[SQUEAKING]

[RUSTLING]

[CLICKING]

PROFESSOR: OK. Great. Now let's dive into the material today. So today's topic is carbohydrates as well as an introduction to membrane structure. And from the very first class, I believe Professor Yaffe talked to you about the four main classes of biological molecules. So proteins and amino acids, you've spent a lot of time talking about that. Nucleic acids is coming up. And the other two are carbohydrates or sugars and lipids.

Today, we're really going to focus most of the lecture on carbohydrates, what they are, structure, something about nomenclature. And then at the end, we're going to talk a little bit about lipids and basic membrane structure. Now carbohydrates and lipids are really critical energy storage molecules for cells. And when we talk about metabolism-- the most interesting part of this course-- after spring break, we're going to delve into this in a lot more detail.

But sugars are also very important to understand nucleic acid structure. Turns out, membranes are essential for signal transduction. Those are the two major topics that Professor Yaffe is going to talk about for the rest of his time. And so this year, we're going to try something different and have me introduce at least some of these topics now, which will deal with some redundancies that otherwise might have existed and maybe set it up better for him to discuss some of the lectures coming up.

Now today's lecture is unfortunately topically a little bit disjointed. But it still has important information about biochemistry. And it will help us all speak the same language, both for the upcoming lectures from Professor Yaffe as well as things that I will start off with when I come back. And it's a nice way to ease back in after the exam.

OK. So what is a carbohydrate or a sugar? So let's break this down, and so it's carbohydrate. So a carbohydrate is effectively carbon in some ratio with water. So all carbohydrates have the same chemical formula, Cn and H2On. And so there are some deviations from this in biology. Sometimes, you can introduce a heteroatom, phosphate, sulfur, nitrogen, et cetera.

Technically, these are not carbohydrates, although they're often lumped together with carbohydrates. And why would nature do this? Because it changes some of the chemical properties that can be useful for either structural or signaling reasons. You may encounter these later-- certainly, in other classes. But we're not going to talk much more about that today. We really just kind of focus on the base carbohydrate, Cn H2On structure.

Now carbohydrates come in different forms. And so they can come as single units with that structure. These are so-called monosaccharides. Or these single units can come together to form various polymers. And those polymers could be two units, so-called disaccarides-- so two sugars stuck together. Or many units, and so sometimes, those are referred to as oligosaccharides or polysaccharides. And there's really no clear distinction between a few chains together, oligosaccharides, many polysaccharides. They're somewhat used interchangeably.

Now you guys have almost certainly heard of many of these things. So what's a monosaccharide? So a good example of that is glucose. So glucose is, of course, the main sugar that exists in your blood. What's a disaccharide? So a common one is sucrose. So sucrose is a disaccharide-- so two sugars stuck together, glucose plus fructose. You've probably heard of both of those things before. Sucrose is, of course, table sugar. It's what you would have mixed into your coffee if you had that this morning. And an example of a polysaccharide is starch-- so what's in a potato.

All right. Now clearly, these are all sugars. They're all relevant to a human diet. You would never confuse-- you've probably not knowingly tasted glucose. It's not particularly sweet. Sucrose is much sweeter. And a potato is not necessarily sweet at all.

Yet, this really points out that how these sugars are built, the different structures matter a lot. They matter for things like how you taste them in your diet. And how carbohydrates are built also matters a lot for all kinds of aspects of biology, which is why it's somewhat important to at least understand some of what we're talking about-- a common language about how to describe these molecules.

OK. So the simplest biological sugars have three carbons that are least commonly used. These are referred to as trioses. And if we take the general formula, C3 H2O3, and we say, what are two ways that we can satisfy that formula? There's two main ways we can do it. One is like this. So if you add up-- count all the carbons, hydrogens, and oxygens, you will see that that is C3 H2O3. This molecule is called glyceraldehyde. OK. And the other way we can do this is like this.

OK. Again, three carbons, three waters. If you add up all the atoms, this molecule is called dihydroxyacetone. And these are sugar-- same chemical formula, different chemical structure. That has a term. That's called an isomer. And it turns out that we can chemically interconvert these molecules in the following way. And so if we carry out this chemistry, we will get this intermediate.

OK. And that will allow you to interconvert glyceraldehyde-- this aldehyde-- with this ketone, dihydroxyacetone. And the enzyme class that carries this out is a class of enzymes called isomerases. And this is exactly the chemistry that that enzyme would use to interconvert these two forms of this triose, this three-carbon sugar molecule. All right.

Now if we look at dihydroxyacetone, there's no stereocenter here. What do I mean by a stereocenter? That's a carbon that has-- reminder from 512-- carbon that has four different non-equivalent substituents around it. However, if you look at glyceraldehyde, that carbon in the middle is a stereocenter-- four non-equivalent groups around it. And so there's two ways that I can draw glyceraldehyde. I can draw it like this. Or I could draw it like this. All right-- so two different ways.

So the one on the left here is D-glyceraldehyde. And the one on the right is L-glyceraldehyde. OK. And I know that this is review. Some people are good at seeing these things. Some people are not. I brought a couple of models here. Here's this-- the blue and the brown are two stereocenters with four different constituents on them. No way you can twist these around to make them identical molecules. Why does this matter?

Well, enzyme-active sites are going to fit this molecule different than this molecule. And this is why these stereoisomers matter so much for biology. It's also something that's really hard to accomplish.

If you think about how do you actually generate stereoisomers if you were in an organic chemistry lab-- really hard. But biology does this all the time. And the real reason is because it's enzymes that ultimately catalyze these interconversions. And different stereoisomers will fit differently into enzyme-active sites.

Now the way that I've been drawing these sugars is a convention called a Fischer projection. And when drawn in this way, the convention is that-- so you put the carbonyl towards the top. If the OH group, the alcohol, is pointing to the right, that's D. If it's pointing to the left, that's L-- and so D, pointing to the right, L, pointing to the left.

Like amino acids, biology has chosen one stereochemistry for most biological sugars because, of course, enzymes act on them. And so in biology, it's D, sugars. This is in contrast to L, amino acids. And so if you can remember that sugars are D, you know that amino acids are the opposite. Or if you remember that amino acids are L, you can remember that sugars are the opposite. OK. All right.

So dihydroxyacetone is really the only sugar with three or more carbons that doesn't have a chiral center. Everything else will. And so if I go to a four-carbon sugar-- draw a couple of them here. OK. So here's C4 H2O4 drawn with a ketone. If you look at this, this is a chiral center. OH group is pointing to the right. This is a D sugar. If I had drawn it with the OH group on this side, it would be an L sugar.

All right. If I draw this sugar as a different isomer, this time with an aldehyde, now, we encounter a bit of an issue because now I have one, two stereocenters. OK. So if there's two stereocenters, that means there's 2 to the n ways that I can draw this as a stereoisomer. And so you can see that this could get really complicated very quickly.

Now this sugar obviously is a D because I drew both OH groups pointing to the right. But you can imagine, I could draw one this way or one that way. And so how do if it's a D or an L sugar? And so the convention is that whether or not a sugar is designated as D or L refers to the stereocenter that is furthest away from the carbonyl.

And so this is the relevant stereocenter that says it's a D sugar. So what do I mean? I can draw. And then any other sugar would have a different name. And so what do I mean by that? Let me draw this a few different ways. And so the sugar that I've drawn here is referred to as D-erythrose.

All right. If I draw it, now the OH group on the carbon furthest from the carbonyl pointing to the left, so this would be L-erythrose. And if I draw it differently by altering the stereochemistry of this carbon, now, it has a different name. And so this carbon is D-- or this sugar is D-threose. All right. Makes sense. If I flip the OH group to this side, it would be L-threose. All right. So lots of possibilities.

Turns out nature only uses a subset of the stereoisomers and makes them relevant for biology. For example, D-erythrose is something that you will encounter when we talk about metabolism later in the course. D-threose, as far as I know, is not used in biology. I would never say, it's never used in biology. Never bet against biology. It can do absolutely everything. There's always an exception somewhere. But, in general, D-threose is not something that really exists, at least commonly in nature.

All right. So if we go through, and you look at all of these different sugars that I've drawn, you can see that they either have an aldehyde, or they have a ketone somewhere in the molecule. All right. So if you have an aldehyde, these sugars are generically referred to as aldoses. All right. And if you have a ketone, an internal carbonyl, these are generically referred to as ketoses.

Now you might say, as you start getting to longer and longer sugars, you can put the ketone anywhere along the sugar, and there would be a ton of different possibilities. But it turns out ketoses always have the carbonyl as the second carbon in from the end. The reason for that is because biology, as you will see when we talk about metabolism, interconverts these via isomerase reactions. And so you can't use an isomerase reaction to interconvert a ketose and an aldose unless the ketone is one carbon away from the end of the sugar. And so this fact really limits some of the diversity of ketoses that can actually exist in nature.

Now most important biological sugars, at least the most common ones, end up having six carbons or five carbons. And these are referred to as hexoses or aldose-- or pentoses. Sorry-- so much nomenclature. OK. So six-carbon sugars are hexoses. Five-carbon sugars are pentoses. And if we just talk about the hexoses, you're very familiar with a couple of them. And so one that we mentioned earlier, blood sugar-- glucose looks like this.

So this molecule is D-glucose. It's a D sugar because the stereocenter here furthest from the carbonyl-- OH group points to the right. So it's a D sugar. It's an aldose because it has an aldehyde. All right. And it's a hexose because it has 1, 2, 3, 4, 5, 6 carbons. And what makes it glucose is the stereochemistry of these other sites that end up being-- this is the molecule glucose.

Now if I carry out that isomerase reaction that I showed you earlier, it'll give me this intermediate. Let me draw the whole thing. Then I interconvert that aldose. Now, it becomes a ketose.

This is D-fructose-- another common sugar that certainly is in the news a lot. D sugar because the stereocenter for this from the carbonyl points to the right, makes it a D sugar. It's a ketose. It's a hexose. This organization of other stereocenters is what makes it D-fructose. All right.

Now if we go through and we count these, there's four stereocenters in glucose, three stereocenters in fructose. That means 2 to the n. There are 16 ways I can make ketose aldose, eight ways I can make a ketose-- I'm sorry-- an aldose hexose, eight ways I can make a ketose hexose. Among those, that's even 12 different ways that I can have D hexoses that are a ketose or an aldose. Could be very, very complicated.

But it turns out, fructose is the only D hexose ketose that really is relevant for nature. There's only two other molecules related to glucose-- only two other hexose aldoses that are sugars used in nature. You've probably heard of these as well. I'll draw them to illustrate a different point.

OK. So this molecule is galactose, an important sugar found in milk. All right. If I draw a glucose next to it again, glucose-- so these two sugars differ here, the stereochemistry there. So they are, I guess, isomers of each other. There's a special name for it I will get to in a second. So that's how galactose is related to glucose. The other major aldose hexose is this one.

This is D-mannose. This differs from glucose here-- that carbon at that carbon. By the way, by convention, the way that you number carbon in sugars is you start with the end that's closest to the carbonyl, either the aldehyde or the carbon one up from the ketone, so this would be carbon 1, 2, 3, 4, 5, 6. So galactose differs from glucose at carbon 4. Glucose differs from mannose at carbon 2.

These isomers have names in relation to each other. And so two sugars that differ by one part of stereochemistry-- so galactose to glucose or glucose to mannose-- are called epimers. And these can be or converted by enzymes called epimerases. We'll talk about how these work later in the course. And so glucose is an epimer of galactose. Glucose is an epimer of mannose. Mannose is not an epimer of galactose because mannose and galactose differ at both carbon 2 and carbon 4-- their stereochemistry.

Why is that relevant? Because if you're going to interconvert galactose and mannose, you would have to do it in two steps, two different epimerase reactions to interconvert those two sugars. All right. Great. So we've discussed now all of the major hexoses that nature uses. We've discussed all the major trioses that nature uses.

The other major length of sugars that ends up being important in biochemistry is the five-carbon sugars, the pentoses. And so I want to mention a couple pentoses and do so in a way that will allow me to basically solidify some of the nomenclature that I've gone through. And, of course, one of the five carbon sugars-- ribose-- is really critical to nucleic acid structure, which is one of the reasons why we're talking about this at this point in the course.

OK. So this is a pentose-- 1, 2, 3, 4, 5-carbon sugar, D-ribose. All right. It's a D sugar because the stereocenter furthest from the carbonyl points to the right. It's an aldose because it has an aldehyde group. I can act on this with an isomerase. I'm not going to draw out the isomerase reaction again. It's exactly what I drew before. If I did this, now, I turn this into a ketose.

Pentose because it's five carbons. Ketose because as a ketone. D sugar because the stereocenter furthest from the carbonyl points to the right. This has a name of D-ribulose.

All right. And it turns out that there is an important epimer of D-ribulose that's found in nature. The epimer changes the stereochemistry at carbon 3-- carbon 1, 2, 3, 4, 5. That's carbon 3. And so if this was acted on by an epimerase that did that, you get this sugar, also a pentose, also a ketose, a D sugar, but an epimer of ribulose. It's called D-xyulose. It's an epimer because xyulose ribulose are epimers because they differ by stereochemistry only at one position.

I'll just say, right off the bat, you should not memorize names of sugars and their structures. These are things you can look up in books. The point of going through all this is just to expose you to some of the nomenclature, remind you about stereochemistry. I realize, these are basic things. Many of you have already encountered this. Some of you find this very easy. Some people find these sort of spatial things more difficult.

This is very well-reviewed, though, in textbooks or other places online if you need to look it up. But the key thing is just to remember this nomenclature because it'll make it easier for us to talk about sugars later in the course. All right let's take a short break, so I can get some board space back. And then we'll build off some of these concepts in a minute.

I've been drawing all of these sugars as straight chains. But you probably know, from high school or from looking at DNA or RNA that the ribose there is not a straight chain but, instead, forms a ring. And, in fact in solution, particular aqueous solution, sugars, particularly five carbons and longer almost always exist as rings. And there is a very clear reason for this. And you probably remember, from 512 Organic Chemistry that alcohols will react with aldehydes and ketones in solution.

And so here, I have a model of glucose and fructose if you want to come and play with them. And so if you look at this, and you just look at the model, you see that this oxygen, right here, this alcohol, in space, is very close or can be moved to be very close to this aldehyde here on the end of the molecule. Or the same thing here with fructose. Here's a alcohol very close in space with this ketone. All right.

So what happens in this situation? Well, if you have-- this is a review of organic chemistry. OK. So here's any generic aldehyde. Here's some alcohol. OK. So those things react. You end up with this so-called hemiacetol. Or the same thing if I do it with a ketone and an alcohol-- now you get this hemiketal. OK.

Now given that you have an alcohol reacting with a carbonyl, an aldehyde, or ketone on the same molecule, well, what happens is you effectively get a ring with oxygen being one of the components of the ring. And so if we draw this for glucose-- so this is D-glucose. All right.

And so if the alcohol here on carbon 1, 2, 3, 4, 5 interacts with the aldehyde on carbon 1-- you can play with the model and see that that is the one that's close in space-- you now end up getting this. This, where you get a ring between carbons 1 and 5. We can number the rest of them-- 2, 3, 4, 5, 6.

All right. Or if I turn this molecule so that you can now draw it in a slightly more chemically proper way, now, you basically have-- this is carbon 1, 2, 3, 4, 5, 6. So carbon 5, oxygen from carbon 5 now bound to carbon 1 gives you this six-membered ring structure. The six-membered ring structure is reminiscent of an organic molecule called a-- looks like that-- called pyran. And so this six-membered ring in a sugar is also referred to as a pyranose. All right. So that's the first thing.

The second thing is that this whole business can be very tedious to draw. In fact, it's very tedious drawing sugars in general, as I'm sure you would agree with me if you're taking notes during this lecture. And so oftentimes, these pyranoses, like glucose, are drawn with shorthand. And the shorthand is as follows, where I basically represent the OH groups as simply lines. And so this is another shorthand to draw that pyranose form of glucose-- again, carbon 1, 2, 3, 4, 5, 6.

Now the last thing is you can see I didn't draw the OH group there on carbon 1. And that's because by making this pyranose ring, if you look at carbon 1, I have now generated a new stereocenter. And so carbon 1 now has four non-equivalent groups on it, which means I could draw the OH group, that carbon 1, in two different ways. And so this is carbon 1. I could draw it such that the OH group points down. Or I could draw it such that the OH group points up. And those are two different molecules.

And so there's a naming convention for this too. And so if the OH group points down using this way of drawing the molecule, it's called alpha. If the OH group points up, it's called beta. All right. And so this alpha versus beta ends up being structurally different because it puts, basically, that OH group pointing in a very different position in space.

So if I make a ring here with glucose, and the OH group is pointing here versus there-- very different position in space. And this has implications for how you build bonds for disaccharides and polysaccharides that make structural differences. And we'll cover this a lot when we get to metabolism.

But it should be very clear now that glucose, if you just take a solution of glucose and put it in water, it is not one thing. There's actually multiple different forms it can have. It could be as I drew it up here with the OH group pointing down. This would be alpha D-gluco-- because it's glucose-- pyranose, because it's in the pyranose ring form. I could have drawn it with the OH group pointing up-- different molecule. That would be Beta D-glucopyranose. Or it could just be the open-chain D-glucose that I was drawing earlier. All right. All of those are perfectly legitimate ways for glucose to exist in solution. All right.

Now it turns out, that in reality, about a third of it in solution is this. Two thirds is that. And a trace amount is this. OK. And that has to do with just what is more favorable forms or not. But which form it's in actually matters for structural reasons, as we'll see later in the course.

Now the final complexity is that this ring is not flat. So if I actually take glucose here and make a form of it-- so here's my glucose molecule. There's no way for me to make this completely flat, say, like benzene. And so there's really two different pyranose confirmations that can be formed. I'll try to draw them, but they're harder to draw. Here's a overhead that you can look at if it's easier. But basically, you can have it form this so-called boat form or this so-called chair form.

So there's the boat versus the chair conformation. Glucose, turns out, prefers the chair conformation. And there's an interesting thing that comes from this because if you take beta D-glucopyranose, it turns out of all the hexoses that exist in possible hexoses that exist, the form of a hexose aldose that best spreads out all the hydroxyl groups is beta D-glucopyranose, the more common one in solution.

Why does this matter? Well, because if this has this reactive aldehyde bound up in this stable ring structure, it's less likely to react with other aldehydes in the cell. And so this is likely why nature chose D-glucose as the most common storage sugar-- why it's sugar in your blood-- because it's the most stable hexose that's out there. And it's not just a random reason that nature picked this one, but actually because of real chemical stability issues for why it's there.

All right. Now I want to mention that ketoses also can form rings. And I'm going to use this as an example to show you that a ketose-- so here's fructose. So this is D-fructose. And so it turns out, this can form two possible rings. It can form a five-membered ring or six-membered ring. So how do I form a five-membered ring?

So if I take the carbon here from carbon 1, 2, 3, 4, 5, the hydroxyl from carbon 5, form a ring there. Now, I get this molecule. So there's 1, 2, 3, 4, 5, 6. OK. Or if I now turn this so that I draw it in the way you're probably more used to seeing it, I'm going to use the shorthand here. So this here would be carbon 1, 2, 3, 4, 5, 6-- hydroxyl from carbon 5, forming a bond to carbon 2.

That creates a new stereocenter at carbon 2. OH group is pointing up. So this is a beta sugar-- OH group pointing up. So this here, as I drew it, would be beta D-fructo and this is a furanose. Why is that? Because the organic molecule that's a five-membered ring with an oxygen in it is a furan. And so the five-membered ring is referred to as a furanose-- beta D-fructofuranose. If I'd drawn it with the OH group pointing down, it would be alpha D-fructofuranose. OK.

There's another possible ring I can do. And instead, I take the hydroxyl from carbon 6 and do that-- form a ring. Now I'm going to form a six-membered ring. We have carbon 1, 2, 3, 4, 5, 6.

So if I now turn this-- so this, here, now I drew the OH group pointing down. So it's an alpha. If I drew it up, it would be beta. So this is alpha D-fructofuranose-- six-membered ring version of fructose, five-membered ring version of fructose. So lots of non-equivalent ways I can draw fructose. And it turns out, these actually matter. And they matter for real things that probably matter to you.

And so I brought with me here two different sweeteners. This is corn syrup. This is honey. Has anyone ever-- I'm sure most of you have had honey. Has anyone ever tasted corn syrup? Come on. Someone's tasted corn syrup. Is a sweet? Which one's sweeter?

Honey, by far-- much, much, much sweeter. I used to have it so you guys could come up and taste them. But I couldn't come up with a way to do that in a sanitary way. So I gave up on it.

But nonetheless-- much sweeter than that. It turns out, these are not pure fructose. They're a combination of sugars. But their composition is actually, from a chemical standpoint, similar amounts of fructose in each one. And it turns out that honey is beta D-fructopyranose. Whereas corn syrup is beta D-fructofuranose. All right. So same sugar, different structure-- one's a furanose, one's a pyranose-- tastes very differently to you, one being much more sweet, one being much less sweet. OK.

Now, of course, I also want to talk about ribose because it's the thing that you guys are going to talk about the most next because it's in nucleic acids. And so just as a reminder, here's ribose. It's a aldose and a pentose. So this is D-ribose. Ribose, as from high school, forms five-membered rings. That's because it links alcohol on carbon 4 to the aldehyde on carbon 1. And that gives you this ring structure.

Now number of carbons-- 1, 2, 3, 4-- alcohol on carbon 4, forming a ring to the aldehyde on carbon 1. This is carbon 5. And the way I drew it, OH group pointing up-- so this is beta D-ribofuranose would be the proper way to have it. And so when you guys talk about this in DNA, well, the base is going to be linked to carbon 1.

It's going to replace that hydroxyl group-- the beta form of the hydroxyl group with the nitrogen. And you're going to talk about bonds being from the 5 prime or the 3 prime end. Those are those hydroxyl groups. That's where 5 prime and 3 prime comes from because those are the 5 and the 3 position on ribose. Great. Perfect.

All right. So we will return to carbohydrates in great detail. We'll discuss how we combine different carbohydrates, different monosaccharides to make disaccharides and polysaccharides, how these different structural properties end up mattering for things like energy storage as well as to produce various structural molecules that can be important for different cells in organisms.

But for the remaining part of the class today, I really want to shift topics to now discuss a completely different class of biomolecules. And that's lipids. So as I said earlier, the reason we're going to do this is because coming up for Professor Yaffe's lectures, lipids end up being really important molecules for various aspects of cell signaling. They're also very important for energy transduction, which is why I'm talking about them as well.

We will spend a lot of time later talking about lipids in great detail. But really, what I want to focus on today is how lipids are used to create membranes. That is, barriers that really separate the outside world from the inside of cells, things that make compartments within cells, and these things also end up being surfaces where you can have key things happen. So you reduce spatial complexity if you go to a 2D surface versus a 3D surface, which is part of why they're so important in signal transduction.

But to talk about these, I have to introduce, first of all, what is a lipid? So lipids are a class of molecules. You think of them as fats. That's how they fit in the nutritional standpoint of what we'll all talk about. But first, I want to give a general definition of what a lipid is.

Now there's lots of different classes of lipids. And we'll cover these later in the course. But in general, at the highest level, almost all lipids consist of two pieces-- consist of something called a fatty acid that's esterified to an alcohol. So what is a fatty acid? Well, a fatty acid is really any molecule that has a carboxylic acid group. So there's a carboxylic acid. And then hooked up to that carboxylic acid is a whole bunch of saturated hydrocarbons-- alkyl chains. Oftentimes, fatty acid would be drawn like this because of all the different saturated chains.

So acid group on one end, really greasy alkyl chain on the other. And it turns out that this can be esterified to an alcohol. So here's just a generic alcohol. And as you certainly remember from organic chemistry, I can use an alcohol and an acid to form an ester. And so then that would be-- so now, I have, basically, this ester bond. And this is esterification between some lipid species and a fatty acid, in general, is the general thing that leads to a class of molecules known as lipids.

Now why this is particularly useful for biology is that this long, greasy alkyl chain is not water soluble. So if you take oil from your cabinet-- canola oil, or olive oil, or whatever, and you pour it in water, what happens? It doesn't mix together. You get these globs of oil floating in the water.

And so if you want to form a barrier between two aqueous compartments, a way to do this is to have, basically, a hydrophobic layer-- a membrane-- basically separate the two aqueous compartments, the inside and the outside of the cell.

Now if I take a lipid, and the lipid, I form this ester, and it doesn't have a charged group anywhere on the molecule, this is sometimes referred to as a neutral lipid. So what do I mean by neutral lipid? It's basically taking this, which is intrinsically a fatty acid, is intrinsically a polar molecule. It has this carboxylic acid on the end of it.

But if I form an ester linkage to an alcohol, and the alcohol has no charge on it, now, it's just this really greasy molecule. And it turns out, that's exactly what is in your olive oil or in your canola oil in your cabinet. It's basically a bunch of fatty acids-- long alkyl chains esterified to non-charged alcohols, which makes this neutral lipid, this greasy molecule, which is great for energy storage in plants, something we'll talk about.

But if you want to mix it together with water, it doesn't do very well. So if you go to make salad dressing, and you pour your oil in with your vinegar, the aqueous thing, you get a bunch of droplets. You don't get a solution. And if you think about it, that's not very good at generating an interface between two compartments. You just get a bunch of droplets. You actually don't get an interface between two compartments.

So if you want to make an interface, you have to do something different. You need to have a charge group, like on this fatty acid, that's going to be happy sticking towards the aqueous side and then a hydrophobic portion that's going to be happy sticking to form a barrier.

Effectively, that's what soap is. So if you want to wash your hands and use canola oil, it doesn't work very well, right? But what happens if you have a bunch of greasy stuff in the water, and you take a drop of dawn dish detergent and drop it in the water?

You get this immediate barrier that forms across the top as you get this film where you basically align up all these charged hydrophilic parts to the aqueous pieces and all of the greasy parts to the hydrophobic side. So you end up having this nice charged molecule with this long hydrophobic part. So you have a hydrophilic end and a hydrophobic end. And that ends up being very useful as a way to form an aqueous hydrophobic interface.

And this is exactly how soap works, as I'm sure you've learned in other classes. As an aside, you know how you make soap? You basically boil the neutral lipids in lye. So boiling it in base, if you remember from organic chemistry, will break the ester linkage. And now, you have these molecules. And that's how you make soap. All right.

Now the way biology does this is they actually assemble lipids that effectively have that same property, where, basically, they have a head group from the alcohol that's charged with a hydrophobic group contributed from these fatty acids. And this is what allows things to assemble into membranes.

And so membranes are largely made up of-- and certainly, for the purposes of the upcoming lectures-- so-called phospholipids. So what is a phospholipid? Well, on a phospholipid, the alcohol part of the lipid is derived from a molecule called glycerol. So glycerol looks like this.

OK. So this is glycerol. All right. 3-carbon molecule-- three alcohols-- actually, very similar. If you look back in your notes to dihydroxyacetone, the difference between glycerol and dihydroxyacetone is carbon 2 was an alcohol here before it was a ketone. Turns out, that's where glycerol comes from-- dihydroxyacetone getting turned into glycerol. And basically, what a phospholipid is that you esterify a fatty acid to two of the alcohols and another phosphate and charged alcohol to the other hydroxyl group. So what do I mean by that?

So like this-- so here's ester linkage number one. I'll draw it this way just for ease. This is the carbon 2. Here's ester linkage number two. So that's a fatty acid esterified to 2 and 3. And then you now make an ester to a phosphate. So there's a phosphate at carbon 1. And then you make another ester linkage to another alcohol where R equals alcohol. And that alcohol also turns out to be charged.

And so the most common phospholipid membrane lipid is a molecule called phosphatidylcholine, which is that structure with the R group being this alcohol. And so this is choline. OK and so phosphatidylcholine is basically that structure.

OK. So this is phosphatidylcholine drawn out in all of its glory. So you have this hydrophilic end. Here, you have a hydrophobic end. That's good. This can point towards the aqueous side. This can point towards the greasy side and make a nice interface.

And so another common word for phosphatidylcholine-- an old word for it-- is a molecule called lecithin. Anyone read the labels on the side of your food ever? In fact, there's an old commercial that makes fun of this. Soy lecithin? What's that? I don't want that in my ice cream.

Well, what is lecithin? It's phosphatidylcholine. It's basically, why is this done? Well, it's commonly added to ice cream because what is ice cream? And it's an emulsion between fat, the cream, and sugar, which is pretty aqueous solubles, you might guess, from looking at what we drew earlier today. And so by putting phosphatidylcholine in your ice cream, you basically stabilize this emulsion between the aqueous and the fat face. So this is why it's added to lots of food. And in fact, it says, soy lecithin, an emulsifier. That's why it's added.

You can do this yourself. This is a common trick that many cooks know. So if you make salad dressing, you put a little mayonnaise in your salad dressing. Why do you do that? Well, mayonnaise has eggs in it. Eggs have a lot of phosphatidylcholine. That mayonnaise that you add into your salad dressing basically stabilizes that emulsion between the oil in the vinegar and helps it be more stable and distribute better across your lettuce.

I think my favorite example of this is, who's made chocolate chip cookies? Everyone's done this, right? OK. So how do you make chocolate chip cookies? So you take butter and sugar, all right, fat, and something that's very non-- very polar, aqueous soluble sugar. And you try to mix them together. You have to cream it, right? And that takes forever. It's a pain in the butt. It doesn't come together very well.

And so you get lazy, and you put the egg in there. And then it all comes together really, really easily. So why is that? The egg is the emulsifier that actually brings it together. Whereas trying to get the butter and sugar to make your cookies nice and fluffy is a lot harder because you're really trying to get these two things to come together. And it's basically this exact chemistry that's taking place when you're doing that act of cooking. All right.

Now phosphatidylcholine is not the only phospholipid found in membranes. But I'll just quickly mention what a couple of the other ones are. So it turns out you have two other major phospholipids by abundance and then another phospholipid that's really important for signaling. So I'll list them here first. So there's phosphatidylserine, phosphatidylethanolamine

These, it turns out, phosphatidylcholine, phosphatidylserine, phosphatidylethanolamine is what makes up the majority of the phospholipids in cell membranes. And then there is a much more minor phospholipid that's important for signaling, which is phosphatidylinositol. So what are these? So serine, ethanolamine, and inositol are just, like choline, different alcohols that can be esterified to the phosphate in exactly the same way I did for phosphatidylcholine.

And so what's phosphatidylserine? So if you remember, this is-- so this here is the amino acid serine. I'm sure you remember that. If we esterify that alcohol to the phosphate, there's phosphatidylserine.

What's ethanolamine look like? So ethanolamine is this alcohol. So that's ethanolamine. Esterify the alcohol to phosphate. Esterify that phosphate to glycerol-- phosphatidylethanolamine.

And the last one is inositol. So what is inositol? Well, inositol is a six-membered hydrocarbon rain where all of the carbons have an alcohol on them. And so if I esterify one of these alcohols on inositol, versus a-- if I esterify one of those alcohols to a phosphate to make phosphatidylinositol, turns out that that ends up being a really useful lipid to make for signaling. And you'll hear a lot about this in a couple of contexts, I believe, from Professor Yaffe later in the course.

All right. So this having these general membrane structure or this general phospholipid structure, where you have this hydrophobic part of the molecule and the hydrophilic part of the molecule is really what allows these lipids to come together to form these membrane bilayers that are often drawn like this. And so when I'm drawing it like this, basically, what those two wavy lines represent-- those are the hydrophobic fatty acid parts, and this is the hydrophilic so-called head group.

That's the charged alcohol stuck on to the end of the-- to the phosphate on the glycerol. And these, of course, assemble such that all of the hydrophilic head groups face an aqueous compartment on either side. OK. And then you have this nice hydrophobic portion that is a membrane. And that is what can create a barrier between two different compartments in cells.

Now just to put this into context for the protein structure stuff that you learned about-- so when you learn about all the different ways you have protein structure, of course, you have amino acids that are hydrophilic, amino acids that are hydrophobic. If you have a protein that's floating in solution, it has all the hydrophilic parts on the outside and the hydrophobic parts in the middle. But you can imagine that you can also have proteins that assemble to sit such that they span the membrane-- so hydrophobic parts that interact with the hydrophobic part, the inner part of the membrane-- hydrophilic parts on either side. These can form channels. These can form all kinds of ways to move stuff across membranes.

Or you might think that you might have a protein that does something like that-- hydrophobic part on one end, hydrophilic part on the other, and really floats on the surface of a membrane. And you will see that the way cell signaling works is that you basically have lots of protein complexes that will assemble that membranes-- two dimensional space. Those membranes, as well as some of the membrane lipids, can then act as messengers that allow cells to carry out various signals. And I will leave that to Professor Yaffe to talk about.

All right. So I will also come back and discuss membranes in a very different context in the context of metabolism during the second half of the course because it turns out, a lot of energy transduction and the way cells really store energy also ends up being really important with respect to membranes.

All right. You guys are lucky. You get out a little bit early today. This is the first time that we've done the lectures this way, so I don't have my timing quite right. But I will see you guys again for metabolism after spring break.