Biochemistry - I

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Lecture#19
Vitamins and Coenzymes-II

We continue our discussion on vitamins and coenzymes. What we learnt yesterday was how these vitamins were actually transferred into cofactors that are utilized for the enzymes to go through their enzymatic mechanisms. Most complex enzyme would have a cofactor or a prosthetic group of coenzyme which could be a metal ion or a small organic molecule. These vitamins are transformed to the small organic molecules that are going to use for the enzymatic reactions.

What we have here is, we considered some of the vitamins, we will go through all the rest of the ones today where we have a certain important role that each of these play. ATP is an extremely important coenzyme that helps in the non spontaneity of some reactions that actually have a $+\Delta G$. But the high phosphate or high energy phosphate bond of ATP when broken gives a sufficient amount of negative free energy that compensates for the $+\Delta G$ for a certain reaction.

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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

Any reaction that requires ATP, will break that high energy phosphate bonds into forming ADP and P_i and depending on whether there is a pyrophosphate required. It will then breaks and form into 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 the bio energetic processes, because each of these steps has redox reactions, certain enzymes that are used for this redox reactions. We will see how these vitamins are transformed into the coenzymes which can then be utilized for those reactions. We have coenzyme A which is another very-very important coenzyme. It is formed from pantothenic acid and it is involved in acyl transfer. Then we have the thiamine which we just started of yesterday then pyridoxine that is involved in amino acids isomerization.

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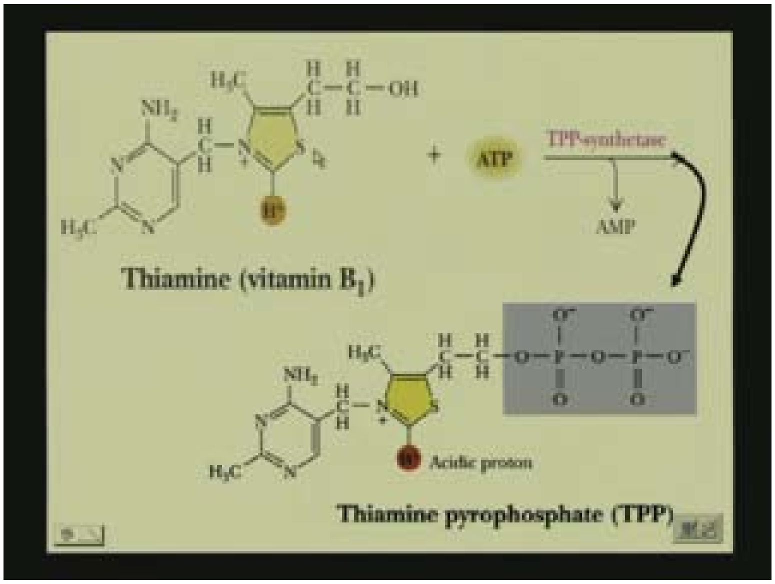

This is something that we looked at in our last class where we have thiamine that has to be transformed to thiamine pyrophosphate for its activity. As thiamine, enzyme cannot use this as it cofactors so it has to be transformed. It has to be transformed by TPP synthatase which is nothing but thiamine phrophosphate synthctase. This is thiamine, pyrophosphate means it has 2 phosphate groups attached to it and since it has this phosphate it is obtained from ATP.

ATP is in the process transformed into AMP. 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 reactions also a trans ketolase reaction. What we need to know is how later on when we get into the carboxylic cycle, we will see how pyruvate decarboxylase is required and in this case we will have TPP assist the enzyme in performing its activity. So basically a reaction like this where you would have pyruvate acid and pyruvate decarboxylase which means that the CO_2 is eliminated from the pyruvic acid forming acetaldehyde.

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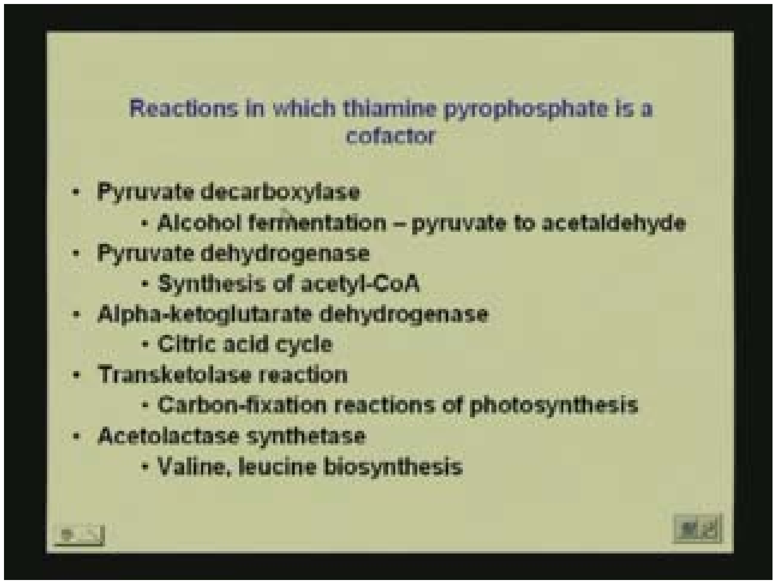

This reaction or this enzyme cannot act without TPP. TPP cannot be formed without thiamine. That is the way the vitamins work so thiamine is transformed to TPP, TPP is utilized. This is one of the reactions where it is utilized for the decarboxylase activity, decarboxylation of pyruvate to form acetaldehyde. You recognize that this is the break down. You are breaking things down and metabolizing these processes. This is another one where you are forming acetolactate synthase, so you are forming acetolactate by the elimination of CO_2. Again this reaction requires TPP or this enzyme rather requires TPP for its action.

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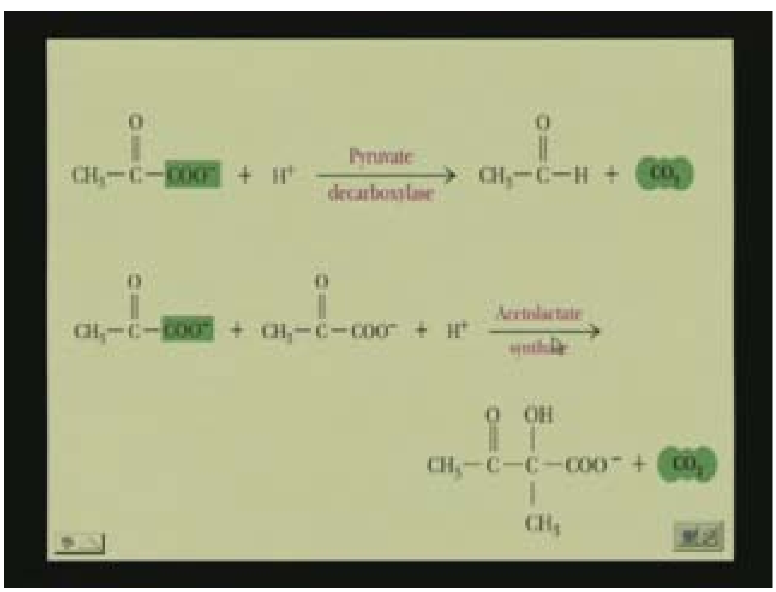

If we get into the next family of vitamins, vitamin B_6. This vitamin again would be a small organic molecule that again has to be transformed into the cofactor that is in the process in turn going to be used for an enzymatic reaction for its mechanism to take place. PLP is a prosthetic group for enzyme that catalyzed reactions that involved amino acids metabolism. You would have amino acids isomerization, amino acids decarboxylation, side chain elimination or even replacements.

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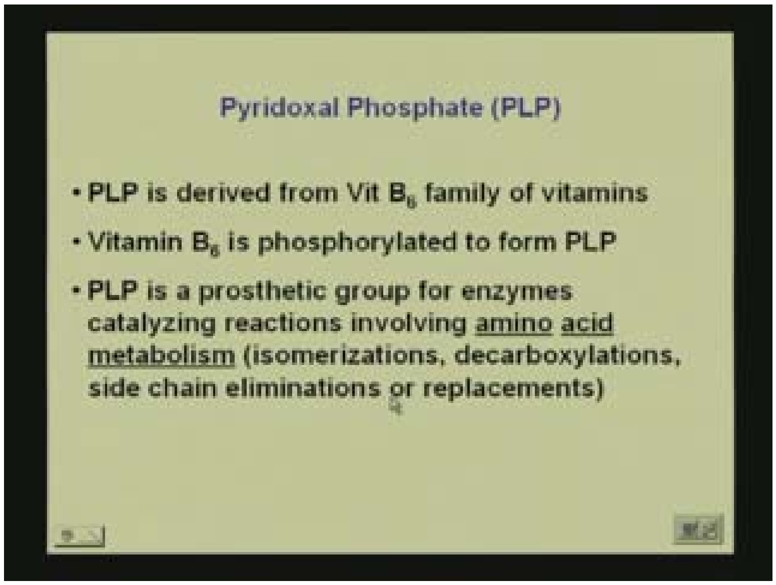

Because you recognize that the amino acids are synthesized in the body so there are certain enzymes that are going to be responsible for the synthesis of these amino acids and these enzymes require pyridoxal phosphate. If you look at the pyridoxal phosphate, this is the pyridine derivative. You recognize the pyridine moiety here and this is pyridoxine, the specific group attached to the pyridine nucleus. The pyridoxal and the pyridoxamine, these are the three forms of pyridoxine that are used in as cofactors in the enzymatic reactions. We have pyridoxine which is a pyridine derivative. We have several different groups. This is the pyridoxine that has the CH_2OH here, it forms pyridoxal where this is CHO the aldehyde and this conform pyridoxamine where it is CH_2NH_2. The rest of the substituents remain the same. We basically have the pyridine derivative.

The biochemical functions of this are actually able. We will not going into details of how it actually does this but as I mentioned in previous slide where it is involved in amino acid metabolism, isomerization, decarboxylations. This role of pyridoxal phosphate is mainly to do with amino acids. Any reaction that would involve amino acids metabolism, isomerization or breakdown of amino acids would require this PLP pyridoxal phosphate.

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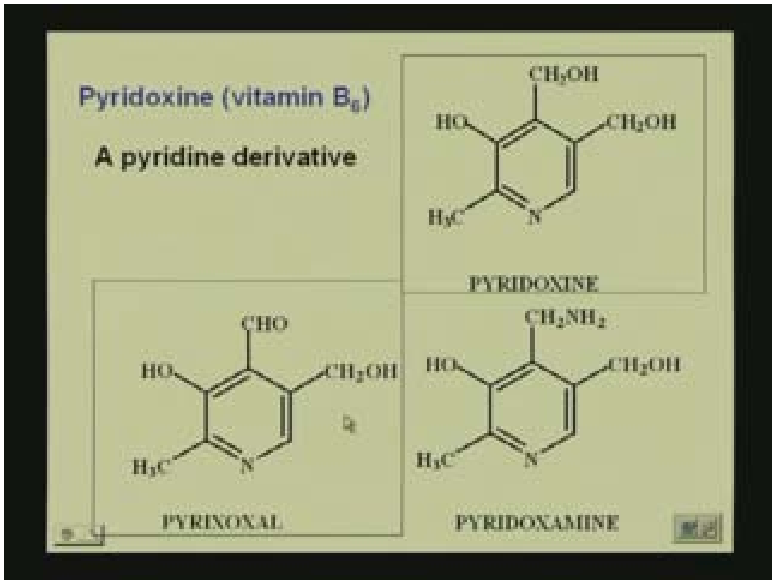

This is the pyridoxal phosphate which you recognize here. After this formed a phosphate it becomes pyridoxal phosphate. Again for the pyridoxal phosphate to form you have to have the pyridoxal. Pyridoxal will form the pyridoxal phosphate. It is that PLP which will be used by the enzyme for the amino acid break down. This is the way, so you have to recognize how each of the vitamins not by themselves are used by the enzymes but after being transformed in some manner is used by the enzymes.

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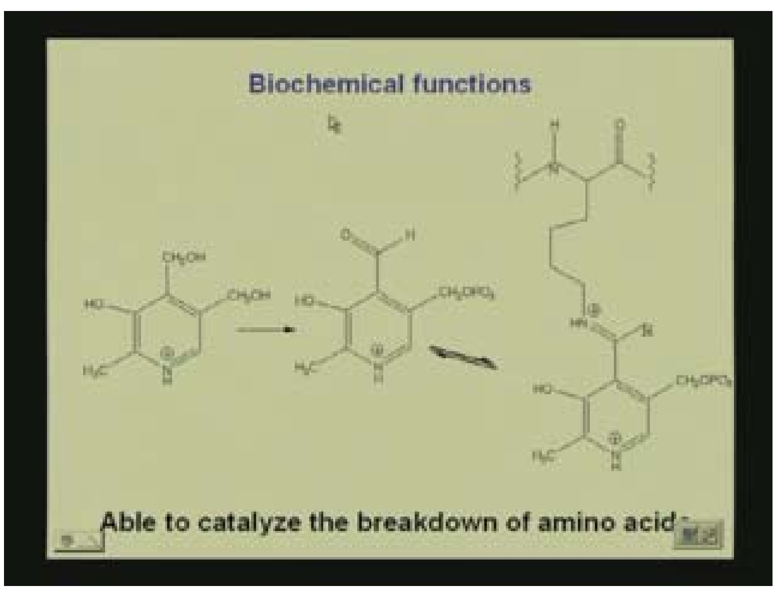

This is the other one. We have vitamin B_7 (biotin). Biotin actually is required, it has to be supplemented in the diet but it is required in small amounts because intestinal bacteria actually make biotin. You do not have to have as much biotin in your diet and there is a protein called avidin in raw eggs which binds biotin extremely tightly. As a result of which it makes biotin unavailable for its enzymatic specific reaction. When this avidin protein binds to biotin, makes biotin less available for its particular reaction. If you cook an egg, which is why we should not have raw eggs, if you cook the egg you denature the protein, you denature avidin and it does not bind biotin anymore. Biotin is available for the enzymatic reaction but it catalyzes. What are these reactions that it catalyzes? We have biotin a prothestic group. What do we mean by prothestic group? It is the group that attaches covalently with the enzymes. That is what a prosthetic group.

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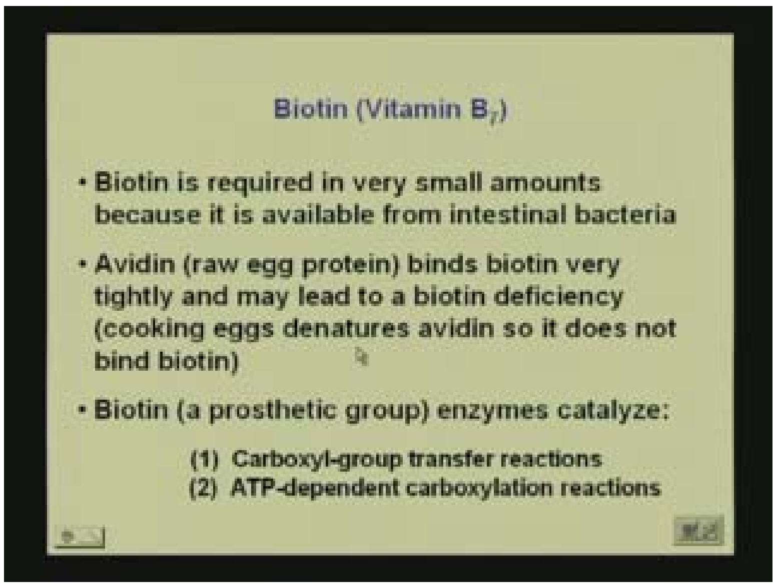

This biotin actually catalyzes two sorts of reactions; one is the carboxyl group transfer reaction where as the name specifies it is possible for the transfer of a carboxyl group. We also have carboxylation reactions where we have ATP dependent carboxylation reactions. Again biotin actually is required in very small amount because it is made by intestinal bacteria, and again it is bound tightly by avidin that mainly to biotin deficiency. It being a prosthetic group and it catalyzes after it is linked with the enzyme. It catalyzes carboxyl group transfer reaction and ATP dependent carboxlylation reactions. So how does it work?

Biotin is actually linked by an amide bond to the epsilon amino group of a lysine residue. What is that? It is this one in blue here is the protein. This is the NH_2 group of lysine. You recognize the side chain $CH_2CH_2CH_2CH_2$ and NH 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 linked to lysine. Where is this lysine? This lysine is in the protein.

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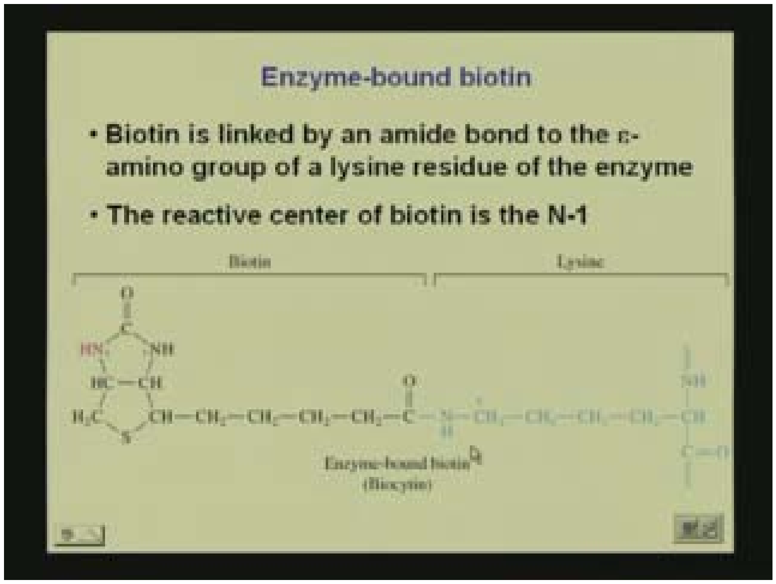

Whatever enzyme that is going to be acted up on, whichever enzyme actually has to perform its function that requires biotin, will link with biotin and then have the biotin performed its function. You have to recognize again that the vitamin biotin is required. What it is going to do? It is going to link 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 coenzyme or cofactors of prosthetic groups that assists the enzyme 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 reactions.

For example; if we look at the reaction that is catalyzed 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 lysine residue in the enzyme. 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. 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 recognize where each of these enzymes come into play.

Because they are going to be different steps in the reaction. These different steps obviously have different enzymes and these different enzymes in turn have different cofactors the presents of which will then allow the enzymatic activities to take place. What happens here is you have a bicarbonate and you have the biotin that is linked to the enzyme. Where it is linked? It is linked to the lysine. It is linked here. What is going to happen here? There is going to be an elimination of the OH, once because this is the reactive centre. This nitrogen is the reactive center, it will act on this carbon forming carboxybiotin eliminating the OH from the bicarbonate.

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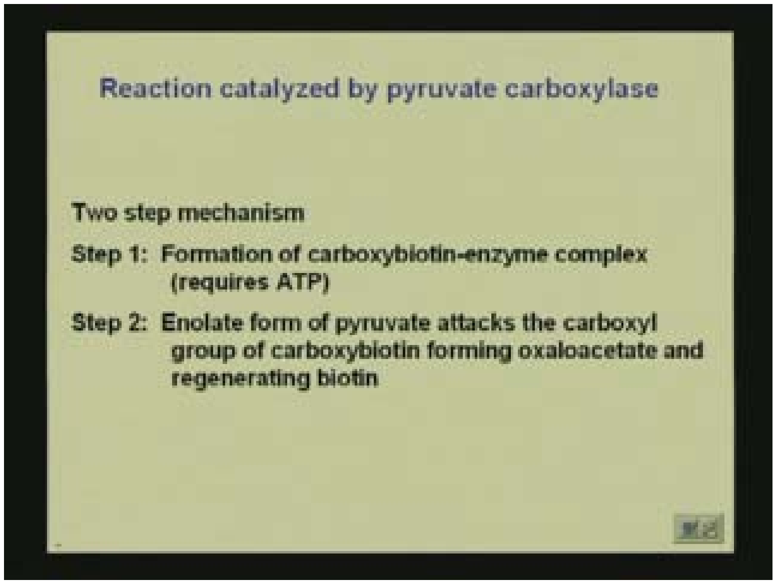

That is the first step so after the biotin has linked with the enzyme, you have the bicarbonate ion here. This is the reactive nitrogen of the biotin that is going to form carboxybiotin. What is that look like? This is what carboxybiotin is (Refer Slide Time: 15:40). How did it form? It formed after the elimination of OH. How did that form? From the lone on the nitrogen present here.

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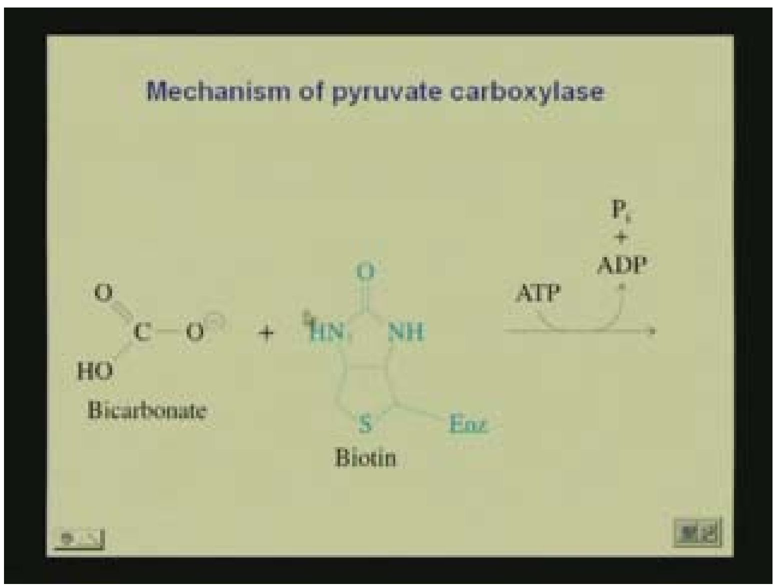

It acts on this carbon eliminating the OH. Once that happens you have carboxybiotin, now this carboxybiotin is now, this is enol pyruvate. It is the enol form of pyruvate. What is pyruvate? It is $CH_3COCOOH$. This is the enolic form of the pyruvate.

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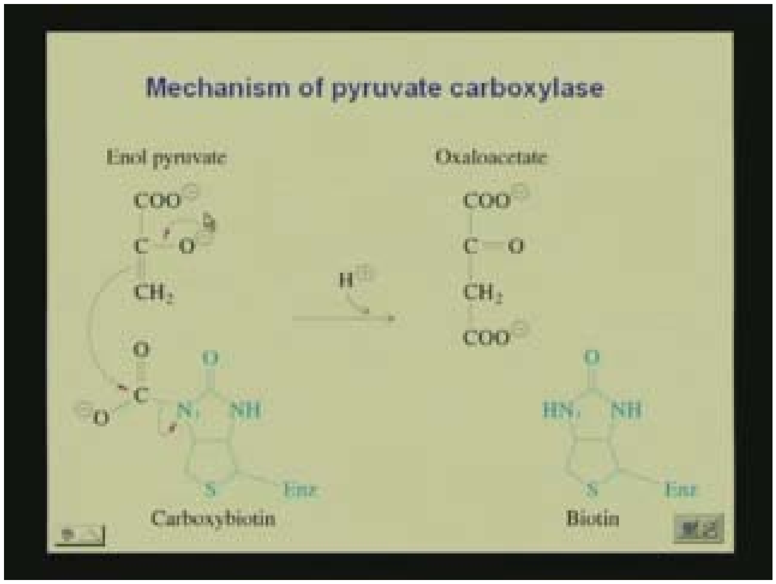

What is happening now? There is going to be the formation of oxaloacetate. What do we have? We have an additional carbon addition. It is a carboxylase that is acting into adding a COO^{-} to enol pyruvate. So what you are doing? You recognize that, this is synthesizing some thing. This biotin is in conjunction with the enzyme. The enzyme alone cannot do this. It has to have the biotin for this particular reaction to occur. Once this reaction occurs, this takes up the extra carbon and forms oxaloacetate. What does happen to the biotin on the enzyme? It is back to where it is started from.

But you have to recognize it exactly like the enzymatic mechanism. The only thing that you need additional prosthetic group in this case for the action of the enzyme, that is the difference in all of these cases. As you recognize, each of the vitamins are required for a particular reaction to take place. So what is the next one? Pantothenic acid. This is vitamin B_5. We are not going in specific order like 1, 2, 3, 4, 5 and 6 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. It is used in a lot of the carbohydrate metabolism cycles. There we have the tricarboxylic acid cycle and pentosephosphate cycle. There are glycolysis, all of these cycles that actually break up glucose or break up carbohydrates into forming small molecules that are again utilized for the synthesis in different other cycles to prepare the amino acids or other proteins that are required in the body. This pantothenic acid, the formula which is given here it serve in the activated form as again the cofactor for coenzyme A and also for the acyl carrier protein (ACP). The acyl carrier protein or coenzyme A also is one that transfers an acyl group. Transferring an acyl group means you are transferring CH_3CO which means you are transferring two carbon atoms at a time.

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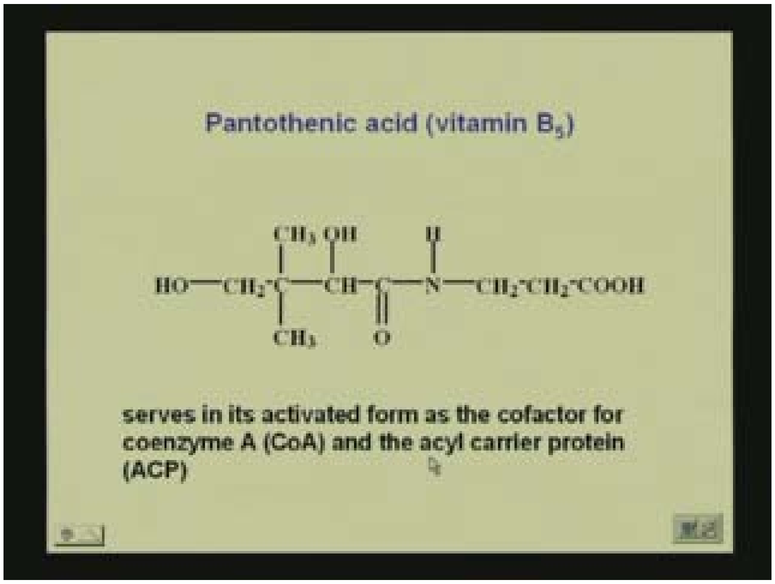

If you are synthesizing a fatty acid, remember I told you that they are always synthesized by two carbon atoms at a time. This is where some of these coming into play. This is what is coenzyme A. You recognize that this is the sugar, this is a base and it has the pantothenic acid part on the top. What is the pantothenic acid part? This is the pantothenic acid part, the CONH. The way we actually considered it is we just put this wavy line here because this is common and we write this as acetyl CoA. This $COCH_3$ at the end of acetyl CoA, what is transferred. So it is involved in a lot of acetylation reactions where you are transferring two carbon atoms. So this is the structure of coenzyme A. What we need to know is this is SH, this become acetyl CoA where the H has been replaced by $COCH_3$.

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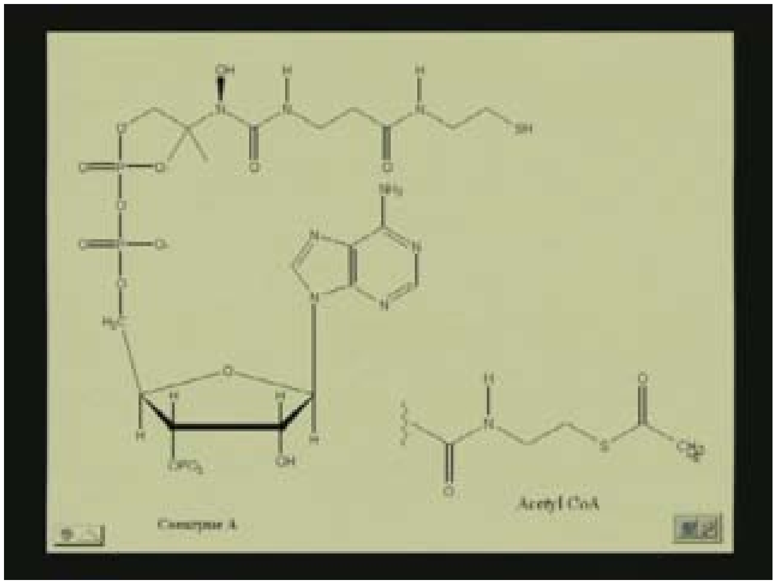

You see this $COCH_3$ that has replaced this hydrogen of coenzyme A. Coenzyme A comes into the picture. How do you get coenzyme A? If you use pantothenic acid. Pantothenic acid in its activated form is part of coenzyme A that then forms acetyl Co A as it is called and this is involved again in number of reactions. What are these? Coenzyme A, it performs a vital role by transporting acetyl group 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 one that we looked at we were transferring only COO^-, that was 1 carbon. You went from enol pyruvate to oxaloacetate in this case you can go by two carbons because you are transferring an acyl group.

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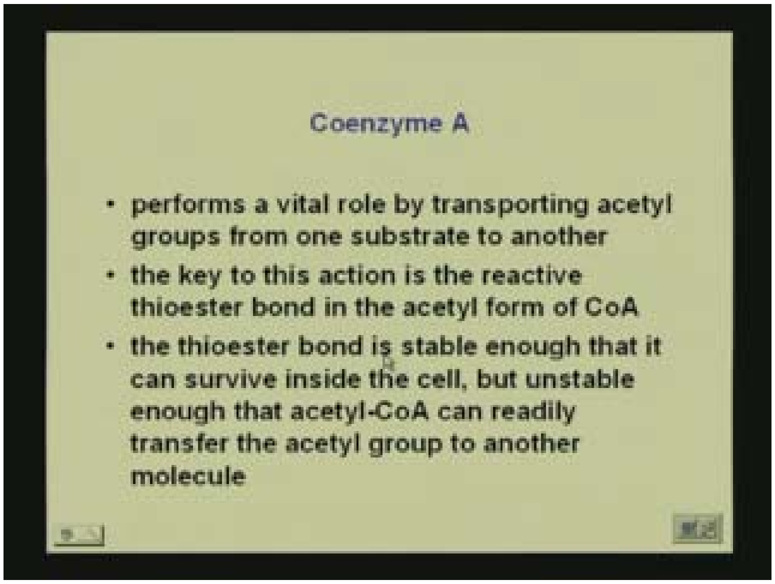

The key to this reaction is the reactive thioester bond in the acetyl form of CoA. This is thioacetyl bond. What is an ester bond? COO or SCO, so it is this ester. This is important, is stable enough so that it survives in the cell but at the same time it can also be broken up under suitable conditions to give the CH_3CO. It is extremely important in the way the enzyme would work into either breaking it up to get the CH_3CO or at the same time surviving inside the cell so it can be taken up by this specific enzyme as and when required.

For example; Acetylating reaction. We have heard about choline, when we did the fatty acids and the tri glycerol phospho phospoglycerides. This is the choline. We had phosphadylcholine that formed a part of a polar head group to a lipid, when we have a hydrophobic tails that are formed by the 2 fatty acids and we have the polar head groups. It was this choline that was at a time, one of the polar head groups for some of the phosphoglycerides. This forms acetylcholine, acetylcholine is an extremely important neurotransmitter. It transforms most of the messages to the brain for whatever activities are going on.

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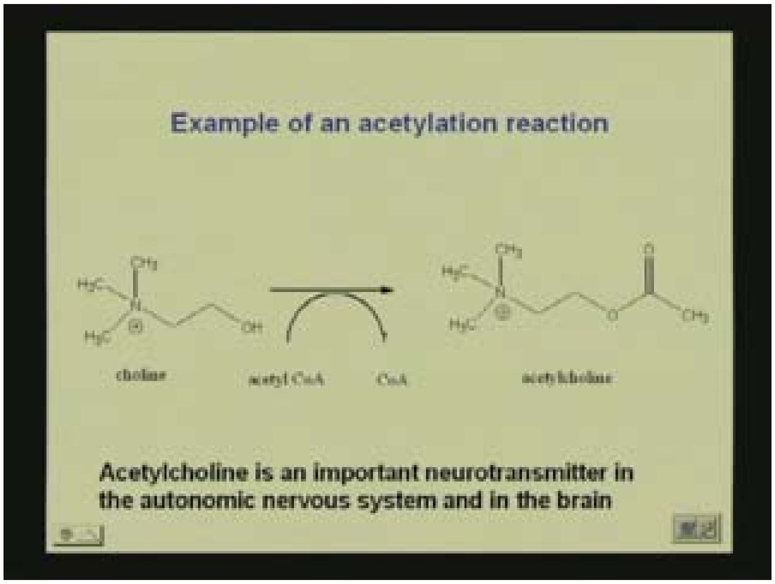

The choline that is present can be transferred to acetyl choline by acetylcoenzyme A, that transfers its acetyl group to acetyl choline in the event becoming coenzyme A. You recognize that the choline being presented with acetyl Co A will form acetyl choline, that as I mention is an extremely important neurotransmitter in our nervous system. It helps in the transmission of messages that is completely an other chapter and in the extremely interesting as to how messages go from one, they are all neurotransmitter, we have chemical messenger and these are the chemical messenger that actually takes the message from other parts of your body to your brain. Vitamin B_2 is riboflavin what we have here is heterocyclic flavin. We will see that is in a moment linked to ribose analogous to the nucleosides in RNA.

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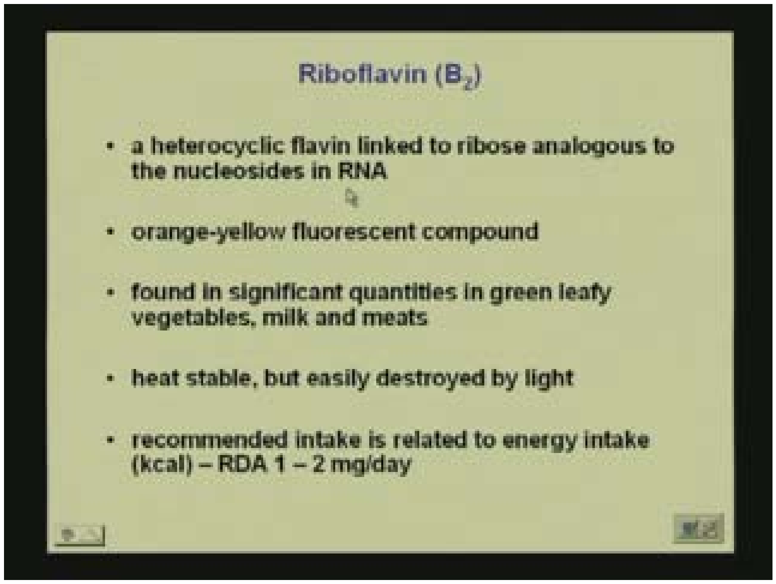

We know what nucleoside is. What is a nucleoside? You have a sugar linked to the base that is the nucleoside. It becomes the nucleotide as soon as you have a phosphate linked to it. It is an orange yellow fluorescent compound found in green vegetables milk and meats. It is heat stable but destroyed by light. We have an RDA that is recommended daily or dietary allowance which is so many milligrams per day. We have to be interested in this structure of riboflavin. This is what is riboflavin. It is called a dimethyl. You see here isoalloxazine.

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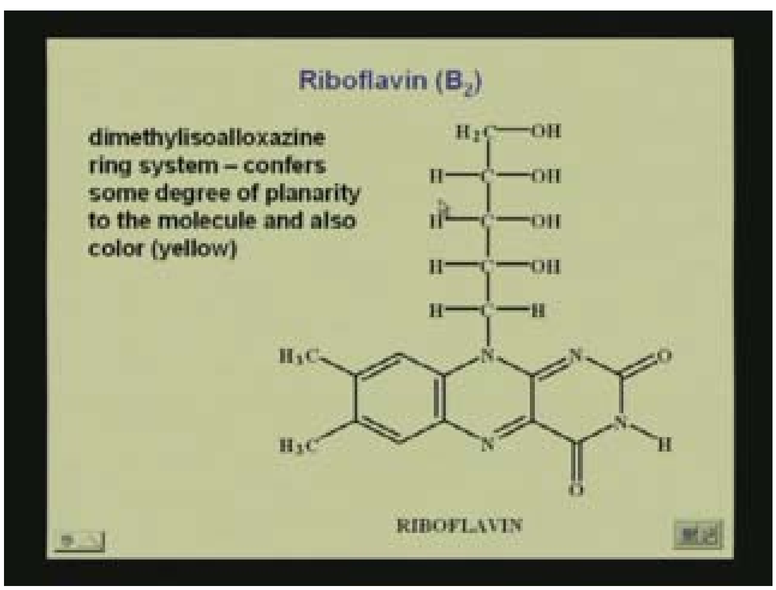

This is the isoalloxazine ring system and this imparts the planarity to the molecule, you have benzene moiety here. This you know is planar so imparts some planarity to the molecule and because of the large number of nitrogen atoms here, it also has the yellowish color to it. This is what is called dimethylisoalloxazine ring system and this is your riboflavin (Refer Slide Time: 26:24). This is the vitamin. What do we have to do the vitamin to get it to act? It has to be transformed into a cofactor, only if it is transformed to a cofactor, it can then help an enzyme to perform it specific function.

Now we are going to see how this can be transformed into a cofactor that is going to be of any use to the body or to the specific enzyme that are going to need riboflavin. There are two cofactors actually involved. These cofactors are extremely important in some of the glycolysis or glycolytic reactions that take 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 the phosphate. We have flavin adenine dinucleotide. What is adenine? 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 that we will study after we when do our bioenergetic part.

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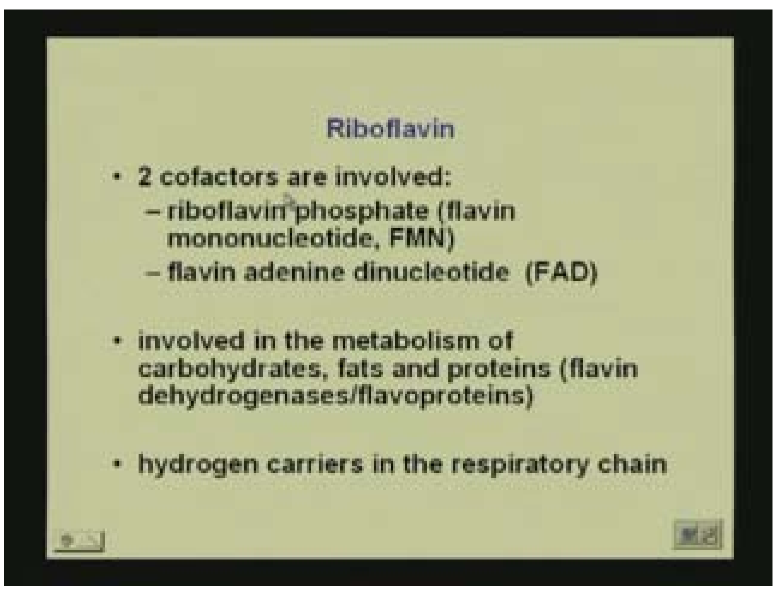

It is involved in the metabolism of carbohydrates fats and proteins so this vitamin is required for the breakdown for a lot of dietary constituents. They also act as hydrogen carriers in the respiratory chain so not only do they act as metabolism of the carbohydrates, fats and proteins they are also involved in hydrogen carriers in the respiratory chain. If you just go back to the structure once more. This is your riboflavin which is vitamin B_2 the two cofactors that it actually forms FMN and FAD. These are what are going to be required in the specific enzymes that are involved in these processes. What do we have? This is your isoalloxazine group. This is riboflavin.

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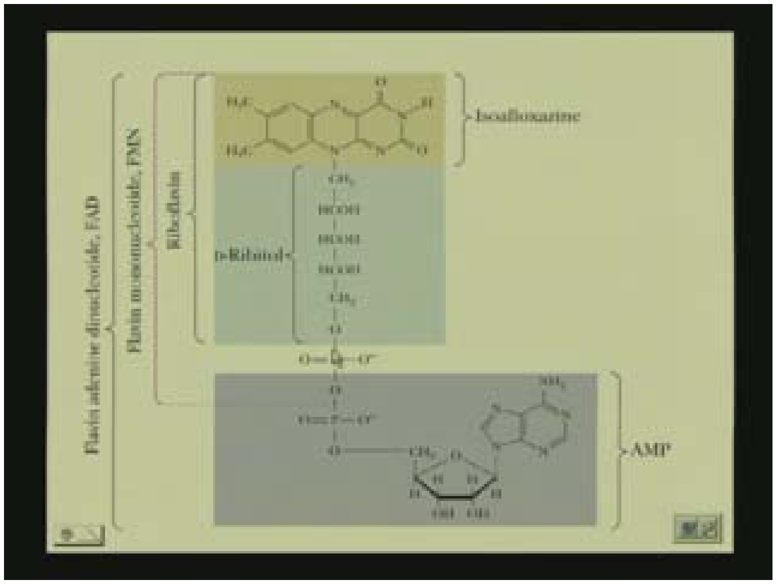

This part, the one in yellow and blue together. Then when you have a mononucleotide attached to the riboflavin, you see a phosphate. I have a clearer picture on the next slide. The picture here is that you have a phosphate; you have the riboflavin attached to the phosphate. riboflavin phosphate. Riboflavin phosphate is the phosphate attached here, if the phosphate is attached here this becomes riboflavin phosphate that is also known as flavin mononucleotide FMN.

When you attach this to adenosine monophosphate (AMP), you have the adenine ring here, the ribose sugar and nucleotide with the phosphate here. This becomes flavin because this is the flavin part adenine dinucleotide. Let us look at the next slide; this is what we are talking about. This is our riboflavin part when this was CH_2OH till here; you are now attaching the phosphate. When you attach the phosphate it becomes riboflavin phosphate that is FMN.

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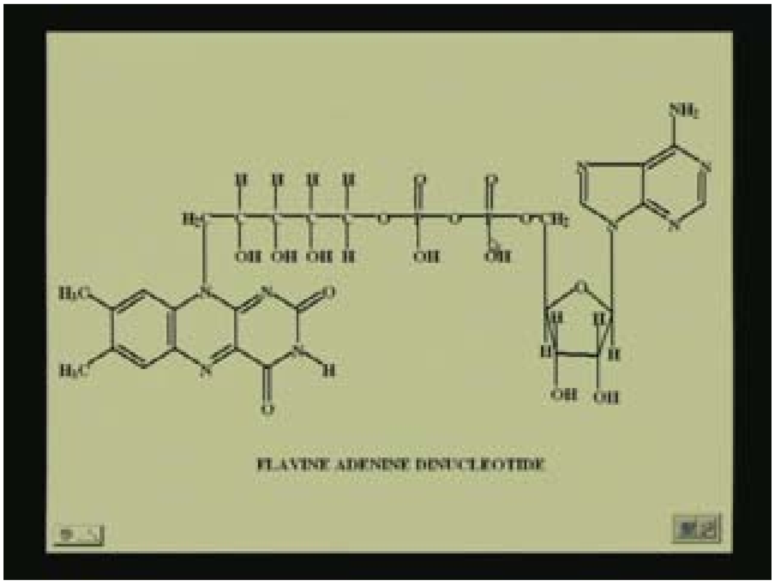

When you attach the adenine, the AMP part. What is AMP? Adenine the sugar CH_2 and the phosphate. It becomes flavin adenine dinucleotide. Why dinucleotide, because you have two of these. What do we have once more? When I form FMN, I am forming FMN. This is up to here is my riboflavin part. This part is my riboflavin part, that is my vitamin. When I am taking this it becomes FMN riboflavin phosphate, when I consider this along with it I have adenine, a sugar and phosphate. It is AMP. When I have the FMN with the AMP, it forms FAD so you have the riboflavin part. The phosphate part that forms FMN + AMP forms FAD. You need vitamin B_2 to form all these.

It is only if you have the vitamin B_2 in its riboflavin part, you will be able to form its phosphate then you will be able to act with the AMP to form the adenine dinucleotide. That is what it is. So basically what happens is you have a FAD. So what is FAD? This is FAD. It becomes $FADH_2$ so it acts with dehydrogenases.

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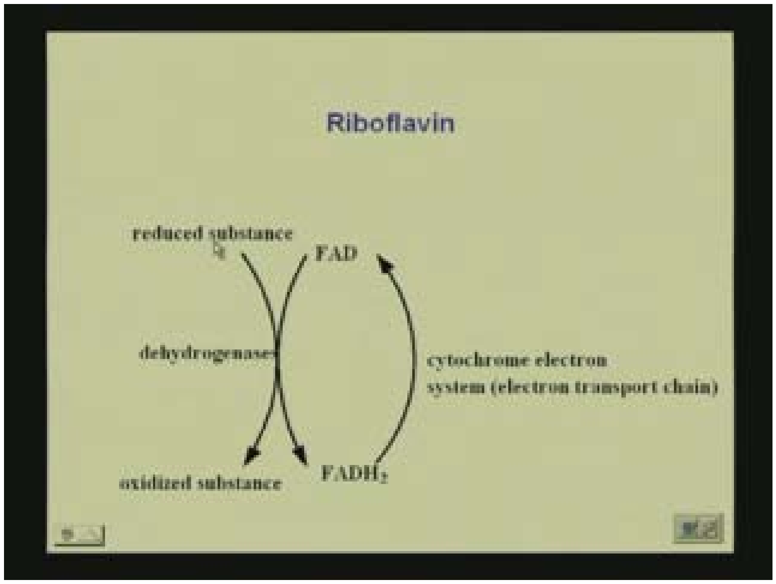

You have a reduced substance that can be transformed to an oxidized substance with FAD, $FADH_2$. Where are these hydrogens taken up? One by this nitrogen, one by this nitrogen. It can act as FAD, FADH and $FADH_2$. It can take it up in steps which is important when you want to do a certain reaction we will not go into probably very much detail of the electron transport chain but you have to recognize that any of these dehydrogenases because if you are taking a substance that has to release its hydrogens, the hydrogens have to go somewhere. Some moiety has to take up the hydrogens. It is this FAD does that, it takes up the hydrogen.

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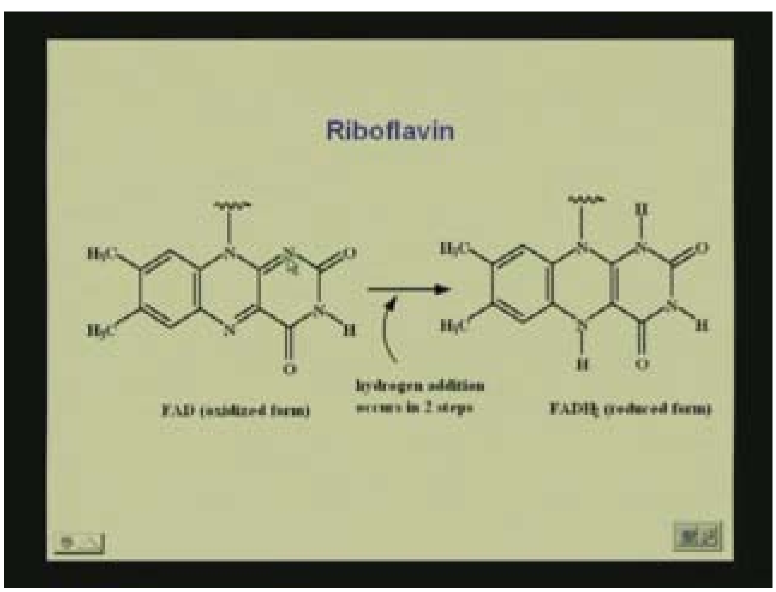

This is the oxidized form, this is the isoalloxazine ring. This is the hydrogen addition that can take place in 2 steps. What do we have here? We have FAD that is now $FADH_2$ and where are the hydrogen been added? One to this nitrogen and one to this nitrogen. We have riboflavin form the phosphate, and then form FAD and the FAD can add the hydrogen from any substance or any chemical moiety that is present and going to release the hydrogen atoms. FAD will take that up and forms $FADH_2$. These are some of the enzymes that require riboflavin cofactors. You see all sorts and what are all these? These are enzymes they are all redox type. Ones dehydrogenase, oxidase, reductase, oxidase, all of these are ones that are require or have to perform a redox reaction. In performing the redox reaction we need the FAD.

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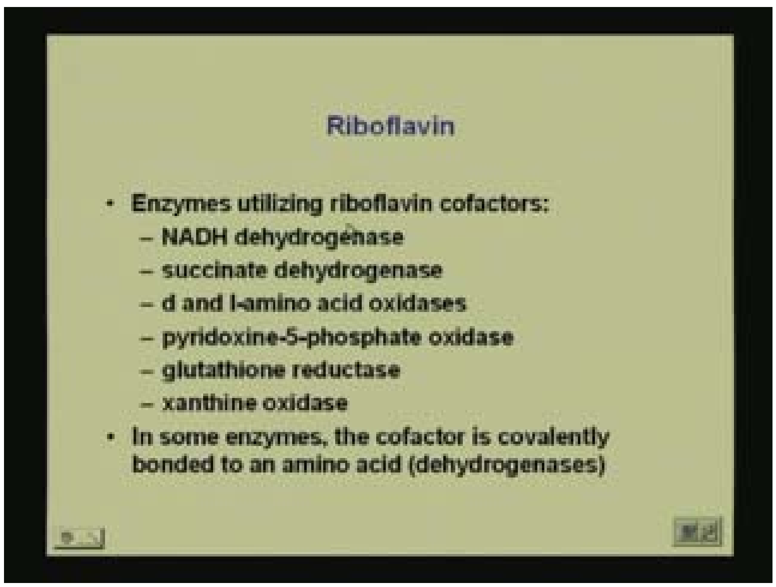

This is another one, we have succinate forming fumarate. What is happening here? It is reading itself of these 2 hydrogen, the CH_2 here and the CH_2 here is becoming CH=CH. Two hydrogens have to get lost. Who is taking them up? FAD, FAD in conjunction with enzyme is taking up the two hydrogens, in the process forming $FADH_2$ and fumarate. There has to be another reaction that place in the enzymatic cycle. That is going to do what? It is going to transform $FADH_2$ back to FAD. It is not this reaction that is going to do it because this reaction has already formed $FADH_2$.

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 enzyme again. It is a cycle remember that is how we are going to see exactly how all of these take place later on. This is another one that use FMN. What we doing here?

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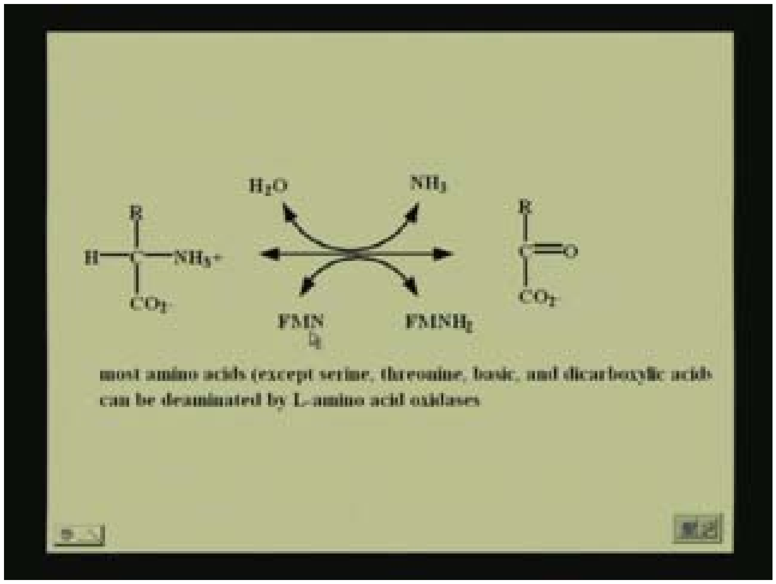

We are forming $FMNH_2$ where we have actually H_2O and ammonia. The next one vitamin B_3. This is nicotinic acid and nicotinamide; again the two forms that are required here are NAD and NADP. Again you realize that each of these vitamins has been transformed into something and that is what is being used by the enzyme. Again for this vitamin, it has to be transformed to a certain cofactor and what are those cofactors? We have the 2 cofactors of niacin are NAD and NADP.

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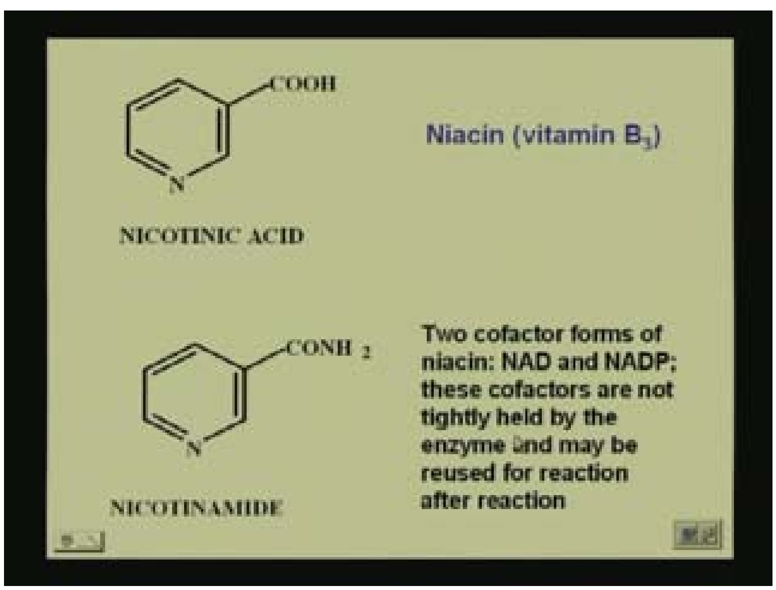

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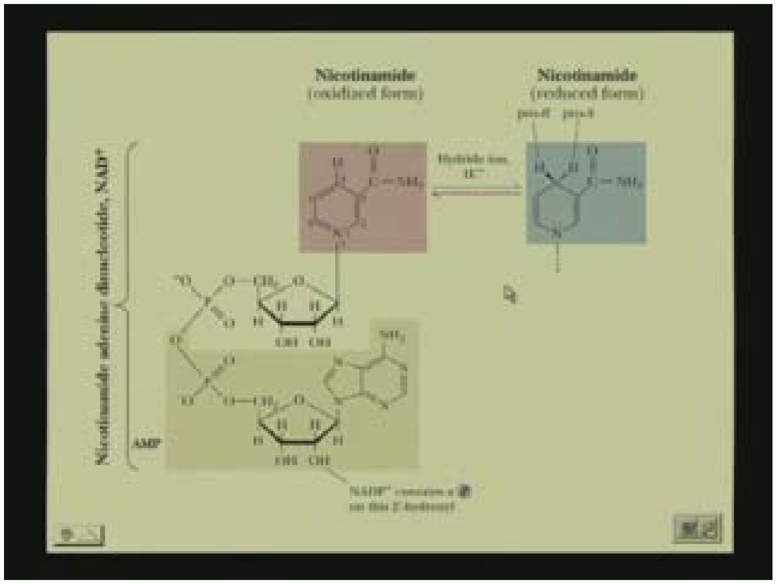

These cofactors are not very tightly held by the enzyme and they used reaction after reaction. It is very smartly organized. What it is look like? If you look at the name nicotinamide, this is nicotinamide. Nicotamine A is adenine dinucleotide, nicotinamide adenine dinucleotide. This is nicotinamide, adenine, dinucleotide. This is dinucleotide form because you have the base, the sugar, the phosphate. What is here? The base, the sugar, the phosphate. Nicotinamide is one, adenine is the other linked by this 2 phosphates dinulceotide. You have nicotinamide that is in oxidized form and that can be also in its reduced form if it takes up H here. So you can have NAD and NADH.

If there is a phosphate at this position, it forms NADP because this already has the phosphate. If at the $2'$ hydroxyl you have a phosphate, it is NADP. You should be able to recognize just from the structure what it is. You recognize that there are 2 nucleotides here and this is adenine. You also recognize that this is nicotinamide, so this is nothing but nicotinamide, adenine, dinucleotide NAD. If we just follow the nomenclature you will never go wrong. We have nicotinemide, adenine and dinucelotide NAD. If it has to be NADP, then it is going to be phosphorylated at the $2'$ position.

This is again involved in a bunch of reactions so this is what it look likes. What is this the nicotinamide? 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. You cannot form the nicotinamide adenine dinucleotide and you cannot get into the reaction that is actually looks at, actually assess. We have NAD^+ or $NADP^+$ that can form NADH, so it can take an extra hydrogen at this position. This is vitamin B_{12}, we are not going into any of the details B_{12} just that since we were doing the vitamin. This is cyanocobalamine and it has the cobalt atoms and cyanide group here. It has the big structure and it is vitamin B_{12} (Refer Slide Time: 40:00-41:00). We will not look at what vitamin B_{12} actually does, we will go on to look at vitamin C.

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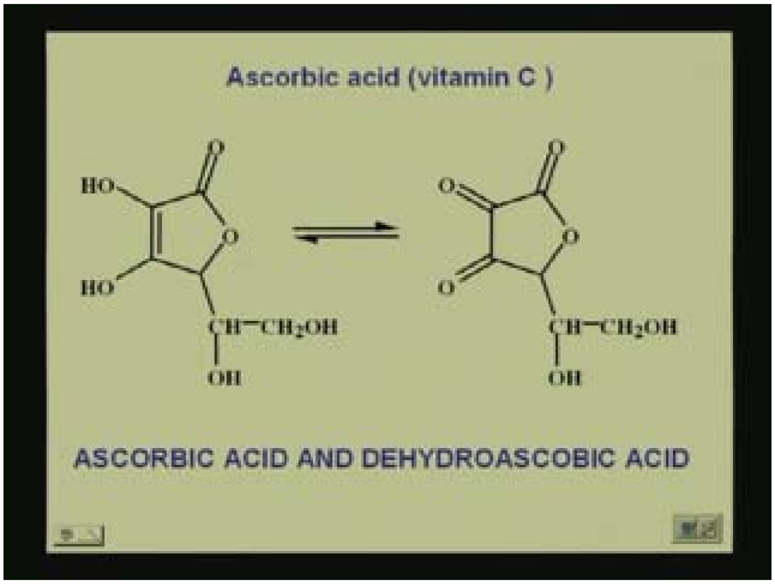

Vitamin C is ascorbic acid. It has to be used again in some reaction, so it has to be transformed into a cofactor. So what we have to know is what it is going to be transformed into. The specific reactions that it actually goes into is the production and maintenance of collagen. Collagen is required in a muscle. It forms the long fibers in the muscles, so it actually transforms the proline into hydroxyproline and lysine into hydroxylysine. It is also used in the electron transport chain that is part of the respiratory chain. The usual one that we look at before, most of them like FMA, FAD, most of them apart from their used in the, some of them are used in the electron transported chain. Mostly used in the carbohydrate metabolism. The break down of the carbohydrates.

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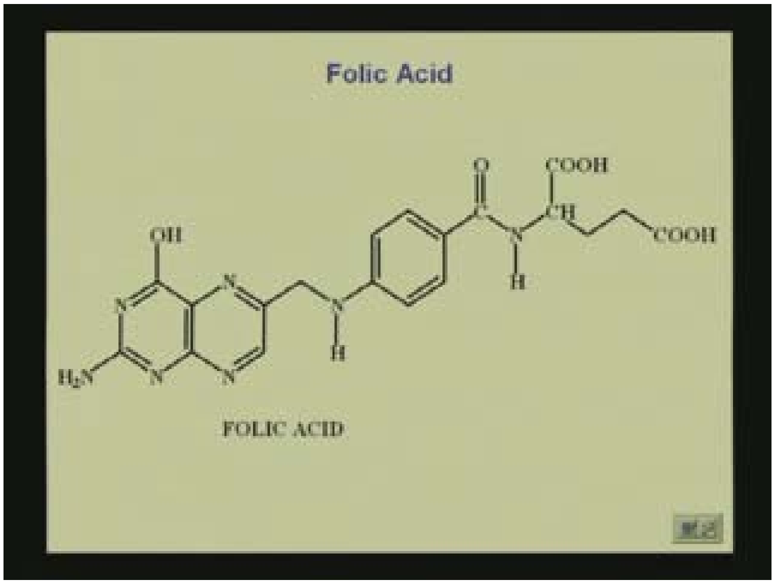

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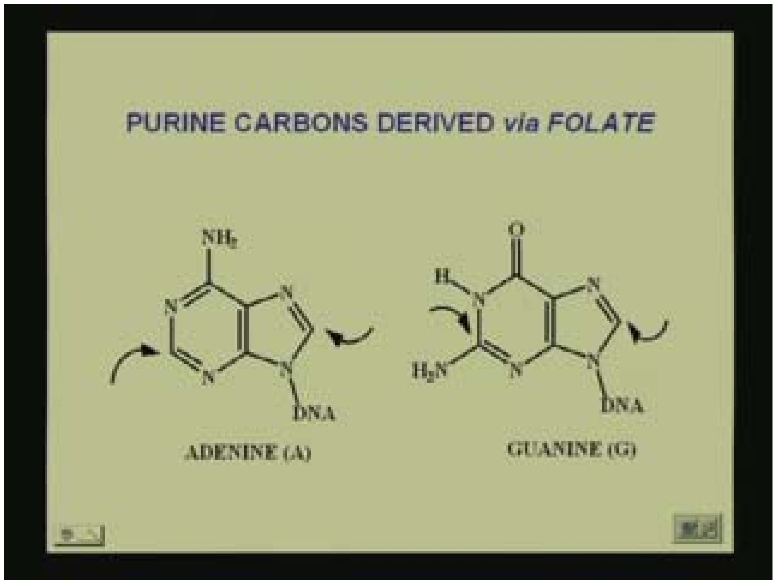

We have ascorbic acid. This is another one; I am just giving you the name as I have told. You do not necessarily need to remember the formulae but if you just look at folic acid, if you look at this moiety, you recognize that it is a part of the nucleus and some of the purine carbons are actually derived from the folate. We have adenine and guanine; they are actually derived from the folate and again in set of an enzymatic reaction. The adenine or guanine are synthesized in the body. They will link with the sugar to form a nucleoside which will link the phosphate to form a nucleotide. The vitamin part that are going to form the cofactors have to be supplemented in the diet.

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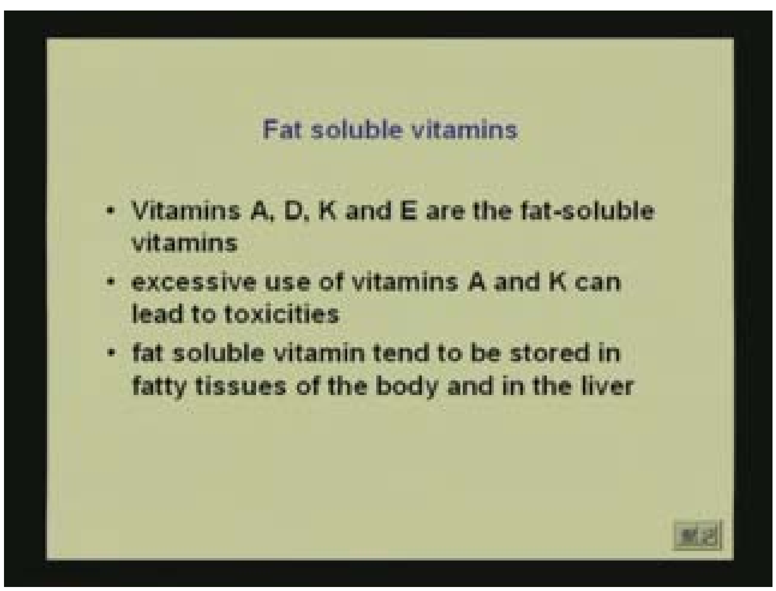

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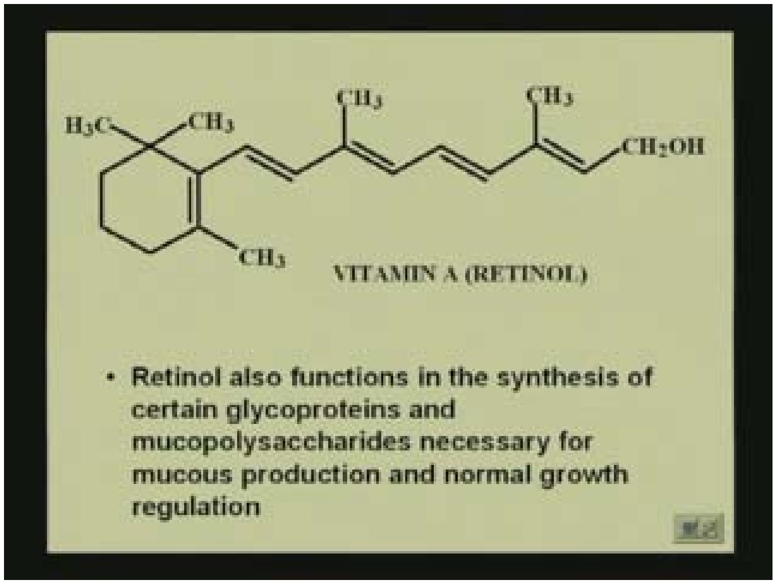

To prepare this, we need the folic acid. This part is made in the body. This will be made in the body if you consume the folic acid so that is how these work. We have the fat soluble vitamins these are soluble in lipids, vitamins A, B, E and K, and they are usually stored in the fatty tissues of the body and in the liver. Let us look at where these will come into play. Vitamin A (retinol), it not only functions in all visual pigments which is extremely important for our visual activities. Going into the details of how that works is beyond we have to do in this course but again it's extremely interesting topic as to how retinol actually is involved in the visual pigments.

It also functions in the synthesis of certain glycoproteins. This is some thing 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 highly uronic acid which is the mucopolysaccharide that is necessary for mucous production and normal growth regulation. Apart from its activity in visual pigments, it is also involved in the synthesis of glycoproteins. Retinoic acid which is the acid form of retinol, when this forms retinoic acid it is also involved in cellular differentiation.

It controls cellular growth so because you have already read that the vitamin A. The deficiency of it's going to call eye blindness. It is good for eyes and so on and so forth. It is also good for a number of others activities here. Vitamin A is involved not only in your visual pigments but also in your glycoproteins and in cell growth. Vitamin D has 2 precursor forms, which is something that is prior to when vitamin D is formed. It is actually a steroid hormone and the precursor form, one of them is 7- dehydrocholesterol. So it is involved in cholesterol formation. Where do we need? We need this cholesterol in the lipid membrane for the fluidity.

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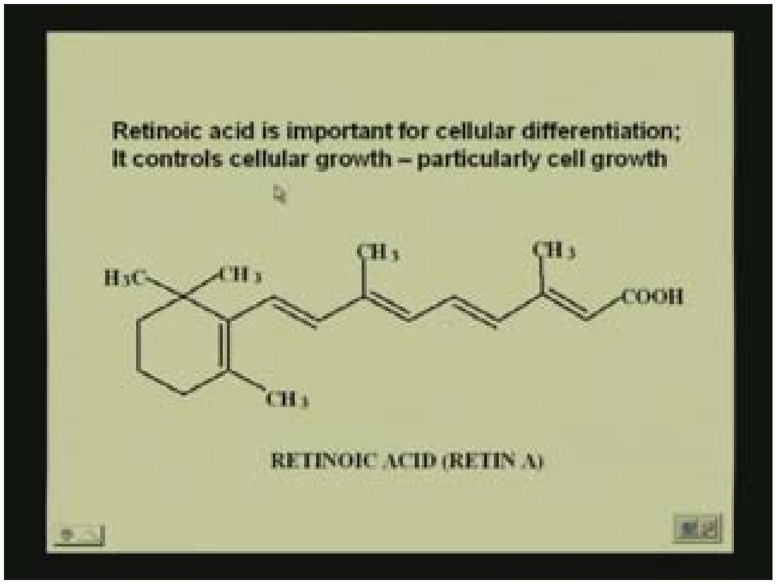

Remember apart from the hydrophobic tails and the polar heads, there were also these additional cholesterol moieties that fitted with hydrophobic tails to form what to give some sort of fluidity to the membrane. This UV irradiation affords cholecalciferol that is vitamin D_3 and ergocalciferol. Actually vitamins D, there are precursor form in the body and vitamin D is formed from these with UV irradiation. If you sit in the sun or you have UV radiation basically then these two precursor forms actually can form cholesterol.

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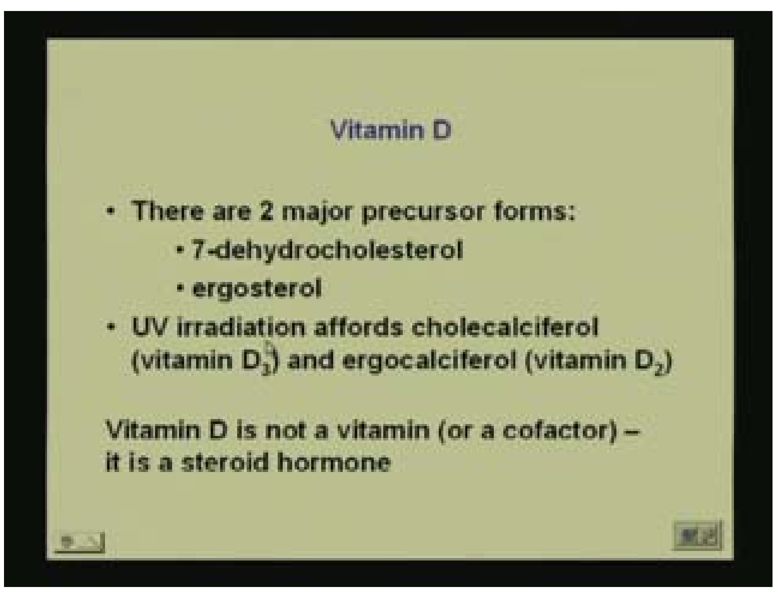

This is actually what happens, we have 7- dehydrocholesterol. That is if you remember the cholesterol structure this was the part of the cholesterol structure where we have the steroid nucleus. We had steroid nucleus and on UV radiation you get pre vitamin D. What you need to know from this is that vitamin D actually is not a vitamin in that sense or a cofactor. There is something called 7- dehydrocholesterol and ergosterol that are two precursor forms of vitamin D. This is actually a steroid hormone that is required. It is formed in the liver and then it is converted in the kidney. This is what we have done so far. We have looked at the structures of each of these. 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.

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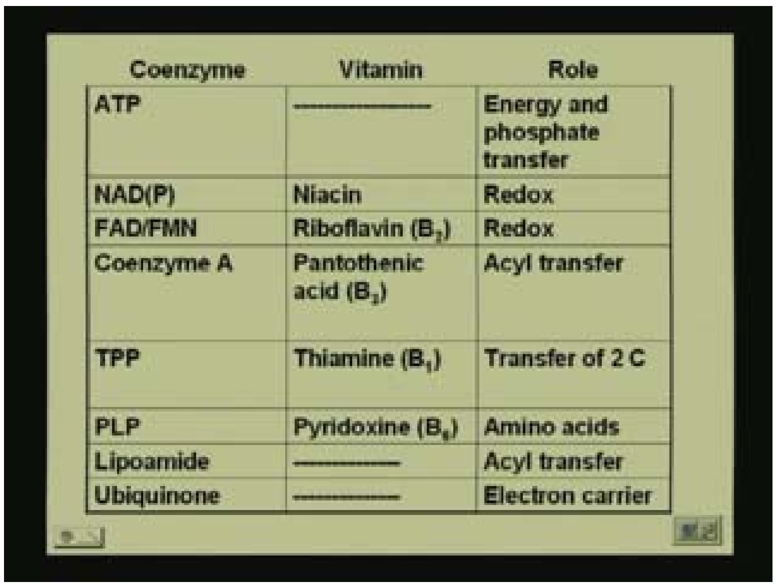

Coenzyme	Vitamin	Role
ATP	----------------	Energy and phosphate transfer
NAD(P)	Niacin	Redox
FAD/FMN	Riboflavin (B_2)	Redox
Coenzyme A	Pantothenic acid (B_3)	Acyl transfer
TPP	Thiamine (B_1)	Transfer of 2 C
PLP	Pyridoxine (B_6)	Amino acids
Lipoamide	-------------	Acyl transfer
Ubiquinone	-------------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

In the sense that you have niacin, what does niacin do? It forms nicotinamide adenine dinucleotide. How is that formed? Let’s go one by one, first of all let us start with ATP. ATP means that you have adenosine triphosphate. It is not formed from any vitamin. It has obviously, each of these have a role. Its role is in energy and phosphate transfer. How does it do? Each of the high energy bonds that are broken is specially the γ phosphate bond that is broken. It is going to give us -30 kilo joules/mol of energy. ATP that is adenosine triphosphate. Where does this adenosine come from? It is one of the adenine bases which are a nitrogenous base belonging to the purine family that is going to be linked to a ribose sugar linked to a ribosugar means we are going to have some thing that looks like this.

We have a ribose sugar which has the OH and the OH, we have our base linked here. So this is where are adenine is linked. We have R3 phosphate, these phosphates; we have 1, 2 and 3. What happens is this breakdown is going to result in a $-\Delta G$ so what usually happens is? This is coupled with another reaction that has a $+\Delta G$ so that the over all is a negative making this non spontaneous reaction a spontaneous reaction.

This will be very clear when we do the bioenergetic and you will see how cleverly the reactions are coupled together. The next one that we looked at was niacin. What is niacin? We require niacin to form nicotinamide. Nicotinamide then is 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 phosphorylated it forms riboflavin phosphate which is FMN, this linked to adenosine monophosphate AMP gives FAD, NAD and FAD are each involved in redox reaction because they can take up hydrogen atoms. FAD can do it two steps so we can have FAD $FADH_2$.

We can have CH_2–CH_2 bond forms a CHCHCH=CH, just because the hydrogen has to go somewhere pantothenic acid was involved in coenzyme A and acetyl coenzyme A. What is that doing? It has rather important role in acyl transfer. Thiamine is involved in the transfer of two carbons or we can have the CO_2 transfer. Then how we looked at, how pyruvate formed acetaldehyde? That is by a certain enzyme that would use TPP. Using TPP means you have to have thiamine to form TPP. Vitamin B_6 pyridoxine which will form pyridoxal phosphate which is used in amino acid isomerization.

Each of the vitamins that we have, have a role in the formation of cofactors coenzymes. Once these cofactors are formed we did not mention biotin but biotin is also there, which is a prosthetic group that is links to the enzyme. Then together with the enzyme, it performs the enzymatic function and that completes the discussion on vitamins and coenzymes. We will go on to nucleic acid structures in our next class followed by bioenergetic and metabolism of carbohydrates.