Enzyme Science and Technology
Prof. Vishal Trivedi
Department of Biosciences and Bioengineering
Indian Institute of Technology, Guwahati

Module - VI
Enzyme Catalyzed Biochemical Reactions
Lecture - 28
Carbohydrate Metabolism

Hello everyone, this is Dr. Vishal Trivedi from Department of Biosciences and Bioengineering IIT, Guwahati. And, what we were discussing? We were discussing about the different properties of the enzyme in the course Enzyme Science and Technology.

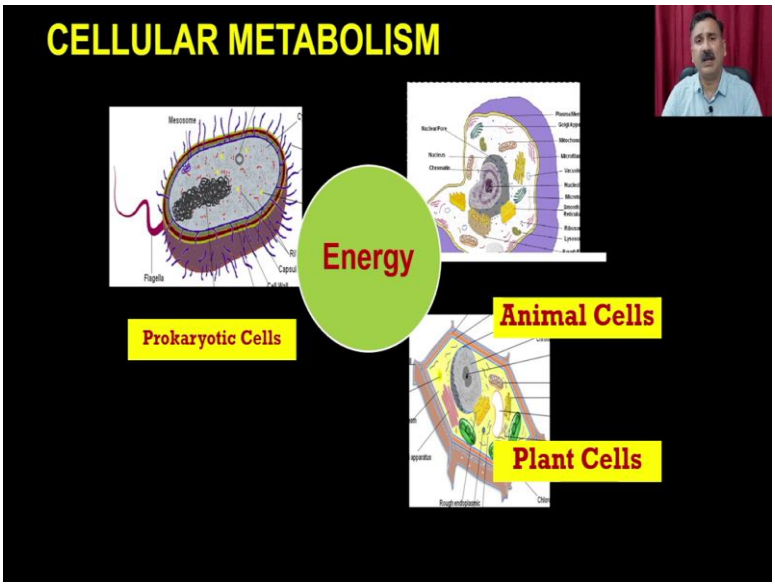
And, so far what we have discussed? We have discussed about the different properties of the enzyme; we have also discussed about the nomenclature and classifications. Followed by, we have also discussed how you can be able to produce the enzyme in the bulk quantities.

Now, the question comes, if you have the enzyme in the bulk quantities or if you have the enzyme in the sufficient quantity, how you can be able to utilize that enzyme for different types of operations or different types of applications. So, you can actually be able to use the enzyme for characterization purposes. For example, you can be able to determine the, what would be the subset specificity of this particular enzyme, you can be able to determine the interactions of the substrates with the product with the enzyme and so on.

So, in this particular module, we are going to discuss how (Refer Time: 01:53) enzymes are very important in terms of catalyzing the different reactions and how if you produce an enzyme, you can be able to use that for catalyzing those reactions and so on. So, when we talk about the reactions, these reactions are important because they are actually going to you know use for converting a one substrate into another product, ok.

This means it is actually going to be used for converting the one chemical entity into another chemical entities and in this process, the biological system is utilizing these enzymes for running the different types of metabolic reactions.

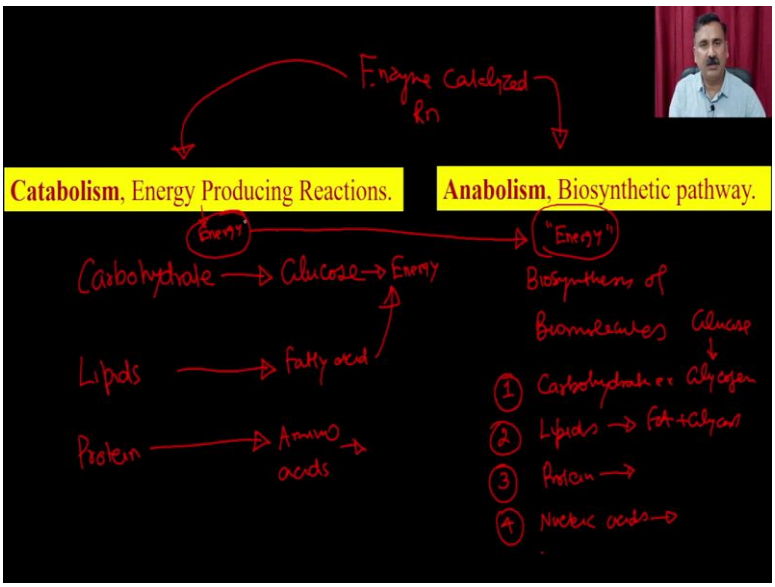
(Refer Slide Time: 02:39)



Now, what you see here is that most of these metabolic reactions are being utilized to in different organisms, whether it is a prokaryotic organism or the eukaryotic organisms for two main purposes – one, it is actually being used for producing the energy so that the energy can be used for many types of operations.

For example, muscle contractions, you can use the energy for heart you know heart pumping and all that; and on the other hand, these reactions are also being utilized to build the different types of biomolecules.

(Refer Slide Time: 03:15)



So, as far as the reaction is concerned, the reactions can be divided into two different pathways. Ok. So, enzyme-catalyzed reactions can be fall into two different categories. One, the catabolic reactions or the energy producing reactions; the other one is called as the anabolic reactions or the biosynthetic pathways or the biosynthetic reactions.

In the catabolic reactions, it is actually going to utilize some of the biomolecules for energy productions. So, the biomolecule which you are going to use under the catabolism is the carbohydrate such as glucose and so, carbohydrate such as glucose, right and you can also able to use the lipids. In very, very small quantities, when there is a starvation conditions, the proteins are also being utilized under the catabolism reactions and that is why the proteins are also going to be utilized.

So, protein are going to be get converted into amino acids and these amino acids are then actually going to be utilized for energy productions. But, that is very rare in those conditions when the person is going through starvation conditions. Similarly, for the carbohydrate, carbohydrates are, you know, examples are glucose and glucose are also going to be used for production of the energy with the help of the different types of the catabolic reactions.

Lipids, lipids are going to form the fatty acids and the fatty acids are going to be used for the energy production. Similarly, in the anabolism, anabolism you can have the biosynthetic pathway which means it is actually going to deal with the biosynthesis of the different different biomolecules. So, under this category, you can have all the biomolecules. You can have four biomolecules which you are going to synthesize. For example, the carbohydrates, example is, for example, the glycogens.

So, you can actually be able to use the glucose molecule and you can be able to produce the glycogen. Similarly, you can have the lipids, right? So, you can actually be able to use the fatty acid and you can use the glycerol to produce the lipids. Then third, you can also have the, you can have the proteins. So, protein synthesis is also a pathway of the biosynthetic pathway and the number four, you can also be able to use the, many of the constituents to produce the nucleic acids such as the DNA and RNA.

So, you can imagine that when you are doing the biosynthesis, you are actually joining the bonds. You are actually synthesizing the new compound. So, as a result, in this particular anabolic reactions, you are actually going to spend the energy. So, this is

actually going to have the expenditure of the energy whereas, all the catabolic reactions are actually going to produce the energy which is actually going to be utilized only for the anabolic reactions.

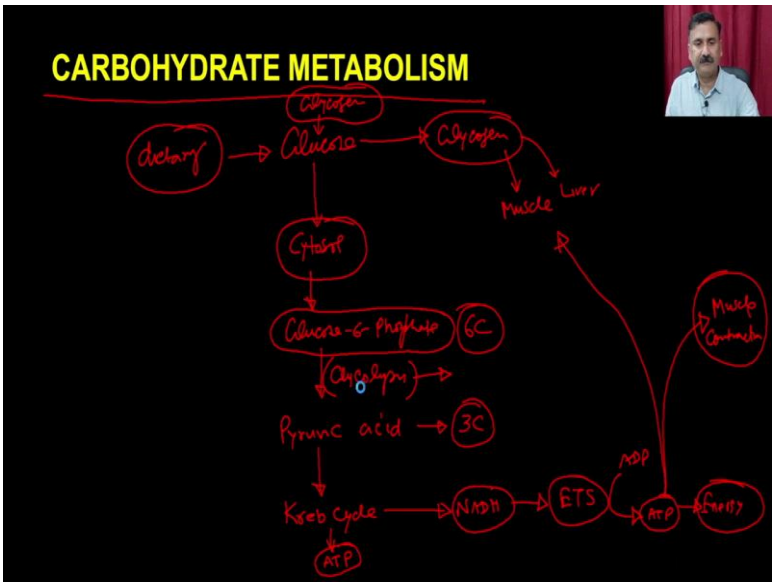
So, you are actually, you know, deriving the energy from the external food, right? In some, some organisms, it is not always true. Like for example, the plants; plants are deriving the energy directly from the sun. But, apart from the plant, you always have the heterotrophic mode of nutrition.

And in that case, you are always taking the, you know, the nutrition from the outside and the nutrition in the form of carbohydrate, lipids or protein, you are actually synthesizing the or you are converting that into the monomeric unit. And, then these monomeric units are entering into the cell and they are producing the energy.

This energy is going to be used for driving the particular process or it also going to be used for the biosynthesis of the some of the biomolecules. What is the utilization of the biosynthesis? The biosynthesis is actually going to use for building of the body actually. For example, if you, you know, when there is a growth, when the cell wants to grow, it has to, you know, synthesize the new biomolecules and that is how it is actually going to utilize the anabolic reactions.

So, in this particular lecture, we are actually going to focusing first on to the catabolic reactions and then we are also going to discuss about the anabolic reactions. So, let us start discussing about the carbohydrate metabolism and how the carbohydrates are being utilized into the energy production with the help of the different types of enzymes.

(Refer Slide Time: 08:07)



So, when we talk about the carbohydrate metabolism, carbohydrate metabolism starts from the glucose, right? And the glucose is actually going to be produced from the polymeric gluco carbohydrates such as the glycogen. So, when there is a glycogen breakdown, the glycogen is going to give you the glucose. Otherwise, you can also get the glucose from the dietary supplements or you can also get the glucose from the diets, right.

Irrespective of all the source, the glucose is going to enter into the cytosol of a particular cell and as soon as it enters into the cytosol, the glucose is going to be get converted into the molecule which is called as glucose-6-phosphate. Now, glucose-6-phosphate then is actually going to be a molecule which is committed for getting into the metabolic reactions.

Because glucose which you are getting from the dietary source can be get into the anabolic reaction and they can actually be able to produce the glycogen so that glycogen is actually going to be stored into the muscles and as well as the liver cells. But this glucose as soon as it is going to be get converted into glucose-6-phosphate, it is going to be committed for energy production.

Now, this glucose-6-phosphate is going to be first get converted into the pyruvic acid with help of the different types of reactions and all these reactions are going to be some rice under the name as glycolysis. So, glucose-6-phosphate is going to be broken down.

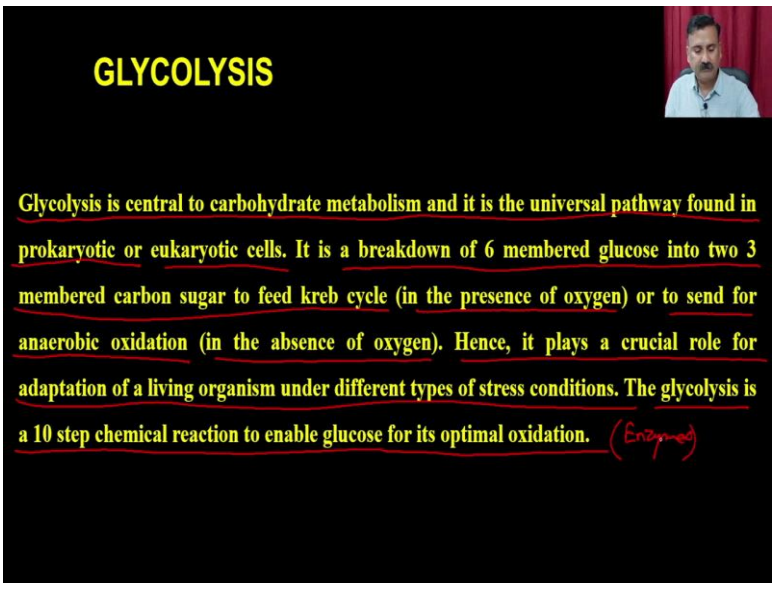
It is a 6 carbon sugar and it is going to be get converted into 3 carbon sugar and that is the pyruvic acid.

And, then the pyruvic acid is actually going to enter into the Kreb cycle and that is how the Kreb cycle is and then the Kreb cycle is actually going to produce two different types of reducing equivalent. It is actually going to produce the ATP or it is actually going to produce the NADH. An NADH is actually going to enter into the electron transport chain and that is how it is actually going to convert the ADP into the ATP and ATP is nothing, but the energy, right.

And that energy can be used for multiple purposes; either you are using the ATP for the synthesis reactions or you are using the ATP for the performing different types of tasks such as the muscle contraction. Now, this is a central pathway through which it is the body is communicating with the various types of metabolic reactions governed by the enzymes.

So, in the glycolysis you have ETN reactions in the Kreb cycle also you have many reactions which are being governed by the an different types of enzymes. So, let us start discussing about the glycolysis.

(Refer Slide Time: 11:25)

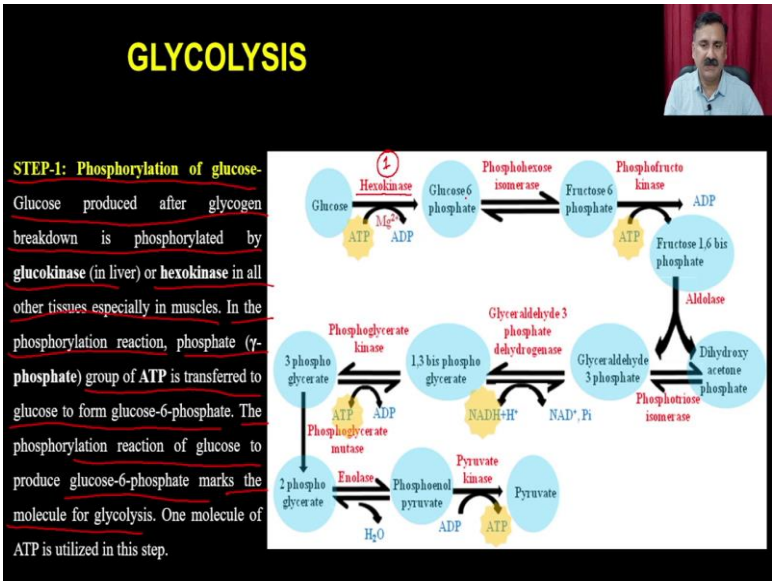


So, glycolysis as the name suggests is central to the carbohydrate metabolism and it is a universal pathway found both in the prokaryotic or the eukaryotic cell. It is the

breakdown of the 6-membered glucose into the two 3-membered carbon sugar to feed for the Kreb cycle in the presence of oxygen and or to send for the anaerobic oxidation in the absence of oxygen.

Hence, it plays a crucial role in adaptation of a living organism under different types of stress conditions. The glycolysis is a 10-step chemical reaction to enable the glucose for its optimal oxidation and all these 10 reactions are going to be catalyzed by the different types of enzymes.

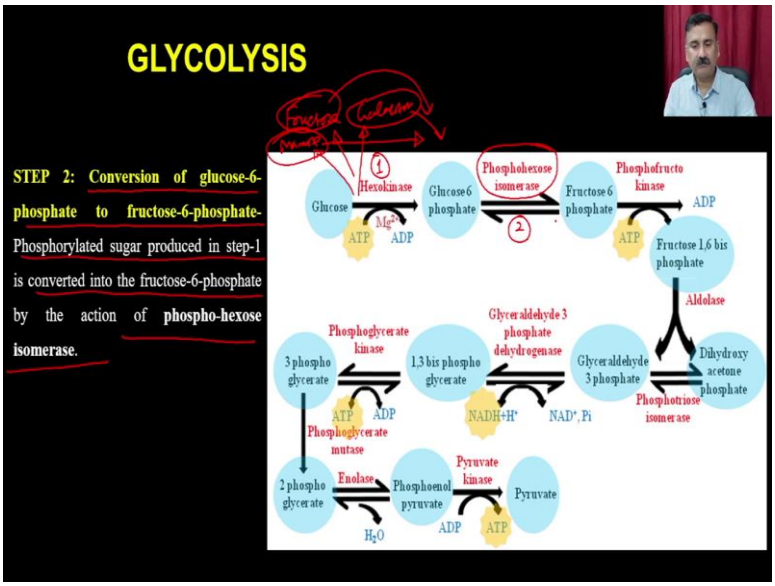
(Refer Slide Time: 12:11)



So, the first step as we already discussed it is actually the phosphorylation of the glucose molecule. So, this is the first reaction, but it is going to be catalyzed by the enzyme which is called as hexokinase. So, glucose produced after the glycogen breakdown is phosphorylated by the glucose kinase or the hexokinase in all other tissues especially in muscles.

In the phosphorylation reaction the phosphate group of ATP is transferred to glucose to form the glucose 6-phosphate. The phosphorylation reaction of glucose is produced to glucose 6-phosphate and it is marked the molecule for the glycolysis which means it is actually going as soon as the glucose 6-phosphate is going to be produced, it is actually going to commit this particular glucose molecule for the glycolysis.

(Refer Slide Time: 13:06)



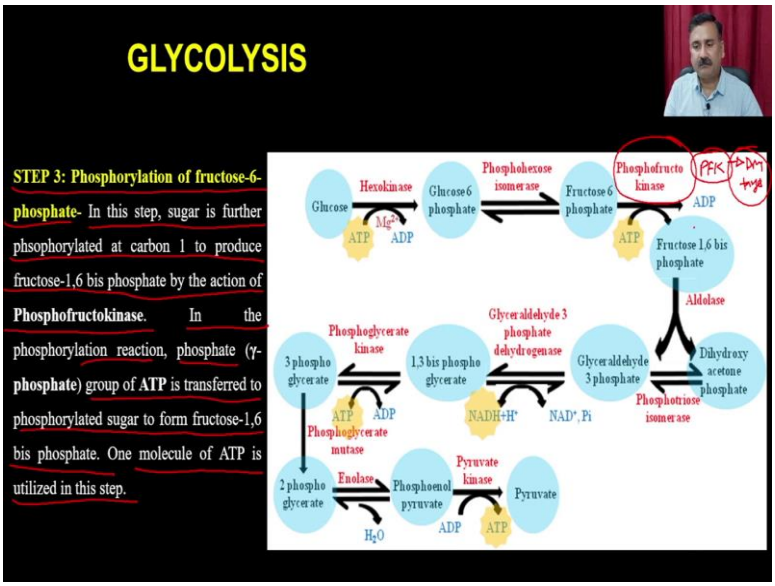
Then the second step is the conversion of the glucose 6-phosphate to the fructose 6-phosphate. So, the phosphorylation step phosphorylated sugar produced in the step 1 is going to be converted into fructose 6-phosphate by the action of the phospho hexose isomerase.

So, you can imagine that in the step 1 you can actually be able to use the hexokinase and hexokinase can be able to utilize the different types of sugar. It can actually be used the fructose; sugar, it can actually be able to use the you know mannose or it can use the galactose. Any of these sugar actually can be a starting material for the glycolysis and correspondingly it is actually going to form the 6-phosphate derivative.

For example, in the case of fructose it is actually going to form the fructose 6-phosphate. In the case of mannose, it is going to form the mannose 6-phosphate and in the case of galactose it is going to form the galactose 6-phosphate. And, ultimately this particular second reaction is actually going to convert whatever the sugar is present in the first step to the fructose 6-phosphate.

So, if it is fructose 6-phosphate no reaction required, but if it is a galactose 6-phosphate or mannose 6-phosphate that also is going to be get converted into the fructose 6-phosphate, so that the fructose 6-phosphate is going to be further put it into the degradation reactions.

(Refer Slide Time: 14:38)



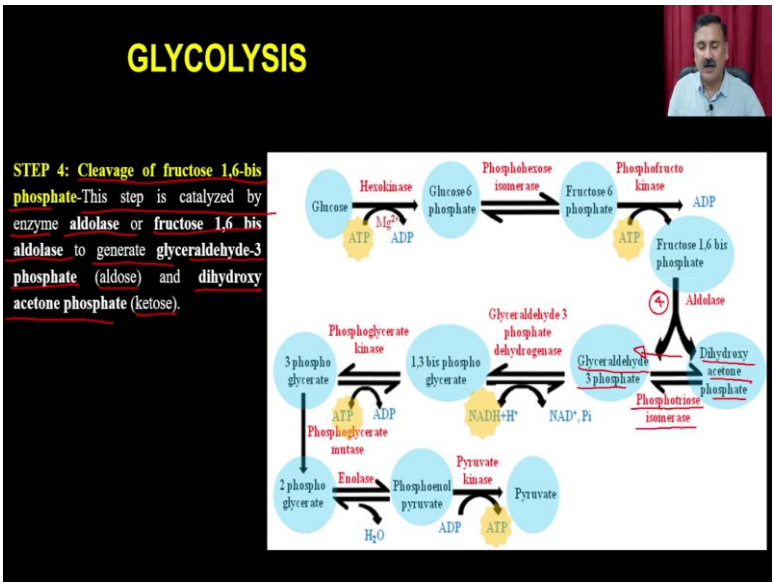
Now, in the step 3 you are going to do the phosphorylation of the fructose 6-phosphate. So, in this step, the sugar is further phosphorylated at carbon 1 to produce the fructose-1, 6-phosphate by the enzyme, action of the enzyme which is called as phosphofructokinase.

And, the phosphofructokinase is a very very important enzyme because it actually converts the fructose 6-phosphate into a fructose 1-6-bisphosphate and that is how it is actually going to you know provide a substrate which can be further utilized by the aldolase to break down.

So, in this so, this is actually going to you know activate the molecule and it is actually going to make the high energy substrate and that is how it is actually going to be ultimately be going to be broken down by the aldolase. So, in the presence phosphorylation reaction, the phosphate group of ATP is transferred onto the phosphorylated sugar to form the fructose 1-6-phosphosphate and in this step also one molecule of ATP is going to be utilized.

But, the fructose 1-6-phosphofructokinase is a very very important enzyme which is also called as PFK. So, PFK is a very very important enzyme and because it catalyzes such a crucial step, the phosphofructokinase is also a very good drug target for some of the organisms where the glycolysis is very very pronounced especially the lower organisms and the bacteria for example.

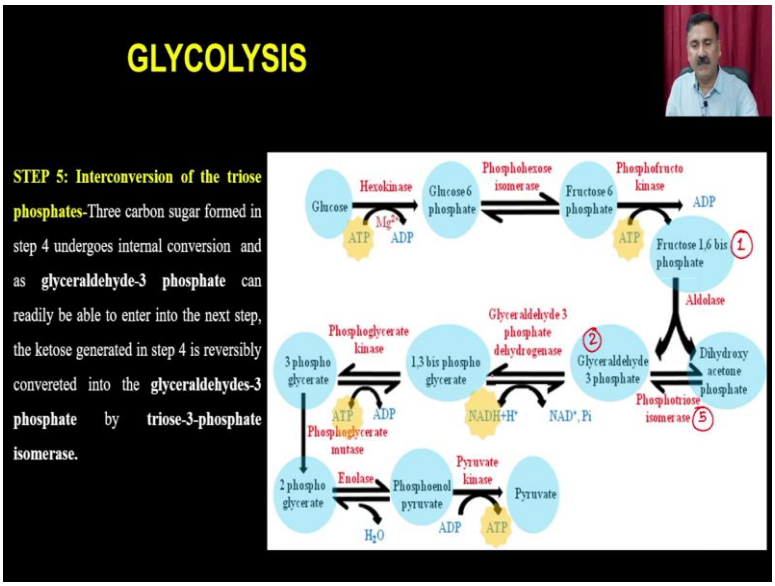
(Refer Slide Time: 16:16)



And, then you can have the for next step and the next step is the cleavage of these fructose 1, 6 bisphosphate. This step is catalyzed by an enzyme which is called as aldolase or fructose 1, 6 bisaldolase to generate the two molecules glyceraldehyde 3-phosphate which is aldose and dihydroxyacetone phosphate which is called as ketose.

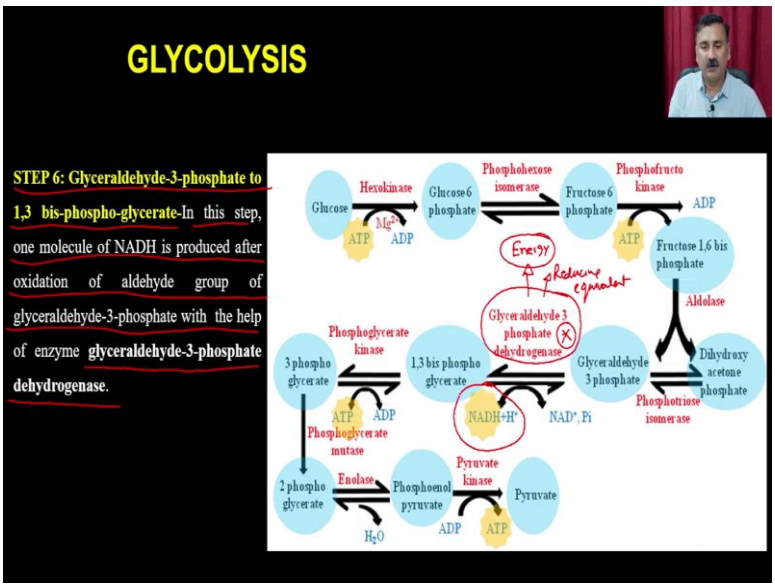
So, at this step the step number 4, the fructose 1, 6 bisphosphate is going to be broken down into the two product one is called as the glyceraldehydes-3 phosphate and other one is called as dihydroxyacetone phosphate and dihydroxyacetone phosphate is going to be get converted into the glyceraldehydes-3 phosphate by the enzyme which is called as phosphotriose isomerase and that is the step number 5.

(Refer Slide Time: 17:04)



So, this is the step number 5. And so, that is how the; with the help of the phosphotriose isomerase the dihydroxyacetone phosphate is going to be get converted into glyceraldehydes-3 phosphate. This means from the one molecule of fructose 1, 6 bisphosphate you have produced the two molecules of the glyceraldehydes-3 phosphate. Now, at this stage it is actually going to catalyze the another reaction, ok.

(Refer Slide Time: 17:33)



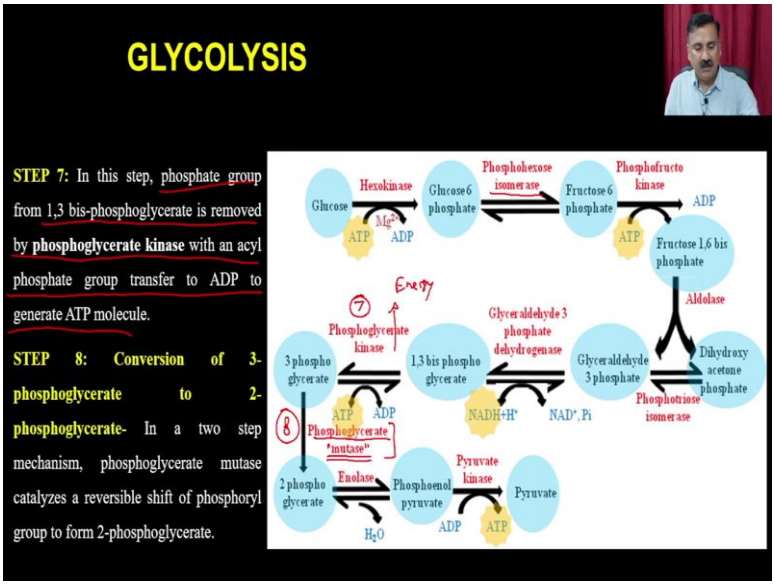
And, it is going to form the step number 6 and the step number 6 the glyceraldehydes-3-phosphate is going to be converted into the 1, 3-bisphosphoglycerate and in this step, one

molecule of NADH is produced after the oxidation of aldehyde group of glyceraldehydes-3-phosphate with the help of an enzyme which is called as glyceraldehydes-3-phosphate dehydrogenase, ok.

And, this enzyme is also very very important because this is an enzyme which is actually going to produce the energy or it is actually going to produce the reducing equivalent in the form of the NADH. And, that is why this enzyme is also a very very important drug target.

So, glyceraldehydes-3-phosphate dehydrogenase is actually going to produce one amount of one molecule of NADH and it will convert the glyceraldehydes-3-phosphate into the 1, 3-bisphosphoglycerate.

(Refer Slide Time: 18:31)



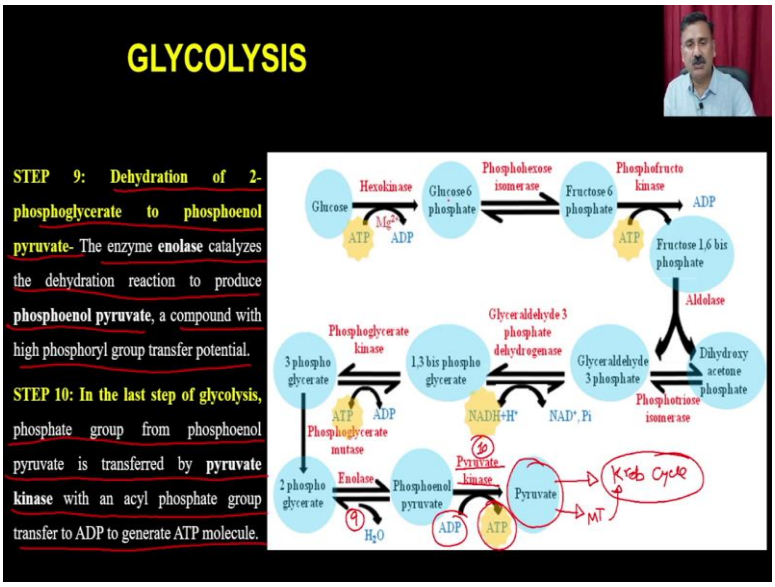
Then we have the step number 7. So, step number 7 and the 8 is in this step the phosphate group of 1, 3-bisphosphoglycerate is removed by the phosphoglycerate kinase with an acyl group transferred to ADP to form the ATP, ok. So, here also you are going to produce the energy again.

And, in the step number 8 you are going to have the conversion of 3-phosphoglycerate to the 2-phosphoglycerate with the help of an enzyme which is called as the phosphoglycerate mutase. Remember that when you are talking about or when we are discussing about the nomenclature, right. We said that sometime you use the term as

mutase, sometime you are using a term which is called as isomerase. So, these are the different class examples of the enzyme which catalyzes the different types of reactions.

In this case you are converting a molecule; you are converting a glucose into the fructose. So, you are actually you know changing the functional groups which is present on the molecule. Whereas in this case you are shifting the phosphate from the one position to another position and that is why this is called as mutase.

(Refer Slide Time: 19:44)



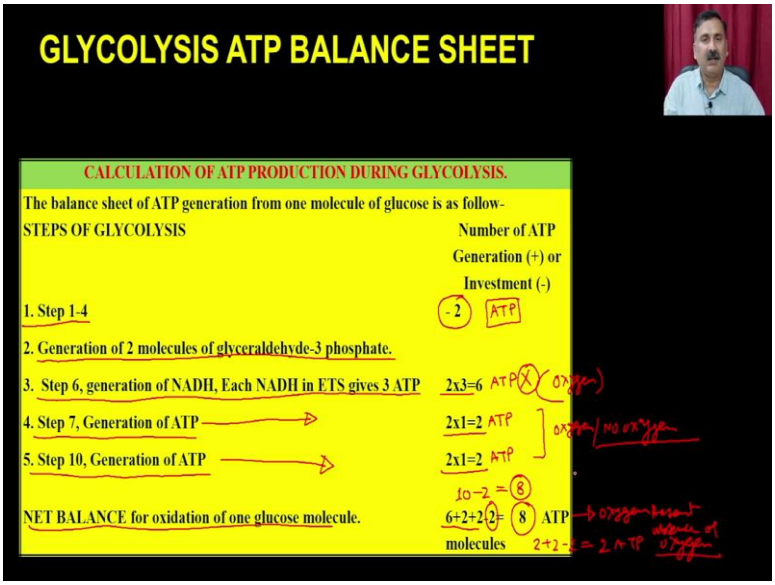
Then in the step number 9, you are going to have the dehydration reaction. So, in the dehydration of the 2-phosphoglycerate to the phosphoenol pyruvate – the enzyme enolase is going to catalyze the dehydration reaction to produce the phosphoenol pyruvate, a compound with the high amount of phosphoryl group transfer potentials.

Now, in the step last step the step number 10 you are going to utilize an enzyme which is called as pyruvate kinase and the with the help of the pyruvate kinase the phosphate group from the phosphoenol pyruvate is transferred by the pyruvate kinase to an acyl group transferred to ADP to generate the ATP. So, it is actually going to produce another molecule of ATP and that is how it is actually going to produce the pyruvate.

This pyruvate will enter into the Kreb cycle and that is how it is actually going to be linked the pyruvate to the Kreb cycle. So, pyruvate will enter into the mitochondria and

within the mitochondria it is actually going to be utilized for the Kreb cycle. Now, how we can actually be able to see the balance sheet of the energy production?

(Refer Slide Time: 21:00)



So, balance sheet of the energy production is as follows. In the step 1 to 4 you are actually going to use 2 molecules of ATP, right. This means you are going to consume the 2 molecules of ATP. First molecule when you are converting the glucose to glucose 6 phosphate and the second molecule when you are converting the fructose 6 phosphate to fructose 1, 6-bisphosphate.

Then after that it is actually going to have the multiple steps of energy production. So, in the generation of the 2 molecules of glyceraldehydes-3-phosphate right, this means all these are going to be doubled. So, then in the step number 6 there will be a generation of NADH, right and if you send the NADH into the electron transport chain it is actually going to produce the three molecules of ATP.

This means and since you have steps splitted the glucose molecule into 2 molecules of glyceraldehyde 3 phosphate. So, 2 into 3 that is the 6; 6 ATP which is going to be generated if the oxygen is present. So, this is important because we are assuming that the electron transport chain is running and all these NADH will go and get oxidized and that is how you are going to produce the maximum number of ATP what is associated with this particular molecule.

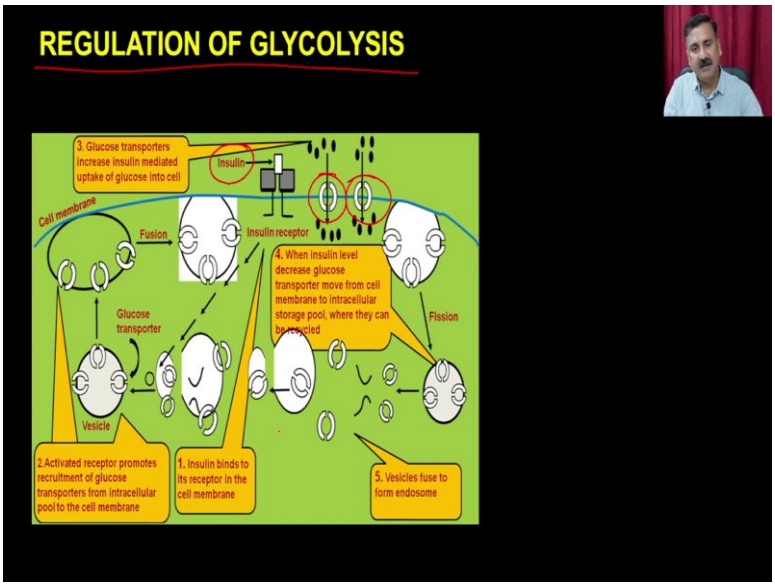
Then in the step number 7 you are generating the ATP so, 2 molecules of ATP you are going to generate, right and Step number 10 you are going to another molecule of ATP. So, this is irrespective of oxygen what you are going to use. So, this is whether the oxygen is present or no present. This this ATP are actually going to produce. So, you are going to have another 2 molecules of ATP.

This means if you see the net balance if the net balance is 8 ATP if the oxygen is present ok which means if it is a aerobic oxidation you are going to produce the net ATP molecule because you have first consumed the 2 molecules of ATP to commit the glucose molecules for the carbohydrate metabolism. And, then you have produced these many ATP which means you have produced the 10 molecules of ATP you have consumed the 2 molecule and that is why you are going to have the 8 molecules of ATP.

But if the oxygen is not present then how much you are going to get? You are going to have no production of ATP in this step right and in that case, you are going to have 2, 2 minus 2 right. So, 2 plus 2 minus 2 that is 2 molecules or 2 ATP molecules if the oxygen is not present.

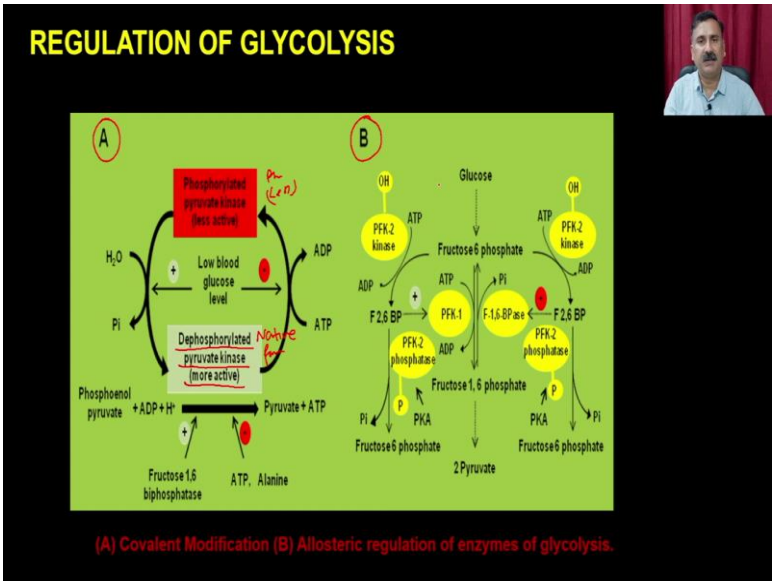
And so, in the absence of oxygen which means if the bacteria is under the aerobic oxidations it is going to produce the 8 molecules of ATP, but if the bacteria is under the anaerobic oxidation, it is actually going to produce only the 2 molecules of ATP. This means it is just going to produce a very small amount of energy so that it is actually going to survive for some time.

(Refer Slide Time: 24:28)



Now, how the different enzymatic reactions are going to be controlled and how you can be able to control the glycolysis. So, there are multiple steps through which you can be able to produce the you can be able to regulate the glycolysis - one is you can actually have the hormonal regulations which is going to be done by the glycolyl by the insulin and that is actually going to control the uptake of the glucose by changing the level of the transporters onto the cell membrane.

(Refer Slide Time: 24:52)



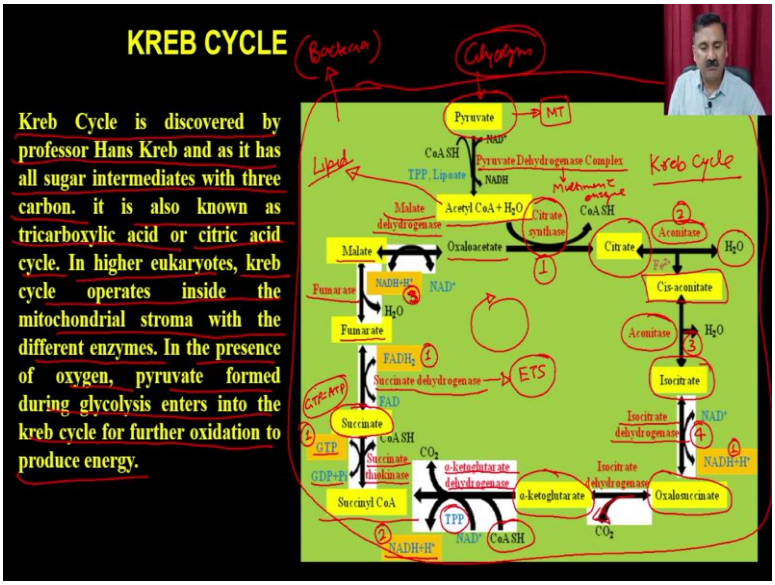
The second is you are actually going to have the enzymatic control and the enzymatic control can be by some of the crucial enzyme. For example, one of the crucial enzyme is the pyruvate kinase or. So, pyruvate kinase can be present in the two forms – one is called as the phosphorylated form, the other one is called as dephosphorylated form and the dephosphorylated form is more active compared to that the pyruvate dephosphorylated form.

So, phosphorylated form is less active, whereas, the De-phosphorylated form or the native form is actually more active. So native form is more active phosphorylated form is less active. So, when the glucose is level is low, it is actually going to shuttle, the enzyme is going to shuttle between the two particular form right, whether it is the phosphorylated form or non-phosphorylated form and that is how it is actually going to control the speed of the glycolysis.

Similarly, you can have these many enzymes like the phosphofructokinase and all that and that is also going to be controlled by the many of these allosteric regulators. So, this all we are going to take care of when we are going to talk about the controlling of the enzyme activity, when we are going to talk about how this you know the enzyme is interacting with the substrate.

Now, the pyruvate is being produced right, pyruvate is being produced from the glycolysis and that is actually going to enter into the Kreb cycle.

(Refer Slide Time: 26:25)



And, so, pyruvate what is being produced from the glycolysis is going to be a feeder or feeding molecules for the pyruvate for the Kreb cycle. So, the pyruvate what is being generated is actually going to enter into the mitochondria, right. So, pyruvate is actually going to enter into the mitochondria and then within the mitochondria all these reactions are actually going to be catalyzed by the multiple enzymatic steps.

And, all these multiple enzymatic steps are coming under the collective name which is called as the Kreb cycle because it is a cyclic event. You can start from here and then you end up here. So, Kreb cycle is actually being discovered by the professor Hans Kreb and it has all sugar intermediate with the three carbon it is also known as the tricarboxylic acid or citric acid cycle. It is called as citric acid cycle because the first molecule what is being generated, in the Kreb cycle is called as citric acid actually.

In higher eukaryotes, the Kreb cycle operates inside the mitochondria, mitochondrial stroma with the help of the different enzyme. In the presence of oxygen, the pyruvate formed during the glycolysis enters into the Kreb cycle for further oxidation to produce the energy. This means this particular cycle which is required for the carbohydrate degradation to produce the energy under the catabolic reaction is not present in the bacteria because bacteria does not contain the mitochondria.

So, you can have the these many reactions. So, first the pyruvate what is being produced from the mitochondria it will enter into the into the into the krebs into the mitochondria and then it is going to be utilized by an enzyme which is called as pyruvate dehydrogenase complex. So, pyruvate dehydrogenase complex is a multimeric enzyme complex and it is actually going to catalyze multiple reactions and that is how the it will going to convert the pyruvate into the acetyl CoA.

And, acetyl CoA is actually a very very important molecule because on one side it is actually going to you know connected to the lipid metabolism and on the other side it is also going to be converted connected to the protein metabolism. Now, acetyl CoA is going to combine with the oxaloacetate and it is actually going to synthesize the first molecule which is called as citrate and the enzyme name is citrate synthesis. So, this is the step number 1, ok.

In the step number 2, the citrate is actually going to go through with the two steps of the dehydrations and that is how it is actually going to produce the cis-aconitase and the

enzyme name is aconitase. So, aconitase is actually going to catalyze the dehydration reactions and that is how it is actually going to produce the cis-aconitase.

Now, it is going to have the another round of dehydration and as a result the cis-aconitase is going to form the isocitrate. So, this is going to be the third reactions and then the isocitrate is going to get you know converted into the oxaloacetate and in this step is going to be catalyzed by an enzyme which is called as isocitrate dehydrogenase. And, this is the reaction number 4 and in this event the first molecule of the NADH is going to be produced.

So, remember that from 1 to 4 only the first time the one molecule of NADH is going to be produced. Then from the oxaloacetate there will be decarboxylation reaction and the this decarboxylation reaction is going to be you know catalyzed to produce the alpha keto-glutarate. And, alpha-keto glutarate is then going to be dehydrated and it is then alpha-keto glutarate is going to be get converted into the succinyl CoA.

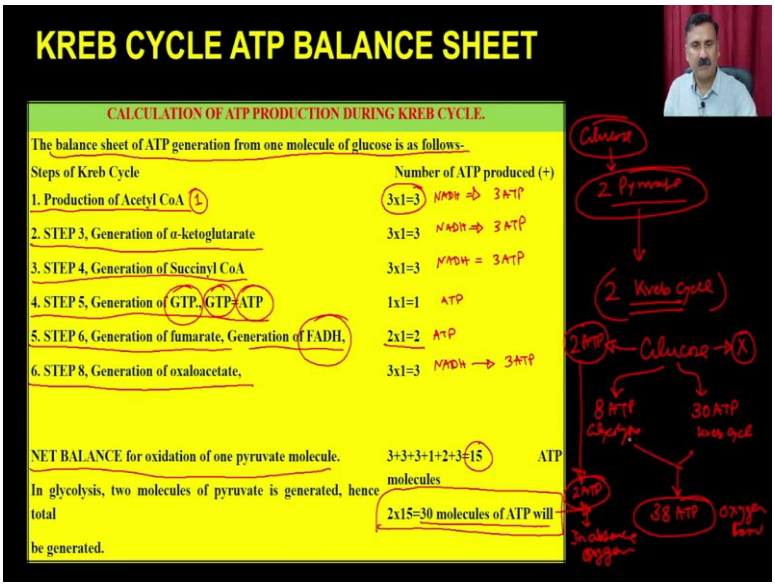
And, the enzyme name is alpha-keto glutarate dehydrogenase and there are many type of coenzyme, but are required like for the TPP or an coenzyme A, right. And, in this step the another molecule the second molecule of NADH is also going to be produced. Then succinyl CoA is going to be get converted into the succinic acid with the help of the enzyme which is called as succinate thiokinase. And, in this step the first molecule of the GDP is going to be produced.

So, remember that GDP is also equivalent to ATP in terms of the energy, ok and then the succinate is going to be get converted into the fumarate and in this step the first molecule of FADH2 is going to be produced and enzyme which is going to catalyze this reaction is called as succinate dehydrogenase. Remember that succinate dehydrogenase is also be a part of is a mitochondrial enzyme and it is actually been called as the you know mitochondrial marker enzyme because it is also ok.

Then the fumarate is also going to be get converted into the malate and the enzyme name is the fumarase and the malate is getting converted into oxaloacetate with the help of an enzyme which is called as malate dehydrogenase. And, the another the fourth molecule of the NADH is also going to reduce. So, third molecule of NADH is actually going to be produced here, ok.

And, once the oxaloacetate is produced it is actually going to take up another molecule of acetyl CoA and that is how it is actually going to going to continue the cycle and that is why this is called as the Kreb cycle. So, you have multiple reactions which are going to be catalyzed by the so many of these enzymes within the mitochondria and that is how it they are actually going to produce the energy, energy in terms of the NADH, energy in terms of the FADH2 and energy in terms of the GTP.

(Refer Slide Time: 33:07)



So, let us see how the energy balance is present in the Kreb cycle. So, the balance sheet of the ATP generation of one molecule of glucose is as follows. So, you remember that the from one glucose molecule, it is actually going to produce two pyruvate molecules which means for one glucose molecule you are going to have two rounds of Kreb cycle.

This is remember this is important to remember so that you should not be get confused when we are going to multiply this number. So, the step 1 in the step 1 where you have produced the acetyl CoA, right you are going to have the one molecule of NADH which is going to be produced right and that is actually going to give you the 3 ATP molecule. Then in the step 3 when you have generated the alpha keto glutarate again the one molecule of NADH is produced and that also is going to give you the 3 ATP molecule.

Then in the step 4, there will be a generation of succinyl CoA and that also is going to produce the NADH and that also is going to give you the 3 molecules of ATP. Then in

the step number 5 there is a generation of GTP and the energy of the one GTP molecule is equivalent to the ATP molecule and that is how the one molecule of ATP is produced.

Then in the step 6 generation of fumarate so, generation of FADH right and FADH actually produces the 2 molecule of ATP during the electron transport chain. So, it is actually going to give you the 2 molecules of ATP. Then in the step 8 when you are actually producing the you know last step where you are actually utilizing the malate and then again you have produced the another molecule of NADH and that is also going to give you the 3 ATP molecule.

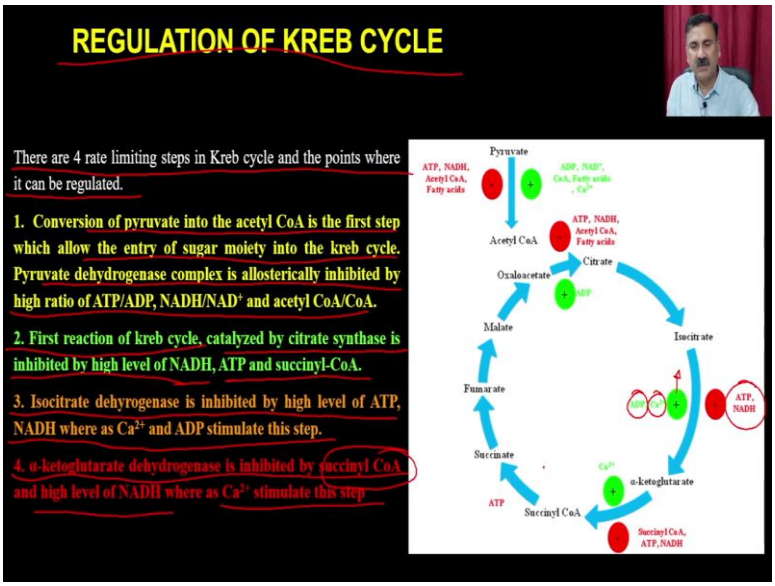
Now, the net balance net balance from the one pyruvate molecule is 3 plus 3 plus 3 plus 1 plus 2 plus 3 and that is the 15 ATP molecule and since the glycolysis is giving 2 pyruvate molecule you are going to multiply this number and that is how the net gain of the ATP from the one molecule of glucose is 30 molecules of the ATP will be generated.

So, this is the final net gain of ATP from the ATP. This means from the one molecule of glucose you are going to have 8 ATP molecules from the glycolysis and 30 molecules of ATP from the Kreb cycle. This is from the glycolysis and this is from the Kreb cycle ok. This means together you are going to have 38 ATP molecule if the oxygen is present.

Now, if the oxygen is not present then the glucose is going to give you 2 molecules of ATP in the Kreb cycle and there will be no glycolysis because the glucose is because the oxygen is very important to run the glycolysis. This means you are going to have the 2 ATP molecule if there is a no generation or no oxygen present.

So, if the in the absence of oxygen you are actually going to reduce 2 molecules of 2 molecules of ATP in the presence of oxygen you are going to produce the 38 ATP molecules. The total production – total production is going to be 40 ATP molecule, but you are utilizing the 2 ATP molecule in the glycolysis and that is why it is actually going to be 38 ATP molecules.

(Refer Slide Time: 37:01)



The Kreb cycle is and the enzymes and the intermediate what are producing in the Kreb cycle are very very important because they are communicating with the different types of metabolic reactions. For example, you are actually going to use you know. So, it for example, in the conversion of the pyruvate into a acetyl CoA and this step is the entry of sugar moieties into the Kreb cycle.

Pyruvate dehydrogenase complex is allosterically inhibited by the high ratio of acetyl. So, the regulation of Kreb cycle is very important because it is actually going to you know control the energy production, ok. So, there are four limiting steps for the Kreb cycle in the point where it can be regulated.

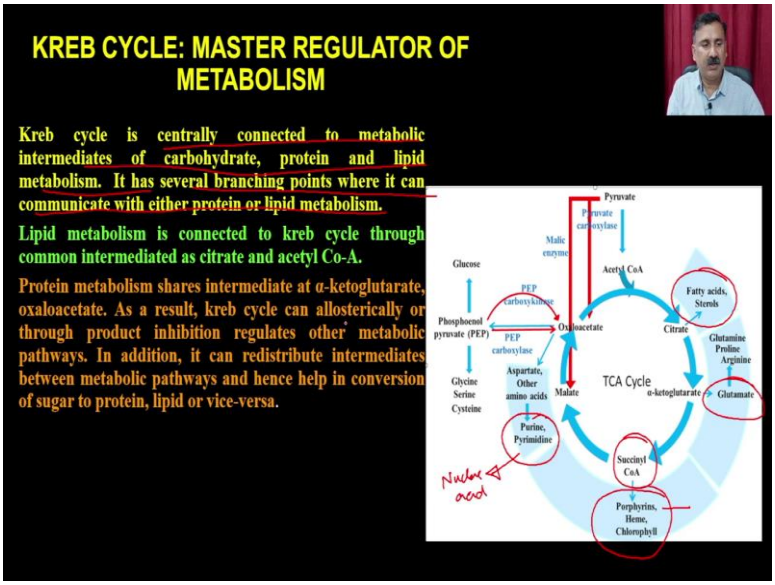
First step is the conversion of pyruvate into the acetyl CoA where the step at which all the sugar molecules are entering and this pyruvate dehydrogenase complex is allosterically been inhibited by the high ratio of ATP and ADP and acetyl CoA versus the coenzyme A.

Then the second is the first reaction of the Kreb cycle catalyzed by the citrate synthase this reaction right is actually going to be inhibited by the high level of NADH, ATP and the succinyl CoA. Then the third is isocitrate dehydrogenase it is inhibited by the high level of ATP NADH whereas, calcium and ADP stimulate this phosphate.

So, this is the isocitrate dehydrogenase isocitrate dehydrogenase. So, if the ADP is present or the calcium is present it is actually going to enhance the activity of this particular enzyme, but if the ATP or NADH is present they are allosterically going to they are actually going to inhibit the activity of these enzymes.

Then the fourth step is alpha-ketoglutarate dehydrogenase and that is actually going to be inhibited by the succinyl CoA or the and high level of NADH whereas, calcium actually stimulates this particular process. Apart from the regulation the Kreb cycle is central to the carbohydrate central to central metabolic pathway and that is why it communicates with the various types of you know other pathways to facilitate the breakdown and as well as to facilitate the biosynthesis.

(Refer Slide Time: 39:21)

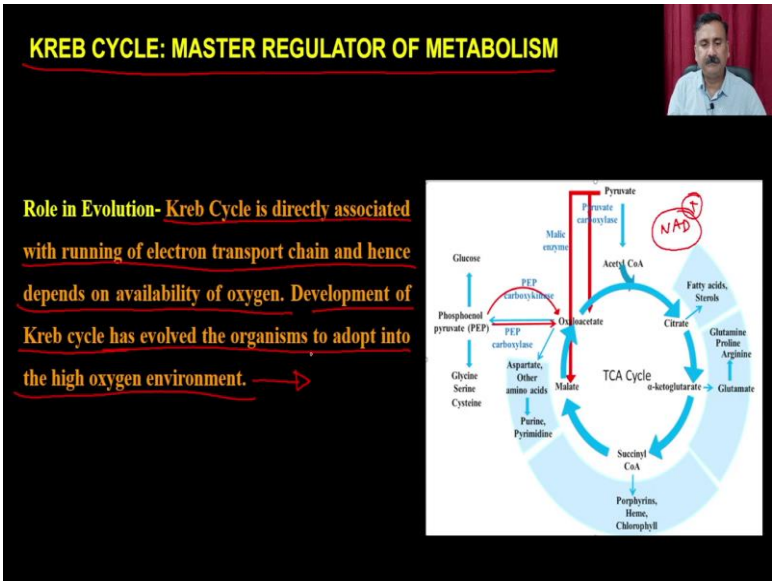


So, Kreb cycle is centrally connected to the metabolic intermediate of the carbohydrate protein and lipid metabolism. It has several branching point where it can be communicating with other protein or the lipid metabolism. So, what you see here is a extensive communication of the Kreb cycle with the many types of pathways. For example, the fatty acid pathways, steroid productions, protein pathways and so on and then it is also connected communicated with the hemin synthesis.

So, succinyl CoA can be utilized by the many types of enzymes which are involved in the hemin synthesis and that is how it is actually going to be utilized for the hemin synthesis. Similarly, you can also you see that it also have the you know the production

of the nucleic acid. So, that is how the Kreb cycle is actually communicating with the many types of pathways.

(Refer Slide Time: 40:36)



Kreb cycle is also or the enzyme what are present in the Kreb cycle are also playing a very crucial role in terms of the adaptation of the organisms. For example, if the oxygens are not present or there is a low level of oxygen then the Kreb cycle enzymes are going to shut down because if there is no oxygen there will be very high concentration of these equivalents and they are actually going to. So, there would be a high level of NAD plus, right.

But, if the oxygen is not present there will be high production of the NADH and so, apart from the Kreb cycle which is master regulator of metabolism, Kreb cycle also play a very crucial role in the evolution also because evolutionary the Kreb cycle was not present in the lower organisms such as bacteria. And as the oxygen evolved the and the organism have shifted from the aerobic oxidations the so many enzymes are been you know.

So, mitochondria was present and that is how the so many enzymes are being placed in such a way that it is actually going to be utilized the pyruvate from the glycolysis to produce the high quantity of energy. So, the Kreb cycle is directly associated with running of the trans transport chain and hence depends on the availability of oxygen. The

development of Kreb cycle has evolved the organism to adopt into the high oxygen environment, ok.

So, this is all about the role of the enzyme in the metabolic reactions. So, we have taken an example of the carbohydrate metabolism and how the different enzymes are catalyzing the different reactions and how they are actually playing a crucial role in terms of the regulation of the enzyme production and regulation of energy production and as well as the you know shuttling the intermediates from the one in one reaction intermediates to the another pathways.

So, with this I would like to conclude my lecture here. In our subsequent lecture, we are going to discuss more about the lipid metabolism and how the different enzymes are catalyzing and regulating the lipid metabolism to produce the energy.

Thank you.