Biochemistry
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Lecture – 20
Vitamins and Coenzymes – II

We continue our discussion on Vitamins and Coenzymes. And what we learned yesterday was how these vitamins were actually transferred into cofactors that were utilized for the enzymes to go through their enzymatic mechanism. So, most complex enzymes would have a cofactor or prosthetic group or coenzymes which could be a metaline, could be small organic molecule and these vitamins are transformed to these small organic molecules that are going to be used for enzymatic reactions.

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Coenzyme	Vitamin	Role
ATP	----------------	Energy and phosphate transfer
NAD(P)	Niacin	Redox
FAD/FMN	Riboflavin (B_2)	Redox
Coenzyme A	Pantothenic acid (B_3)	Acyl transfer
TPP	Thiamine (B_1)	Transfer of 2 C
PLP	Pyridoxine (B_6)	Amino acids
Lipoamide	------------	Acyl transfer
Ubiquinone	------------	Electron carrier

Now, what we have here is we considered some of the vitamins. We will go through all the rest of the once today, where we have a certain important role that each of these play. Now, ATP is an extremely important coenzyme that helps in the non-spontaneity of some reactions that actually have a positive delta g. But, the high energy phosphate bond of ATP when broken gives a sufficient amount of negative energy. Negative free energy that compensates for the positive delta g for a certain reaction.

So, any reaction that requires ATP will break that high energy phosphate bond into forming ATP and PI and depending on whether there is a pyrophosphate required and form into an AMP + PPI. We also have NAD, which we will see today. FAD and FMN. Each of these are used in Redox reaction that plays a very important role in bioenergetics processes. Because each of these steps have Redox reaction, certain enzymes that are used for this Redox reaction and we will see how these vitamins are transformed into these coenzymes which can then be utilized for those reactions.

We have coenzyme A which is another very important coenzyme. It is formed from pantothenic acid and it is involved in Acyl transfer. Then, we have Thiamine, which we started off yesterday. Then pyridoxine that is involved in Amino acids isomerization.

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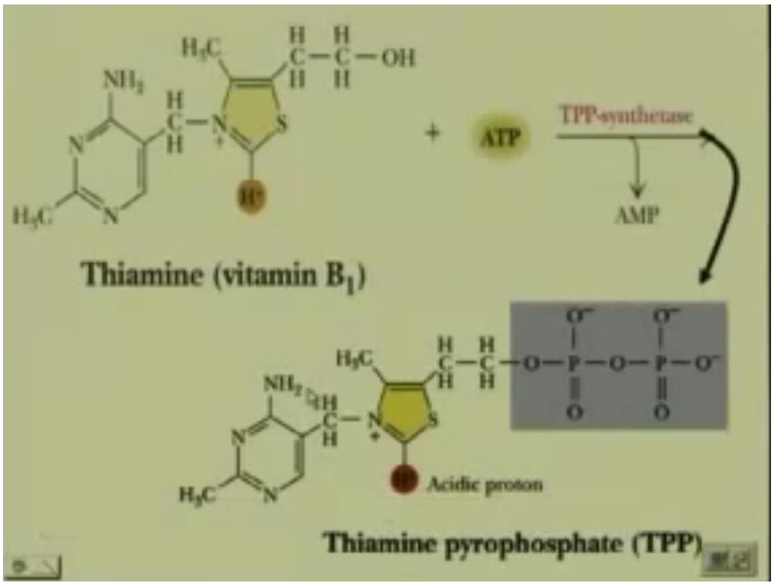

Now, this is something that we looked at in our last class, where we have Thiamine that has to be transformed to Thiamine pyrophosphate for its activity. As thiamine enzyme cannot use this as its cofactor, so it has to be transformed. It is transformed by TPP synthesis which is nothing but thiamine pyrophosphate synthetase. This is thiamine, a pyrophosphate means it has two phosphate groups attached to it and since it has this phosphate it is obtained by ATP. ATP is in the process transformed into AMP.

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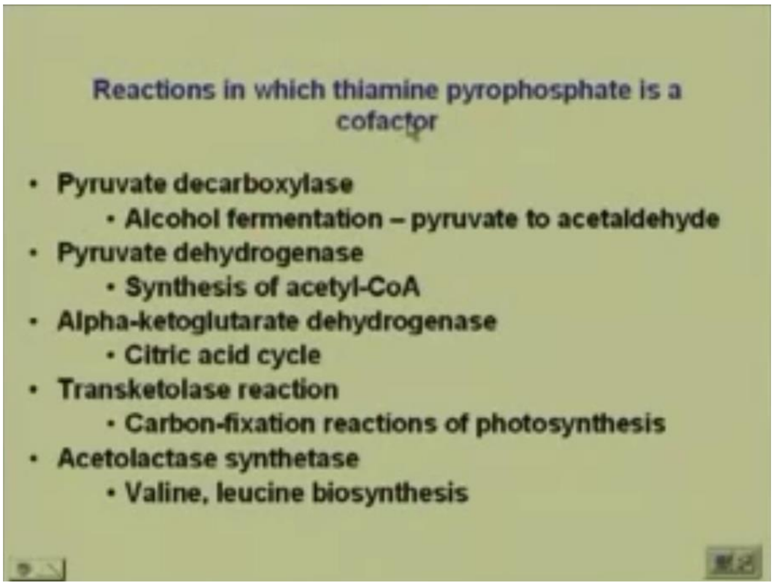

Now, these are some of the reactions that thiamine pyrophosphate is required for as a cofactor. These are decarboxylase reactions, where CO 2 is released. Dehydrogenase reactions another dehydrogenase reaction also a transketolase reaction. What we need to know is how later on, when we get into carboxyl acid cycles, we will see how pyruvate decarboxylase is required and in this case, we will have TPP assist the enzymes in performing its activities.

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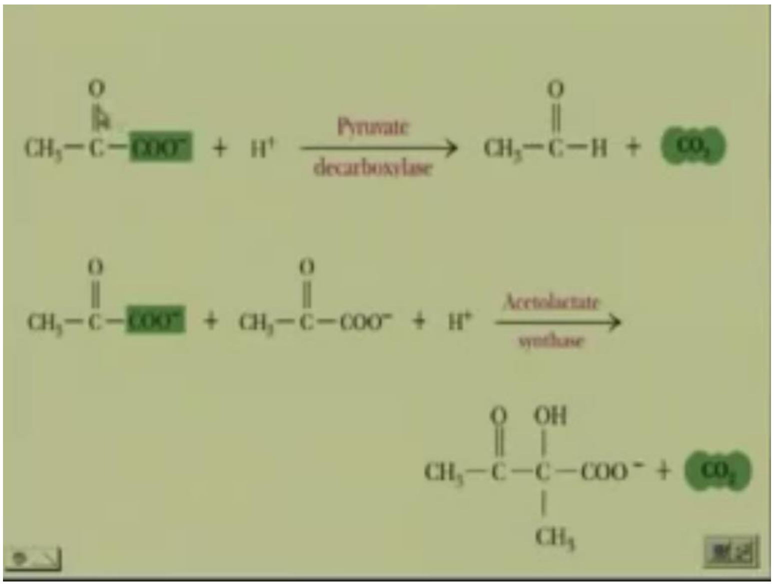

So, basically a reaction like this where you would have pyruvic acid, you have pyruvate decarboxylase which means that the CO2 is eliminated from the pyruvic acid forming acetaldehyde ok and this reaction or this enzyme cannot act without TPP. And TPP cannot be formed without thiamine. So, that's the way the vitamins work. Thiamine is transformed to

TPP. TPP is utilized, this is one of the reaction where it is utilized for the decarboxylase activity, decarboxylation of pyruvate to form acetaldehyde.

And you recognize that this is a breakdown, you are breaking things down. You are metabolizing these processes. This is another one where you are forming acetolactate synthase. So you are forming acetolactate by the elimination of CO2. Again, this reaction requires TPP or this enzyme rather requires TPP for its action.

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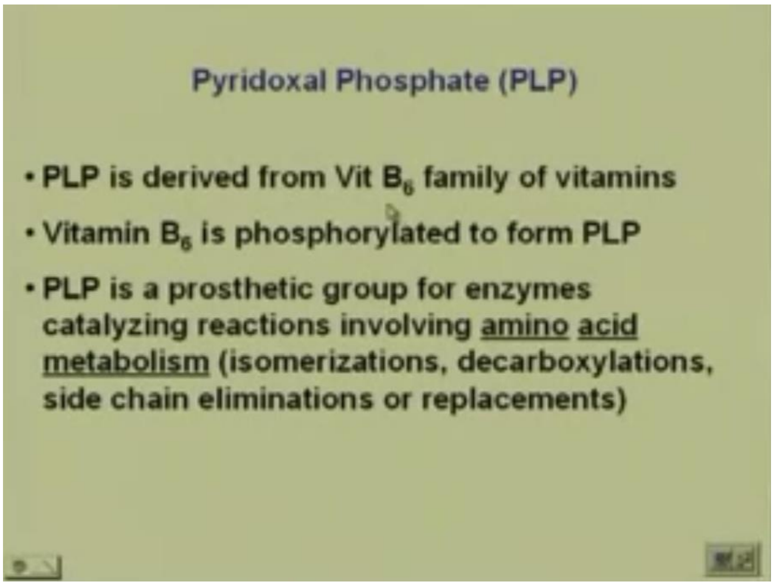

So, if we get into next family of vitamins. Vitamin B 6. This vitamin again be a small molecule, a small organic molecule that again has to be transformed into the cofactor that is in the process in turn going to be used for an enzymatic reaction for its mechanism to take place. So, PLP is a prosthetic group for enzymes that catalyze reactions that involve amino acid metabolism. So, you would have amino acid isomerization, amino acid decarboxylation, side chain elimination or even replacement.

Because, you recognize that the amino acids are synthesized in the body. So, there are certain enzymes that are going to be responsible for the synthesis of these amino acids. And these enzymes require pyridoxal phosphate.

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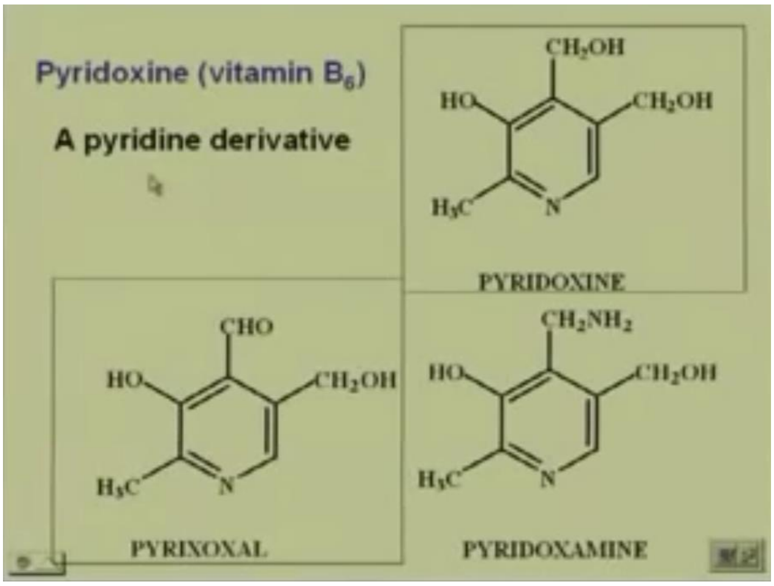

So, if we look at Pyridoxal phosphate, this is a pyridine derivative. You recognize the pyridine moiety here. And this is pyridoxine, the specific groups attached to pyridine nucleus. The pyridoxal and pyridoxamine. These are the three forms of pyridoxine that are used as cofactors in the enzymatic reactions. So, we have pyridoxine which is a pyridine derivative and we have several different groups. This is the pyridoxine that has CH2OH here.

It forms pyridoxal, where this is CHO, the aldehydes and this confirm pyridoxamine, where it is CH2NH2. The rest of the substituents remain the same. So, we basically have the pyridine derivative.

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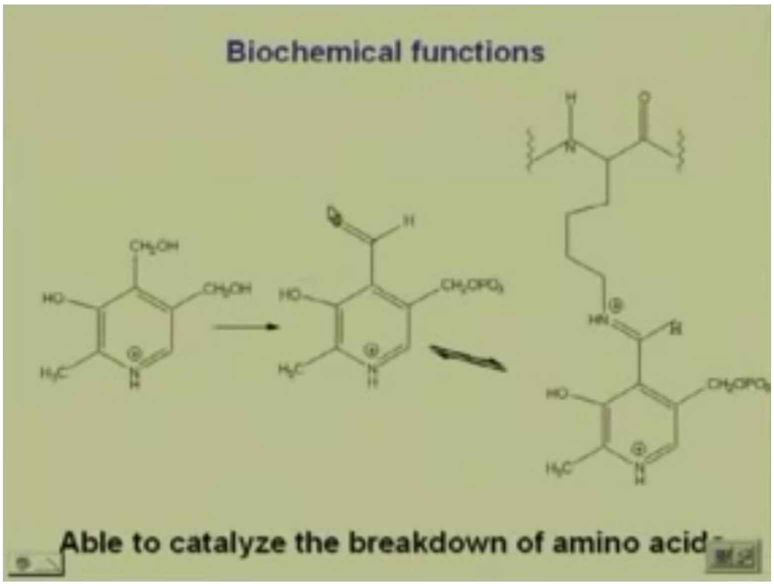

Now, the biochemical function of this is, it is actually able, we will not go in detail of how it is actually does this, but as I mentioned in previous slide that it is involved in amino acid metabolism isomerization, decarboxylation. So, this the role of pyridoxal phosphate is mainly to do with amino acids. Any reaction that would involve amino acid metabolism, isomerization or breakdown of amino acid would require this PLP pyridoxal phosphate.

So, this is the pyridoxal, which you recognize here. Now, after found as phosphate it becomes pyridoxal phosphate. So, again for the pyridoxal phosphate to form, you have to have the pyridoxal. So, pyridoxal will form pyridoxal phosphate. It is that PLP will be used by the enzyme for the amino acid breakdown. This is way you have to recognize how each of the vitamins not by themselves are used by the enzymes but after being transferred in some manner is used by the enzymes.

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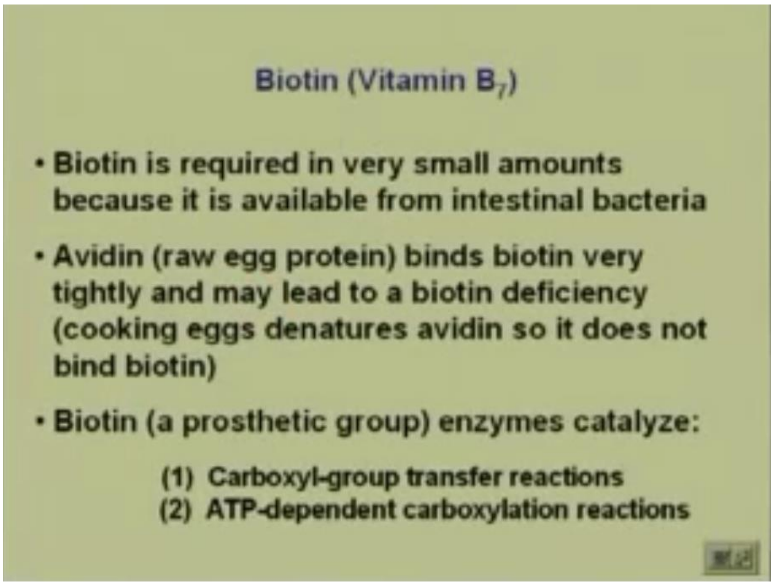

This is another one. We have Vitamin B 7 here. Biotin. Now, Biotin actually is required. It has to be supplemented in the diet, but it is required in small amounts because intestinal bacteria actually make Biotin. So, you do not have to have much Biotin in your diet. There is a protein called Avidin in raw eggs which binds biotin extremely tightly as a result of which it makes Biotin unavailable for its enzymatic specific reaction.

So, this avidin protein, when binds to biotin makes biotin less available for its particular reaction. Right? So if you cook an egg, which is why they say you should not have raw eggs. If you cook egg you denature the protein. You denature avidin and it does not bind biotin anymore, so biotin is available for enzymatic reaction, but it catalyzes. So, what are these reactions that it catalyzes? We have biotin, a prosthetic group.

Now, what do we mean by a prosthetic group? It is a group that attaches covalently with the enzyme. That is what a prosthetic group is. This biotin actually catalyzes two sorts of reaction. One is a carboxyl group transfer reaction, whereas the name specifies it is possible for the transfer of a carboxyl group. We also have carboxylation reaction, where we have ATP dependent carboxylation reaction.

So, again biotin is actually required in very small amounts because it is made by intestinal bacteria. And again it is bound tightly by avidin that may lead to biotin deficiency and it is being a prosthetic group it catalyzes after it is linked with the enzymes. It catalyzes carboxyl group transfer reactions and ATP dependent carboxylation reaction. So, how does it work?

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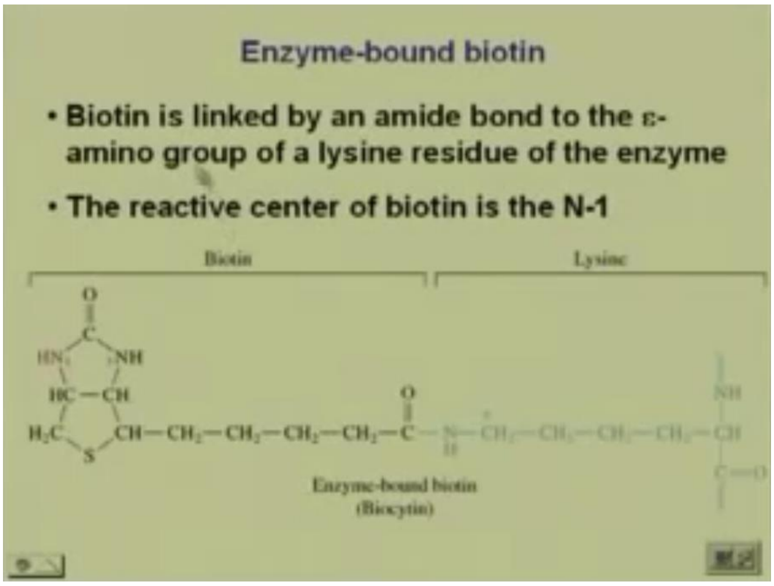

Biotin is actually linked by an amide bond. To the epsilon amino group of a lysine residue. What is that? This one in blue here is the protein. This is the NH2 group of lysine. You recognize the side chain, CH2, CH2, CH2, CH2 and NH here. And this is biotin. This part. This biotin is linked to the lysine. The reactive group of biotin is this nitrogen that is marked in red. So, what do you have? You have biotin, which is this that is linked to lysine.

Where is this lysine? This lysine is in the protein. Whatever enzyme that is going to be acted upon or whichever enzyme actually has to perform its function that requires biotin will link with biotin and then have the biotin perform its function. So, you have to recognize again that vitamin biotin is required. What it is going to do? It is going to link with the lysine that means the lysine that was present in the enzyme itself cannot perform its enzymatic mechanism without biotin.

Which is why we call these coenzymes or cofactors are prosthetic group that assist the enzymes in their activity. These are not simple enzymes that can act just by the capability of their side chains to perform a reaction. They require these enzymes bound or cofactors or coenzymes associated with them for their specific reaction.

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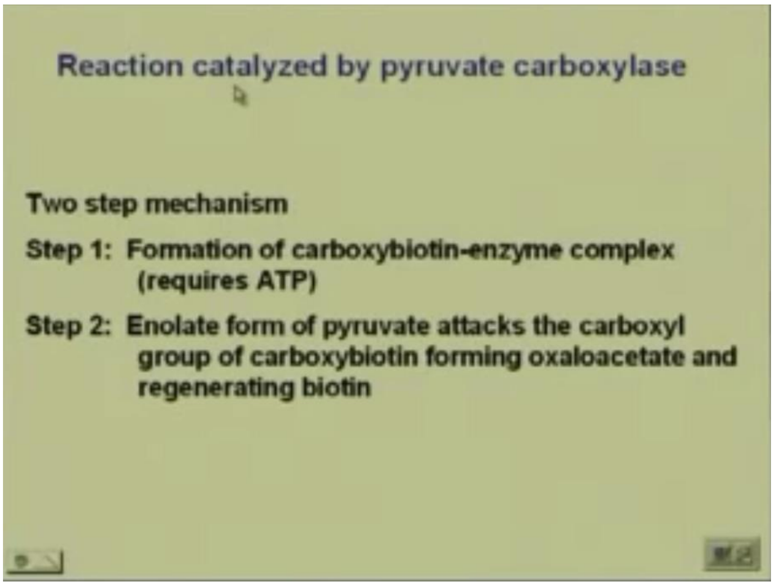

For example, if we look at the reaction that is catalysed by pyruvate carboxylase, the first thing is the formation of a carboxybiotin–enzyme complex. In the formation of this carboxybiotin-enzyme complex, it means that it requires the linking with the lysine residue in the enzyme because that is where the biotin is going to link. The second step has an enolate form of pyruvate that attacks the carboxyl group of carboxybiotin forming oxaloacetate.

Now, this reaction, the pyruvate formation, the enolate form of pyruvate going to oxaloacetate is a very important reaction in what is called the carbohydrate metabolism, which we will see when we do bioenergetics. You will then recognise, where each of these enzymes come into play. Each of these enzymes because there are going to be different steps in the reactions. These different steps have obviously different enzymes and these different enzymes in turn have different cofactors the presence of which will then allow the enzymatic activities to take place.

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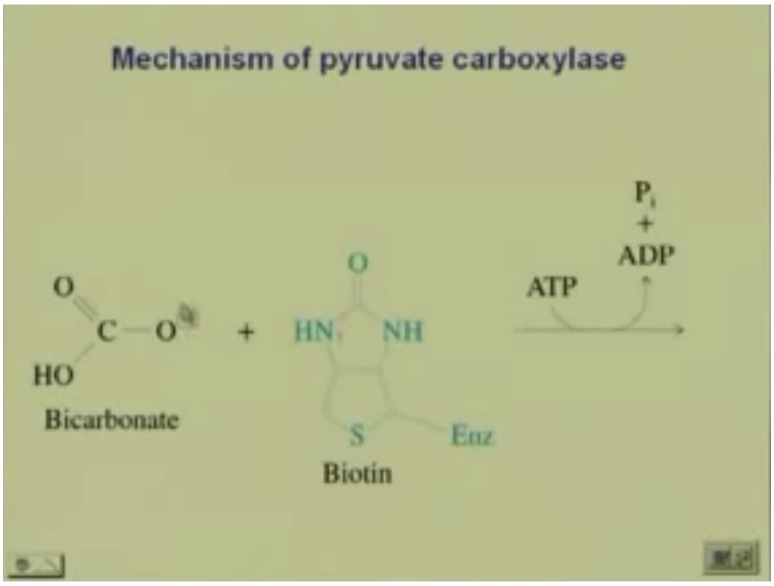

So, what happens here is, you have a bicarbonate and you have the biotin that is linked to the enzyme. Where is it linked? It is linked through the lysine. Now, it is linked here. What is going to happen here? There is going to be an elimination of the OH, because this is the reactive centre. This nitrogen is the reactive centre. It will act on this carbon forming carboxy biotin eliminating the OH from the bicarbonate.

So, that is the first step. So, after the biotin has linked with the enzyme you have the bicarbonate ion here. This is the reactive nitrogen of the biotin that is going to form carboxybiotin. So what does that look like?

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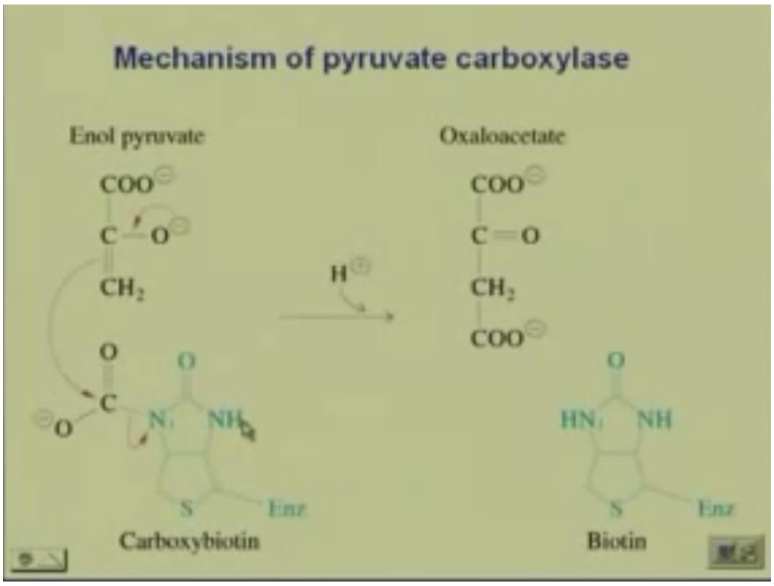

This is what the carboxybiotin is. How did it form? It formed after the elimination of OH. And how did that form? From the lone pair of nitrogen present here. Ok. It goes and acts on this carbon eliminating the OH. Once that happens you have carboxybiotin. Now, this carboxybiotin is enol pyruvate. It is the enol form of pyruvate. What is pyruvate? You have CH3, CO, COOH. That is what pyruvate is. This is the enolic form of pyruvate.

What is happening now, is there is going to be the formation of oxaloacetate. What do we have? We have an additional carbon addition here. So, it is the carboxylase that is acting into adding COO- to enol pyruvate. So, what you are doing is you recognise that this is synthesising something. So, this biotin in conjunction with this enzyme. The enzyme alone cannot do this. It has to have the biotin for this particular reaction to do occur.

So, once this reaction occurs this takes up the extra carbon and forms oxaloacetate. What happens to the biotin and the enzymes? It is back to where it started from. But, you have to recognise that it is exactly like the enzymatic mechanism, the only thing that you need the additional prosthetic group in this case, for the action of the enzymes. That is what the difference in all of these cases.

And you recognise each of the vitamins are required for a particular reaction to take place. So, what is the next one?

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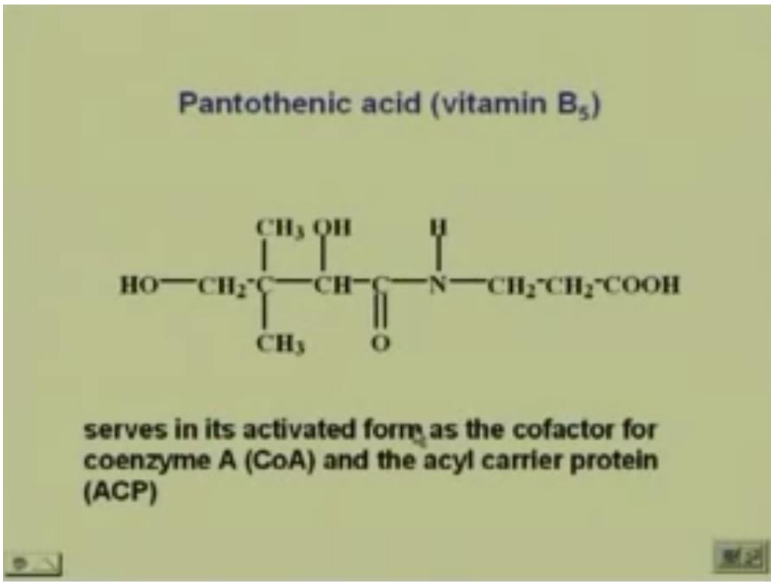

Pantothenic Acid. This is Vitamin B 5. We are not going in specific order like 1, 2, 3, 4, 5, 6. It is just depending on how we are getting to the particular activities of the enzymes. Now, this is a very important vitamin. The reason being that it actually is the cofactor for what is called coenzyme A. Coenzyme A is used in a lot of the carbohydrate metabolism cycles, there we have the tricarboxylic acid cycle there. We have a pentose phosphate cycle there.

There is glycolysis. All of these cycles that actually breakup glucose or breakup carbohydrates into forming small molecules that are again utilised for the synthesis in different other cycles to prepare the amino acids or other proteins that are required in the body. So, this pantothenic acid which the formula of which is given here, it serves in its activated form as again the cofactor for coenzyme A and also for the acyl carrier protein (ACP).

Now, the acyl carrier protein or coenzyme A also is one that transfers an acyl group. Transferring an acyl group means, you are transferring CH3CO, which means you are transferring two carbons at a time. So, if you are synthesising a fatty acid, you remember I told you that they always are synthesised by two carbon atoms at a time. And, this is where some of these come into play.

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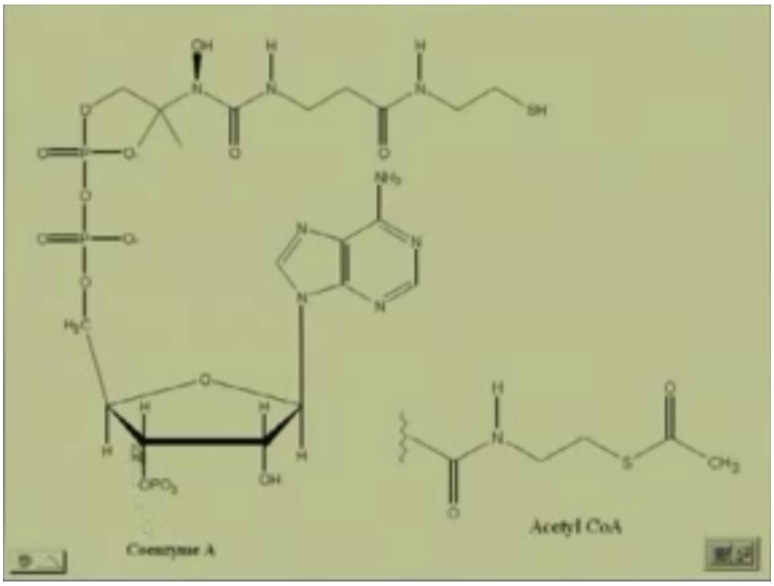

This is what is coenzyme A. You recognise that this is a sugar, this is a base and it has pantothenic acid part on top here. What is the pantothenic acid part? This is the pantothenic acid part. COONH that is here. And the way we actually consider it is, we just put this wavy line here because this is common and we write this as acetyl CoA. This COCH3 at the end of acetyl CoA is what is transferred.

So, it is involved in a lot of acylation reactions, where you are transferring 2 carbon atoms. So, this is the structure of coenzyme A and what we need to know is this is SH. This becomes acetyl CoA, where the H has been replaced by COCH3. You see this COCH3 that has replaced this hydrogen of coenzyme A. So, coenzyme A comes into the picture, how do you get coenzyme A? If you use pantothenic acid.

Pantothenic acid, in its activated form, is part of coenzyme A that then forms acetyl CoA, as it is called and this is involved in a number of reactions.

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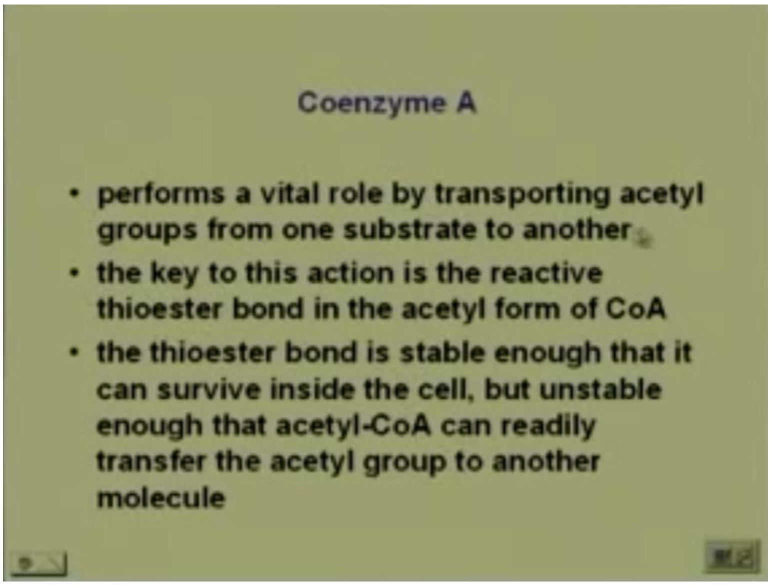

What are these? Coenzyme A, it performs a vital role by transporting acetyl groups from one substrate to another and the reason why this is extremely important as I keep mentioning is because you can transfer 2 atoms at a time. In the previous ones that we look at, we are transferring only a COO- that was one carbon. You went from enal pyruvate to oxalo acetate. In this case, you can go by 2 carbons because you are transferring an acyl group. The key to this reaction is the reactive thioester bond in the acetyl form of CoA.

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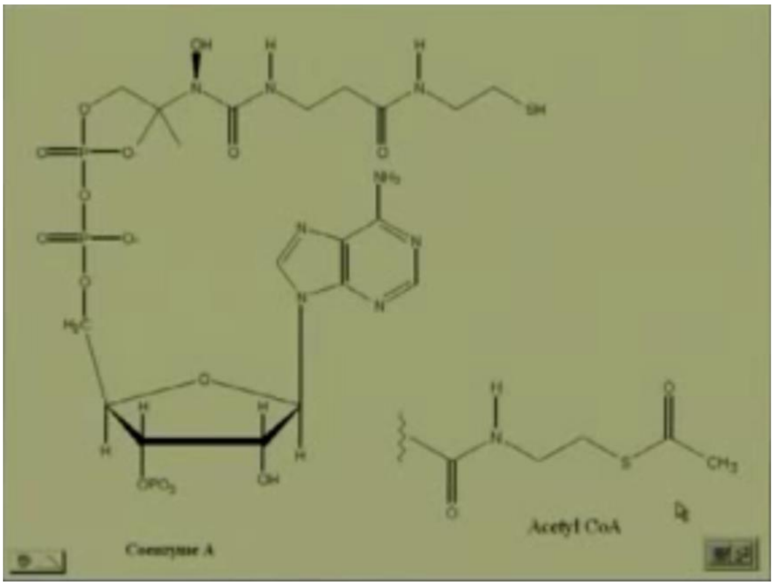

This is acetyl CoA and this is your thioester bond. What is an ester bond? COOR and this is an SCO. So it is a thioester.

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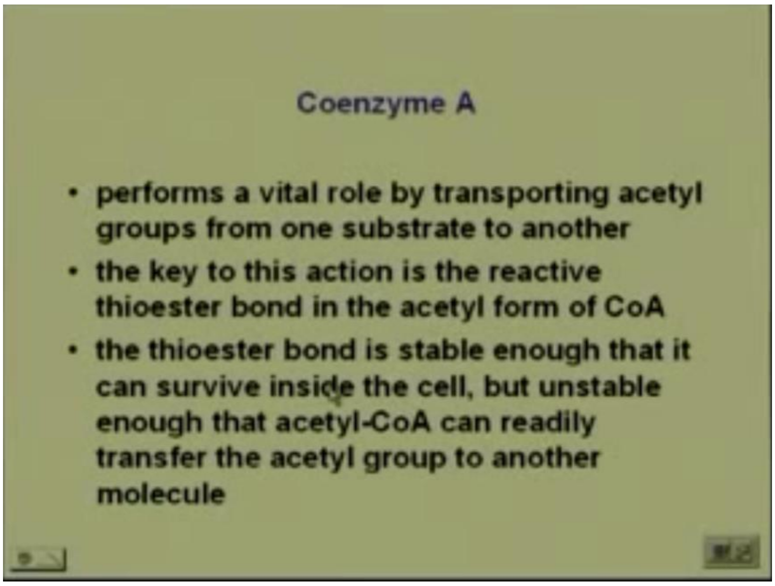

The thioester bond, this is important; it is stable enough that it survives inside the cell but at the same time it can also be broken up under suitable conditions to give the CH3CO. So, it is extremely important in the way the enzyme would work into either breaking it up to get the CH3CO or at the same time surviving inside the cell so it can be taken up by the specific enzyme as and when required.

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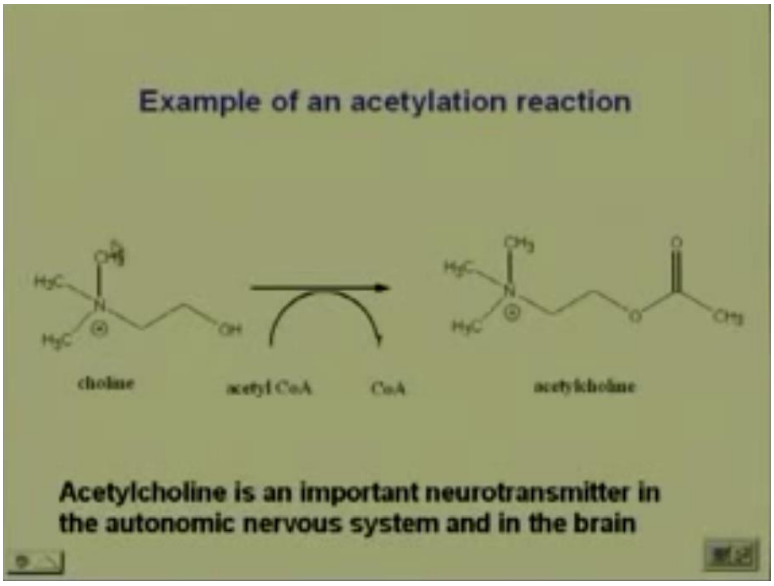

This is an example of an acetylation reaction. We have heard about choline, when we did the fatty acids and the triglyceride and phosphoglycerates. What will happen? We have phospo choline that form a part of the polar head group to a lipid. When we have the hydrophobic tails that are formed by the 2 fatty acids and we have a polar head group, it was this choline at that time one of the polar head groups for some of the phosphoglycerates.

Now, this forms acetylcholine. Acetylcholine is an extremely important neurotransmitter. It transforms most of the messages to the brain for whatever activities are going on. So, the choline that is present can be transferred to acetylcholine by acetyl coenzyme A, which transfers its acetyl group to acetyl choline in the event becoming coenzyme A. So you recognize that the choline being present with the acetyl CoA will form acetylcholine that is I mentioned is an extremely important neurotransmitter in our nervous system.

It helps in the transmission of messages that is completely another chapter and is extremely interesting as to how messages go from one. There are neurotransmitters, we have chemical messengers and these are the chemical messengers that take the message from other parts of your body to your brain.

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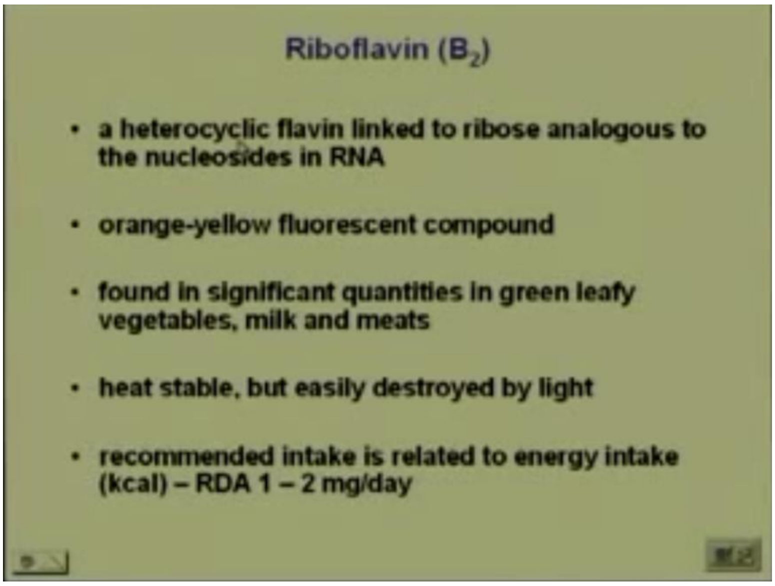

Vitamin B2 is riboflavin. What we have here is, we have heterocyclic flavin, and we will see that in a moment, linked to a ribose analogous to the nucleosides in RNA. We now know what a nucleoside is. What is a nucleoside? You have sugar linked with the base, which is a nucleoside. It becomes a nucleotide as soon as you have a phosphate link to it. It is an orange-yellow fluorescent compound found in green leafy vegetables, milk and meats.

It is heat stable but destroyed by light and we have RDA that is recommended daily or dietary allowance which is so many milligrams per day. But, we have to be interested in this structure of riboflavin.

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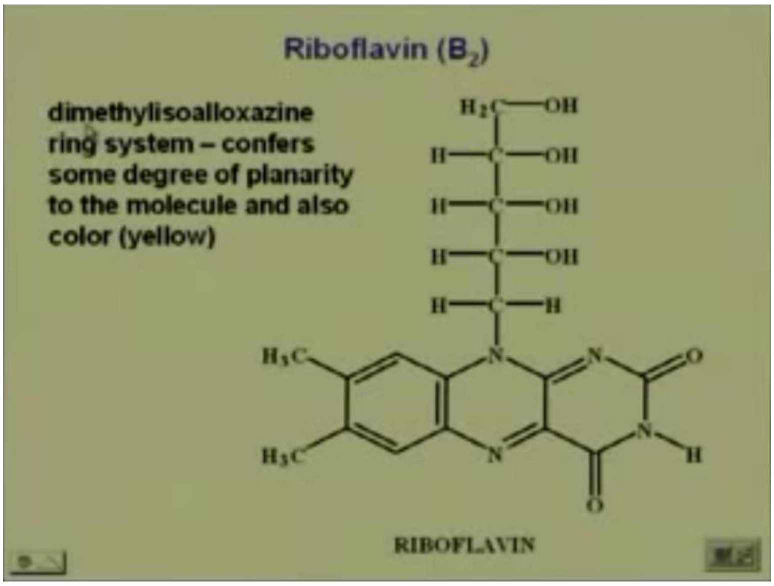

This is what riboflavin is. It is what is called a dimethylisoalloxazine. That is the dimethyl you can see here. This is the isoalloxazine ring system and this imparts a planarity to the molecule. You have a benzene moiety here. So, this you know is planar. So it imparts some planarity to the molecule and because of the large number of nitrogen atom here, it also has a yellowish colour to it. So, this is called dimethylisoalloxazine ring system and this is your riboflavin. This is the vitamin.

Now, what do we have to do to the vitamin to get it to act? It has to be transformed to a cofactor. Only if it’s transformed to a cofactor, can it then help the enzyme to perform a specific function. So, now we are going to see how can be transformed into a cofactor that is going to be of any use to the body or to the specific enzymes that are going to need riboflavin.

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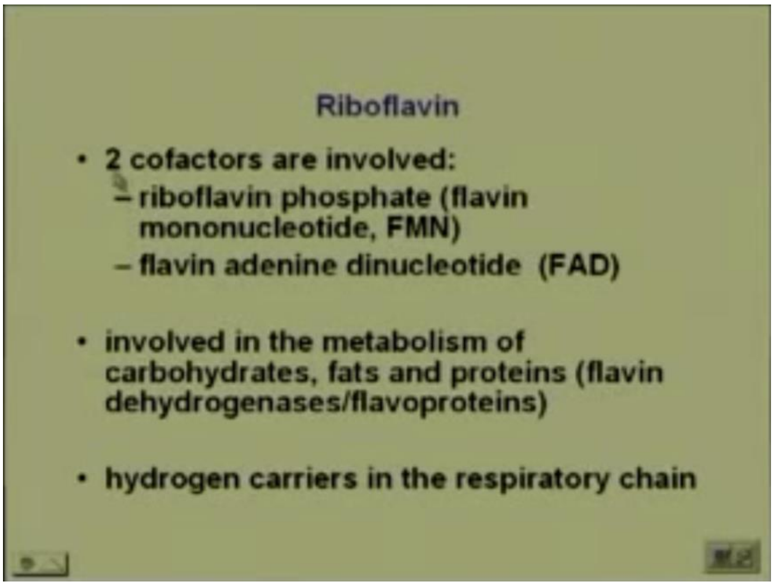

Here, there are actually 2 cofactors involved. Now, these cofactors are extremely important in some of the glycolysis or glycolytic reactions that takes place. We have riboflavin phosphate, which is also called flavin mononucleotide. The nucleotide means it has the phosphate. FMN that is flavin mononucleotide. So, it has the riboflavin and it is a phosphate. We have flavin adenine dinucleotide. What is adenine now? We now have a purine base attached to it.

We will see what the structure is in a moment but this is an extremely important cofactor, FMN and FAD, because they are involved in the metabolism of carbohydrates, something we will study when we do our bioenergetics part. So, it is involved in the metabolism of carbohydrates, fats and proteins. This vitamin is required for the breakdown of a lot of our dietary constituents ok and they also act as hydrogen carriers in the respiratory chain.

So, not only do they act as metabolism of carbohydrates, fats and proteins, they are also involved in hydrogen carriers in the respiratory chain. So, if we go back to the structure once more, this is your riboflavin which is vitamin B2. The 2 cofactors that it actually forms are FMN and FAD. So, these are what are going to be required in the specific enzymes that are involved in these processes here.

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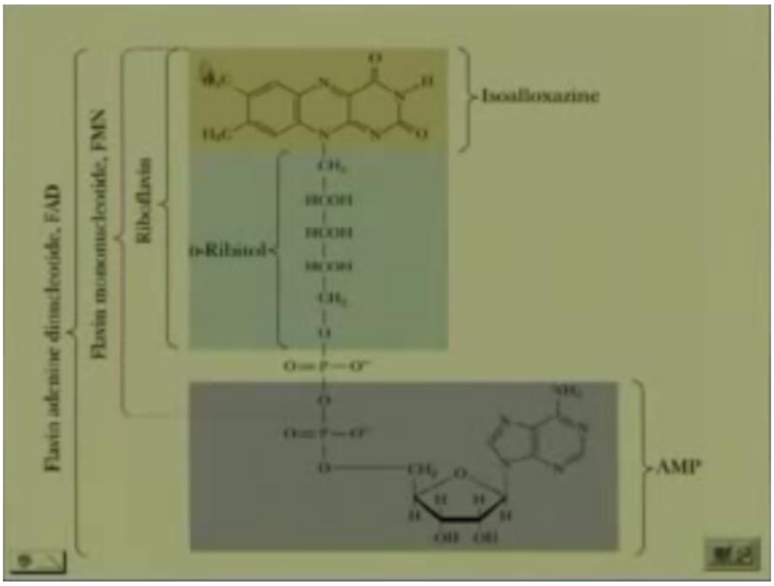

So, what do we have? This is your isoalloxazine group. This is riboflavin, this part the one in yellow and blue together. When you have a mononucleotide, a tide attached to the riboflavin, you see a phosphate. I have a clearer picture on the next slide but in the picture here you have the phosphate and you have the riboflavin attached to the phosphate.

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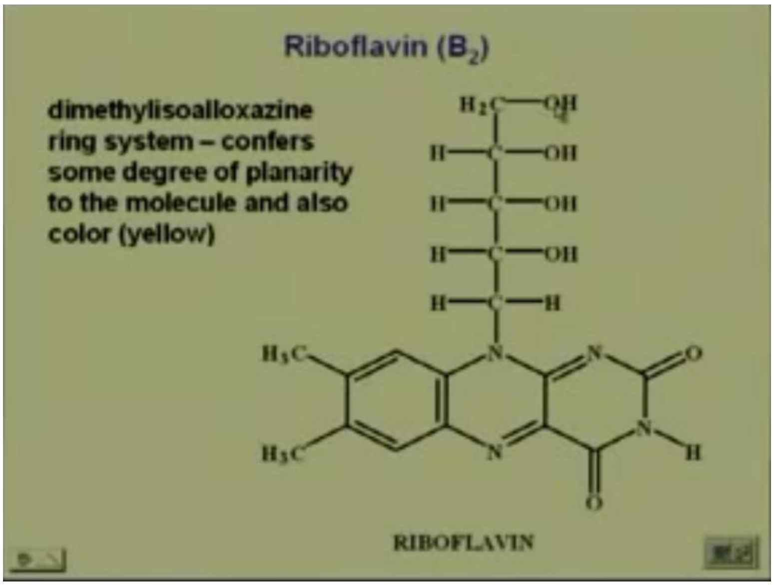

Riboflavin phosphate is the phosphate attached here. If the phosphate is attached here, this becomes riboflavin phosphate that is also known as flavin mononucleotide FMN.

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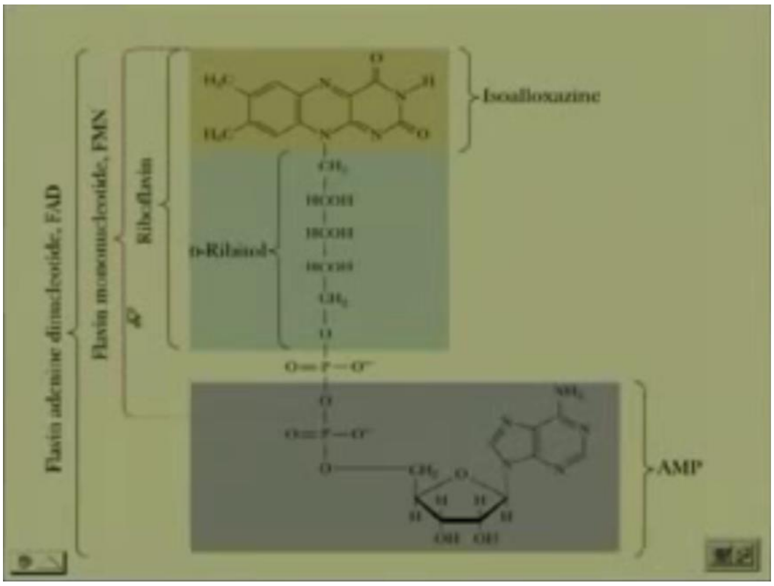

When you attach this to AMP, adenosine monophosphate, you have the adenine ring here, the ribose sugar, the nucleotide with the phosphate here. This becomes the flavin, because this is the flavin part, adenine dinucleotide. Let's look at the next slide.

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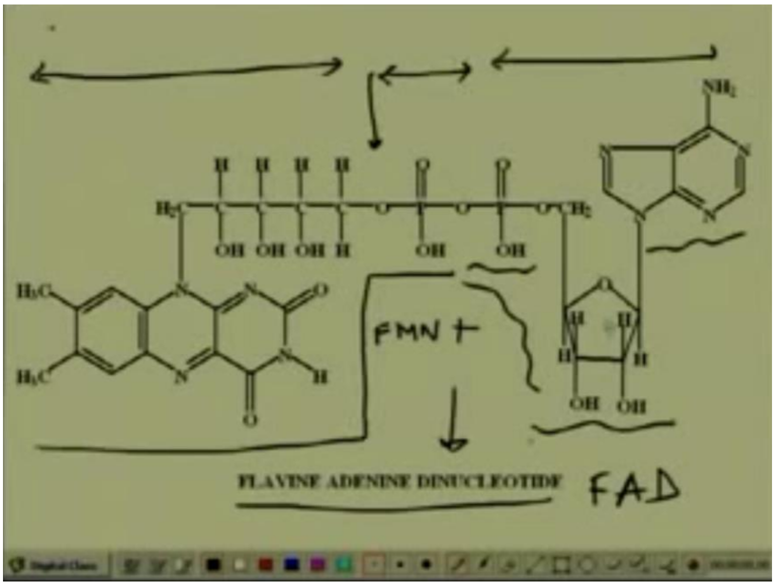

This is what we are talking about. This is our riboflavin part when this was CH2OH till here. You are now attaching the phosphate. When you attach the phosphate it becomes riboflavin phosphate that is FMN. When you attach the adenine the AMP part, what is AMP? It's adenine, sugar, the CH2 and the phosphate. It becomes flavin adenine dinucleotide. Why dinucleotide? That's because here we have 2 of these now. So, what do we have once more? When I am forming FMN, this is up to my riboflavin part, that's my vitamin.

When I take in this, it becomes FMN, riboflavin phosphate. When I consider this along with it, I have adenine, sugar and phosphate. It is AMP. So, when I have the FMN with AMP it forms FAD. So, you have the riboflavin part, the phosphate part that forms FMN. This plus this part which is AMP forms FAD. So, you need vitamin B2 to form all this. Only if you have vitamin B2 in its riboflavin part will you be able to form its phosphate, then it will be able to act with the AMP to form the adenine dinucleotide.

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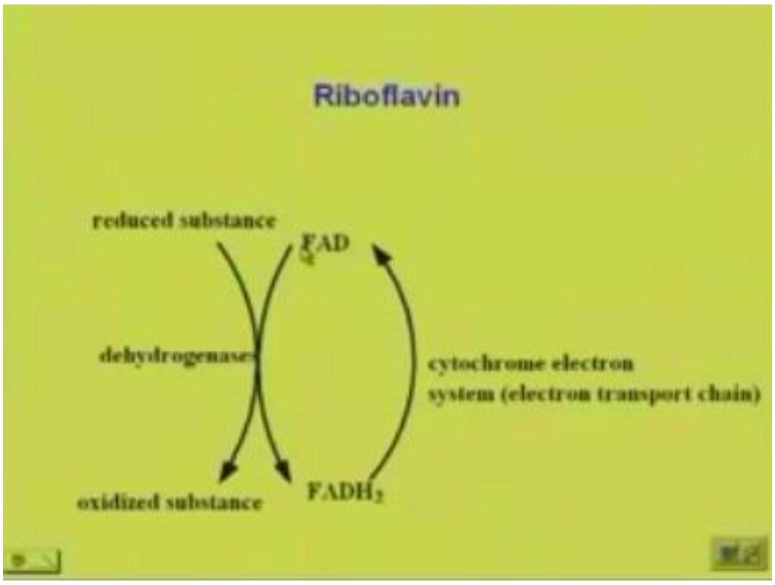

So basically, what happens is, you have an FAD. So what is FAD? This is our FAD. Now it becomes FADH2. So, it acts with dehydrogenises. You have a reduced substance that can be transformed to an oxidized substance with FAD and FADH2. Where are this hydrogen taken up, one by this nitrogen and one by this nitrogen. So, it can act as FAD, FADH and FADH2. So, it can take it up in steps which are important when you want to do certain reaction.

We will not probably go into more detail about the electron transport chain, but you have to recognize that any of these dehydrogenises because if you are taking a substance that has to release its hydrogens. The hydrogens have to go somewhere. So some moiety has to take up the hydrogen. It is this FAD that does that. It takes up the hydrogen.

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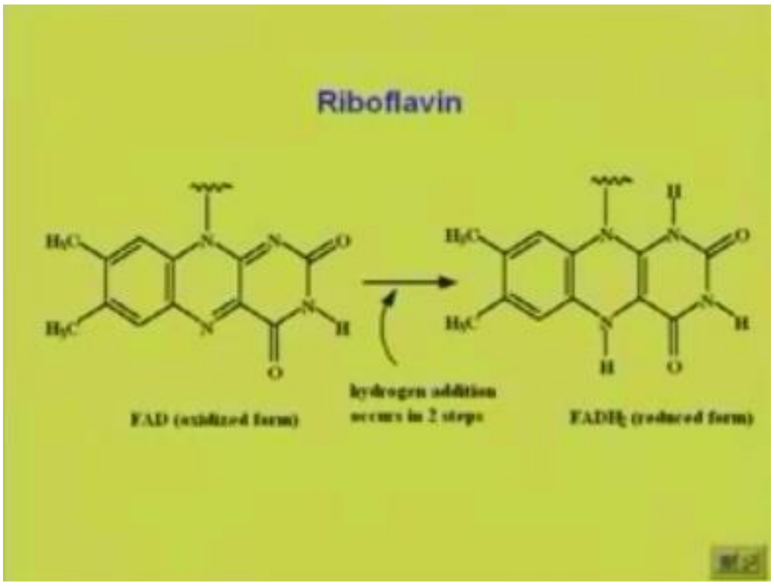

So, this is the oxidized form. This is what the isoalloxazine ring. This is the hydrogen addition that can take place in 2 steps. So, what do we have here? We have FAD that is now FADH2. Where are the hydrogens been added? They are added one to this nitrogen and one to this nitrogen. So, we have riboflavin form the phosphate, then form FAD and the FAD can add the hydrogen from any substance or any chemical moiety that is present that is going to release the hydrogen atoms. FAD will take that up and form FADH2.

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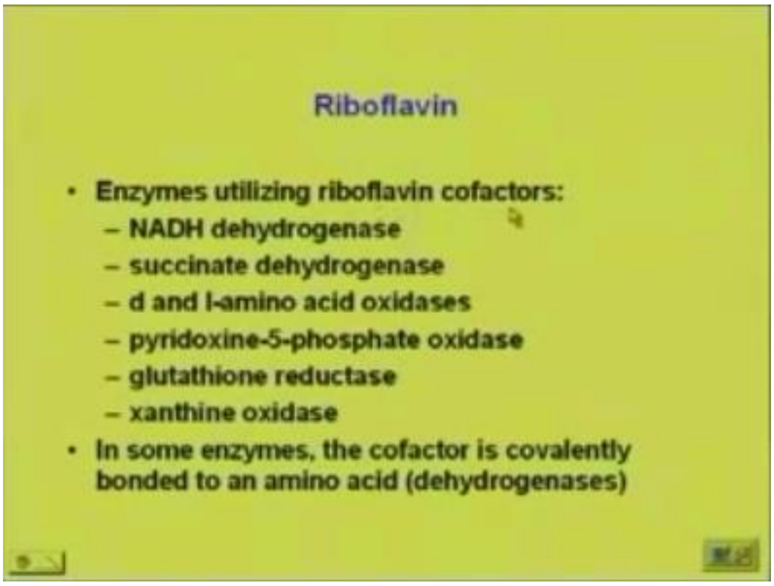

Now, these are some enzymes that require riboflavin cofactors. What are all these enzymes? They are all redox type ones like dehydrogenase, oxidase, reductase. All of these are ones that require or have to perform a redox reaction. Now, in performing the redox reaction, we need the FAD.

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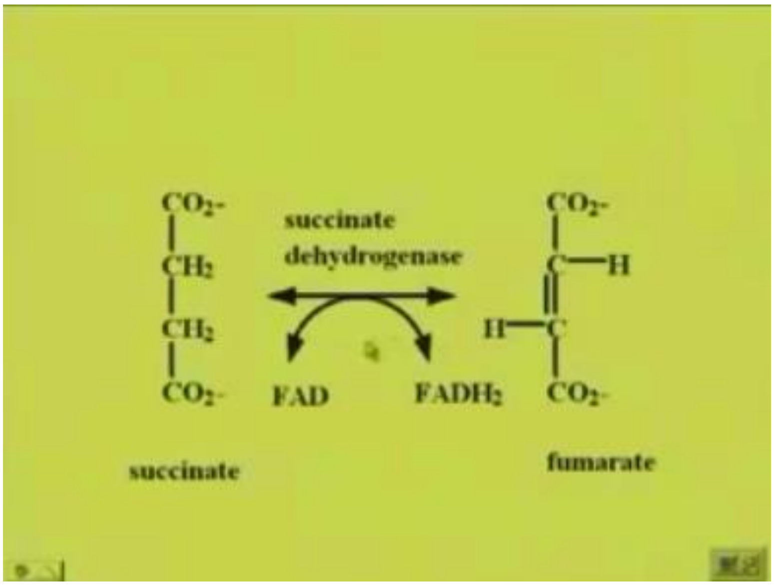

This is another one. We have succinate forming fumarate. What is happening here? It is reading itself of these 2 hydrogens. The CH2 here and the CH2 here is becoming CH double bond CH. So, 2 hydrogens have to get lost. Who is taking them up? It's FAD. FAD in conjunction with enzyme is taking up the 2 hydrogens in the process forming FADH2 and forming fumarate. So, there has to be another reaction that takes place in the enzymatic cycle that is going to do what?

It is going to transform FADH2 back to FAD. It is not this reaction that is going to do it because this reaction has already formed FADH2. But, it has to be some other reaction in the cycle that is going to form the FAD back again, because that has to be utilized by this enzyme again. It's a cycle remember. So, that is how we are going to see exactly how all of this takes place later on.

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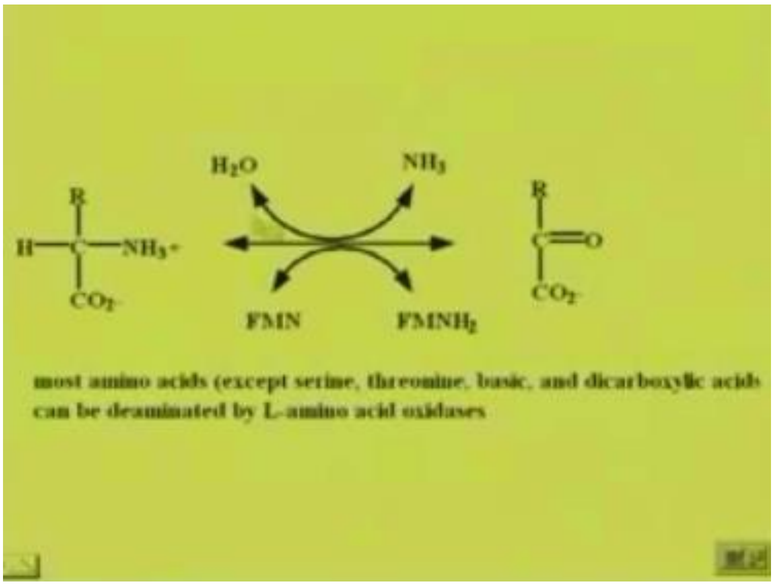

This is another one that uses FMN. What are we doing here? We are forming FMNH2, where we actually have H2O and ammonia.

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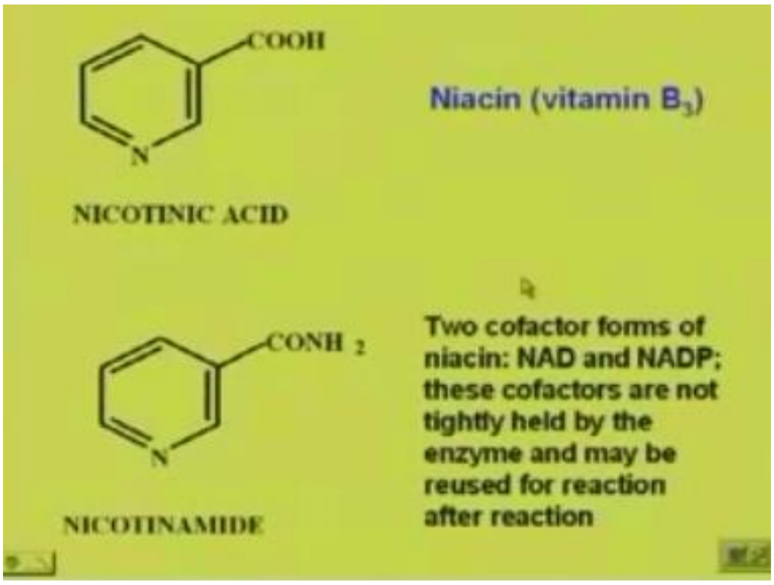

The next one is vitamin B3. This is nicotinic acid and nicotinamide. Again the 2 forms that are required here are NAD and NADP. I hope you realize that each of these vitamins are being transformed into something ok and that is what is being used by the enzyme. So, again for this vitamin, it has to be transformed to a certain cofactor and what are those cofactors? We have the 2 cofactors of the niacin are NAD and NADP. These cofactors are not very tightly held by the enzyme and they are used reaction after reaction. It is very smartly organized.

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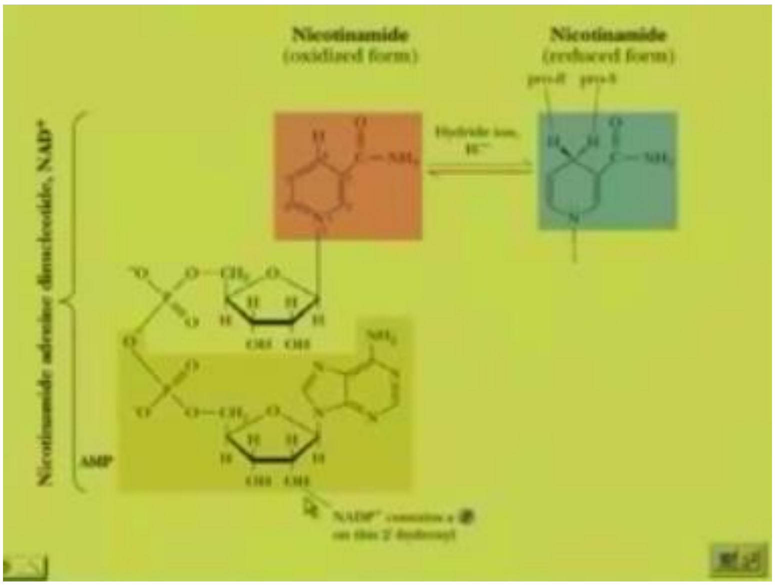

What does it look like? If you look at the name nicotinamide, this is nicotinamide. Nicotinamide A is adenine dinucleotide. This is nicotinamide adenine dinucleotide. This is the dinucleotide form because you have the base, the sugar and the phosphate. What is here is the base, the sugar and the phosphate. Nicotinamide is one adenine is the other linked by these 2 phosphates dinucleotide.

So, you have a nicotinamide that is in its oxidized form that can also be in its reduced form if it takes up an H here. So, you can have NAD and NADH. Ok If there is a phosphate at this position, it forms NADP because this already has the phosphate. If at the 2 prime hydroxyl you have a phosphate, it is NADP. So you should be able to recognize just from the structure what it is. You recognize that there are 2 nucleotides here. You recognize that this is adenine. You also recognize that this is nicotinamide.

So, this is nothing but the nicotinamide adenine dinucleotide which is NAD. If you just follow the nomenclature, you'll never go wrong. We have nicotinamide, adenine and dinucleotide - NAD. If it has to be NADP, then it is going to be phosphorylated at the 2 prime positions.

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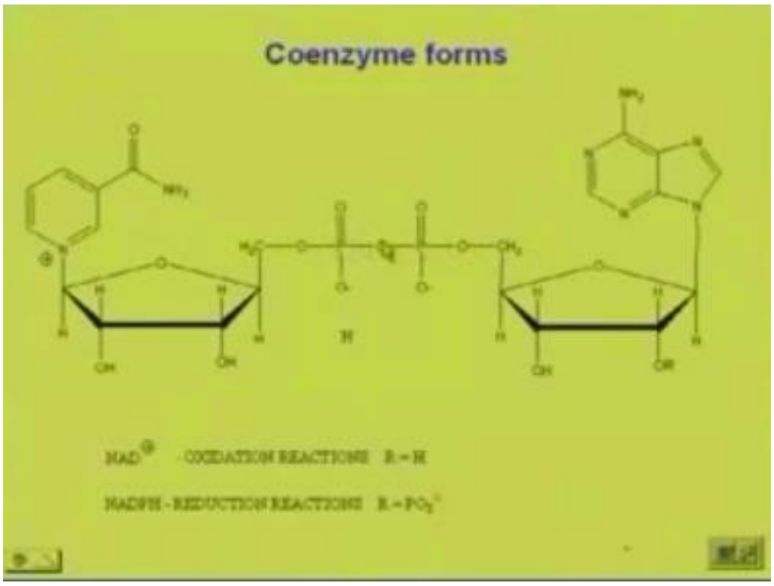

This again is involved in a bunch of reactions. So, this is what it looks like. What is this? This is nicotinamide and these are the 2 phosphates and this is the adenine. So, if you do not take in this vitamin, you do not have the nicotinamide and you cannot form the nicotinamide adenine dinucleotide and you cannot get into the reactions that it actually looks at.

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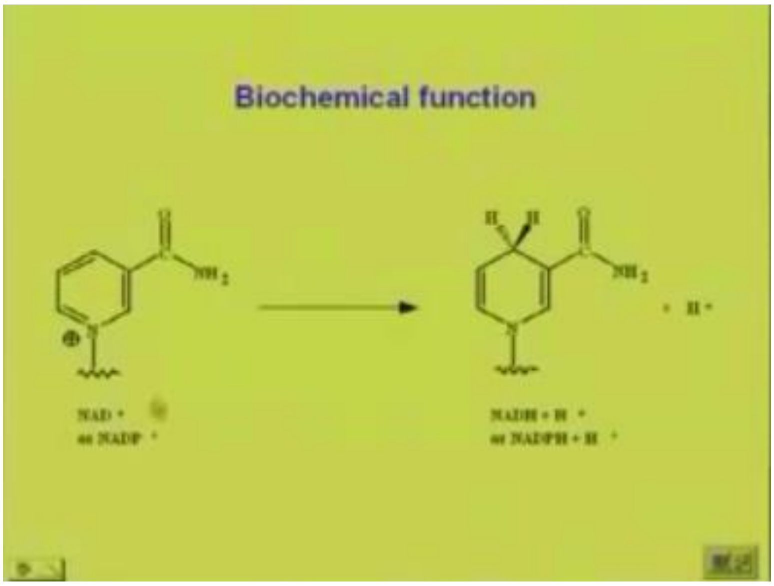

So, we have NAD+ or NADP+ that can form NADH. So, it can take an extra hydrogen at this position.

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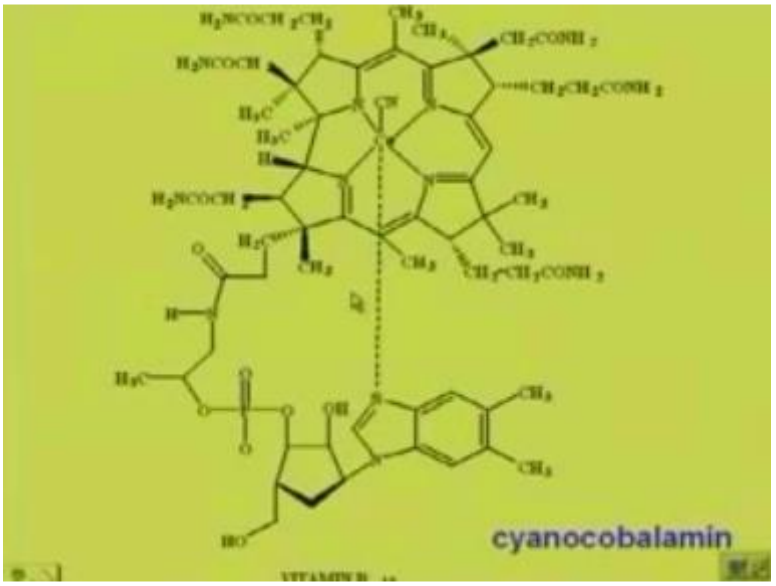

This is vitamin B12. We are not going into any of the details of vitamin B12. Just since that we are doing the vitamins, this is cyanocobalamin and it has the cobalt atom here and the cyanide group here and it has this big structure and it is vitamin B12. But, we will not look at what vitamin B12 actually does.

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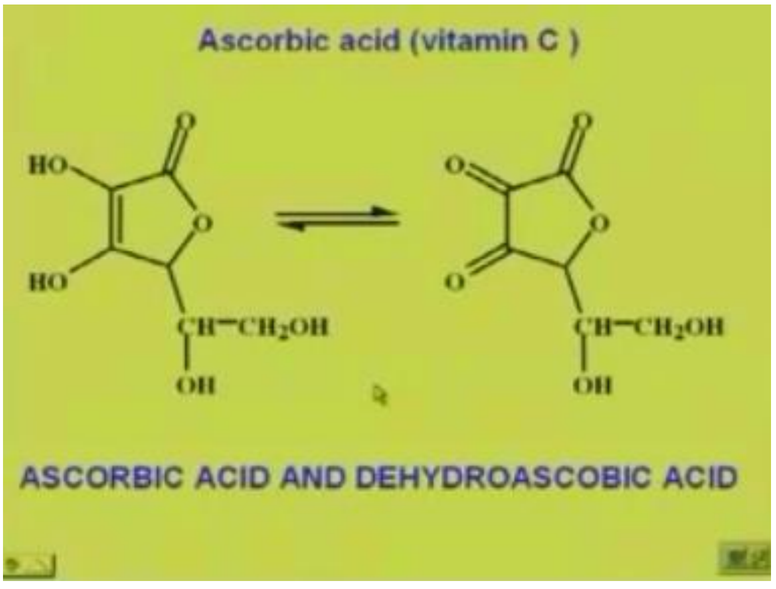

We will go on to look at vitamin C. Vitamin C is ascorbic acid. It has to be used again in some reaction. So, it has to be transformed into a cofactor. So, what we have to know is what it is going to be transformed into.

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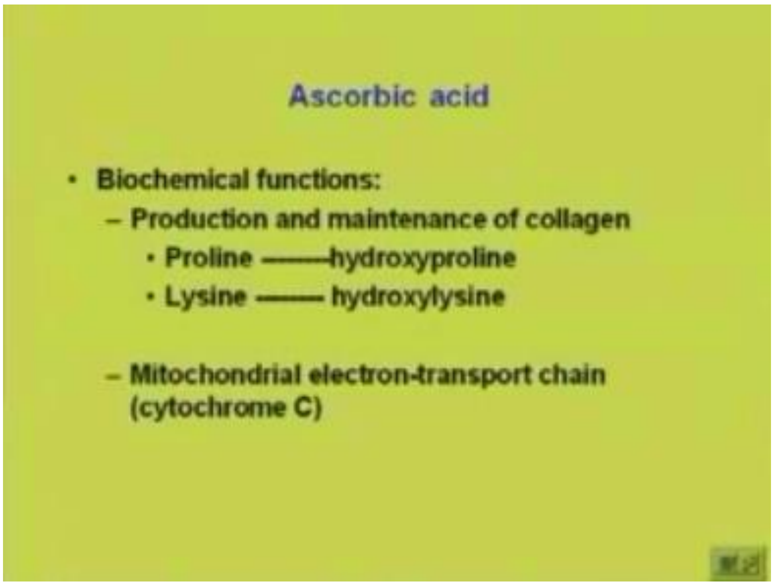

The specific reactions that it actually goes into is the production and maintenance of collagen. Collagen is required in our muscles. It forms long fibres in the muscles. So it transforms proline into hydroxyproline and lysine into hydroxylysine and it is also used in electron transport chain that is part of the respiratory chain. The usual ones that we looked at before, most of them like FMN and FAD, apart from their use in the electron transport, are mostly used in the carbohydrate metabolism, the breakdown of the carbohydrates. So, we have ascorbic acid.

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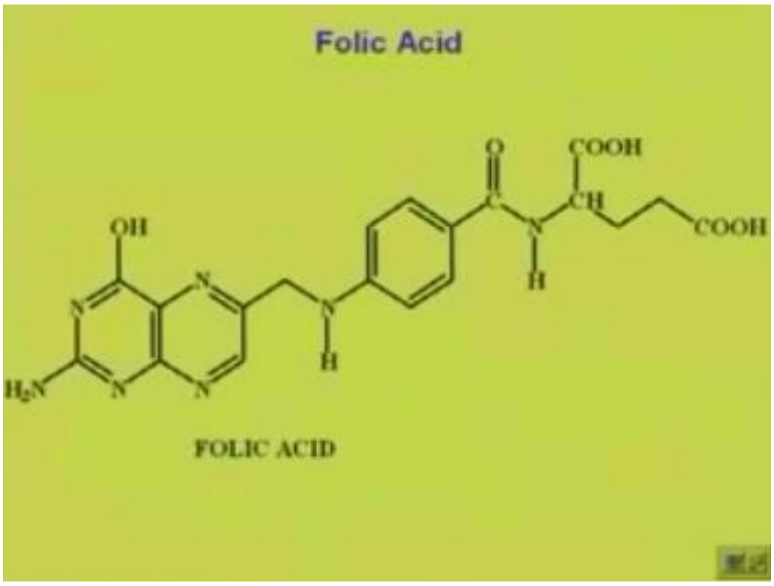

This is another one. I'm just giving you the names. As I told you, you do not necessarily need to remember the formulae, but if you just look at folic acid, if you look at this moiety you can recognize that it is part of the nucleus.

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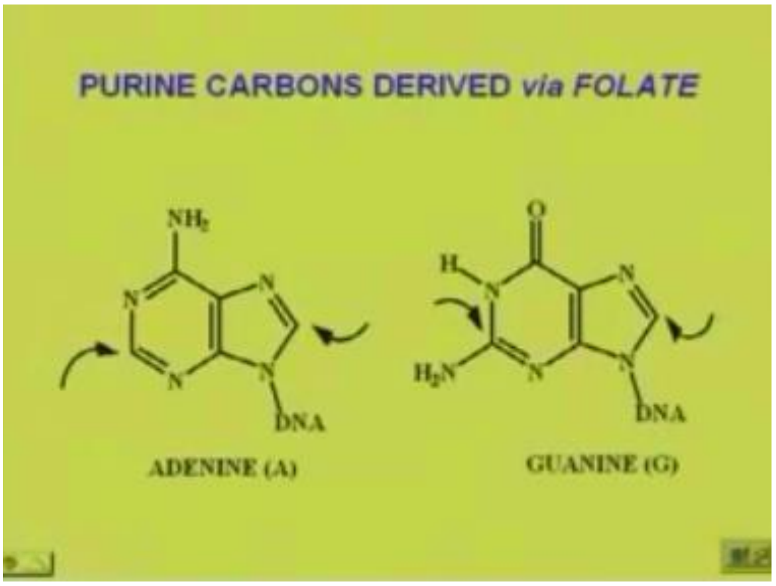

And some of the purine carbons are actually derived from the folate. So, we have adenine and guanine that are actually derived from the folate and in a set of enzymatic reactions. So, the adenine and guanine are synthesized in the body. They will link with the sugar to form a nucleoside, which will link with the phosphate to form a nucleotide, but the vitamin parts that are going to form the cofactors have to be supplemented in the diet. So, to prepare this we need folic acid. This part is made in the body, but this will be made in the body if you consume the folic acid. So, that is how these work.

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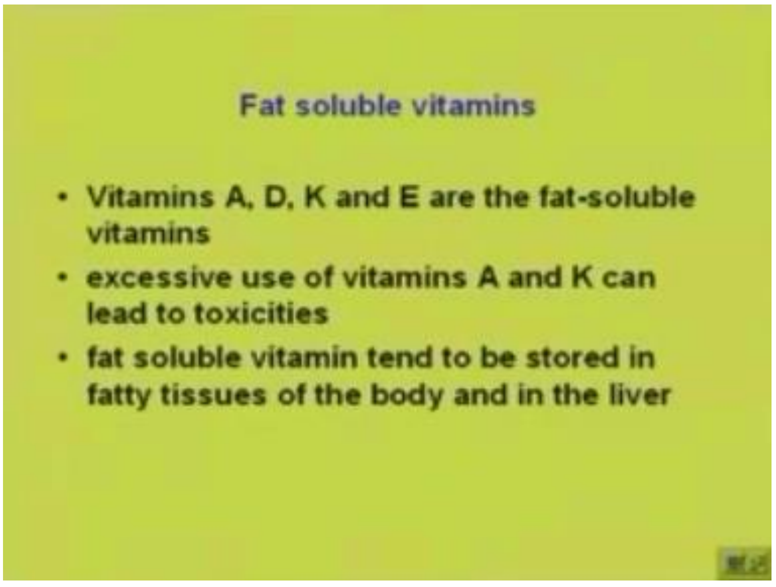

Again, we have the fat-soluble vitamins. These are soluble in lipids. Vitamins A, D, E and K and they are usually stored in the fatty tissues of the body and in the liver. So, let us look at where these will come into play.

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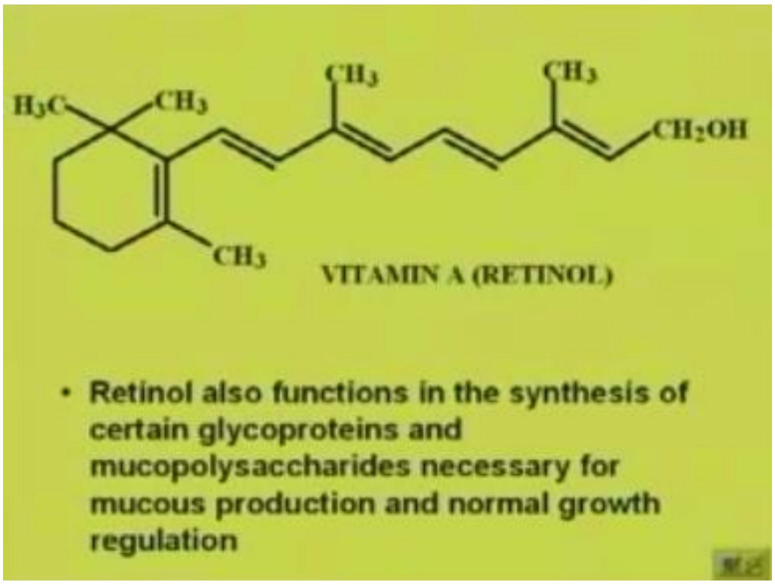

Vitamin A is retinol. It not only functions in our visual pigments, which is extremely important for our visual activities, going into the details of how that works is beyond what we have to do in this course, but again it's an extremely interesting topic as to how retinol actually is involved in the visual pigments. But, it also functions in the synthesis of certain glycoproteins.

This is something we have studied before, where we have looked at glycoproteins means we have proteins linked with carbohydrates and retinol also helps in the synthesis of those glycoproteins and mucopolysaccharides. We did hylnuronic acid, which is a mucopolysaccharides that is necessary for mucus production and normal growth regulation. So apart from its activity in visual pigments, it is also involved in the synthesis of glycoproteins.

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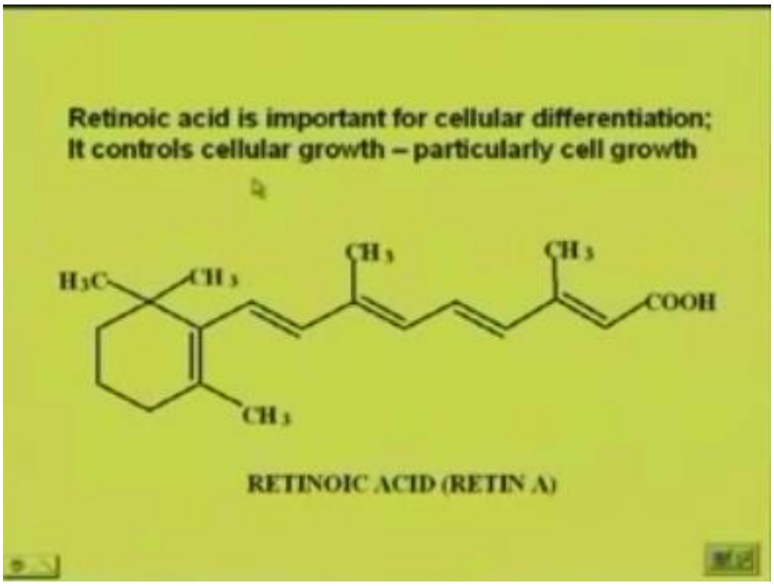

Retinoic acid is the acid form of this. This is Retinol and it forms retinoic acid. It is also involved in cellular differentiation and it controls cellular growth. You have already read that the deficiency of vitamin A is going to cause night blindness; it is good for your eyes and so on and so forth. It is also good for a number of other activities here. Vitamin A is not only involved in your visual pigments but also in your glycoproteins and in cell growth.

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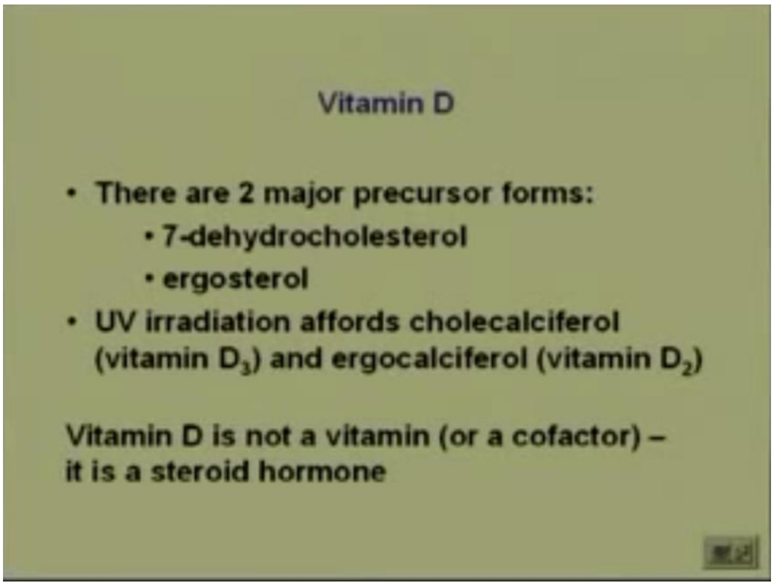

Vitamin D actually has 2 precursor forms as it is called, which is something that is prior to when vitamin D is formed. It is actually a steroid hormone and one of the precursor forms is 7-dehydrocholestrol. So, it is involved in cholesterol formation and where do we need this cholesterol? We need in the lipid membrane for the fluidity. Remember apart from the hydrophobic tails and the polar heads, there was also these additional cholesterol moieties that fitted into with the hydrophobic tails to give some sort of fluidity to the membrane.

This UV irradiation affords cholecalciferol that is vitamin D3 and ergocalciferol. So, actually in vitamin D, there are 2 precursors that are actually in the body and vitamin D is formed from this UV irradiation. So, if you sit in the sunlight or you have UV radiation basically, then these 2 precursor forms actually can form cholesterol.

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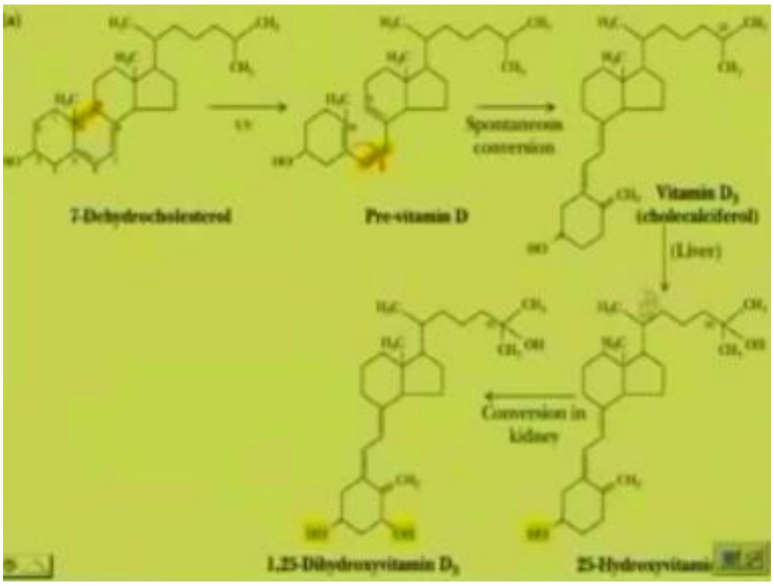

So, this is actually what happens. We have 7-dehydrocholestrol that is if you remember the cholesterol structure, this was part of the cholesterol structure, where we had the steroid nucleus and on UV radiation you get pre-vitamin D. Now, what you need to know from this is that vitamin D actually is not a vitamin in that sense or a cofactor. There is something called 7-dehydrocholestrol and ergosterol that are 2 precursor forms of vitamin D. And this is actually a steroid hormone that is required. It is formed in the liver and converted in the kidney.

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Coenzyme	Vitamin	Role
ATP	————	Energy and phosphate transfer
NAD(P)	Niacin	Redox
FAD/FMN	Riboflavin (B_2)	Redox
Coenzyme A	Pantothenic acid (B_3)	Acyl transfer
TPP	Thiamine (B_1)	Transfer of 2 C
PLP	Pyridoxine (B_6)	Amino acids
Lipoamide	————	Acyl transfer
Ubiquinone	————	Electron carrier

So, this is what we have done so far. We have looked at the structures of each of these and what you have to recognize is that for all of the vitamins that are supplemented in the diet each of them have a specific role to play. In the sense that you have niacin, what does niacin do? It forms nicotinamide adenine dinucleotide. How is that formed now? We will go one by one. Let's start with ATP. ATP means that you have adenosine triphosphate. It is not formed from any vitamin, but each of these obviously has a role.

Its role is in energy and phosphate transfer. How does it do that? That's because of each of the high energy bonds that are broken; especially the gamma phosphate bond that is broken is going to give us -30 kilojoules per mole of energy. So, this ATP that is adenosine triphosphate, where does this adenosine come from? It is one of the adenine base, which is nitrogenous base belonging to the purine family that is going to be linked to a ribose sugar, which means we are going to have something that looks like this.

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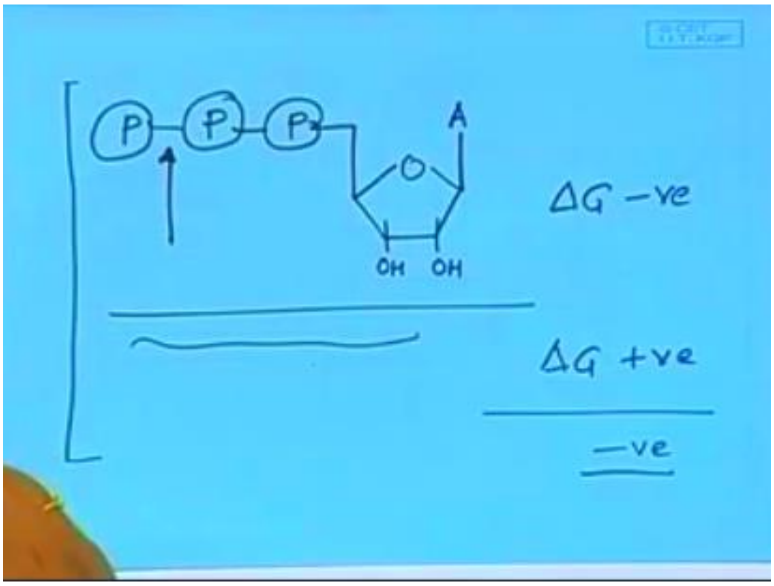

We have our ribose sugar which has the OH and the OH and we have our base linked here. So, this is where our adenine is linked. And to this we have our 3 phosphates. We have 1, 2, and 3. Now, what happens is this breakdown is going to result in a delta G that is negative. So, what usually happens is this is coupled with another reaction that has a delta G positive, so that, the overall is a negative, making this non-spontaneous reaction a spontaneous reaction. This will be very clear, when we do the bioenergetics and you will see how cleverly the reactions are coupled together.

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Coenzyme	Vitamin	Role
ATP	————	Energy and phosphate transfer
NAD(P)	Niacin	Redox
FAD/FMN	Riboflavin (B_2)	Redox
Coenzyme A	Pantothenic acid (B_5)	Acyl transfer
TPP	Thiamine (B_1)	Transfer of 2 C
PLP	Pyridoxine (B_6)	Amino acids
Lipoamide	————	Acyl transfer
Ubiquinone	————	Electron carrier

The next one that we looked at was niacin. What is niacin? We require niacin to form nicotinamide. Nicotinamide is then going to link with nicotinamide adenine dinucleotide. You see how adenine comes into the picture a number of times. Riboflavin has the isoalloxazine group to it. When it is phosphorylation it forms riboflavin phosphate, which is

FMN. This linked to adenosine monophosphate ANP gives FAD. NAD and FAD are each involved in redox reaction because they can take up hydrogen atoms.

FAD can do it in 2 steps. So, we can have FAD and FADH2. So, we can have CH2CH2 single bond to form CHCHCH double bond CH, just because it can and the hydrogens has to go somewhere. Pantothenic acid was involved in coenzyme A and acetyl coenzyme A. What does that do? It has an important proline acyl transfer. Thiamine is involved in the transfer of 2 carbons or we can have the CO2 transfer there. How is pyruvate formed? Acetaldehyde. That is by a certain enzyme that would use TPP.

Using TPP means you have to have thiamine to form TPP, again vitamin B6, pyridoxine which will form pyridoxal phosphate which is used in amino acid isomerization. So, each of the vitamins that we have a role in the formation of cofactors and coenzymes. Once these cofactors are formed, we didn’t mention biotin in this list, but biotin is also there, which is the prosthetic group that links to the enzyme.

Then, together with the enzyme it performs the enzymatic function. And that completes our discussion on vitamins and coenzymes. We will go onto nucleic acid structures in our next class followed by bioenergetics and metabolism of carbohydrates. Thank you.