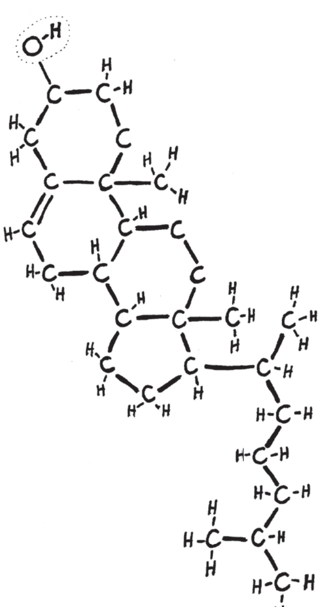
This illustration gives us a rough idea of what a memebrane might look like. You can see peripheral proteins on both top and bottom, and several types of transmembrane proteins that go all the way through. The circles are sugars and the hexagons are cholesterol.

If the phospholipids in the membrane can shift their position and move about, this creates a problem for structures that must work together (like the carpenter's tools). How will they stay together so they can work together? One answer is to secure all of them into a structure called a ***lipid raft***. The raft is made of a certain type of phospholipid that is very good at sticking to another molecule that is present in all membranes: ***cholesterol.*** You may have heard the word "cholesterol" used during a discussion about foods that are bad for you. Cholesterol is a lipid molecule that your body makes, but you can also consume it in your diet. It is most often found in food that contain animal fats. Eating too much cholesterol can sometimes be a problem, but the molecule itself is not "bad." Cholesterol helps to hold fatty acid tails together. Lipid rafts are areas that contain many cholesterol molecules. The protein structures embedded in these rafts stay in place. The rafts themselves seem to be able to move about, but the movement of the entire raft does not interfere with the ability of the protein structures to do their job. Protein tools that need to be together stay next to each other.



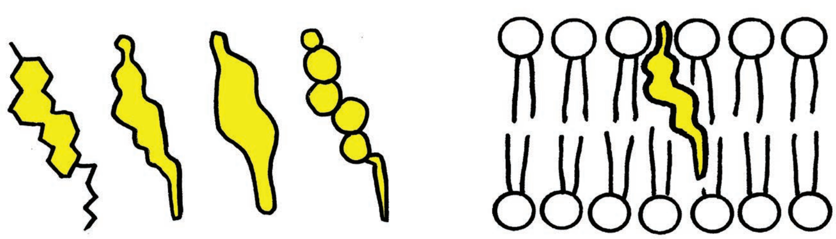
The lipid raft is marked in yellow.

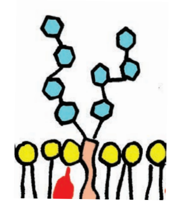




The cholesterol molecule is a member of a group of molecules that are based on hexagonal (6-sided) rings of carbon atoms. Other members of this group include vitamin D, and hormones such as testosterone, estradiol, progesterone, and cortisol. (You don't need to remember these names.)

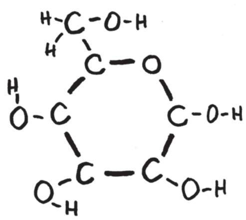
You can see that the cholesterol molecule has three hexagonal rings of carbon, one pentagon, and a "tail" of carbons that reminds us of a fatty acid. The entire molecule, except for the O-H part at the top, wants to be tucked into the fatty acid tails of the phospholipids. The O-H is hydrophilic like the heads, so it stays as closes to the heads as it can. Since this molecule is so complicated, you'll see a variety of short-cuts, some of them with neat hexagons, and others very blobby.



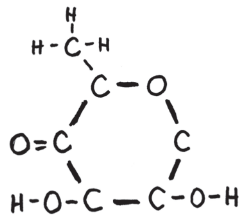


Before we end this chapter, there's one last feature of the membrane that must be mentioned. If you looked carefully at the illustrations on the previous page, you may have noticed strings of little circles or hexagons. They represent sugar molecules. As funny as it might sound, cells are "sugar coated."

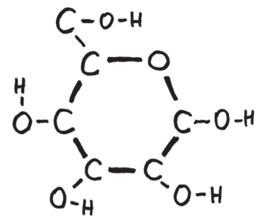
The smallest and simplest sugar molecules are hexagonal in shape and made of carbon, oxygen and hydrogen atoms. (The last one is a special sugar that include a nitrogen atom.)



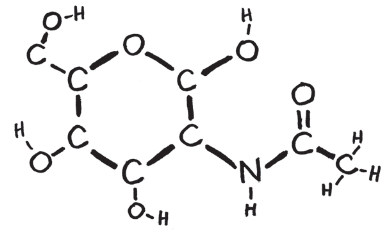
GLUCOSE



FRUCTOSE



MANNOSE



"GlcNAc

(*You might be wondering where "table sugar" fits into this scheme. Table sugar, or "sucrose", is made of a glucose molecule attached to a fructose molecule. Your digestive system breaks them apart and puts them into your blood. Your cells take in the glucose molecules and then break them apart to harvest energy.)*

Sugars can be used as a source of energy, but your cells can also use sugars for many other purposes. Just like wood can be either burned for energy or used to make furniture, sugars can also be either "burned" for energy or used to build things. The sugars that the cell uses to build things include these simple sugars shown above, but also include more complicated variations. It isn't necessary for us to go into the chemistry of these more complicated sugars to appreciate what they do. Here are some examples of ways that various sugar-based molecules are used by cells. (Let's called them by their official name: ***glycans.*** The root "glyc-" means "sugar.")

1) Glycans can function as "**mailing labels,**" helping manufactured parts to get to their destination inside the cell. (We will mention this again in the chapter on Golgi bodies.)

2) Your red blood cells have short glycans sticking out of their membranes, and, depending on what the string looks like, your blood will be "typed" as **A, B, AB, or O**. (There are other blood types, as well, though we don't hear much about them because a mismatch is not life-threatening like the ABO types.)

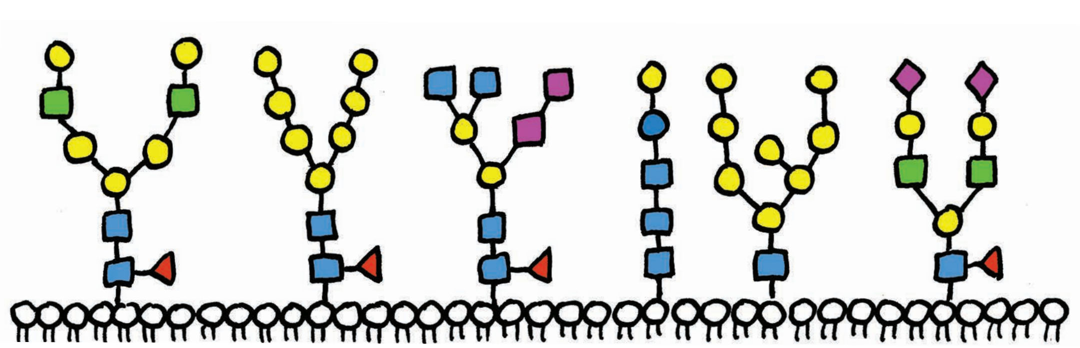
3) A sugar called "O-GlcNAc" is a key player in **cell division**. Scientists used to think that cell division (the cell cycle) was controlled by proteins called cyclins. Then new research revealed that these proteins were being controlled by glycans, especially O-GlcNAc. Too much of this sugar was as bad as too little—either way, things went terribly wrong when the cell duplicated itself. A new cell might end up with two nuclei, or with a wrinkled, weird-looking nucleus where all the DNA was crumpled on one side.

4) A dense coat of glycans can act as a **protective coating**. Bacterial cells are the most striking example of this "sugar-coating," but all cells make at least some protective sugars. One way this protection can happen is by "hiding" the cell's peripheral proteins from the natural, protein-dissolving chemicals that roam throughout the body looking for bits of protein "garbage" that need to be recycled.

5) Certain glycans on key molecules help to control the **growth of embryos**.

6) Glycans can act as **clips** that hold molecules in a storage area, so the molecules will be ready to go if the need arises.

7) The cells of our immune system use a "sugar code," using glycans to **communicate** with each other.



Diagrams always give you a key to let you know which shapes represent which types of sugars. For example, here we have squares for GlcNAc, circles for mannose, diamonds for glucose.

Don't forget to check the "Cells" YouTube playlist for animations of what you just read!

<u>Comprehension self-check</u> **If you can't think of the answer, go back and read that part of the chapter again until you find the answer. If you need to check your answers, check the answer key.**

1) The word "lipid" means: a) protein b) fat c) sugar d) membrane

2) The most natural shape for a group of phospholipid molecules to make is:
a) flat surface b) ball c) long line d) cytoskeleton

3) How many bonds (to other atoms) can an oxygen atom make? ____ (Look at the water molecule, for example.)

4) How many bonds can a phosphorus atom make? _____ (You can count the lines coming out of it.)

5) What does glycerol do in the phospholipid molecule?
a) keep the phosphate and the lipid together b) push the phosphate toward water
c) push the lipid away from water d) allow the cell to stick to other cells

6) Which hates water? a) the phosphate head b) the lipid tail

7) Where would you find a membrane-bound protein?
a) all the way through the membrane b) stuck to the inside of the membrane
c) stuck to the outside of the membrane d) all of the above

8) Which of these elements would you NOT find in a phospholipid molecule?
a) carbon b) potassium c) nitrogen d) hydrogen e) oxygen f) phosphorus

9) Which one of these would you NOT find as part of a phospholipid molecule?
a) glycerol b) fatty acids c) water d) phosphate e) serine

10) TRUE or FALSE? Micelles are made and used in your body to transport fats through the blood.

11) TRUE or FALSE? A micelle is a made of a bi-layer of phospholipids.

12) TRUE or FALSE? The only place you find phospholipid bi-layers is the outer layer of a cell.

13) TRUE or FALSE? Tiny molecules, such as oxygen, O_2, might be able to go through a phospholipid bi-layer, but larger molecules cannot.

14) TRUE or FALSE? The correct name for the outer membrane of a cell is the "plasma membrane."

15) Which one of these is *least likely* to be an example of a transmembrane protein function?
a) tunnel b) portal c) anchor d) pump

16) What happens to cells that do not have an ID flag on their surface?
a) Nothing. b) They take one from another cell. c) They are killed by immune system cells.

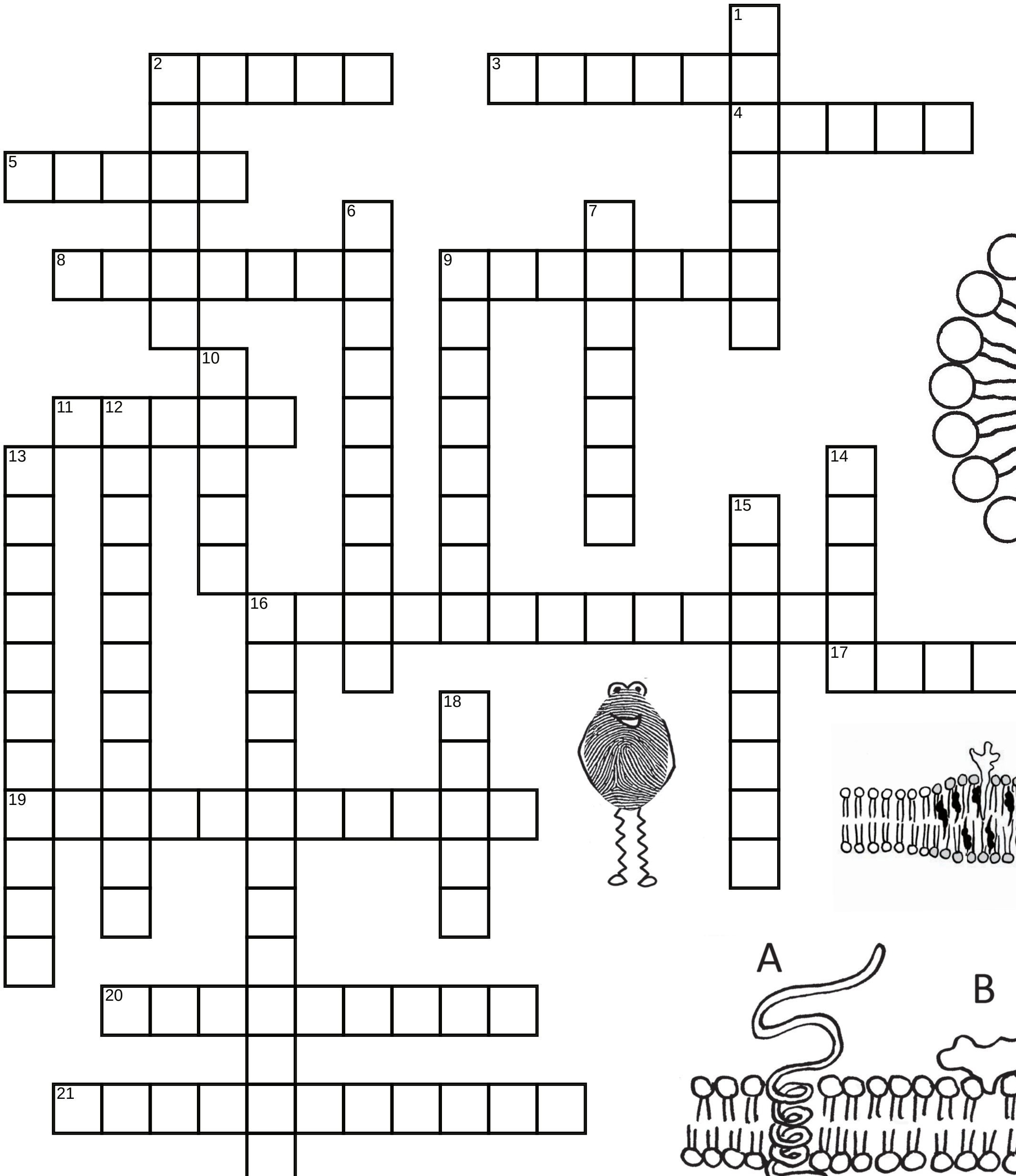
17) Which one of these is NOT a function that a protein on the outside of the membrane might perform?
a) act as an ID flag b) act as a mailbox to receive messages
c) act as an anchor for the cytoskeleton fibers d) act as an anchor for "cables" that attach to other cells

18) The word "mosaic" means:
a) a moving picture b) pattern made with tiny pieces c) surface layer

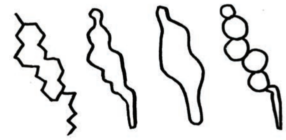
19) This substance is found through the membrane but is particularly concentrated in lipid rafts:
a) cholesterol b) phosphate c) glycerol d) water e) phospholipids

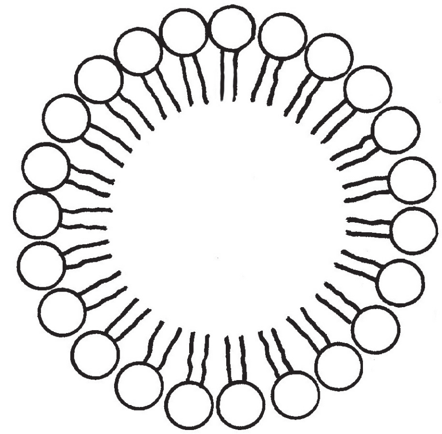
20) Which one of these is something that sugars do NOT do?
a) act as protective coating around the cell b) allow cells to communicate c) control growth
d) act as mailing labels for product made inside the cell e) act as channels that allow molecule to enter cell

ACTIVITY 2.1 Review crossword puzzle



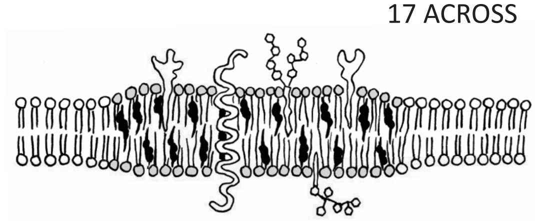
19 ACROSS

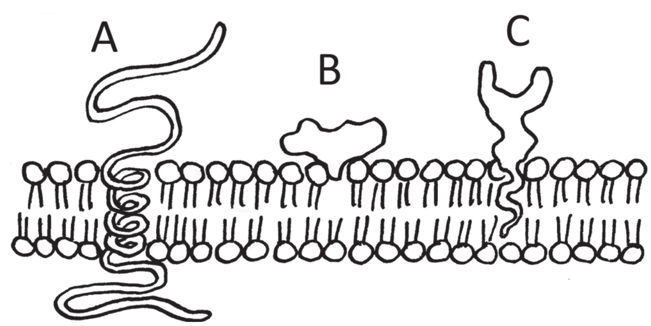




8 ACROSS

17 ACROSS





ACROSS:
2) Glucose and fructose are examples of ____ molecules.
3) The appearance and texture of cell membranes is often described as a fluid ______.
4) The person who gave us the name "cells."
5) The scientific name for fat is _____.
8) A single layer of phospholipids forming a ball shape.
9) Sugars most often take this 6-sided geometric shape.
11) Sugar tags known as A, B and O are found on ____ cells.
16) Proteins that go all the way through a membrane are called ________ proteins.
17) An area of membrane dense with cholesterol that keeps phospholipids and proteins together is called a ____.
19) This molecule has 3 hexagonal rings and a tail made of a string of carbons, and helps to keep phospholipids together.
20) This molecule is made of 1 phosphorus and 4 oxygens.
21) A molecule that "hates" water and won't interact with it.

DOWN:
1) This scientist worked with Schleiden to develop "cell theory."
2) Protein A, shown above, probably acts as a ____.
6) Protein B, shown above, is a ______ protein.
7) Protein C, shown above, probably acts like a _____.
9) Cholesterol is similar to both vitamin D, and a group of molecules called ______.
10) Water is a _____ molecule because electrons spend more time circulating around the oxygen atom.
12) This scientist is called the "father of microscopy."
13) Sugar codes can allow immune system cells to ____.
14) One oxygen atom and 2 hydrogens make ____.
15) This type of electron microscope gives us 3D images.
16) This type of electron microscope gives us flat images.
18) This scientist gave us the word "nucleus."