Environmental Chemistry and Microbiology

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Module - 8
Lecture - 37
Cell Chemistry - II

Welcome everyone to the second part of Cell Chemistry.

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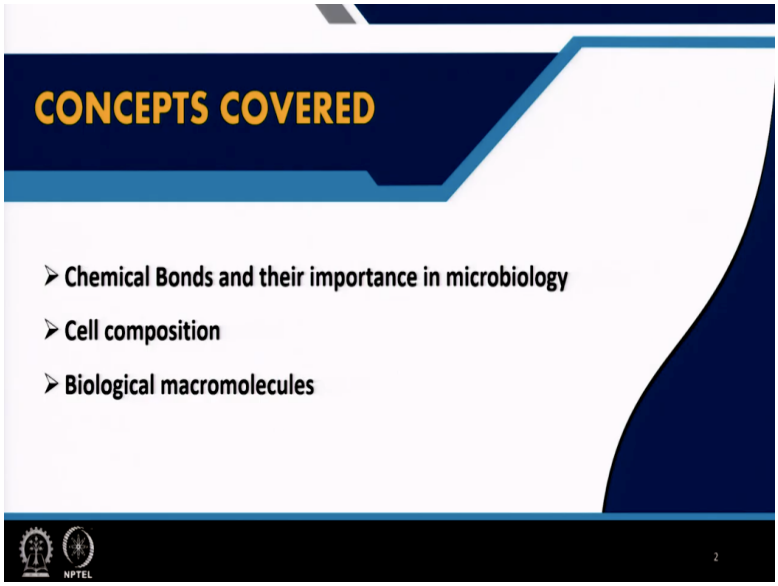

So, we are going to be covering the remaining part of this topic.

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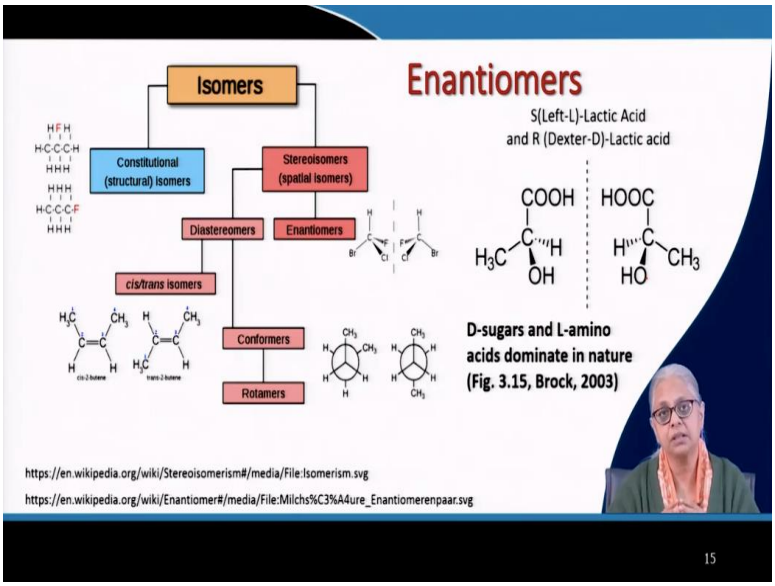

We come to another interesting observation about the compounds that are present in microorganisms as well as higher organisms; and that is isomers. So, you have already studied about stereoisomers. Within stereoisomers, we have enantiomers and these enantiomers have chiral properties. So, you know they are mirror images of each other. The compound is; there are 2 different types of isomers or stereoisomers of the same compound.

They have chiral properties, which means they cannot be superimposed on each other, rather they are chiral in nature. So, you have the right-handed sugars and the left-handed sugars. So, you have over here, lactic acid. You have the one on the left, which is; S stands for sinister or left and R stands for right or dexter. So, you have the left-handed lactic acid and the right-handed lactic acid.

Now, what is interesting in nature is that nature has a preference for right-handed sugars and left-handed amino acids.

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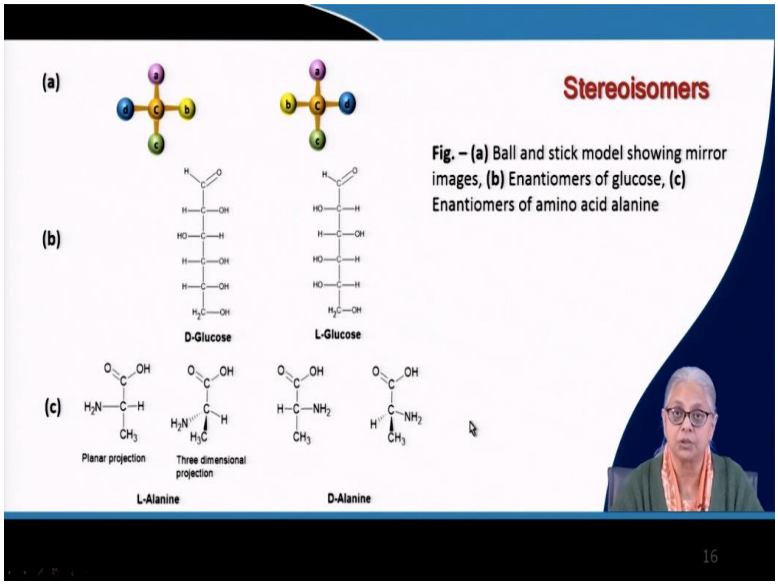

So, here are different types or ways of writing the structures of these stereoisomers. And again you may say, what is all this got to do with biochemical reactions? Like I said, if you are wondering why these stereoisomers have so much importance; this is a fundamental property of biomolecules that both chiral; or rather both stereoisomers do not have equal bioactivity. Nature prefers D-sugars and L-amino acids.

So, if you have an L-glucose molecule, it is not going to be digested by the microorganisms or even by human beings. It will bypass the digestive system and it will be excreted. And that is the basis of some of these what are called sweeteners. So, these sweeteners, they give the same sweet taste to the mouth, but because they are bypassing the digestive system, the body does not have the ability to digest an L-glucose molecule. So, the taste satisfaction is there, but the

sugar is not ingested or rather digested by the human being. So, that is one example of a stereoisomer not being utilized. And this is true for microorganisms and many other stereoisomers as well. So, in fact, many of the toxic properties of certain compounds are also associated with these kinds of stereoisomers of real compounds and so on.

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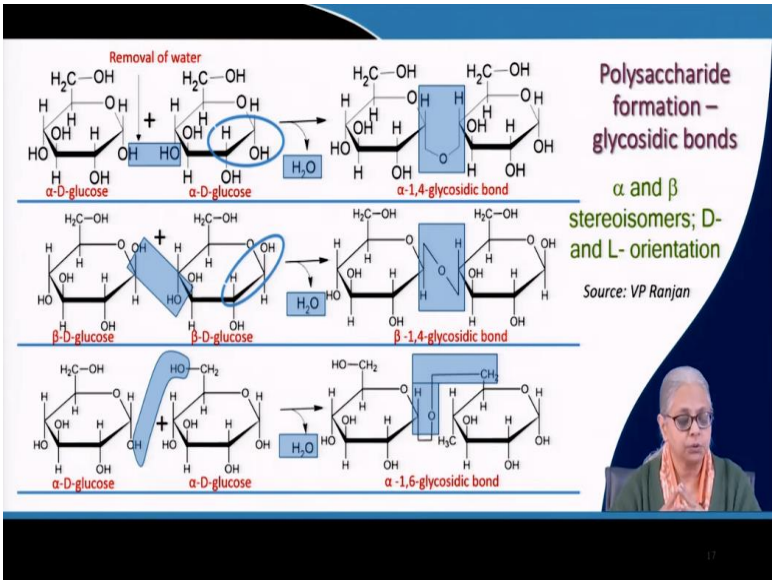

Here we have the formation of polysaccharides. Now, how do these polymers of sugars form? So, there are 3 basic bonds. These are all glycosidic bonds. Glucose molecules will bond together in different ways. So, there are 3 types of glycosidic bonds that are shown in this particular slide.

So, you can see at the C1 position, you have a hydroxyl group which is bonding with the carbon on the adjacent glucose molecule at the C4 position. So here, hydrogen from one at the C1 position; and OH from the C4 position on the adjacent glucose; they are going to be lost in this synthesis reaction. So, you have 2 glucose molecules bonding together at 2 different positions, C1 on one glucose will bond with C4 on the adjacent glucose and that is why it is called an alpha-1,4-glycosidic bond. This is very important for the nomenclature. So, they are all D-glucose molecules. That is how the alpha-D-glucose, two alpha-D-glucose molecules will come together by bonding at the C1 position of one and C4 position of the other. And that is why it is called an alpha-1,4-glycosidic bond.

Now, if you have two beta-D-glucose - alpha and beta are stereoisomers, it is going to bond with that. And therefore, you will get what is called the beta-1,4-glycosidic bond and then we have another permutation that is possible. So, C1, the hydrogen on the C1 position is going to bond with the hydroxyl at the C6 position. And therefore, it is called alpha-1,6-glycosidic bond. What does all this have to do with macromolecules?

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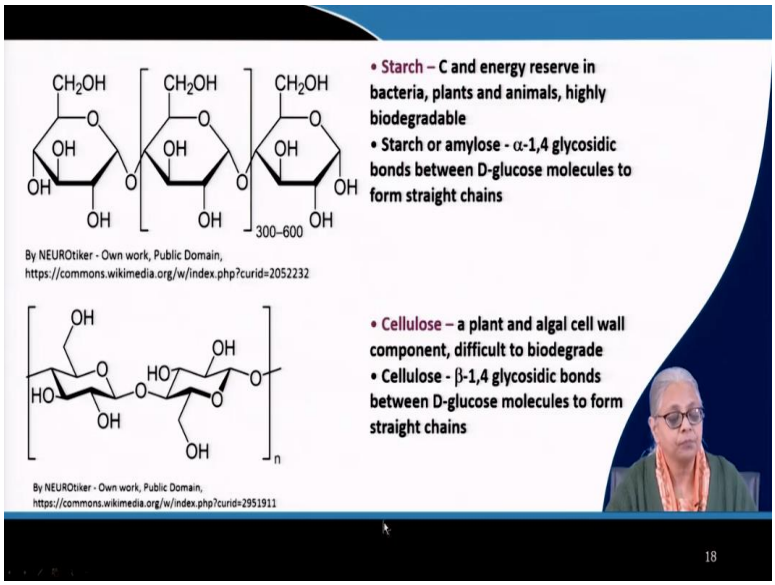

The first one, alpha-1,4-glycosidic bond is what you see over here, starch. Starch, as you know, is common in food. You know, whatever you eat, rice, many of the vegetables, they are all high in starch. And you know, starch is highly biodegradable. It is very easy to digest. Those of you who like rice and potatoes, rice and potatoes are pure starch. When you eat rice and potatoes, you get a very quick energy release. So, they are extremely good reserves of carbon and energy, not just for us, but for bacteria, for plants, for other animals. They are highly biodegradable. And they are basically polymers formed by alpha-1,4-glycosidic bonds. So, starch or amylose, as it is also called, is basically nothing but D-glucose molecules that form straight chains.

Now, we also have another polymer; and that is cellulose. Cellulose is found in the cell wall of plants and algal cells. It is very difficult to biodegrade. So, you have seen that; if you look at plants, when they die and they start rotting, it is the leafy part of it that degrades first and the stem and the branches are much harder to degrade. Those stems and branches are formed of cellulose and these cellulose polymers are made out of beta-1,4-glycosidic bonds. So, here is our beta-1,4-glycosidic bond and these are also straight chains. Let us see this point; that this beta-1,4-glycosidic bond is harder to break, compared to the alpha-1,4-glycosidic bond.

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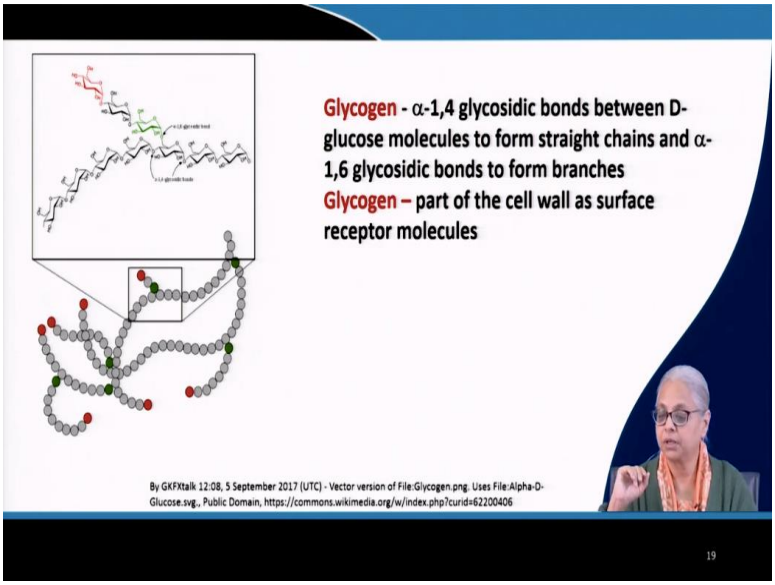

And then we come to glycogen. Glycogen has a mix of alpha-1,4-glycosidic bonds and alpha-1,6-glycosidic bonds. Now, it is a part of the cell wall; it is a surface receptor molecule; and it is branched. So, the straight part of the molecule is made by alpha-1,4-glycosidic bonds, just like starch. And the branches, wherever there is branching, that is the alpha-1,6-glycosidic bonds. And that is the difference between starch and glycogen. So, this is again a very interesting point in sugars and polysaccharides.

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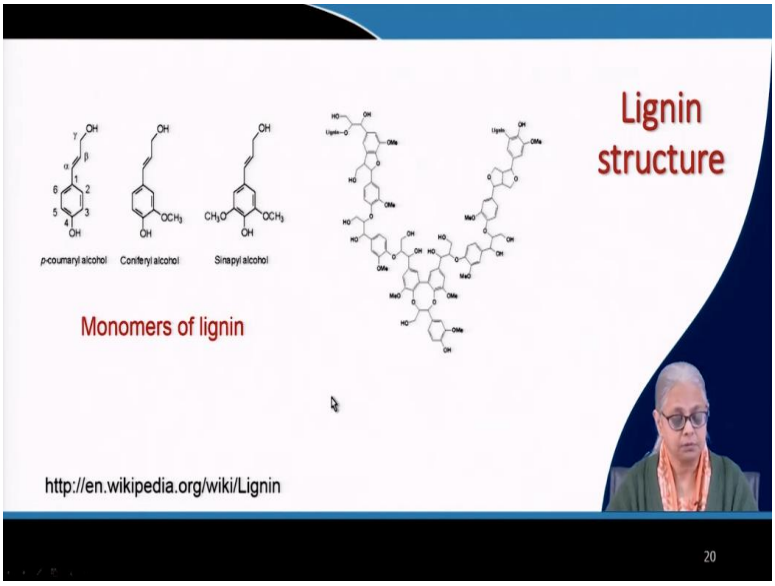

Plant cell walls are made out of cellulose, but the rigidity of the plant and its ability to stand erect is because of a combination of lignocellulosic molecules. And we have many applications for these lignocellulosic molecules. Because, whenever we think about the biodegradation of both natural organic matter and so many other compounds, especially natural organic matter, it is basically the degradation of lignocellulosic compounds that we are looking at.

So, lignin is one of the most difficult to biodegrade compounds in nature. They are, the monomers are alcohols. So, you can see these aromatic alcohols. And the coniferyl alcohols is what gives pine and all of these coniferous plants their peculiar smell. And you can see that, when lignin bonds with cellulose, that is where you get the lignocellulosic bonds. And like I said, they are resistant to biodegradation.

So, from an environmental microbiology point of view, it is very important for us to understand. And that is what we are all working on in terms of research. We are working on our understanding of the degradation of lignocellulosic molecules.

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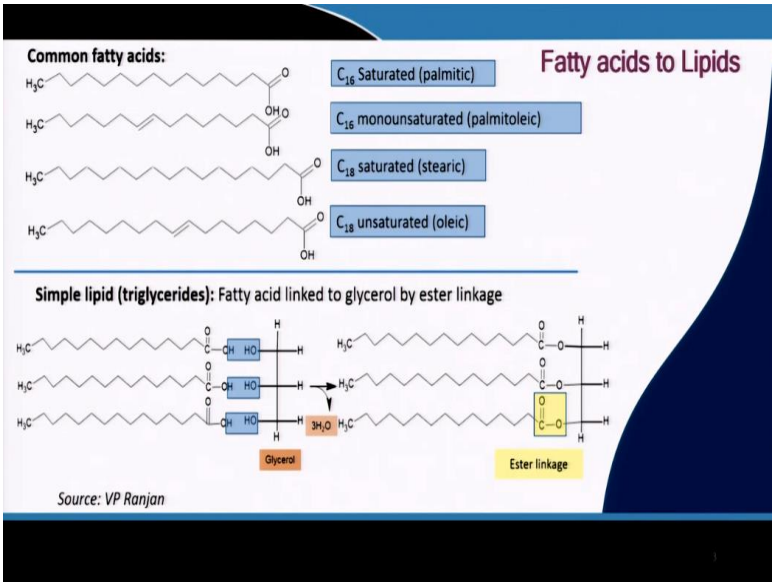

So, coming to the next set of polymers, we now look at the monomers that are related to lipids. So, what we have here in this slide are 4 examples of some common fatty acids. So, some of them are saturated. You can see the first one. Palmitic fatty acid is a completely saturated C16 molecule and then we come to palmitoleic fatty acid which has 1 unsaturated bond. So, that is a monounsaturated fatty acid. It is also a C16 molecule.

Then we come to another C 18 molecule, which is stearic, fatty acid; and that is completely saturated and that is followed by oleic acid and that is another C 18 molecule, with a single unsaturated bond. So, again, this is a monounsaturated fatty acid. What is the importance of these? These fatty acids are going to be linked to let us say something like a glycerol molecule.

So, a simple lipid which is what the triglycerides are; these triglycerides are fatty acids that are linked to glycerol by an ester linkage. So, this is an example of the ester linkage. So, you have the carboxyl group bonding with the hydroxyl group; a water molecule leaves; and you get this

ester linkage and the formation of triglycerides. And I think I also have a mention of this ester linkage (which) serves as a biomarker.

So, one of the major differences between bacteria and archaea; if you remember the 3 domain classification that is now very popular in every microbiology textbook, it is based on these 2 kingdoms, bacteria and archaea. Archaebacteria do not have ester linkages between the fatty acid and the glycerol molecule. They have ether linkages. So, it is a biomarker to differentiate these types of bacteria. They are all bacteria. They are all prokaryotes. But we have archaebacteria and the regular normal bacteria.

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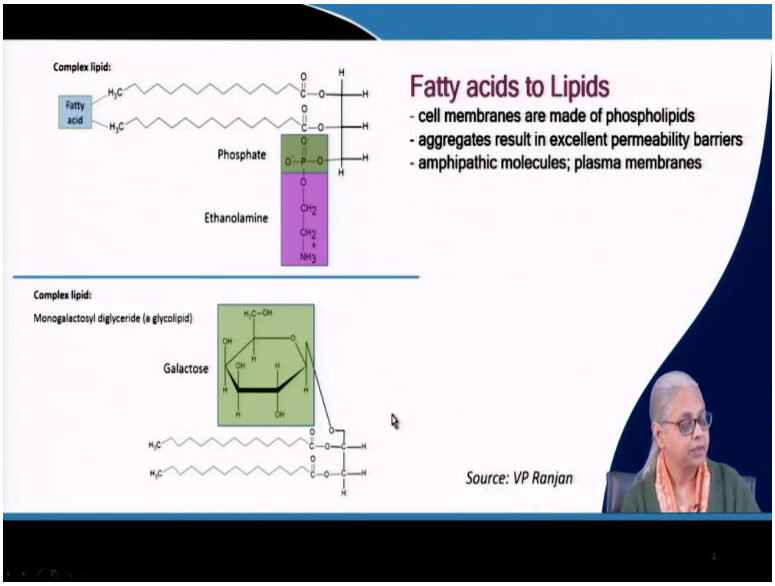

So, we have, like I said, these are simple triglycerides. And now we come to a slightly more complex lipid. So, here we have 2 chains of fatty acids attached to a glycerol molecule. And at the third position, we have a phosphate. So, we have ethanolamine phosphate. Now, what this kind of structure does is that it creates an amphipathic molecule. So, this amphipathic molecule has a fatty acid tail and a head that is polar.

So, this part of the molecule is polar and it likes water. And the rest of the molecule is hydrophobic; it does not like water. So, this gives it amphipathic properties. And these amphipathic properties are the fundamental basis of the formation of plasma membranes. So, it is the hydrophilic-hydrophobic interaction that results in a plasma membrane. Because you get an orderly arrangement, where all the heads face water and all the tails face each other, forming a layer in between.

And this layer becomes relatively impermeable, because you have a non-polar layer sandwiched between water on both sides; because, the plasma membrane has water on both

sides. So, that is how it forms. And this is very important in determining what goes in to the cell and what goes out of the cell. So, these cell membranes, the plasma membranes are made out of phospholipids and this is an example of a phospholipid. And that is, like I said, what gives it excellent properties in terms of determining what goes in and what goes out. And it is this double layer that is formed, that makes it an excellent barrier against the environment.

Then we have complex lipids. So, we have a glycolipid here. So, the same glycerol molecule now has 2 fatty acids, with a galactose attached at the C3 position. And that is the basis of the plasma membranes.

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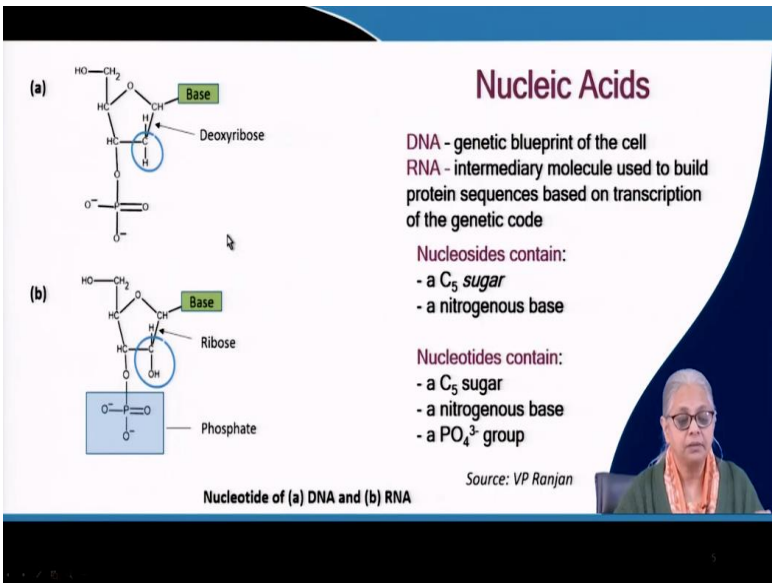

Let us now come to the next set of macromolecules; and that is nucleic acids. So, these nucleic acids, like I said, are pentoses. That is the sugar part of it. And that sugar; so, this is the ring form of the sugar. That is a C5 sugar. And it has a phosphate attached at the C3 position. This is the C1, C2 and C3 position. So, at the C1 position, you have the nitrogenous bases.

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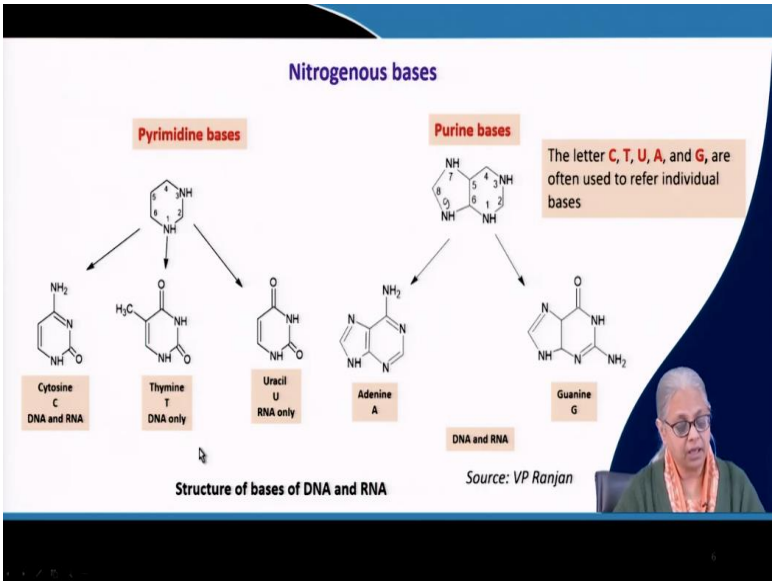

So, we have 5 nitrogenous bases, which I showed you in a previous lecture. So, you have these 5 bases. DNA has cytosine, thymine, adenine, guanine; and RNA has cytosine, uracil, adenine, guanine. So, that is the difference between DNA and RNA. And that is the sequence. So, the backbone is made out of this sugar and phosphate. And it is the nitrogenous (base), which looks like a flag over here, which gives it the sequence and that is the genetic code for the DNA.

And in the RNA molecules, which are intermediary molecule. So, you have the DNA. The DNA, after the strands are split apart, a single strand of the DNA is going to serve as a template for the messenger RNA. The messenger RNA and the transfer RNA will then come together on the ribosomal RNA to bring the amino acids in the right sequence and form new proteins. So, these are, all the RNAs are intermediary molecules that are used for building the protein sequences based on transcription of the genetic code. What is a nucleoside? A nucleoside has only 2 parts. It has a sugar and a nitrogenous base. So, the sugar and the nitrogenous base, just the 2 of them are called nucleosides. And a nucleotide is the sugar, the nitrogenous base and the phosphate. So, all 3 of them together are the nucleotides. And let us go to the next one.

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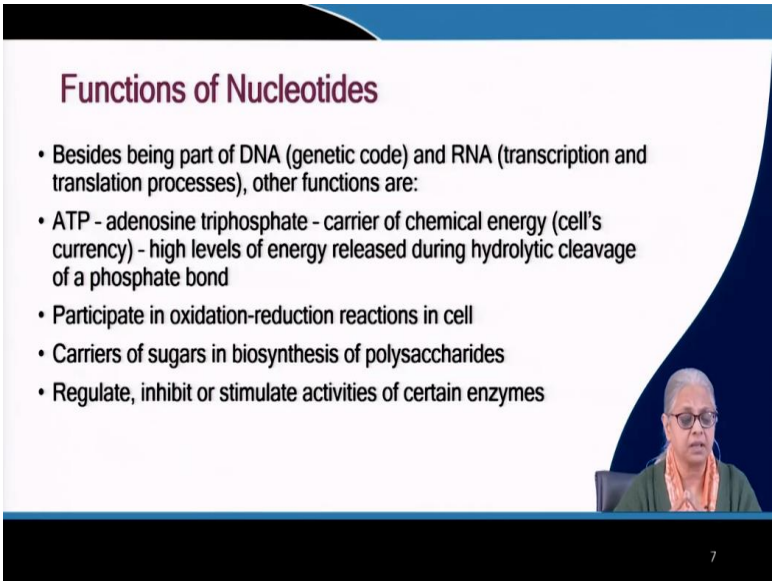

What is the function of these nucleotides? I have already mentioned that DNA is the genetic code; and RNA is what allows the proteins to be formed. So, it has the transcription and translation processes, going from DNA to RNA and RNA to proteins. So, RNA is the intermediary. That is the basic function of these 2 nucleic acids. Then we also have ATP. ATP, as you know, is the currency, the cell's currency in terms of energy.

So, it is the carrier and the way for the cell or the microorganism to store chemical energy. It is called, the full form is adenosine triphosphate and you have high levels of energy released during the hydrolytic cleavage of the phosphate bond.

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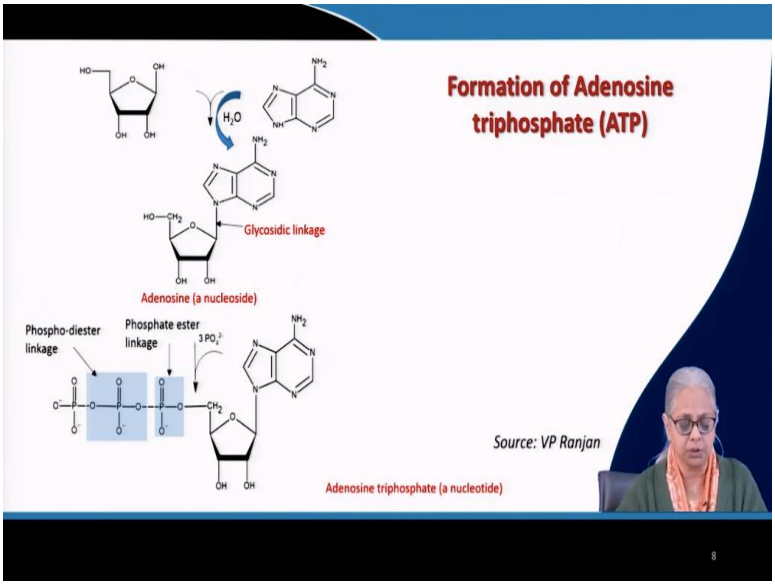

So, here we have the formation of adenosine triphosphate. So, we have a ribose sugar. And the nitrogenous base adenine is attached at the C1 position by a glycosidic linkage. This together forms adenosine, which is a nucleoside. So, the sugar plus nitrogenous base is your nucleoside.

Phosphate is attached at the C5 position. So, the first phosphate is what gives us adenosine monophosphate. That is a low energy bond. So, this particular bond between phosphate and C5, carbon on the ribose is a low energy bond. The remaining 2 phosphates are linked to each other by phospho-diester linkages. Both of them are high energy bonds. So, when you have 3 phosphates, that is adenosine triphosphate. It is a high energy molecule. And adenosine diphosphate is also a high energy compound or molecule or whatever you want to call it and AMP, adenosine monophosphate is a low energy containing compound.

So, that is why ATP is the cell's way of storing chemical energy. And the reverse of this reaction will give you release of the phosphate molecule and release of energy along with it; the last 2 phosphates. So, this phosphate, when it is released, will release energy. And the second one also when it is released, will also go with the release of energy.

These are high energy bonds. These nucleotides also participate in oxidation reduction reactions within the cell. They also are carriers of sugars, in the biosynthesis of polysaccharides. And they are involved in the regulation, inhibition and stimulation of the activity of certain enzymes.

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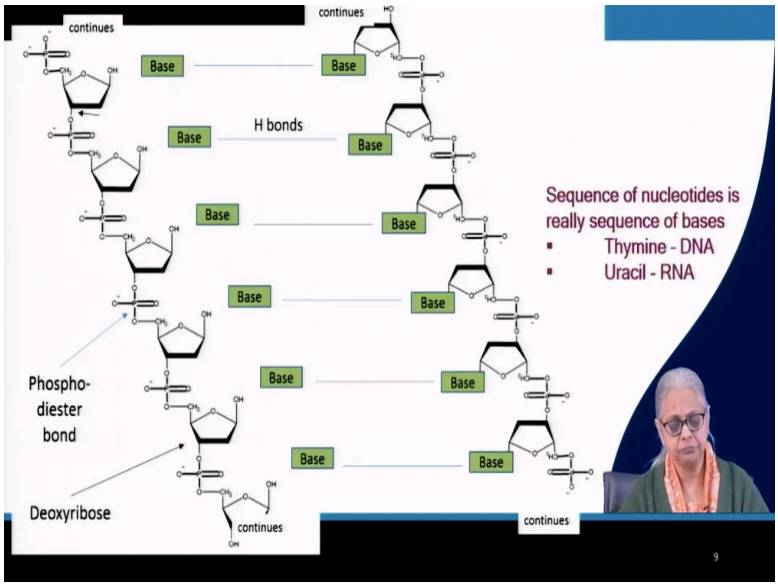

Let us take a look at the structure of a DNA molecule. So, here we have a strand. It has repeating sugar phosphate nucleosides. And then you have the bases, the nitrogenous bases attached at the C1 position. Now, this is one strand on the left. So, the reverse of this strand is on the right-hand side. Now, I have already mentioned in a previous slide.

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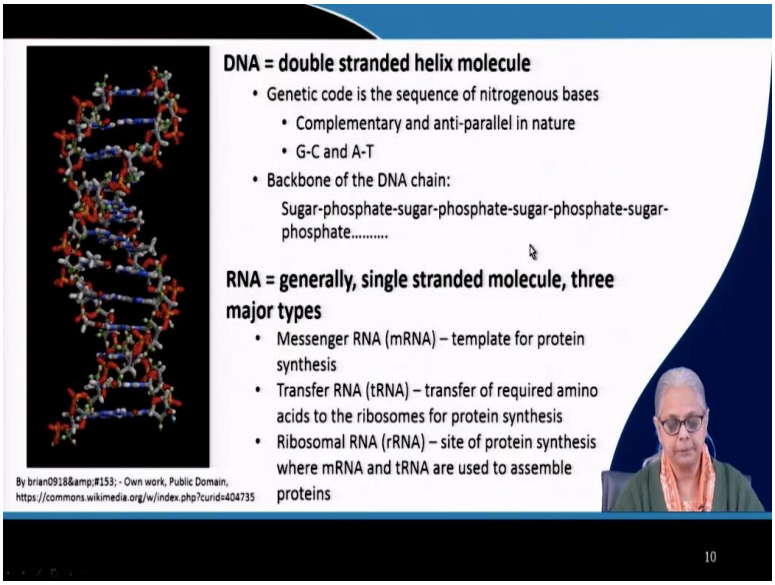

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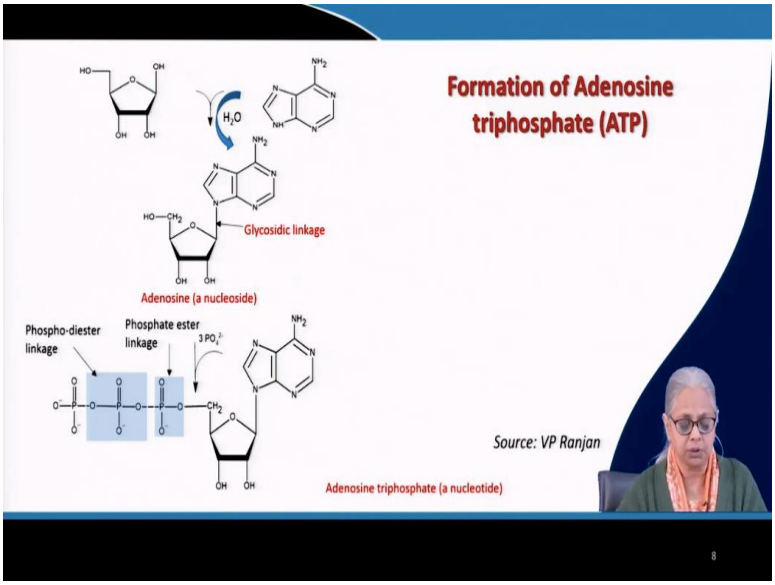
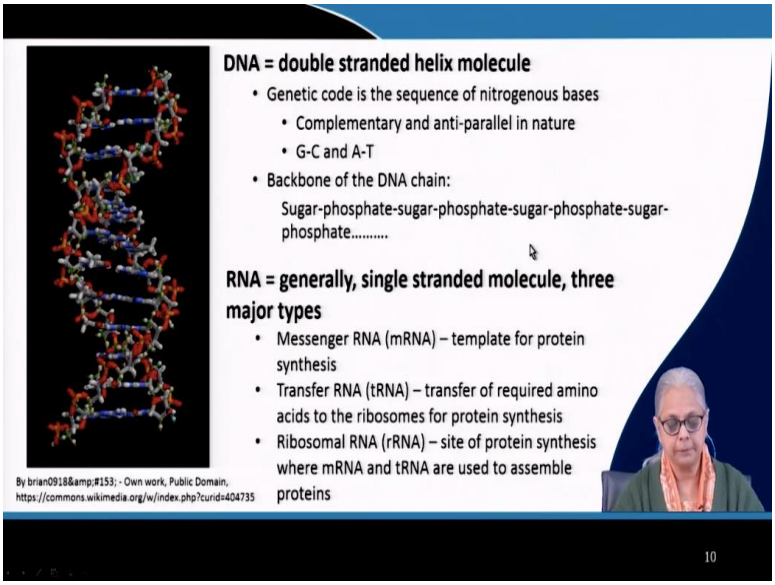
That you have guanine, which is complimentary to cytosine and adenine which is complimentary to thymine. So, when you have 2 strands, if you have guanine on one strand, it will bond only with cytosine on the other strand and vice versa. So, if you have adenine on one strand, it will bond with thymine on the other strand. So, they are complementary and antiparallel. The 2 double strands are complementary and antiparallel in nature and this helps to preserve the sequence of nitrogenous bases. So, that is the backbone and the sugar phosphate, repeating sequence of sugar phosphate; (Video Ends: 21:28) let me just show it to you again.



So, you have the ribose, phosphate; it is attached to the next ribose; and the next phosphate. So, that is the backbone. And the coding, the genetic coding is (the sequence of) the nitrogenous bases.



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So, you can see, an animation of the DNA molecule and it is simple; it is because of the nature of the molecules that are involved, that you get this spatial arrangement of the atoms. So, you can see. The colour codes are; each colour is for a particular element and the bonding of the 2 double strands is simply hydrogen bonds.

RNA is a single stranded molecule. There are 3 types of RNA. We have messenger RNA, which serves as a template for protein synthesis. We have transfer RNA, which collects the amino acids and assembles them on the ribosome, for the protein synthesis to happen. And then you have the ribosomal RNA, which is the site of the protein synthesis, where the messenger RNA and transfer RNA are used for assembling the proteins. (Video Ends: 22:41)

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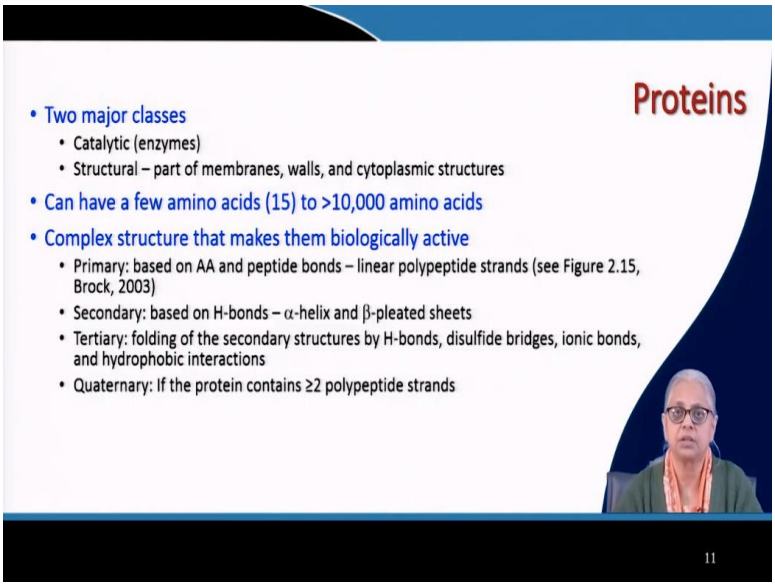

Since we are looking at proteins, there are 2 classes of proteins based on their function. So, we have catalytic proteins, which are enzymes. And we have structural proteins, which are part of the membranes, walls, cytoplasmic structures and these are the proteins that have very important functions as well. Now, you can have proteins which have very few amino acids, as small as 15 amino acids; and you can have proteins which have more than 10,000 amino acids. I have already mentioned in a previous lecture that they have very complex structures. And the complexity of the structure is what makes it biologically active. So, I have already mentioned that the primary polypeptide strand is based on amino acids and peptide bonds. You can refer to the textbook for more details and more graphics.

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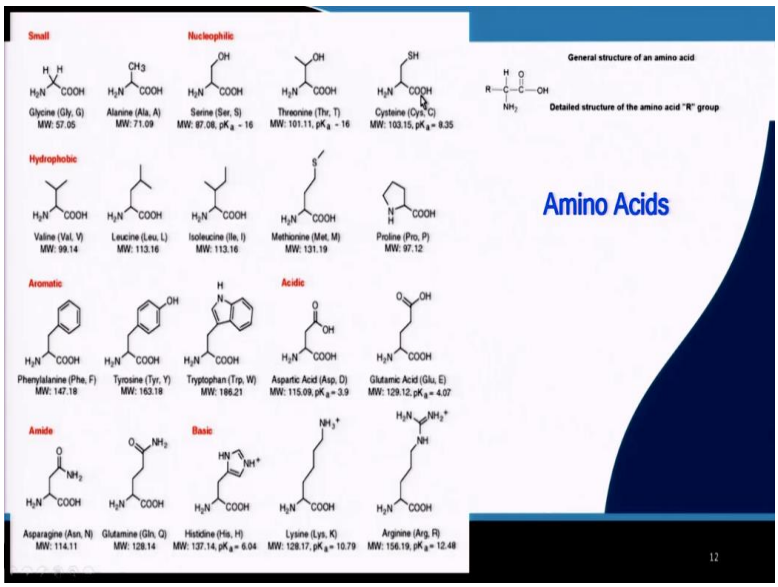

So, what we have here is the general structure of the amino acid at the upper right corner. So, this is a simple structure where you have 2 carbon atoms; or you can say, 1 carboxyl group; and 1 amine attached to a single carbon. And on the left-hand side of this structure, you see R. R stands for the various different functional groups that are shown in the remaining part of the slide. So, this R can be any one of the 20 amino acids that are common.

And so, what you see; for example, the smallest one is glycine. So, this glycine may be one possibility over here. Then you have alanine; you have these 2 small amino acids; you have nucleophilic amino acids; you have serine, threonine and cysteine. You have the hydrophobic ones. So, when I was talking to you about hydrophobic interactions, these are the functional groups that will play a part in the folding of the polypeptide strands and the interaction between the strands.

So, you have valine, leucine, isoleucine, methionine and proline. These are the hydrophobic ones. Then you have the aromatic ones. You can see the ring structure in 3 of them,

phenylalanine, tyrosine and tryptophan. And then you have the acidic ones, aspartic acid and glutamic acid. You have the amides, asparagine and glutamine. And then you have the basic ones, histidine and lysine and arginine.

So, these are the 20 common amino acids that are going to be participating in the formation of the primary structures of the polypeptide strands. And then, the nature of these functional groups will determine how the proteins fold within themselves and around the other polypeptide strands. So, this is crucial to the bioactivity of proteins.

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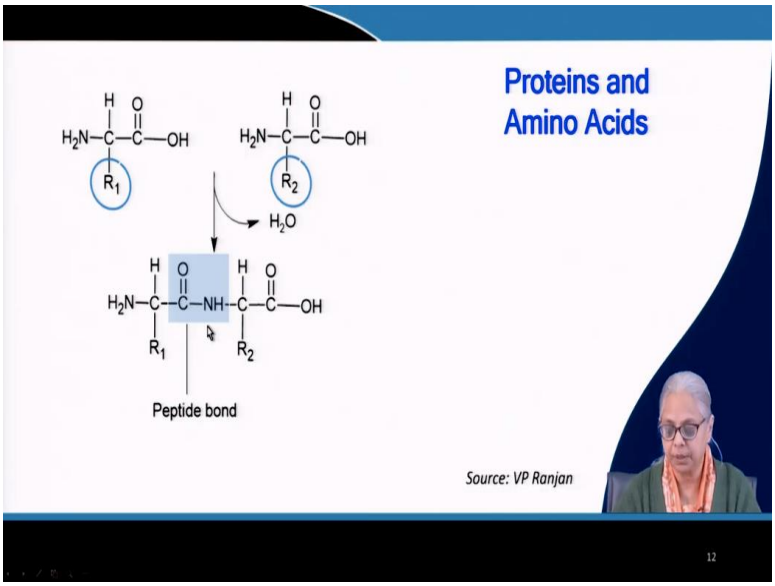

So, here we have R_1 and R_2. So, let us say we have 2 different amino acids. They will come together by releasing water. So, hydrogen on one of them and OH on the other. So, you can see it over here. So, hydrogen from here and OH from here, will be lost as a water molecule. And you get dehydration. This is called dehydration synthesis; and a peptide bond is formed. So, this is what we call dehydration synthesis and the formation of a peptide bond.

So, this is the primary structure. This is the nature of the primary polypeptide strand. It is a linear polypeptide strand. Now, the bioactivity is based on the folding of these molecules. And I have already mentioned to you that you have helix structures and pleated structures. Let me show you something about that.

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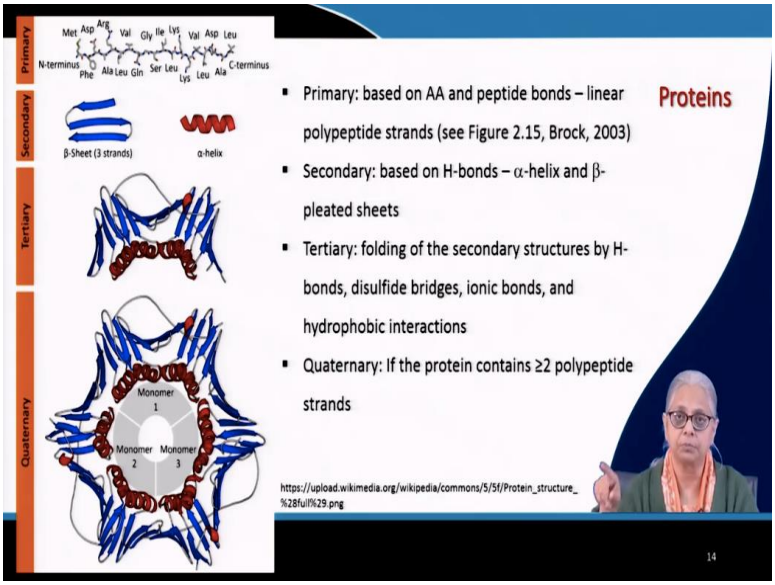

So, these are the higher level structures of proteins. So, you can see at the top, that is the primary structure. You have a series of amino acids, all strung together in a linear fashion. And then we have pleated structures. Now, these pleats are not evident over here. But like I said, they are fan-folded sheets or; you can imagine a strip of paper; and then you fan fold it. So, that would give you a pleated sheet structure.

And then I have already explained to you what a helix looks like. So, these are beta sheets and alpha helices. Now, these pleated and helical structures are going to again be folded to form the tertiary as well as quaternary structures. The quaternary structures are formed only when there is more than one polypeptide strand. So, hemoglobin, like I already said, has 3 (correction – 4) polypeptide strands.

One more point to remember that the secondary structures are based on hydrogen bonds; and the tertiary structures are based on a combination of covalent bonds, hydrogen bonds, disulphide bridges, ionic bonds, hydrophobic interactions; all these things are part of the tertiary structure. And then, I think the quaternary structures are again just folding of the polypeptide strands.

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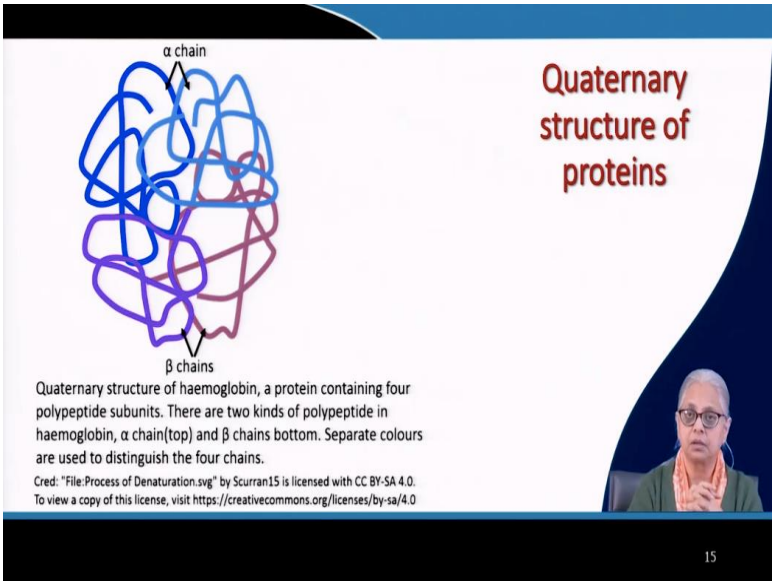

So, here is our hemoglobin structure. It has 4 polypeptide strands. I will refer you to many other sources on the internet. You can see animations of how the hemoglobin functions. There are heme groups attached to each of the individual polypeptide strands. And it is the iron at the center of the heme group that gets; it is the oxidised form. And the deoxidised form that basically allows the transfer of oxygen in the blood. So, all of that is done very well.

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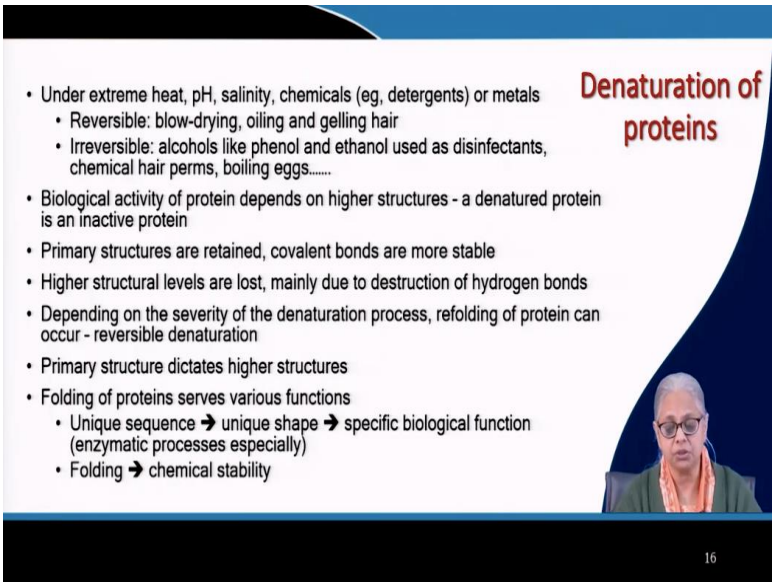

But let us come to something else that is just as important as hemoglobin. And that is: How do other proteins function? And what causes denaturation of proteins? Now, for any protein to function, basically the biological activity of any protein is based on, like I said, the folding of these higher level structures. When you apply either heat; acid; salt, salinity; or certain chemicals like detergents, ammonia and so on; or metals; any of these factors can cause disturbance to these higher level or even the primary structures.

Now, most of you know about blow drying your hair. If you are trying to style your hair, what do you do? When it is wet, you blow dry it and you set it in a particular way. So, that is, your hair, remember is protein, it is keratin. Your genetic code determines whether it is straight or curly. So, some people have straight hair; some people have wavy hair; some people have curly hair. Now, people with straight hair want curly hair; and people with curly hair want straight hair. So, how does that happen? So, you blow dry it. And when that blow drying is done, the protein which is set based on your genetic code; it is either curly or straight or any other pattern; the moisture is removed and you set it in a different pattern. So, you are changing the fold of the protein.

The way the protein folds biologically, you are changing that. When you wash your hair again, it goes back to its original form, which is dictated by your genetic code. Same thing happens with oil; same thing happens with gel. So, you have all these products in the market, which allow you to set your hair; but it is reversible, because when you wash it, it comes back to its original form.

There are other chemicals that can be used to break the biologically dictated structure. So, you can use alcohols, you can use certain chemicals, like I said, ammonia and other detergents and so on. These are harsh chemicals. You can use a combination of heat and these chemicals; and get what is called a perm. So, those of you who want to try it, you can go to a hair salon and ask them for a perm.

And that is an irreversible change in the structure of your hair protein. A more routine example is boiling an egg. So, your egg, the white part of the egg is albumin, that is egg albumin. And when you boil it, you are applying extreme heat; and the nature of that albumin changes. So, it is translucent in its original state. And when you boil it, it becomes opaque and white. Can you reverse it? Not possible, right. So, that is an irreversible change in the nature of that protein. So, the biological activity of that albumin has been destroyed forever. Because, when you boil it, it is completely gone. So, this biological activity depends on the preservation of the higher structures. So, the denatured protein is an inactive protein. It has lost all its ability to do any of its biological functions. The primary structure is intact. Nothing has changed. You have not broken it. You have not mineralized it. The primary structure is completely retained. The covalent bonds are stable. It is the higher level structures that are irreversibly lost. And that is basically due to destruction of these hydrogen bonds. Depending on the severity of the denaturation process, you can cause refolding. So, like I said, your hair is the best example of reversible as well as irreversible changes in the structure of the protein, that is keratin.

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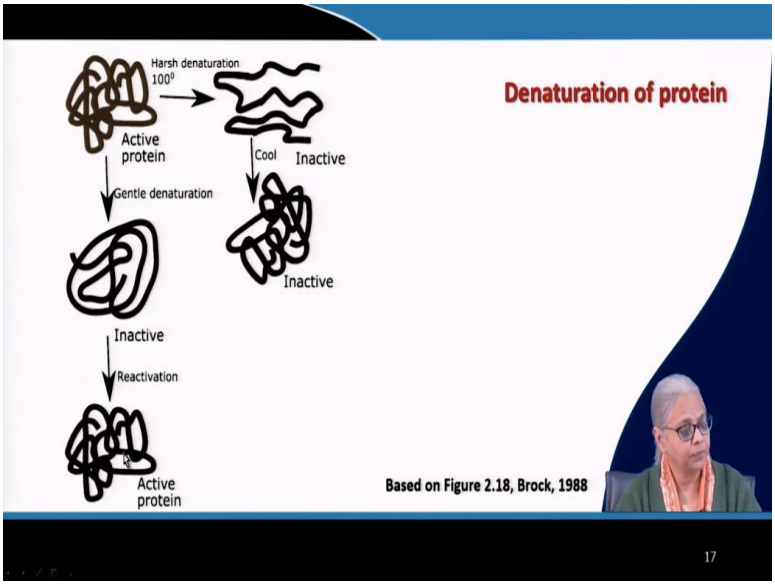

Let me just show you an example. So, let us say you have an active protein. It is folded in a particular form. And if you boil it, which is considered harsh denaturation, you will get the primary structure. That will be retained. But when it cools down, it will not come back to this particular folded form. And because it cannot come back to its original folded form, it becomes biologically inactive.

If you apply a gentle denaturation agent like mild heat; so, blow drying your hair is mild heat; oil or gel is again a mild chemical that you are applying and setting your hair in a particular fashion. So, when it is gentle denaturation, it will change the structure and the fold. It will become inactive. But then, when you remove that factor; wash it out; and it will go right back to its original form.

So, this is again very important in determining the bioactivity of these compounds or these proteins. And the primary structure dictates higher structures. So, the folding of the proteins serves various functions. The unique sequence determines the shape and the shape determines the biological function. The folding will determine the (bio)chemical stability of that protein.

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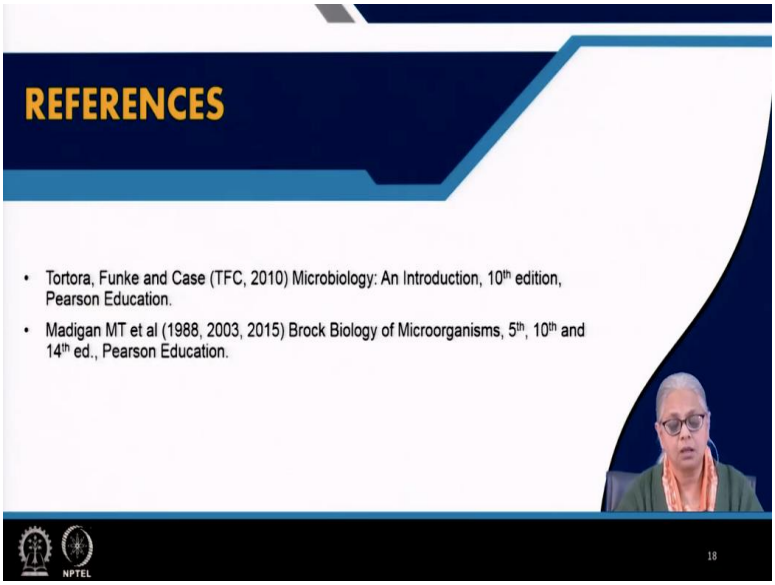

That brings me to the end of Cell Chemistry. And we will now go to the next topic which is Cell Biology.