OK. So the thing that we're going to talk today about are macromolecules. And often these are polymers. Now, all macromolecules comprise of multiple carbons joined together in some way. But the real definition of a polymer is that there is some kind of monomer that is joined together in a repeated way to make some kind of multimer that forms the polymer. OK. Now, integral to understanding all of this is the notion of chemical bonds. And you're going to, in this week's Section you're going to be addressing, remembering, understanding what chemical bonds are. And here are some concepts that are essential that you understand for chemical bonds. Let me list them on the board. And then we'll go through them in some more detail. And then I'm going to move on. And you are going to deal with this more in Section, but this is really integral to understanding the rest of the course. So one of the terms you need to know is electronegativity. Anyone want to give me an electronegativity definition? I may be able to find another chocolate fish for an electronegativity definition. Where? A little hand. Yeah? Say it again. OK. Good. Yeah. How strongly an atom attracts electrons. This is good. You see, you get to practice catching and I get to practice throwing. So the relative affinity of a particular atom for electrons. OK? So that's one think you need to know. Valance. Super important. Valance. Yeah? How many electron slots available for connections. Try to rephrase. Yes, but rephrase it a bit. We're talking about chemical bonds. So? OK, how many bonds. I did not give that away. OK. How many bonds a molecule can, an atom can make. OK? OK. And then we get into the bonds per se. And I'm going to list them here. I'm going to list them in order from strong to weak. Covalent bonds. Ionic. I'll go through some slides in a moment. Hydrogen and something I'll call hydrophobic. OK. And covalent bonds are the strongest and these so-called hydrophobic bonds are the weakest bonds. Ones that we are particularly interested in, actually, we're interested in all of them, but I would say covalent, hydrogen and hydrophobic bonds are particularly important. And you will see when we talk about DNA, hydrogen bonds are very important. So let's go through some pictures. This is a table from your book, I'm not going to dwell on too much, but you really need to be familiar with this, you need to understand what is in this. And it will indicate for you what the nature of the different bonds are. OK. Covalent bonds, really, the two atoms become very closely joined together. And, again, you're going to deal with this. Let me just move onto, in your recitation. Let me deal with two things that I want to dwell on a little bit. The first is the notion of polar and nonpolar molecules. OK? So polar molecules have got differential charge distribution. All right? So we can add that actually to our list. If you want to go back and add something to your list, its part and parcel of the notion of electronegativity, but let's also write polar versus nonpolar molecules. In a polar molecule, the charges in the molecule are asymmetrically distributed. Whereas, in the nonpolar molecule the charges are uniformly distributed and there is no net asymmetry of charge in that particular molecule. And that will become important in a little bit. Here is one that, again, you will dwell on in Section but I will introduce now. Hydrogen bonds are between a hydrogen and an oxygen, and the hydrogen or something else, something that is more electronegative, the hydrogen, it's the hydrogen, this is not a covalent bond. And the hydrogen interaction is integral to the structure of DNA, as we will discuss in this lecture and when we talk about molecular biology. OK. So that is a very cursory introduction to something that you will be dwelling on more in Section this week. OK. So I want to talk now about polymers. And I want to talk how they form biologically. And I'm going to tell you about two types of reactions that you should understand. Condensation reaction which forms a polymer and a hydrolysis reaction which breaks a polymer. So let's look at a diagram here that I've taken from your book. Here are two monomers. And you can see there is a hydroxyl group and a hydrogen group and a hydrogen. And those two things react with one another and, with the use of energy, water is released, and the two monomers are joined to one another. OK? Again, you're going to have plenty of practice at this. Don't try to draw this diagram here. OK? You can, we'll deal with it in a little bit. Just look at it and understand what I'm saying at the time and it really is sufficient. So, here, you've got the exclusion of water, the use of energy to get two monomers joined up, and then the process continues and you get a polymer being built up of more and more monomers. Now, the converse of that is hydrolysis where you add water and also use energy to break up a polymer and release a monomer. So either hydrolysis reaction or a condensation reaction are energy requiring reactions. And this energy has to come from somewhere. And we will spend a lecture talking about where the energy comes from. So I want to draw the analogy, and it may seem hokey to you, but it's actually quite useful, a useful way for me to think about this, so I want to share it with you. I want to draw the analogy to the cell as a factory. And I want to begin by talking about the materials that the factory uses to synthesize whatever it is it's going to synthesize. And then as we move through the biochemistry section I'll talk about the machinery within the cell that makes the synthesis take place. So we're going to talk about the materials that are present in the cell. And particularly we're going to talk about four groups of macromolecules, the big four from which everything else is built and that really are pivotal for life. These are proteins. And, actually, let me not list them in that order. Let me list them in the order in which I'm going to talk about them. I'm going to talk about lipids, carbohydrates, nucleic acids. And I'll talk about those three today. And then next time I'll talk about proteins. So if you look at the dry mass of a cell it's very interesting. Lipids comprise about 5% of the dry mass, carbohydrates about 25%, nucleic acids 10%, and proteins about 55%. OK. So that's what we're going to be talking about, these four groups of macromolecules that make up the components of the cell. Now, two things that I want to point out as we talk about these macromolecules is that very often in biology the polymers have two properties that are very important. One, they have polarity. That means one end is different from the other end. OK? And the other thing that they very often have, not always but some classes in particular, is a linear order. OK? So that's, both of those properties, if you give this a moment's thought, you will see are very similar to sentences. There's a beginning and an end of a sentence, and within a sentence the words come in a particular order. And that gives you an information content. That gives you a way to carry out or to store information. So I'll point this out. This is particularly true for the proteins and the nucleic acids. It's also somewhat true for carbohydrates and less so for lipids. So these two properties of biological polymers are fascinating and they are crucial for life to proceed. All right. So let's move onto one of the big four. Lipids. Lipids. So lipids are a somewhat large and almost amorphous group of molecules in that I cannot give you a chemical formula, really, to say this is definitely a lipid and this is not a lipid. They have one property that is crucial for defining them as lipids, and this is that they are hydrophobic -- -- or nonpolar. And this property of being hydrophobic, so lipids in foods. What are the lipids just, you know, in your food pyramid? It's just to make sure we're all talking about the same stuff here. Fats and oils, right. Yes. And you can come and get a fish later. OK. So fats and oils. They're used for a couple of things. One of the things about fats and oils is that they store a lot of energy. So they serve as a long-term energy source for the cell. And the other thing they do really has to do with their insulation properties. And their insulation properties fall into multiple categories. The most important one we touched on last time when we talked about the components of a cell. We talked about the fact that the cell is a cell, and the organelles in the cell are organelles because they are membrane bound. And I threw out at you the term lipid bilayer, and I'll throw it out at you again in a moment. This is something made of lipids that insulates the cell from its environment or subcellular compartments from one another. So part of the insulation property are membranes. And, again, this term, I'll write on the board this time, lipid bilayer. And the other aspect of insulation or the more classical things you think about, you don't get cold because you've got a layer of fat under your skin, and that stops yourself from losing heat. So heat loss. And, for example, birds use lipids to waterproof their feathers so that they can stand in the rain and not get wet. OK. Another aspect that I'll throw out at you also here is that lipids also make things called hormones, which are substances that control various aspects of body function. I'll have a little more to say about them in a couple of minutes, and then will have quite a bit more to say about them when we talk about reproduction. So let me see what is next here. OK. So let's talk about some typical lipids and some examples of lipids. This is a diagram from your book, so you can go and look at it at your leisure, of a triglyceride. Now, what I want you to take from this is that, so triglycerides, tri meaning three. And the glyce- part is from glycerol, which is this molecule up here, onto which three long carbon chains are added. And these long carbon chains are called fatty acids. And that's important to know. So a triglycerides is glycerol onto which three fatty acid chains have been added. And it's the fatty acid chains that are hydrophobic. So triglycerides are a very common type of lipid. Now, after I just told you, ah, it's fixed. After I just told you that lipids were all hydrophobic. I'm now going to tell you that some lipids are amphipathic. And they're amphipathic, so amphipathic means that they have both polar plus nonpolar components. And one of the most important amphipathic molecules in the lipid field is a phospholipid. So this is a molecule that's got these fatty acid long carbon chains on one end and on the other end has got a very polar phosphate group. OK? And here's phosphate with something called choline added onto it. So this is phosphatidylcholine. And phospholipids, and I spelt amphipathic incorrectly. Phospholipids are essential for formation of the lipid bilayer membranes. And the reason they are is because of this dual charged and noncharged portion. So here is a diagram that I showed you last time that was not as well labeled. This is a diagram of a lipid bilayer, so one of the membranes that surrounds your cells and your organelles. Facing out onto the water of the cell are the hydrophilic heads of this phospholipids, the charged heads. And then facing one another are two rows, OK, of these hydrophobic fatty acid tails. So the bilayer is because you have one layer of these molecules with the hydrophilic heads facing the water, the hydrophobic tails pointing in. And those interact with another layer where the hydrophilic heads are pointing to the water and the hydrophobic tails are pointing inwards. The hydrophobic tails interact with one another and you get this very stable lipid bilayer. OK. It's very cool. That's how things work, and they work very easily. And you can get them to be synthesized in a test-tube very easily. Here is another one. Saturated versus unsaturated fats. Unsat, OK, as an unsaturated. In saturated fats, the fatty acid side chain contains no double bounds. OK? So it saturated four hydrogens. In unsaturated fats, there are some double bonds that would allow one to add more hydrogens if they were broken. OK? So saturated versus unsaturated fats. So saturated fats are the things you find in butter and in hard fats. And they're supposed to be bad for you. OK? So saturated fats have been implicated in raising something called low density lipoproteins which are involved in various aspects of cell function that are believed to lead to heart disease. But it turns out that there's more to it than that. So if you've ever been really bored and you've read the ingredients on the box of cookies that you've eaten, you may see something that says partially hydrogenated vegetable oil. Yeah? OK. Now, your vegetable oil is rather unsaturated. OK? It's got a lot of double bonds. And one of the reasons that it is liquid is because these double bonds are there and you don't get the chains of the lipid packing very tightly and it's a liquid. But you can take your vegetable oil with lots of unsaturated bonds and you can partially saturate it. And you can get out of that two kinds of partially saturated fat, partially hydrogenated fat. You can get this stuff called transunsaturated fat. Now, if you look at this diagram, you will see these fatty acid side chains are in nice order here. OK? And they are because the hydrogens that are across from the double bonds are intrans from one another. They're kind of diagonally opposite from one another. And what that does is to allow these side chains to pack very tightly, and you get a very hard fat that way. Somehow this partially hydrogenated stuff is very bad for you. It raises your LDL, it reduces this stuff called high density lipoprotein, which is good for you, and it increases your heart disease risk. Interestingly, you do not find these types of molecules in nature. You only find them when you hydrogenate your vegetable oil and make your margarine or make the stuff that McDonald's cooks its French fries in, OK, and its chicken nuggets. So a couple of years ago there was so much issue about this that McDonald's pledged to find a different vegetable oil in which to fry its fries. And it's still searching, apparently, because there's some issue with taste being compromised as you go to healthier fats. OK. Now, in contrast to the transunsaturated fats there's this sysunsaturated fat also. And if you look here, you can see that these side chains are kinked. And the reason they're kinked is that the hydrogens across the double bond are on the same side of the molecule as one another. That has the effect of not allowing the side chains to pack tightly. So you get side chains floating all over the place, and that changes the energy of the fat so that it is a liquid rather than a solid. And these are much better for you, these sysunsaturated fats. And you find them in lots of vegetable oils and vegetable fats. OK. Here's another one. Here's our joke for the day. OK. Steroids. Steroids are a lipid. They are derived from, OK, so let me just say for this unsaturated. I mentioned sys and transunsaturated fats. I'm going to mention steroid hormones. There are a few of them. Steroids are not all hormones, although cholesterol, we don't think of cholesterol as a hormone, although, actually, I think it really is. Vitamin D is a vitamin that works together with other molecules. Cortisol and testosterone are classically thought of as hormones. Very small amounts of them will change body function in profound ways. And we'll have more to say about testosterone later on in the course. The androgens that lead to people who have large green muscles are a class that are related to testosterone, androsterone and so on, but they're all the structures with these four rings in this characteristic way are all characteristic of a steroid. All right. So that is all I have to say about lipids. Let's move onto either number two here, carbohydrates. So carbohydrates have as their -- OK. Carbohydrates. Also classically known as sugars. And because of that there are a couple of functions of carbohydrates. They are the major source of short-term energy. If you need short-term energy you use carbohydrates. They're also a carbon source, so we'll talk extensively about building up molecules. And you need carbons to do that. Carbohydrates serve as a carbon source for building other molecules. And, as I'll mention briefly, they also can convey information. Carbohydrates have, as their chemical principle, so we can find a chemical principle that unifies them, they all contain carbons that are joined to a hydrogen and to a hydroxyl, and obviously to other things as well. So you can loosely give carbohydrates the formula of CH_2O to the N. Now, the monomer, now we can actually, with lipids it's very hard to talk about a monomer and a polymer. In carbohydrates one can. And one can talk about the monomer, which is called a monosaccharide which polymerizes to form a polysaccharide. And they do so. One can also get, let me just write it here, one can also get disaccharides where disaccharides are two and polysaccharides are really more than two. They're usually more than ten or so, but for our purposes more than two is fine. OK. So in order to form a polymer of carbohydrates, one forms a glycosidic linkage or glycosidic bond. So it's a covalent bond where one has -- Two carbohydrates or two monosaccharides interacting with one another through a condensation reaction, classical condensation reaction with the elimination of water to give you, excuse me, yeah, no. I wrote this down incorrectly in my notes. Apologies. OK. To give you a glycosidic linkage. OK? So this is a classical condensation reaction. Now, polysaccharides or carbohydrates are interesting. They can either be rings or they can be linear. And they can also be modified. So like the lipids where you could get phospholipids, carbohydrates can have various extra things added onto them that changes their properties. Let's take a look at a few of them. Here are some monosaccharides. And the ones that are super important for you to know are these two down here. OK? And you should know the structures of these. This is ribose and deoxyribose. And the reason for this will become clear when I move onto the next class of macromolecules, DNA and RNA, because those sugars are part of DNA and RNA. OK? So these ribose and deoxyribose are five carbon rings. You can see they're not quite a five, they're not a five carbon ring. They are five carbon sugars. And this is an isomer of one of the forms that this five carbon sugar can take. OK. So some of you may be lactose intolerant and might not be able, in fact, to enjoy digging in and enjoying a bowl of creamy delicious ice cream. So, in fact, the reason, I didn't make that up, though the reason you cannot is because you need a specific protein, a specific enzyme that we'll talk about, not the specific enzyme, but we'll talk about the notion of enzymes in a couple of lectures that breaks a bond between the disaccharide that is lactose. So lactose is a disaccharide that is a galactose joined together with a glucose. OK. So these are six carbon sugars. And there's a bond between the two of them that you have to break in order to digest the lactose from milk. And if you cannot then this lactose causes you digestive issues. Here on the top is sucrose which is a dimer, a disaccharide, a glucose joined to a fructose. OK. So here's an interesting question. I don't know when you were little, but when I was little I used to try and eat grass. And, clearly, that doesn't work very well. Humans cannot eat grass. Whereas, cows and many animals can survive just very well on a diet of just plants. And that is because we cannot deal with this carbohydrate in plants called cellulose. Now, interestingly, we can digest other plant carbohydrates, particularly starch or amylose which is what most of the carbohydrates that we eat come from. The reason for this is interesting, and it has to do with these glycosidic linkages. OK. So here we have a linkage between glucose, two glucoses that give something called maltose. And maltose is part of the starch carbohydrate, or the amylose carbohydrates. And what you should know here about these chains, these circles, and you should remember from old chemistry as if there is a bold part in the front of this ring then it is coming out of the board towards you. OK. So here you have these two glucoses linked such that a bond joining them is coming out of the board towards you. Now, conversely, and this is called an alpha 1, 4 bond where the bonds coming out of the board towards you in cellobiose, which is a precursor for cellulose, the grass carbohydrate, the bond goes back, OK, back away from the rings. And that's called a beta 1, 4 linkage. And we can break this alpha 1, 4 linkage but not this beta 1, 4 linkage. And I'll come back to this when we talk about enzymes. We do not have the correct enzymes to do so. And finally with respect to carbohydrates, I mentioned that they were sources of information. One of the interesting sources of information from carbohydrates is in your blood cells. So your blood group is as a result of adding specific chains of specific carbohydrates, specific monosaccharides, and a whole bunch of them, onto particular red blood cell surface proteins. So if you're an A blood group, you have a series of specific carbohydrates added on in order to one of these cell surface proteins. If you're a B blood group, you also have this carbohydrate chain but the specific carbohydrates, the specific monosaccharides are different. All right. So let's move onto the reason that you're all really sitting here. So, really, the reason that you're all sitting here is because of this next group of macromolecules. And I don't mean that that's the reason, you know, you're alive, that you exist in life. I mean that's the reason you're talking 7.013. Because nucleic acids are the thing that have, and the understanding of nucleic acids is what has revolutionized biology so that -- So that everyone in every discipline at MIT has some association, has some way of using the information from nucleic acids to their advantage and in their careers. OK. So nucleic acids, as I'll discuss, do serve as an energy source or as a way of storing energy, but most important is their function, and that's a super important function. But the reason you're talking 7. 13 is not because of that. The reason you are is because of the information content that nucleic acids are able to carry and to perpetuate from one generation to another. So, really, what they are involved in is information storage and transfer. All right. So, again, as for carbohydrates, we can talk about monomers and we can talk about polymers. The monomers for nucleic acids is a nucleotide. Oh, OK. Enough air play. Watson and Crick get a lot of air play, so that's enough. You can go and look at their picture at your leisure. OK. So I've taken this from your book and I'm going to draw some stuff on the board. I want to point out that in the new edition of your book, you will find there is a mistake in the structure of your nucleotides. That was true in the last edition. I wrote to the senior author. I said there is a problem with the sugar structure in the nucleic acids. Would you please change it for the next edition? And he said absolutely we will. And the new edition came out and there we are. OK? So we'll have to, so we're going to deal with that, but I think we'll get you all free copies, or your successors free copies of the next edition of the book or something to make up for this. But, actually, it's a good exercise for you because you can learn the proper structure of the sugar. So what is a nucleotide? OK. A nucleotide, as you gather, has a sugar associated with it. It has, the sugar it has associated it with is either ribose or deoxyribose. This sugar is joined to a phosphate group. And the sugar is also joined to something called a base. Now, the sugar is a five carbon ring. I'll come back to this slide in a moment and we'll talk about the bottom part of it. The sugar is a five carbon ring. OK? Here it is. It's actually a four carbon ring with an oxygen and there's another carbon sticking out. And what they've done in your book is to forget about this carbon up here and turn this oxygen here into a carbon. So it's kind of weird. Later in the book the structure is correct, but you should bear this in mind. I've pointed this out in your PowerPoint handouts. OK. So what's really important, there are two things about nucleotides that are really important. One is this phosphate and sugar because that is the way nucleotides polymerize with one another. And the other is the base which is the part of the molecule that gives rise to the information. Actually, let me just stop this and write the bases here. So let me tell you the names of the bases. And you need to know these. There are four of them. Five really. There is adenine, guanine, cytosine and thymine. And then there's also something that's an alternate to thymine called uracil. And they are abbreviated by their first letters. OK? So A, G, C and T and U. And you need to know these letters. And you need to know what they stand for. All right. So let me, in the last two minutes, tell you about some properties. Actually, let me tell you about the bond that forms the nucleic acid polymer. And then I'll finish this off next lecture. The bond that forms the polymer is called a phosphodiester bond. And it forms by the reaction of the phosphate and the sugar with one another, or groups on the phosphate and the sugar with one another. The base has got nothing to do with this polymerization. So we have here a phosphate with some oxygens that's joined onto the sugar. So I'm abbreviating the phosphate P, I'm abbreviating the sugar S, and I'm abbreviating the base B. OK? And the sugar is attached to a base. And the sugar has, in one part of it, a reactive hydroxyl group. And the phosphate has some reactive oxygen groups. And let's not worry too much about bonds and double bonds and things for now. OK. And I'm not worrying about charges on oxygens and things either. What happens, basically, is that there is an interaction between this hydroxyl group and the phosphate group, OK, or one of the oxygens on the phosphate group. And you get out of this a linkage that goes -- OK. Where you get between the sugar and the phosphate this phosphodiester linkage. OK? An OPO linkage that joins the two sugars to one another through a phosphate molecule. This is your phosphodiester bond. And I want to point out that the bases, which I will tell you next time, are the part of the molecule that carries the information, have got nothing to do with the polymerization of nucleic acids. So I'm going to continue with this next time and briefly finish nucleic acids and then move onto the proteins.