

Monomer of nucleic acids is called a nucleotide, which I will abbreviate NTIDE. And a nucleotide comprises three parts-- a phosphate, a sugar, and a base. Phosphate, sugar, base --that we will abbreviate P-S-B. The polymer of nucleotides makes up ribonucleic acid, RNA; or deoxyribonucleic acid, DNA. You need to know the full names of those. I'm not going to write them out. And those are all polynucleotides.

And the way that polynucleotides are put together is through the joining of the phosphate and sugar into a sugar phosphate backbone, from which the bases hang. And so they look kind of like this. There's phosphate, sugar, phosphate, sugar, phosphate, sugar. And from the sugar hangs the base. The phosphate and the sugar, as I've just said, forms the sugar phosphate backbone. And the bases, as we'll discuss in a moment, comprise the information that is encoded in nucleic acids.

Let's talk more about this nucleotide and the structure of the nucleotide and the kinds of components there are in the nucleotide. The sugar of the nucleotide is a pentose. It's a five carbon sugar. It is called ribose, and it's cyclic. And it's called ribose in RNA, and as you will see, deoxyribose in DNA.

There are four bases in DNA. They are called adenine, guanine, cytosine, and thymine. And they are abbreviated A, G, C, and T-- by their first initial. But you need to know the whole name. In RNA, the bases are the same, except instead of thymine-- there is no thymine. Instead, there is something called uracil, which is closely related, and abbreviated U.

The bases have a particular structure. You do not need to be able to draw them, but you should be able to recognize the class of base. There is a class called purines, which comprise two rings. I'll show you some slides in a moment. And adenine and guanine fall into that category. And then, there's another class called pyrimidines, which are made of one ring. And cytosine, thymine, and uracil fall into that class.

Let's draw the structure of a nucleotide out in chemical formula. We're not going to draw the bases. We're going to draw mostly the sugar and the phosphate, because it will be important when we think about polymerizing nucleotides. And then I'll show you some slides.

So nucleotide structure-- the best way to draw a nucleotide structure is to start with the sugar. So start with an oxygen. And then you can put in the carbons. And the carbons are numbered, because, in

many macromolecules, there are so many carbons, it can be very useful to give them specific numbers. And that's true in the sugar. It's also true in the bases.

But the sugar numberings of the carbons are very important for you. There's a one prime carbon, two prime, three prime, four prime, and five prime. The base is attached to the one prime carbon. And the phosphate is attached to the five prime carbon.

The two prime and the three prime carbon are also notable. The three prime carbon always has a hydroxyl group. And it's this hydroxyl group and this hydroxyl group of the phosphate that react together when the sugar phosphate backbone forms covalent bonds. The two prime carbon can either have a hydrogen, as in DNA, or a hydroxyl as RNA. Hydroxyl groups are reactive, and having this extra hydroxyl group on RNA makes this sugar more reactive than the one in DNA.

OK. That is your nucleotide structure. And you should know it. Let's see what we have for slides here. Nucleic acid monomer and polymer. We're going to draw in one moment the nucleic acid polymer on the board, but here it is. Here is the sugar, the base, and the phosphate group.

All right. Let's think about how you actually get this sugar phosphate backbone formed. And let us draw formation of a dinucleotide. And I'm going to abbreviate on one of the nucleotides the phosphate as PO<sub>4</sub>, otherwise we won't fit this on the board.

So let's put the sugars first. And let me actually just make sure that you guys understand that the sugar can be drawn as I've drawn it, with all the carbons there, or it can be drawn in this way, where the carbons are the apices, or at the ends of a line. If this is a new you-- if this is new organic chemistry formula to you or chemical formula to you, then please come and see one of us, and we'll make sure that you get up to speed, because you really do need to know that for this course.

Okay so let us draw some sugars. Actually, I'm going to erase this one and put it even closer to the top of the board, because these are small boards no-- new boards, nice but small.

Okay. And we're going to put here a phosphate group. I'm going to extend this. And we'll put a phosphate group here. And we're going to put a base. And we're going to put a three prime hydroxyl. So here is the five prime carbon and the three prime hydroxyl. And this is going to be nucleotide one.

And then we'll draw an identical one below it, which will be nucleotide two, where now I'll draw out the

phosphate. Let's again start with the sugar and a hydroxyl. And then let's put in the phosphate. Okay. And this is going to be nucleotide two-- so nucleotide one and nucleotide two.

The phosphate, hydroxyl, and the sugar-- and we can put in some negatives here. On the phosphate, that's fine. Depends on the pH as to what the ionization of the phosphate group is. This hydroxyl group and this phosphate group, are going to interact. And the outcome is going to be a dinucleotide, where the two nucleotides, as you will see, are joined by a particular linkage called a phosphodiester linkage or a phosphodiester bond.

We'll leave a phosphate there attached to the five prime carbon. Here's the first base. And now, we've got-- and I've got to fit it in. Okay. So here is our dinucleotide-- slightly skewed, but OK. And there are three features that I want to point out to you on this dinucleotide.

The first is the bond that joins them together, which is this guy. It is called a phosphodiester bond or phosphodiester linkage. And the second is that the two ends of this dinucleotide are different. On one end, there is a free phosphate group. And where there is a free phosphate group, that is called the five prime phosphate, or the five prime end. But the five prime end has got a phosphate. That's part of its property.

On the other end, you'll see, there is a free hydroxyl group. And that is called the three prime hydroxyl, or the three prime end. And they're equivalent, pretty much. But you should know that at one side, there's a free hydroxyl group, the other side a free phosphate group. You will see later on that this is pivotal in synthesizing DNA, as in DNA replication and mitosis, meiosis, and so on.

All right. Few more slides-- here are the sugars that are found in nucleic acids. There's the deoxyribose and ribose. I just put these up for you for recap. Here are the bases. Here are the pyrimidines-- cytosine, thymine, and uracil-- and then the purines, with this interesting di-ring structure.

This I drew for you, okay? And so it's on your PowerPoint. If you're a bit shaky as to what's on the board and how we got there, you can go and get this from the PowerPoints that I'll post after class. All right.

Now, in contrast to lipids and carbohydrates, nucleic acids, and as you will see, proteins, have two extraordinary properties that allow them to encode information in really a way that is extremely rich. And those two properties I've already touched on. One is that the ends are different. They're different in a dinucleotide, and they're different in a polynucleotide that's a thousand nucleotides long.

So they have different ends. And the bases have a linear order. And this linear order is part and parcel of the information that the nucleic acid encodes. So let's draw out, for instance--- and we're going to start with five prime. Phosphate, sugar, phosphate, sugar, phosphate, sugar phosphate-- and we're going to end with the sugar that has the three prime hydroxyl. Okay, so we've got a five prime and a three prime end. And from this, the bases are hanging.

Now, when nucleotides are incorporated into a nucleic acid polymer, there is an order of synthesis, which is why the linear order of the molecule eventually can be used for information. The base nearest the free five prime phosphate is the first added. And the base-- so it's part of the nucleotide-- nearest the three prime hydroxyl is the last added. It's really important that you know this.

Furthermore, when we write out nucleotides, nucleotide sequence, when we write out a nucleic acid sequence, we don't generally write the sugar phosphate backbone in. We just write the bases. So it's written five prime, base, base, base, base, three prime. But of course, the bases can be anything. So for example, we could have five prime, adenine, guanine, guanine, cytosine, three prime.

And there's a convention that you have to follow. And it doesn't matter how long you're in this business. When you write out a nucleic acid polymer, you always write the five prime and the three prime end. I've been in this business for 30 years now, and I still have to write the five prime and the three prime end. If you don't, you get lost, and you will get mixed up in your calculations, both in this course and in real life.

Now, there are lots of combinations of bases, even though there are only four bases. For example, if there are four bases and you have a three nucleotide polymer-- four bases, three possibilities, 64 possibilities. Genes can be thousands and thousands of bases in length. And so the information, the combinatorics involved in the nucleic acid polymer is very large.

So genes can be, let's say, 100 to ten to the fifth nucleotides long. And so the number of possibilities is really extraordinary. And it's one of the reasons that all of life can be encoded in nucleic acids.

And the last thing that I want to tell you about nucleic acids-- which will become and will remain one of the most important things you learn in this class-- is that DNA is usually double stranded. RNA is too, but it's really DNA that uses this in an extraordinarily important way. So DNA is usually double stranded.

What does that mean? It gets to be double stranded via something called base pairing-- you'll see what

this means in a moment-- which also means, or there's another term that's used, which is complementarity, as you will see. And this double strandedness does not involve covalent bonds. It involves that special type of bonds that we discussed last time, which are the hydrogen bonds.

And there are rules about this. Adenine will form two hydrogen bonds with thymine or uracil. Guanine forms three hydrogen bonds with cytosine. And that is a rule that is one of the most important rules in nucleic acids.

From your book, here is a picture of the two bases, adenine and thymine, that can be lain opposite one another such that these dotted lines are hydrogen bonds between oxygen and hydrogen or nitrogen and hydrogen-- and the same kind of thing for guanine and cytosine. You don't need to know these structures, exactly, but you do need to know base pairing inside, outside, and never forget it.

Okay. Why is this important? I'll tell you why this is important. It's important for DNA replication and for the passage of hereditary information from one generation to the next. So, in DNA replication, the idea is to pass genes on, unperturbed, in the same sequence from one generation to the next at every cell division.

So let's just, for instance, start with a polymer here. Ah, and something else that I needed to tell you, which I will in a second, is that when nucleic acids form double stranded structure, one strand of nucleic acid-- my one arm-- will form a double stranded structure with another strand of nucleic acids, like so. Okay. That's what's referred to up there. The adenine's on one polymer. The thymine is on another polymer.

When these polymers form, they form in what's called an anti-parallel direction. It's really hard to do. But if this is my five prime end and three prime end, the five prime end of one and the will be opposite the three prime end of another strand. I guess I can do it this way-- topologically easier. Okay-- so five prime opposite three prime, five prime opposite three prime.

So let's draw the complement of this for the nucleotide polymer. There'll be thymine, cytosine, adenine, thymine. And look what I've done to the five primes and three prime. Means they are one five prime opposite a three prime, and the other three prime opposite a five prime. This arrangement called an anti-parallel arrangement of nucleic acids. And it is super important that you never forget this.

During DNA replication, the strands of this double stranded polymer separate. And so you have five

prime AGTA three prime-- is one strand-- plus three prime TCAT five prime-- two single strands. And here's the magic, and this is what Watson and Crick got the Nobel Prize for long ago for understanding that when DNA replicates, those strands get filled in.

So this five prime AGTA three prime will now get synthesized opposite its complement-- three prime of TCAT five prime plus this guy-- three prime TCAT five prime will get its complement made. And look what you have got. You have started with one strand, one double stranded moiety, and you've landed up with two identical replicas of what you started with-- so two identical replicates.

That's redundant, but it really pushes the point home-- two identical replicates of this parent molecule that we started with. We'll have a lot more to say about this when we spend a whole lecture on DNA replication, but you should understand that this is one of the profound natures of DNA as the hereditary information.

And from your book-- double stranded DNA. We'll have more to say about this, but double stranded DNA, because of chemical considerations, goes into its most stable chemical state, which is this very beautiful double helix that has structure and is able to pack very tightly so that you can get lots of genetic information in one cell.

Last thing about nucleic acids-- RNA is often single stranded, but it can also form structures that are partially double stranded. And this is one such RNA that's formed this very complicated, partially double stranded molecule.