MIT OpenCourseWare
http://ocw.mit.edu

7.014 Introductory Biology, Spring 2005
Transcript – Lecture 2

Today we're going to start get into at least the nitty-gritty stuff of the course. I think a point I want to, just to give you a very broad perspective apart from why biology is interesting, I want to talk about just very briefly how we study biology. I sort of talked about it the other day by sort of the levels at which we could do it, from the biosphere all the way down to the molecular level. But there is another way of looking at it.

And I just want to remind you of what I said the other day. Biology is an experimental science What we know or think we know at the moment is because of people having made observations, designed hypotheses, tested them and so on. And what you're seeing is sort of the sum of the current state of human knowledge when I'm talking to you right now. There are various, two sort of major disciplines that have been used to get at how biological function works.

As you'll see, the main actor for many of the things that happened inside of cells and in living organisms are proteins. And we'll be talking about what those are and their structures in some detail at the next thing. But the information is not coded in the proteins. The information for coding everything that's in a cell is in units called genes which are made of, as you probably all know, DNA.

So there have been, classically there were two approaches towards studying biology in detailed ways. One was the approach of the biochemist who basically took whatever it was, put it in a whirling blender or something, and ripped everything into little pieces. Sort of like taking the alarm clock and shaking it so hard all you've got is all the little bits. And once you got it into all little bits then you can purify a little thing like a spring or a little wheel or something and try then to figure out what that does in the context of the cell.

You can get very detailed information. And this is in a sort of trivial way the science of, discipline of biochemistry. Geneticists take a different sort of approach. And what they do is they take the living organism and look for a variant where there has just been one single change in that whole organism and they study its properties. And what you learn from that is physiologically relevant information.

And if you broke up a car and purified the ashtray you could postulate that that was really important for the car. But if you made a mutant that was missing the ashtray and it still ran, you know, you'd learn that that wasn't what was correct. And one of the really powerful things that people could only do in very rare instances for a long time was to unite the kinds of observations that biochemists made with the kinds of observations geneticists made.

And the explosion in knowledge that's happened over the last couple of decades, probably, well, since probably 1975 when recombinant DNA came in, was a whole new realm of sort of a general discipline we call molecular biology that allowed us to clone genes, to sequence them, to many of the things we'll be talking about. But one

of the real powers in looking at this sort of way of thinking about how we study biology is that it suddenly enabled one to put these two sorts of things together.

If you were a biochemist and you purified a protein and you found out a chemical property that it had and you wondered what it did in the cell, you could sequence the protein and deduce what some of the DNA sequence was, find the gene, disable the gene in the organism, look and see if your idea was right. Or vice versa, if you were a geneticist and you found a mutant that had an interesting property and you wondered how it was working then you could clone the gene, look at the protein and try and figure it out.

And that's partly way since about 1975 there has just been this absolute upheaval in our knowledge of biology. And we'll be talking about all of these disciplines here as we go through the course. Three or four of you were honest enough to say I'd rather be anywhere on earth but in this class. I'm a senior. I really didn't want to be here. And I said to you the other day if you'll come I'll give you the best I have to try and show you why I think it's exciting and why it's so relevant to you and your life as you go looking forward to moving on with your careers and your family and everything else.

However, even if you're not interested in this course, don't get caught in the trap because we're not going to be doing differential equations that it's easy. Part of the reason biology is hard is each one of these disciplines has a different kind of thinking. And to be very effective in biology right now you have to be able to think like a chemist, how bonds are formed and broken and what's reasonable.

You need to be able to think in 3-dimensional structures because everything happens in 3-D and biology is very much about fitting shapes together. Genetics is more like probability and statistics. Some of those logic games that you sort of used to try and do. It's more like that. PCR is, I don't know, recombinant DNA, all this sort of stuff is sort of a strategy kind of game.

So you'll find, as you go through this course, that there maybe some things that are easy and some that are difficult. But for you, easier or difficult, you'll need to do a lot of different thinking. And then, at the moment, you cannot do biology anymore by just being a biochemist or just being a geneticist. You could in the old days, but now you've got to do it all.

So where we're going to start right now will be with biochemistry. And just before I do that I just want to show you -- Let's see. I wonder if we're going to be able to see these slides with that light on. I think we'll see if we can do this. So the green fluorescent protein, thanks, that's great. The green fluorescent protein, which we showed you the other day, is a protein. And we're going to be talking about that.

And you'll see it's got structures. You've got these sorts of sheets and you'll see little helices. And in a couple of days you'll know what this is all about. But I wanted to tell you a couple of things just before I get into this. This actually was, I showed you that little Barney thing to try to emphasize that if you looked at evolution that way, you can see most of it was at the level of single cells, and that's why things are so common when you get down to the cellular and molecular level.

I've actually done that demo one other place, and that was after, I'm an American Cancer Society research professor, and they asked me to give a talk for the 50th

anniversary of the Illinois Division of the American Cancer Society on the importance of basic research. And it was after dinner, 500 people in tuxedos and evening gowns and bottles of wine, and they kept shortening my time.

And finally I had ten minutes to get up there in my tux and tell them about the importance of research, basic research. And I finally decided maybe what I could do is help them understand why when they gave money to cure cancer biologists went, ah, signed this one off, and studied all these other organisms, fruit flies and everything. So I did this little demo.

So I was up on the stage at the Sheraton holding the Barney and the dinosaur doing what you saw me do here. And I thought of briefly about putting my tux on just to kind of, you know, give a little zip to the extra lecture, but decided not to because I'd get chalk all over it or something. So if you think I look stupid doing this, you know, my cats thought I was absolutely an idiot afterwards.

They looked very, very puzzled as to what was going on. OK. So I'm going to start talking in a couple of minutes about covalent bonds, and you're going to roll your eyes upwards and think I've heard about that since I was a baby, or some of you will think that. But I just want to keep, you've got to understand something about how the parts that are used in biology are built or it won't make sense. And so just to sort of give you something to sort of keep you going here, I want to sort of foreshadow a couple of things that are coming.

Here's an example of what happens with genetics. This is a single mutation in one gene of an individual. This woman has what's known as Werner syndrome. That's what she looked like as a teenager. That's what she looked like at age 48. That's one of these mutations that causes advanced aging. And people are working very hard on what that, you know, trying to understand aging.

During your time at MIT, there are going to be some, there already have been some amazing discoveries in the last five years, and it's going to be a time of explosive growth. But that's just one change. And it offers a huge clue as to why we age. Here's another example. These are people who have a human condition called Xeroderma Pigmentosum. And this was the way they used to look before we understood it. They have a deficiency in handling damage to their DNA that's caused by sunlight.

So if they went out in the sunlight once they'd get skin cancer. You can see they get skin lesions and everything else. It was due to a defect in just one gene. And it took out an important kind of DNA repair. Now they know how it works. The kids who do this only go out at night. They go to summer camp at night. They call them "Children of the Moon".

They look normal and they don't get skin cancer, but they have to live a kind of special life because of this problem. And people are working on fixing that. That's the sort of thing that can come out genetics. Single change, absolutely dramatic affect. You can sort of make inferences that something important is broken in that individual because the rest of us don't have this problem.

The biochemists, you know Watson and Crick, and we'll talk more about their structure of DNA. But DNA has to get replicated. In fact, just in the last couple years we now know that's what's wrong with this person is that they're lacking a special

DNA copying machine that is able to copy over strands of DNA that have damage in them that's caused by sunlight. It's got a very sort of flexible active site.

It can accommodate the bulkiness of this UV induced lesion. And so here's a case where we've now united our understanding of that disease at the ultimate biochemical molecular level and the high level human syndrome. So that's kind of one thing to sort of keep you going. OK. So here's a cell. That's the fundamental unit of life. I said the other day remember cells carry out metabolism.

They do regulated growth. They do reproduction. That's what makes them different from just a bag of proteins and nucleic acids and things. And we could think about cells at a couple of different levels. We could think about them in terms of their atomic composition. I guess we can. Let's see. And if we think about it that way it's not particularly exciting. Hydrogen is about 60%, oxygen is about 20%, carbon is about 12%, nitrogen is about 5%, and then there's a whole lot of other stuff present at lower levels, phosphorus, sulfate, magnesium, manganese, selenium, etc.

This isn't a particularly helpful way to think about cells. This is perhaps a more useful way, and that's to think about it in terms of molecular composition. And we're about 80% water. Virtually all living organisms, more or less the same, 80% water is what our cells are made up of. And of the rest of them, there are four major classes of macromolecule, large biological molecules that make up the rest of cells.

And that's what we're going to be focusing on in a little bit. There are proteins, which I've already mentioned today, and that's about 50% of it. Nucleic acids, that's DNA and RNA, we'll say that's about 15%. Carbohydrates, which we'll be talking about today. Lipids about 10%. And there is a bunch of little stuff that is important but makes up the remaining amount.

But to understand biology we're really going to have to try and figure out how cells work. We're going to need to talk about the properties of those molecules. And just so you'll know, this picture is actually, this was made by somebody at Lawrence Berkeley National Labs. As far as I know she still hasn't published it. This is an image of an actual cell.

It's made by a very fancy technique called x-ray tomography where she sort of takes a zillion little sort of slices and then assembles the whole thing. This is a yeast cell. That purple thing, artificially colored, is the nucleus. This thing in the middle is a big storage thing called a vacuole in the cell. We cannot see the other cellular components right now, but that is a real cell. It looks like a textbook, but it's actually a yeast cell that got its picture taken by this very fancy thing.

So, as I say, we're going to charge right now into starting to think about these various molecular forces that make possible, that give these various biomolecules or biomacromolecules their properties. And I just want to give you sort of a game plan for how we're going to do this over the next couple of lessons, couple of classes. They're sort of classes of chemical forces.

And today we'll be talking about covalent bonds and hydrogen bonds. And we'll go onto to talk about other ones in the next class or two. And then we're going to talk about these biological macromolecules that I just listed. Proteins. Actually, the order we'll be talking about them, carbohydrates, nucleic acids, proteins and lipids. So the

way I'm going to do this is I can tell you about the properties of carbohydrates by just talking about covalent bonds and hydrogen bonds.

And once we've discussed those we'll go on here and I'll give you a couple of examples. And once we've learned some more we'll go on and I'll give you some other examples. And, as I said, in a second I'm going to say covalent bonds. It's going to seem boring. Here's just something to sort of keep in, we'll get another one in a minute, to look ahead, why do we want to do this sort of stuff? I showed you this picture the other day.

These are E. coli swimming along. Those things I told you are those sort of long spiral things are bundles of protein filaments called flagella. They're being rotated by a motor at the end of the bacterium that's rotating ten to a hundred thousand RPM. And that thing is moving at such a rate, so many body lengths a second that if it was me moving at that speed I'd be going 300 miles per hour that many body lengths.

So these are bacteria swimming around. The motor that drives them is made of proteins. And this is a textbook representation of that motor. It has familiar parts to some of you. Here's a rotator. There's a bushing. There's a drive shaft and so on. It's got parts that you would recognize as an engineer, but it's all made out of proteins. And that's a textbook diagram. What I want to show you in the next slide is they've taken a whole lot of electron micrographic images of those things, and the resolution isn't so good, but they averaged a whole bunch of them.

And this is what it looks like. So you can sort of see this really is a machine. It's built of proteins. And to understand how these machines work you have to understand some of these forces. So that's why I'm going to start in and we're going to begin with covalent bonds so that we're all on the same page right from the beginning. And another aspect, as you'll see, even though you may have heard about some of these bonds before, there's a new issue that's going to need to occupy your attention.

And that is, what's the strength of the bond in the context of temperatures and conditions that are relevant to life? If you can break a bond at 1000 degrees it doesn't matter because you cannot have life at that temperature. You've got to be thinking about a much more restricted temperature sort of range. So covalent bonds, as most of you know, this is the principle force that holds atoms together. It involves a sharing of the electrons.

And an example you can all do in your sleep, I'm sure. If we take four hydrogen atoms and a carbon atom we can come up with this molecule which has four covalent bonds. This is methane. That's the molecule that the cow we saw the other day burps 400 liters of. Those are the little bubbles you see coming up when you walk around the edge of a lake. And it's usually those pairs of electrons, as you know, that are usually represented like this.

The typical length is about 0.15 to 0.2 nanometers. And the important thing about these bonds is these are strong. It takes about 83 kilocalories per mole to break a carbon-carbon bond. So at physiologically relevant temperatures they don't break. They can rotate, they can stretch and they can bend, but they're not going to break. And so if you have a carbon-carbon bond in a biological organism it will be doing this.

The carbons will be going this way. They'll be bending back and forth this way but they won't be breaking. And to just give you a sense of how far away they are from breaking, the energy of, say, one of these vibrational modes is about 0.6 kilocalories per mole so that you have -- The average bond is so far away from breaking, even though it's a distribution, and some are more than others that our molecules stay together, which is good because we wouldn't want our DNA flying apart because the covalent bonds were breaking under physiological conditions.

But that also leads us to the need for one of the things that we'll have to talk about, which is one of the great secrets of life, is that the metabolism, all stages of life involve the making and the breaking of bonds. And you cannot just add a platinum catalyst and put it at 500 degrees centigrade under a thousand atmospheres of pressure. All the chemistry that happens in life has to take place in aqueous solution pretty close to pH 7 at about, you know, 25, 37 degree centigrade.

There are a few organisms that can do it out, but most of it is somewhere around body temperature. Room temperate is where all that has to take place. So what you can see is that there had to be some, in order for life to occur there had to be some invention that would let bonds be broken and be formed under physiologically relevant conditions. And those are enzymes. I know most of you have heard of those.

We'll talk about them in a maybe more sublevel, beyond what some of you have heard anyway. But that -- Keep in mind now that's the driving force for why we need enzymes, because covalent bonds are so strong. I also remind you that there are different types of covalent bonds. That's a single bond. This would be a double bond or a triple bond. And they get stronger as you share more electrons.

It gets harder and harder to break them. These are double and triple bonds called unsaturated bonds. When we talk about unsaturated fats and things that's because they have double bonds in them. So olive oil has double bonds in it and beef fat, for example, doesn't. Other molecules that have double bonds that are important are oxygen and nitrogen gas, which has got a triple bond.

And when Penny talks to you about the nitrogen cycle this is one of the really important ones thinking about ecology because we all use nitrogen, but most organisms including ourselves and most things on earth cannot break that bond. Yet we all need nitrogen. It has be what they called fixed, so it's joined to something like ammonia or nitrite or something like that.

And that little fluorescently labeled bacteria I showed you invading a plant, we'll see it again, is able to form a symbiosis of plant. It's one of the few creatures on earth that knows how to break that bond. And that's why you can get plants that can grow, like peas and beans and alfalfa and things that can grow without nitrogen fertilizer. Because they have a little bacterium who knows how to break that bond and they figured out how to get together and collaborate in a symbiosis.

So these bonds are very important. So there's another characteristic of these bonds which is going to be very important for thinking about biology. And it's known as chirality. And it comes from the fact that our life on this planet is based on carbon, and carbon's ability to form remarkable kinds of bonds. And, as you see over there, carbon forms four bonds. But right now we have to start thinking in 3-dimensional space because carbon is a tetrahedron.

Carbon, four single bonds. And they're in a tetrahedral arrangement. So if I label them like this, this means it's coming out of the board, I'm sorry. A, B, C. And that means it's going back into the board. So if I do a mirror image, if I looked at what this would look like, if I could look at its reflection in a mirror, I would see it would look like this. So these are what are known as optical isomers.

And depending on how you are at thinking in 3-dimensions this may be obvious to you or it may not be obvious to you, but you cannot superimpose those. And this is critical because all through biology there are carbons that have four different substituents that join to them. And every time that occurs, biology chooses one of those arrangements, not the other.

And we have sort of a macro way of perhaps communicating this. So you've been at the party at the dorm. I was housemaster in McCormick for six years a while back so I've lived at least in that environment. It's early February, you're having to go back across the Mass Ave bridge, it's minus 20 and the wind is whipping along and your hands are freezing. And you reach into your pocket to get your gloves and uh-oh, two left gloves.

Right there you have the problem. Biology, as a theme you'll hear over and over again, is about fitting shapes. And your hands are mirror images of each other. And you could think of your gloves as being sort of a receptor. And if the receptor is designed to take your right hand, take your left hand, I guess, let's say, you cannot get your right hand into the glove. It just doesn't fit.

And it's at a molecular level. It's exactly that same thing. So we're going to have to worry as we go through this about not only how many bonds there are, but this is why the exact molecular shape, including this optical isomer issue is going to be very important. There's another very important principle of covalent bonds that has, again, a huge impact on biology. And that concerns how the atoms involved in the forming that covalent bond think about sharing electrons.

In some cases the sharing is pretty much equal, as in a carbon-carbon bond. That would make sense since it's the same thing on both sides. Or a carbon-hydrogen bond. The sharing of electrons is pretty much the same, so the electrons on average are distributed in between them. And this is what's known as a nonpolar bond. However, there are important cases of unequal sharing. And the characteristic of an atom or an element that determines how this sharing goes is known as electronegativity.

And you could think of this as sort of a euphemism for the greediness of an atom for electrons. So if you have an oxygen-hydrogen bond, oxygen is more electronegative than hydrogen. What that means is that although the electrons are still shared, this is not an ion or anything, the electrons are shared, there's going to be a little bit of a negative charge on the oxygen and a little bit of a positive charge on the hydrogen.

And that means you, you know, this will have all sorts of consequences, as you'll see in a minute. And there's one important molecule, which if we did the molecular composition you can see there's a lot of it around, and that's water. And it's got two OH bonds. And here's where the structure of water is important, that these two bonds are not 180 degrees opposite to each other.

They're 104.5 degrees. So you end up with a little negative charge here, a little positive charge here, a little positive charge there. And so every single water molecules sort of have a negative side and more or less a positive kind of side. And this has consequences because this means that the water molecules are going to interact. And to understand that part I need to introduce you to this second force which we know as the hydrogen bond.

And this is the -- This is a bond that takes place, that arises because of the slight positive charge of an H bonded to oxygen or nitrogen -- -- and the slight negative charge -- -- of the oxygen or the nitrogen itself. And right in water we see this is an issue, because if we have water like this with a couple little bit of positive charges here and there and a little negative charge here, and there's another water molecule over here, a little positive charge, a little negative, a little positive, we can get here what's known as a hydrogen bond.

The hydrogen bond is about one-twentieth the strength -- -- of a covalent bond. And that number is really important, because what that means is that at temperatures that are relevant for life, not all the molecules will have enough energy to break, in a population will have enough energy to break that bond. But some of them will. So hydrogen bonds, let me just write that down, so at physiologically relevant temperatures some molecules -- -- have the energy to break a hydrogen bond.

And we'll talk about it next time. But probably many of you know that DNA is made of two strands. And the whole principle of copying the genetic information is you can pull the strands apart and copy the complimentary information. And we'll spend a lot of time talking about that. But the relevant thing for the moment is those two strands, each of which are joined by covalent bonds, are held together by a whole series of hydrogen bonds between the different base pairs.

And so right there sort of is the root of why the cells are able to pull those apart, put them together. And so these hydrogen bonds are really, really important. And because our life on this planet is based, we're water-based, and the reason water is such a good solvent is that it is able to form these hydrogen bonds. So this is just a little movie showing the hydrogen bonds, a little simulation of how they can move around and rotate.

The green thing would be the hydrogen bonds here. This is not really a full representation because the water molecules are constantly changing partners so they form little cages and little shells, but they keep forming hydrogen bonds. They'll break one with one water molecule and immediately reform with another. This is a simulation that someone did. It's a picosecond of what would happen to water molecules at zero degrees centigrade where they're liquid.

So, at this point, they haven't frozen but they're just above that. And you can sort of get the sense how they're changing partners here. Here's another simulation done at 100 degrees centigrade. So this would be a boiling temperature. And what you can see now is every now and then one of the molecules gets enough energy to break free of these cages.

And that, when you're watching something boil in a kettle, that, at a molecular level, is what's happening, is one or another molecule is finally getting enough energy to break free of this sort of chains of hydrogen bonds that are formed. And it's when we go to think about how things interact in water, when you dissolve sugar in water or

something in water, you try and dissolve butter in water, when you stick something into water you have to break a whole lot of bonds.

So there's an energy cost to just simply putting something into water. And what makes things dissolve or not is whether once they're in there they can form bonds back again because water is carbon and hydrogen bonds. There is no polarity. To get it to dissolve you'd have to break hydrogen bonds. That costs energy. And it cannot form any because it's only got nonpolar bonds in the butter so the butter floats around on the water.

But this is really a very, very important force. And, in fact, you know, this is why when some of the really interesting properties of water come from. You all know about surface tension. You've watched little bugs skate around on the surface of the water. This is the lizard that lives in the rainforest of Central and South America, and it's about two and a half feet long.

And it can take advantage of this surface tension that's due to the hydrogen bonding of water to go scooting right across the water. This is not the greatest of videos. It's what I've managed to find so far, but you get the idea. It actually runs across the water. And you're watching the hydrogen bonding in action here. When I was a grad student my work thesis was on the synthesis of ribonucleotides, little pieces of RNA.

And I went in a thesis competition. And at the end, where you're supposed to give a talk about your thesis, and there were four of us, I thought, well, at least I have a fighting chance. And when I got in there it turned out one of the other people who was competing was a guy who studied this lizard, so his talk was full of movies of these lizards running back and forth across ponds of water.

And I thought I'm dead meat. But it actually turned out I won it, so I was very surprised. But every time I see something like this it reminds me of it. OK. And just to remind you, too, I mean you may not have been thinking of it in this way, but of course what was all that fuss about when they sent the expeditions to mars? They were looking for traces of water. And why is that so important? It's because water has this amazing capacity to form hydrogen bonds and be the solvent that can let life go.

The moon on triton has methane. All nonpolar bonds, they're talking about raining methane and rivers of liquid methane and stuff. You might think about whether it is possible to design a life form or not or at least what ways things would have to be different. OK. And we've done enough that I can quickly now introduce you to our first class of molecules which are carbohydrates.

Julia, would you mind flipping that light back on for a minute? OK. So carbohydrates have the general property, general formula. They're CH20. And you can have different numbers of them. N-1 carbons have a COH bond. That's known as a hydroxyl group. And one carbon has a double bond oxygen which is either known as an aldehyde if it's at the end of a chain or as a ketone if it's in the middle.

And these things can come in different numbers. So if N equals three it's a triose. If N equals five it's a pentose. The sugars that you'll see in DNA and RNA are pentoses. They're five carbon units. A six carbon unit is a hexose. And a very common hexose that you're all familiar with, at least familiar with the name of is glucose. And the

structure of glucose in a linear form, if I draw it out here, it's got the double bond at one end, so it's an aldehyde in that case.

And then there's an OH this way, OH this way, OH, let's see. One, two, three, four, five, six. OH. And it's just going off the bottom of the end here, bottom of the board for some of you probably. But we have hydrogens in the other places. Now, what I had to do in order to put up this depiction was kind of flatten this molecule, which you'll know every one of these is a tetrahedral arrangement.

And flatten it down so I could write it on the board. So there are actually four chiral centers in a glucose molecule. And, furthermore, although this is a representation that you can find in textbooks and I can write it on the board that's not how it appears in nature. What happens is that the oxygen here comes up and actually cyclizes to this carbon.

And this hydrogen goes and sits up here. And it gives you, the way glucose is actually found in solution, this would be what's known as beta-glucose. And the reason I'm saying beta is we've got a new chiral center that's formed by this cyclization. And just to give you a sense of where we are, this is one, two, three, four, five, six going this way. And over here it's one, two, three, four, five and six that way. And you can sit there and work this out yourself afterwards.

This is known as a pyranose ring because it's got, it's actually a six-member ring, but you can see one of the oxygens is now part of the ring and the extra carbon is sticking out here. And in solution, because of this new chiral center, we've now got the possibility of this thing joining so that the OH is up or the OH is down. And when it's up, the OH is up, that's known as the beta form.

And if the OH is down, that's known as the alpha form. So, again, we've got to keep our eyes on all these chiral centers. This kind of depiction, again, is sort of hard to draw. So, again, people tend to sort of flatten it out. And you'll see this kind of representation. You have to realize that this is approximately the 3-dimensional shape.

This is a representation. Here's beta-glucose there. Every time that you change the position of one of these hydroxyls, we end up with another sugar. So this is beta-galactose, sugar with very different properties. And the difference is here the hydroxyl is up, here the hydroxyl is down. Two different sugars, two different properties, but as simple a difference as that. And then a thing that happens in nature is you can join different sugar molecules together by a principle that you'll see over and over again.

And that you'll split out a molecule of water and you get a new covalent bond where this oxygen joins over to the carbon over here. And what that gives you is galactose beta-1,4 glucose. This beta-1, 4 glucose is a molecule that you know as lactose or milk sugar. And part of the reason we know about it is because in order to metabolize that you need to have a special enzyme that cuts right here. That enzyme is known as beta-galactosidase.

That's an enzyme. It's a protein, which we'll be talking about in the coming lectures, and it's able to cause this bond to break. And what happens when you become lactose intolerant is you lose the beta-galactosidase that we all have as a baby,

because we need to be able to eat milk. And if you don't have it then the lactose passes through your stomach without getting metabolized.

It gets into your intestine and there are those ten to the fourth bacteria. They metabolize it, break that bond, and then that causes the gas and discomfort that's associated with lactose intolerance. So all the textbooks use lactose as the, beta-galactosidase as the common enzyme. So the first time I thought that I'd teach this course I thought, boy, I have a really good idea.

I'm going to come up with a sample enzyme that's different, but I have to learn what it was. And it was inspired by there's this product called Beano which is supposed to reduce the side effects that are commonly associated with eating beans, which probably many of you are familiar with from summer camps and things. And the technical term is flatulence. But, in any case, this was supposed to be something that reduced flatulence.

So I thought it's got to be an enzyme. I know it had something to do with all of the saccharide s that will change the sugar. So I looked at the little thing of Beano, and it said Hotline, any questions call. So I phoned up and said, hi, this is kind of an unusual question. I'm a college professor and I'm going to be teaching an introductory biology course.

And I was wondering if I could find out what enzyme you had in Beano and what it did to what was in the beans. And I said, you know, it's really sort of an odd question but, you know, maybe I could talk to one of the scientists in the lab. And a woman says, hello, Beano. And she listens to me. And she says, yes, we have a special package we send out to college professors. And the next thing I knew I got this huge flood of stuff.

So I am now able to quickly tell you why beans are the musical fruit. And the basis of it is if you join a glucose and a fructose together by an alpha-1, 2 linkage you get sucrose. And you all know that's table sugar. We can eat sucrose no problem. But what beans have is beans have a galactose alpha-1, 6 linkage to sucrose. Or they actually, sometimes they have two galactose alpha-1, 6 linkages to sucrose and we cannot metabolize them.

And that's sort of related to the same idea as the lactose intolerance that they go through a stomach, and then the bacteria know how to break that bond and that causes the problems that you encountered at summer camp. And so what Beano turned out to be is it's a sort of low-tech biotech product. It's a food-grade mold called neurospora. And it's a very, very crude preparation of an alpha-1, 6 galactosidase.

In other words, an enzyme that can break that molecule. And once it breaks it you have sucrose, which we can eat, and galactose, which we know what to do with. And that's the basis of that. So the very last thing is to talk about polysaccharides. These come when you join together multiple sugars. And, as you can appreciate by now, there are many, many ways of joining sugars together.

But suppose we take N glucoses. There are two common ways they can get joined. They can get joined together by alpha-1, 4 bonds. And these give a helical confirmation. And you know these as starch or glycogen. These are energy storage molecules. And I've run marathons, some of you may have, but at least you

probably know about carbo-loading. What you're trying to do before you go is you're eating pasta and everything, which is full of starches, so it's got polymerized sugars.

And you're trying to get your body to take these in and polymerize them into glycogen so your liver is as loaded with glycogen before you start the race. And hitting the wall in a marathon is when you run out of glycogen. And then you start burning fatty acids and it's no fun at all. But that's what carbo-loading is all about, is manipulating glucoses that are in an alpha-1, 4 confirmation, if you just make a beta-1, 4 confirmation.

So the only difference that's happening in the way we join glucoses together is whether the hydroxyl is up or down when you join the two of them together. You get something that's a linear molecule that forms hydrogen bonds between the sugars. So you have a linear chain of sugars. And I'm not going to show the details of the hydrogen bond, but you have one chain going this way and another chain of sugars here.

And you can get hydrogen bonds between them. And you know this as cellulose. So there are two very important biomolecules that are made up of glucose. That's just some glucose there. And if you join them by alpha-1, 4 linkages you get starch, corn starch, which you've all encountered. If you join them by hydroxyl in the other direction you get cellulose. Cellulose is important in biology.

It's what plants make their cell walls of. That's why you can have trees that are so enormously high. And I guess I'll close with one last. So most of the paper we get from cellulose is from trees. If you've ever tried to make beer or wine or something, you probably know you've got to keep fruit flies away or you're going to get vinegar. And the reason you get vinegar is that the fruit flies carry on their feet a bacterium called acidobacteria.

And it likes to live at the surface between the water and the air. And what it does then, in order to do that is it makes cellulose, and it floats itself right at the, it makes this great thick mat of cellulose. And it floats itself right at the air surface interface. And you can get a mat that's half an inch thick of absolutely perfect cellulose. And so you don't ever want to see that if you're trying to make beer or wine or something.

But it's a bacterium that's making this molecule. So you find it in other places besides trees. So, OK, we'll see you on Monday.