Basics of Biology

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Lecture 17

Carbohydrates (Part 2)

Hello everyone. This is Doctor Vishal Trivedi from Department of Biosciences and Bioengineering, IIT Guwahati. And what we were discussing? We were discussing about the biomolecules. And the understanding of biomolecules is very important for us to realize the importance of these biomolecules in running the several types of cellular activities. So, so far what we have discussed? We have discussed about the nucleic acids.

So, in that we have discussed about the DNA and RNA. And these two molecules are important for the information to be stored in from the one generation to another generation. And that is how they are actually going to relay the information from the one generation to the next generations. And subsequent to that we were also discussing about the carbohydrates. And carbohydrates are mainly been required for energy production, and as well as in some cases they are also been part of the building blocks where they are actually modifying some of the crucial cellular factors and other things.

So, if you recall in our previous lecture we discussed about the different types of carbohydrates. We discussed about the monosaccharides, disaccharides and polysaccharides. In addition we have also discussed about the different types of structural as well as the biochemical details of these different types of carbohydrates. And the carbohydrates are present in the linear chain or to the cyclized form, and they are also showing the different types of isometric properties. So, with this brief discussion in the previous lecture in today's lecture, we are going to discuss about how the carbohydrates are participating into the energy production.

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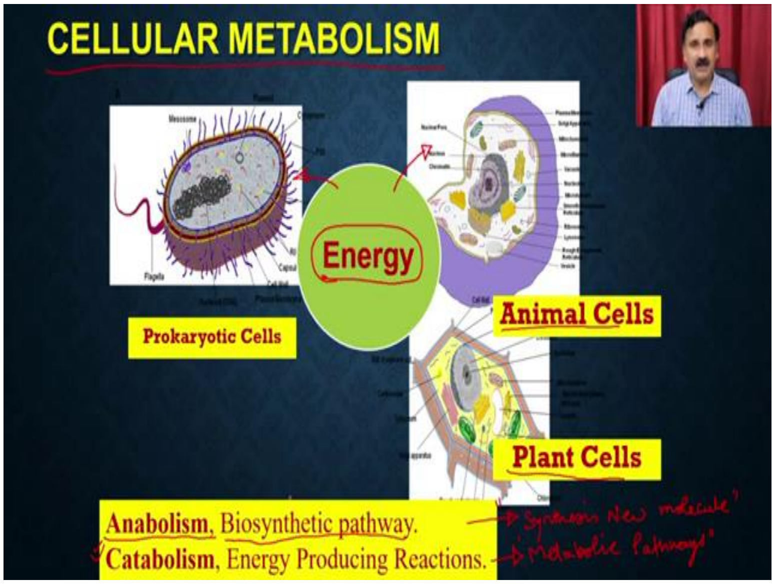

So, as you can see that the energy is the ultimate source or ultimate thing what is required for running the metabolic reactions, whether it is a prokaryotic cell or whether it is a eukaryotic cell, whether it is a eukaryotic animal cell or to the plant cells. So, when we talk about the energy production we have to run the cellular metabolism. And cellular metabolism could be of two types. It could be an anabolism or to the catabolisms.

So, what is meant by the anabolism? Anabolism means is a biosynthetic pathway, which means, anabolism means it is actually being going to synthesize the new molecules. If you recall when we were talking about the nucleic acid we have discussed about how the nucleotides are been synthesized and what are the composition of the nucleotides. Similarly, if you want to develop the sugars or if you want to synthesize the sugar also, that also has to be synthesized under the anabolic reaction.

Then we have the catabolic reactions. Catabolic reactions are the reactions which are responsible for the energy producing reactions. So, in this you are actually going to have the different types of metabolic pathways or metabolic reactions. And these metabolic pathways or reactions are ultimately going to destroy or oxidize the given biomolecule, and that is how they are actually going to produce the ATP as well as the other reducing equivalents.

So, we are going to discuss about the catabolic pathways and how the catabolic pathways are, or what are the different types of catabolic pathways are involved into the breakdown of the carbohydrates, and then as a result it they are actually going to produce the energy in the form of ATP or the reducing equivalents such as the NADH.

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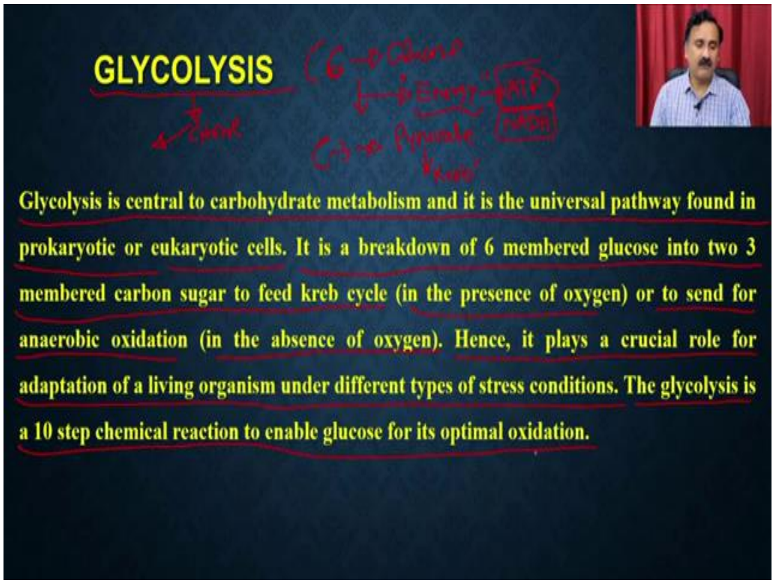

So, when we talk about the cellular metabolism, the cellular metabolism of the carbohydrates, it actually going to start with the glycolysis. So, glycolysis is the first pathway which is involved into the catabolism of the carbohydrates. So, glycolysis is central to carbohydrate metabolism and it is a universal pathway which is found into the prokaryote or the eukaryotic cell. So, glycolysis is a metabolic pathway which is present in the cytosol, and it is actually been present in all the cells which are utilizing the carbohydrate as a source of energy irrespective of whether it is a prokaryotic cell or the eukaryotic cell.

What is going to happen in glycolysis? It is going to break down of the 6 membered glucose into the two 3 membered carbon sugar to feed the Kreb cycle in the presence of the oxygen, or it is going to send through the anaerobic oxidation in the absence of the oxygen. So, what are the glycolysis is going to do is it is actually going to take the 6 membered carbon sugar like the glucose, and it is actually going to convert that into the 3 membered carbon sugar such as pyruvate. And it is going to have the different types of reactions through which it is actually going to do this kind of breakdown. And under these conditions it is actually going to utilize the energy what is been stored into the glucose into the form of the ATP or to the NADPH. So, it is actually going to produce ATP as well as the NADH, and these two molecules are actually going to provide the energy into the cell.

Hence it plays a crucial role for the adaptation of a living organism under different types of stress conditions. So, glycolysis is the major pathway which actually allows the organism to adapt for the different types of environmental conditions. As you can see that it is actually going to break down the 6 membered glucose into the 3 membered carbon sugars in and that 3 membered carbon sugar which is the pyruvate is eventually going to go into the Kreb cycle.

But it goes into the Kreb cycle only if the oxygen is present. And if oxygen is not present then it is actually going to feed the pyruvate into the anaerobic pathway. And that is how, depending on the availability of the oxygen the glycolysis can be able to shuttle the final product into the two different types of pathway, and that's how it actually can allow the adaptation of the different types of stress conditions. The glycolysis is a 10 step chemical reaction to enable the glucose for its optimal oxidation.

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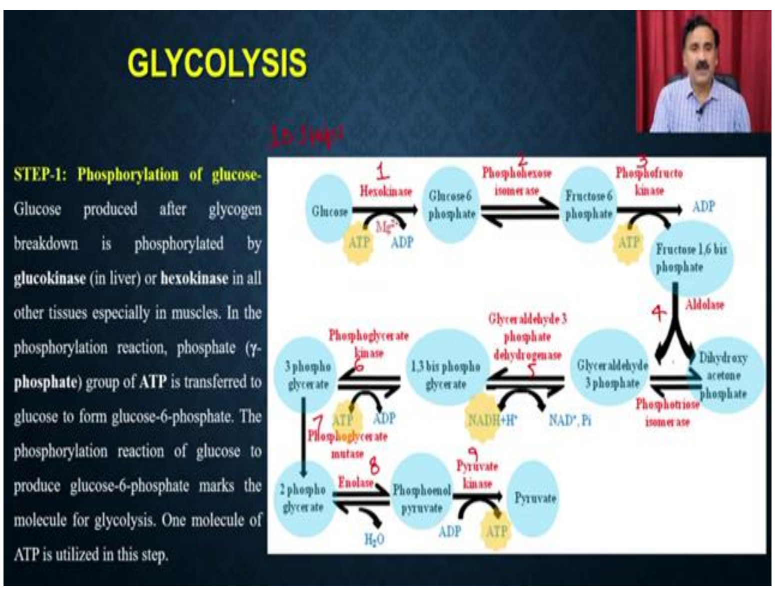

So, let us see what are the different steps what you are going to have. So, in the glycolysis, as I said, it is a 10 step reaction. So, it is going to have 10 steps, like you see here. The step number 1, step 2, step 3, step 4, step 5, 6, 7, 8 and 9. So, it is going to have a 10 step reaction. And this is actually another step. So, we are going to discuss each and every step and we are also going to discuss what are the relevance of these steps, and so on.

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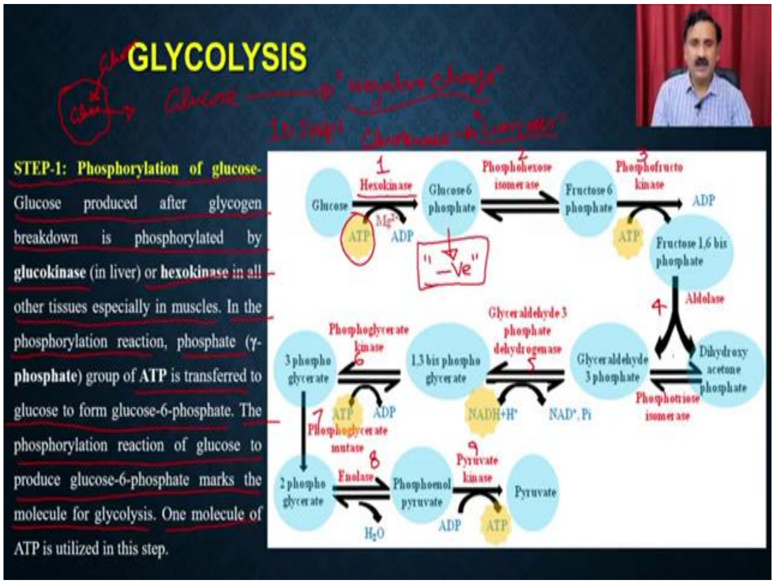

So, in the step 1, step 1 is called as the phosphorylation of the glucose. So, you can imagine that as soon as you have a cell and this cell is actually going to receive the glucose from outside, this glucose is going to be available for the glycolysis. This glucose is available for the glycolysis but as the glucose is a uncharged molecule, it required to be trapped inside in the cell. So, that process is being done in the step 1.

So, glucose is going to be get phosphorylated. And what will happen when glucose is going to get phosphorylated? So, glucose is a uncharged molecule, and once you do the phosphorylation it is actually going to develop the negative charge. And because of that it is actually going to be trapped inside the cell and is going to be committed for the oxidation process.

So, glucose produced after the glycogen breakdown is phosphorylated by the glucokinase. So, there are two enzymes which are involved into the glucose phosphorylation. One is called as the hexokinase which is present in the all other tissues, whereas it is also been phosphorylated by another enzyme which is called as glucokinase. So, glucokinase is only present in the liver cell whereas the hexokinase is present in all other cells, or the hexokinase in all other tissues especially in muscles.

In the phosphorylation reaction the phosphate which is the gamma labeled phosphate group of ATP is transferred to the glucose to form the glucose 6 phosphate. The phosphorylation reaction of glucose to produce the glucose 6 phosphate marks that particular molecule for the glycolysis, and one molecule of ATP is going to be utilized in this step. So, in the step 1 the glucose is actually going to be phosphorylated by the glucokinase in the liver cell or by the hexokinase by all other cells especially the muscle cells. And one molecule of ATP is going to be utilized in this process, and as a result it is actually going to produce the glucose 6 phosphate.

As soon as it generates the glucose 6 phosphate it is actually going to cause the negative charge on this particular glucose molecule. And as a result, this glucose monocle which has entered into the cell cannot go out. If it wants to go out then it cannot be a passive transport. It has to be an active transport. And because of this only, the first phosphorylation is happening so that the glucose is going to be trapped inside the cytosol and it is going to be committed for the glycolysis.

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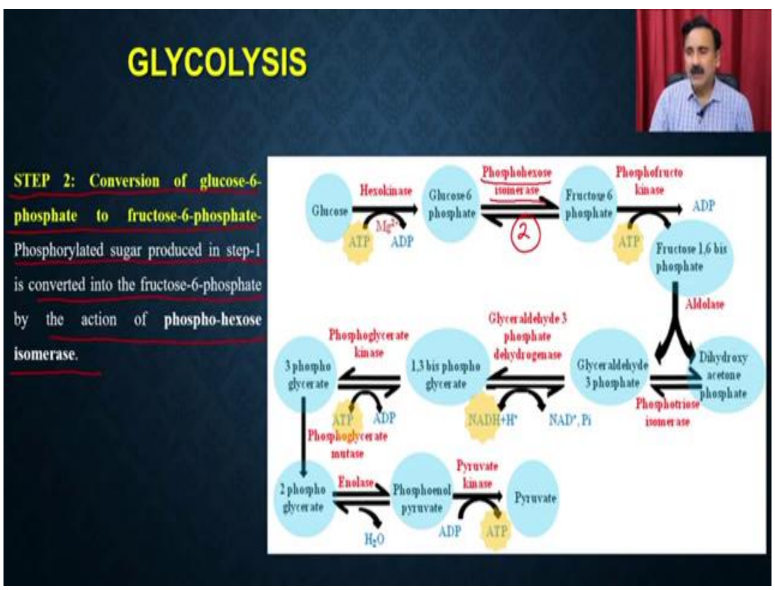

Then in the step 2, there will be a conversion of the glucose to the fructose-6-phosphate. So, this is a isomerization reaction. So, in the step 2 you are actually going to do the isomerization so that the glucose is going to get converted into the fructose-6-phosphate. And the enzyme what it is going to use is the phosphofructoisomerase. So, phosphorylated sugar produced in step 1 is converted into the fructose 6 phosphate by the action of the phosphofructoisomerase.

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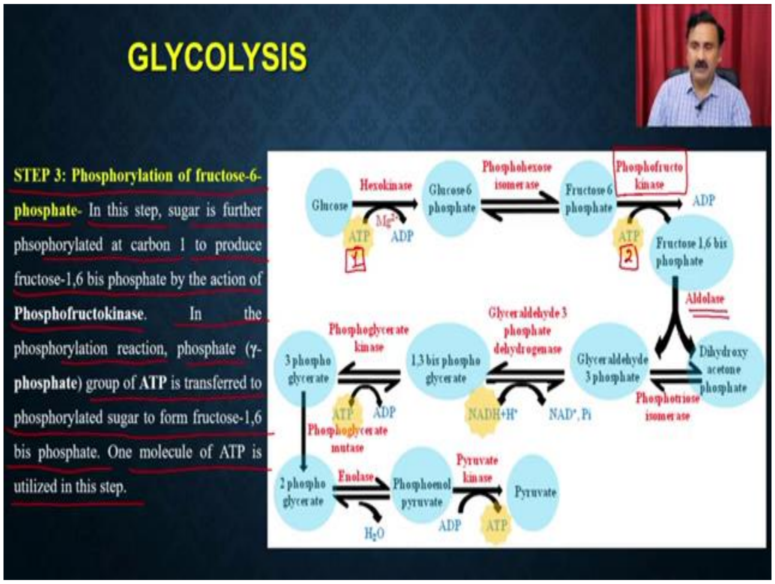

Now, in the step 3, it is actually going to do the another round of phosphorylation. In the step 3 phosphorylation of fructose-6-phosphate, so in this step, the sugar is further phosphorylated at the carbon 1 to produce the fructose 1, 6 bis phosphate by the action of the enzyme which is called the phosphofructokinase.

In the phosphorylation reaction the phosphates, that the gamma-labeled phosphate group of ATP is transferred to the phosphorylated sugar to form the frutose 1,6 bis phosphate, one molecule of ATP is going to be utilized in this process. So, in the step 3 the fructose-6-phosphate is going to be phosphorylated with the help of the ATP and it is going to generate the fructose 1, 6 phosphate and enzyme name is phosphofructokinase. So, you can see that it is actually going to consume the two molecules of ATP. One molecule is here, another molecule is here.

Now, once the fructose 1, 6 bis phosphate is been generated it is going to be utilized by the another enzyme which is called as the aldolase, and that is why it is going to do the further degradation.

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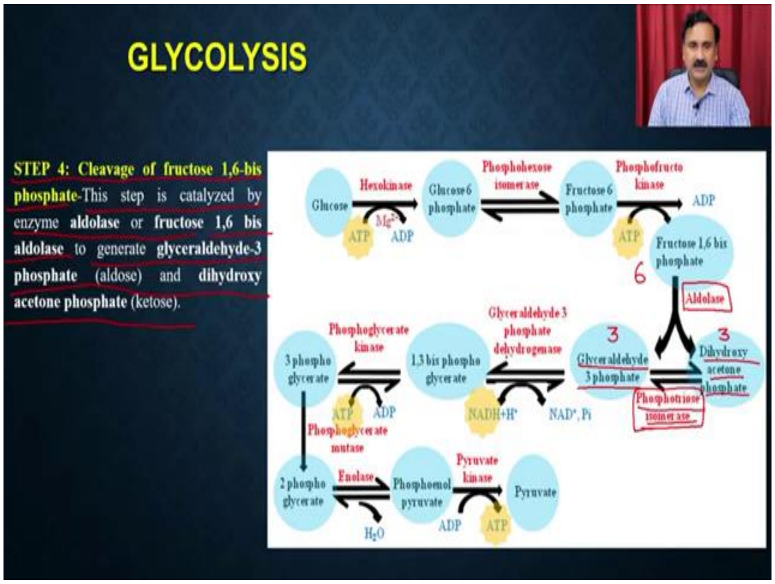

So, in the step 4 there is called as the cleavage of the fructose 1, 6 bis phosphate. So, as soon as the fructose 1, 6 bis phosphate is going to be generated it is actually going to be cleaved in the step 4. So, this step is catalyzed by the enzyme aldolase or the fructose 1, 6 bis phosphate aldolase to generate the glyceraldehyde 3 phosphate and the dihydroxy acetone phosphate.

So, as soon as the fructose 1,6 bis phosphate is generated it is going to be act by the enzyme which is called as the aldolase and that aldolase is actually going to bring the breakdown of this 6 membered carbon sugar into the two 3 membered sugar. It is going to generate the glyceraldehyde 3 phosphate and the dihydroxy acetone phosphate. These two are actually the isomeric forms.

So, they are actually going to be converted to each other by the enzyme which is called as the phosphotriose isomerase. And because of that the dihydroxyacetone phosphate is going to be converted into the glyceraldehyde 3 phosphate. And then glyceraldehyde 3 phosphate will further breakdown and that is how it is actually going to run the glycolysis.

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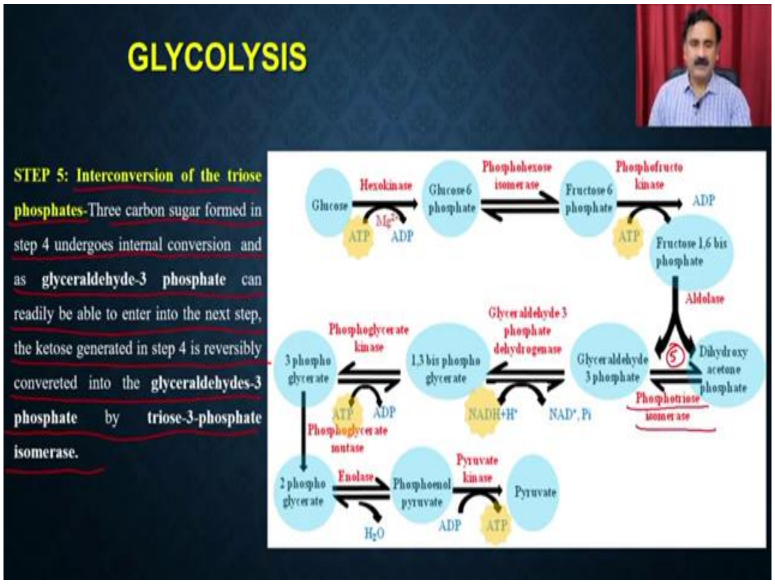

So, in the step 5 the inter-conversion of the triose phosphate, so 3 carbon sugar formed in step 4 undergoes the internal conversion and as the glyceraldehyde phosphate can readily be available to enter into next step, the ketose generated in the step 4 is reversibly been converted into the glyceraldehyde 3 phosphate by the triose phosphate isomerase. So, in the step 5, so this is a step 5, the dihydroxyacetone phosphate which is been a keto sugar is been converted into the glyceraldehyde 3 phosphate by the enzyme which is called as phospho triose isomerase.

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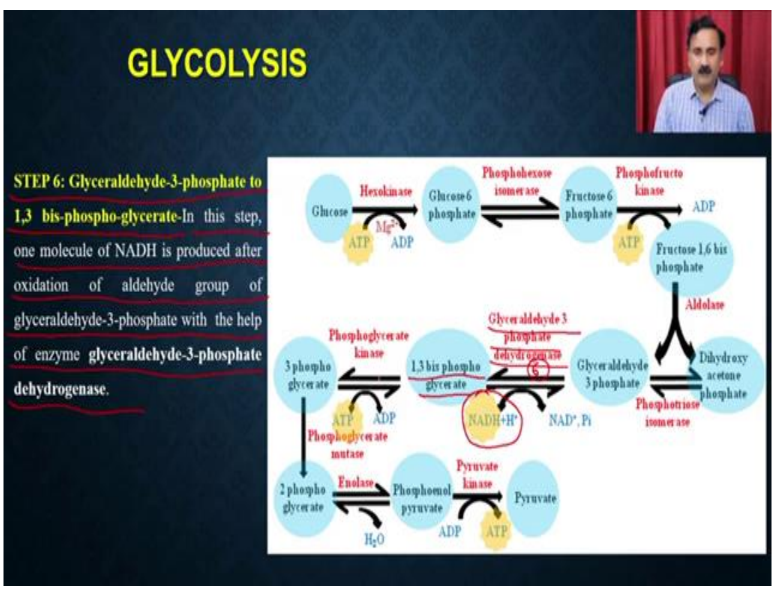

Now, in the step 6 the glyceraldehyde 3 phosphate is going to be produce the 1, 3 bis phosphoglycerate. So, in the step 6 the glyceraldehyde 3 phosphate is actually going to be get converted into the 1, 3 bis phosphoglycerate. And you can see that it is actually going to produce the one molecule of NADH.

So, in this step, one molecule of NADH is produced after the oxidation of the aldehyde group of the glyceraldehyde 3 phosphate with the help of an enzyme which is called as the glyceraldehyde 3 phosphate dehydrogenase. So, in the step 6 the glyceraldehyde 3 phosphate dehydrogenase is actually going to the oxidation of glyceraldehyde 3 phosphate, and that is why this aldehyde group is going to be oxidized by the enzyme and it is going to produce one molecule of NADH. And the product what is going to be formed is 1, 3 bis phosphoglycerate. Now, 1, 3 bis phosphoglycerate will enter into the next step, which is the step 7.

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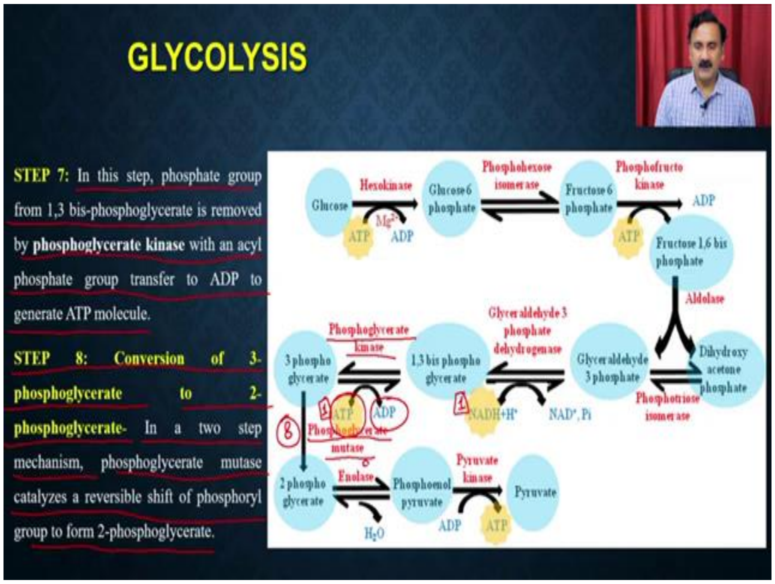

In this step, the phosphate group from the 1, 3 bis phosphoglycerate is removed by the phosphoglycerate kinase with acyl group transferred to the ADP to generate the ATP molecule. So, in the next step the 1, 3 bis phosphoglycerate, the phosphate is going to be taken up by this particular molecule by the enzyme which is called phosphoglycerate kinase, and that is how the ADP is going to be converted into the ATP. So, this is going to be the first time when the ATP is going to be generated in the glycolysis, whereas this is the first time when the NADH is going to be generated.

In the step 8 conversion of the 3- phosphoglycerate to the 2- phosphoglycerate, so in a two step mechanism the phosphoglycerate mutase catalyzes the reversible shift of the phosphorylation group to form the 2- phosphoglycerate.

So, once the 3- phosphoglycerate is been produced, in the step 8 there will be conversion of the 3- phosphoglycerate to the 2- phosphoglycerate. And so there will be a shifting of the phosphorylated group from the third carbon to the second carbon by the enzyme which is called as the phosphoglycerate mutase. And once the 2- phosphoglycerate is going to be produced, it is going to be entered into the next step which is called as the step 9.

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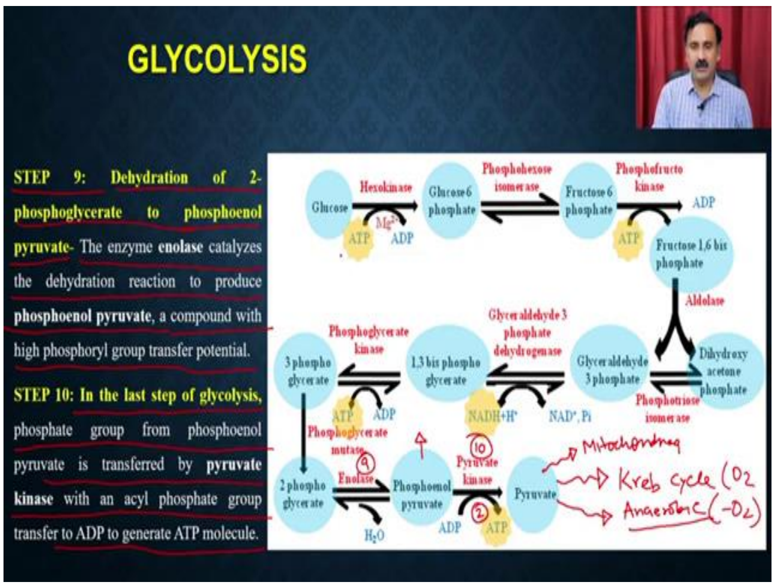

So, in the step 9 it is going to be a dehydration reaction. So, in the step 9 the enzyme enolase is going to catalyze a dehydration reaction and because of that it is actually going to produce the phosphoenol pyruvate. So, the step 9 the dehydration of the 2- phosphoglycerate glycerate to produce the phosphoenol pyruvate. The enzyme enolase catalyzes the dehydration reaction to produce the phosphoenol pyruvate, a compound with the high phosphate transfer potential. So, this is going to have the high energy phosphate group and from the 2- phosphoglycerate the enolase is actually going to remove the one molecule of water, and that is how it is actually going to produce the high energy high phosphate containing molecule which is called the phosphoenol pyruvate.

And then in the phosphoenol pyruvate is going to enter into the last step which is the step number 10. And in this last step of the glycolysis the phosphate group from the phosphoenol pyruvate is going to be transferred by the pyruvate kinase with acyl phosphate group transfer to the ADP to generate the ATP molecule. So, in the last step the phosphoenol pyruvate, the phosphate group is going to be transferred from the phosphoenol pyruvate by the enzyme pyruvate kinase, and that is how the ADP is going to be get converted into the ATP. So, this is the second time when the ATP is going to be generated and then it is going to produce the pyruvate.

And this pyruvate then further move on and it will enter into the Krebs cycle in the case of the oxygen is present. If the oxygen is not present then this pyruvate will enter into the anaerobic oxidation if the oxygen is not present. So, that's once the pyruvate is been produced then pyruvate will be transferred either to the mitochondria for the Kreb cycle or it is going to be sent for the anaerobic oxidations.

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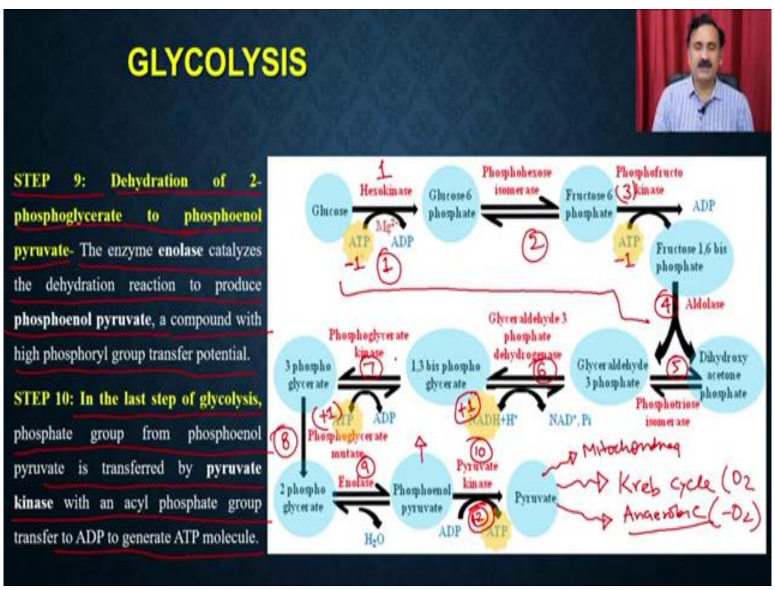

Now, let us see how the energy is being consumed or how the energy is going to be produced after the glycolysis. So, what you see here is that wherever the energy is being utilized first to run these reactions. So, we have the first place where the ATP is going to be used. So, I am just writing the minus 1 so that I will tell you that these are the things where ATP is being utilized. So, minus 1, then we have another place where we have ATP is used so this is also minus 1. So, these are the two steps, like the step number 1 and the step number 3, these are the places where the ATP is being utilized by the system. So, that it is actually going to energize the system so that it is actually going to participate into the further breakdown reactions. And then what you see here is that the first molecule of ATP is being produced here, and the second molecule of ATP is going to be produced here. Apart from that it is also going to produce the one molecule of NADH.

So, if you see the balance sheet, how the balance sheet of the ATP production within the glycolysis is, you are going to see that from the step 1 to step 4, so this is the step 4, this is the step 5, this is the step 6, this is the step 7, this is the step 8, this is 9, and this is 10. So, this is number 1, this is number 2, this is 3, this 4, 5. So, what you see here is that from the step 1 to 4 there is a utilization of the energy by the system. And then from the 5 onwards there is production. So, let us see how it is being done.

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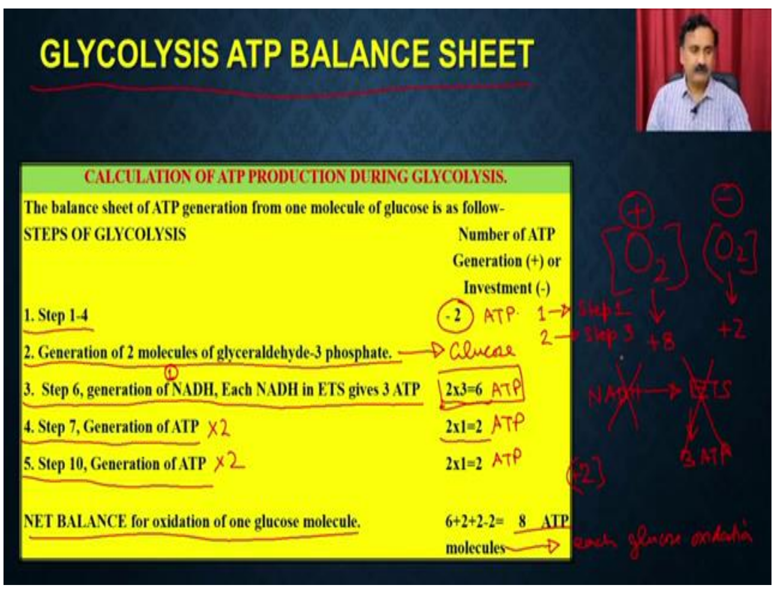

So, what you see here is a balance sheet, the ATP balance sheet. So, in the step 1 to 4 we are actually utilizing the two ATP. So, we are utilizing the two AT, one ATP which is actually in the step 1, and the second ATP which we are utilizing in the step 3. Then we have the generation of the two molecules of the glyceraldehyde 3 phosphate. Remember that when the aldolase is cleaving and producing the two molecules of glyceraldehyde 3 phosphate and the dihydroxyacetone phosphate and then there is internal conversion and that is how the two molecule of glyceraldehyde 3 phosphate is being produced from the single glucose molecule.

Now, in the steps 6 there is a generation of NADH. So, that NADH, because there is one molecule of NADH production from one molecule of glyceraldehyde 3 phosphate and that's how there will be two molecules of NADH is going to be produced from the single glucose molecule. And that's why, and each NADH is actually, then going to be, gone to the electron transport chain, it is actually going to give you the 3 ATP. That is why the number of ATP what is going to be produced is 6, because 2 into 3 is equal to 6 ATP molecule. Now, in the step 7 there will be a generation of ATP.

So, since we have the two molecule of glyceraldehyde 3 phosphate we are actually going to see the production of 2 ATP. So, there will be two ATP molecules which are going to be produced. And then, in the last step, the step when the pyruvate is being generated, again we are actually going to have the ATP generation. And since we are starting with the two molecules of glyceraldehyde 3 phosphate there will be two ATP molecules which are going to generate here.

Now, if you see the net balance, the net balance is that we have the 6 molecules, 2 molecules, 2 molecules. So, 10 molecules which are being generated and then we have utilized the 2 molecules, so actually the 8 ATP molecule are going to be generated after each glucose molecule oxidation. And that is only when the oxygen is present. If the oxygen is present you are going to see the 8 ATP molecules which are going to be generated.

If the oxygen is not present, which means if there will be absence of oxygen then the electron transport chain is actually not going to be functional. So, this 3 ATP, this 6 ATP is not going to be produced. And in that case the net ATP that is going to be formed is only 2, because 2 is what use you are utilizing and the 4 what you are actually producing. And because of that it is actually going to give you the 2 net ATP in the absence of oxygen. So, in the presence of oxygen there will be a net production of 8 ATP. In the absence of oxygen the net production is only 2 ATP.

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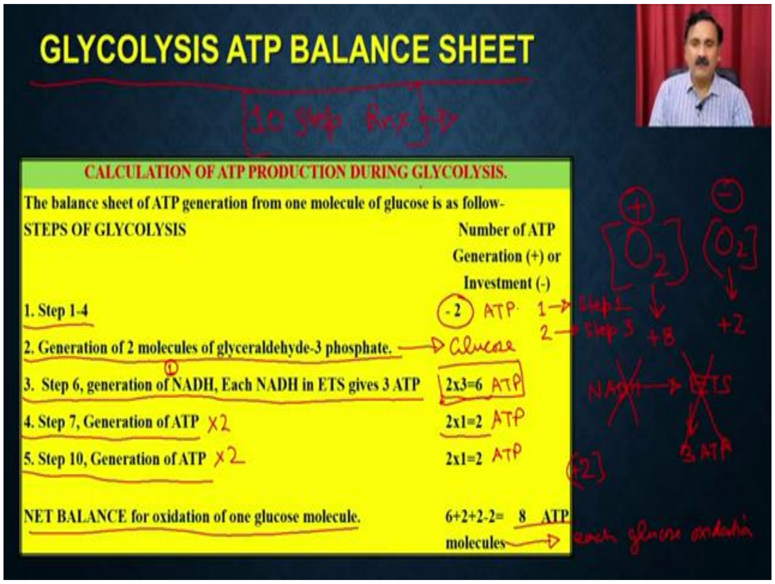

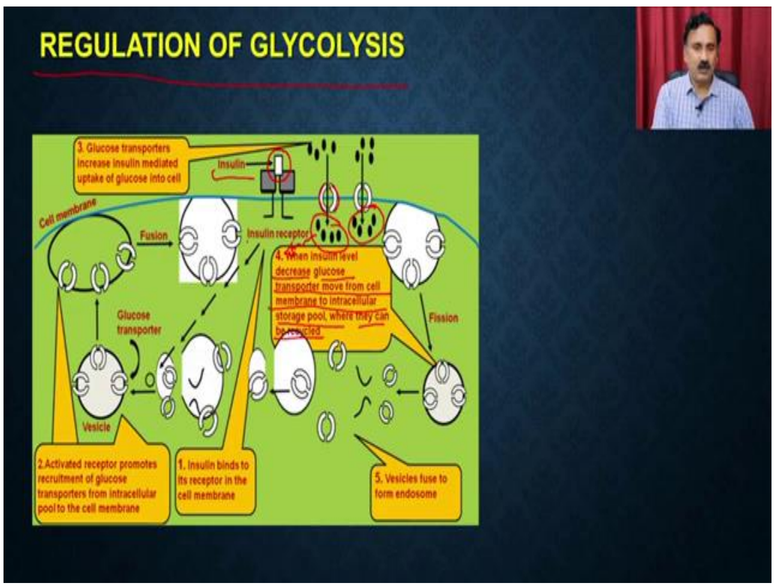

Now, let us see how and what are the different steps at which the glycolysis can be regulated. So, you see that glycolysis is a 10 step reaction. And if you recall the first step itself is the phosphorylation reaction. So, as soon as the glucose will enter into the cytosol or glucose will enter into the cell it is actually being phosphorylated by the glucokinase or the hexokinase, and that is why it is actually going to be committed for the glycolysis.

So, that is the first step where the glycolysis can be regulated. You know that when we take the food, the polysaccharides are going to be digested by the different types of enzymes what is present in the stomach or the small intestine, and then these monosaccharides are going to be absorbed from the alimentary canal into the blood. So, once the blood sugar level is going to go high then the insulin which is the hormone is actually going to bind the insulin receptor, and as a result once the insulin is going to bind the insulin receptor, it is actually going to open up the glucose transporters. So, once it will open up the glucose transporter, the glucose is actually going to be entered into the cell.

Now, once the insulin level, so as soon as there will increase in glucose level there will be insulin production and that insulin will go and bind to the insulin receptor. And as result there will be transport of glucose. Once the transport of glucose is happening then this glucose is going to be committed, or it is actually going to increase the rate of glycolysis. When the insulin level is going to decrease, the glucose transporters are going to move from the cell membrane to the intercellular storage pool where they can be recycled.

So, as soon as the blood glucose is going to be down there will be decrease in insulin level, and as a result the receptors or the channels what are present on to the cell surface is also going to be stored into the intracellular vesicles. And that is how they are actually going to be recycled back on to the membrane, and they were virtually going to utilize on a second round of the transport. So, the entry of glucose is mainly been regulated by the hormone which is called as the insulin hormone.

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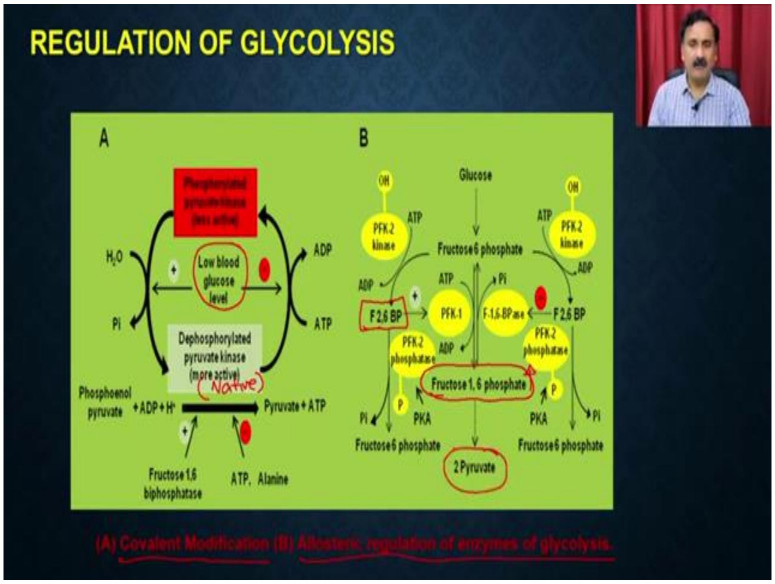

Apart from that, the glycolysis can also be regulated at two event. One is called as the covalent modification. The other one is called as the allosteric regulation of the enzyme of the glycolysis. So, the covalent modification means that you are actually going to regulate the enzyme by the covalently modify, so one of the classical covalent modification is that you are actually going to do the phosphorylation.

So, in this case if the pyruvate kinase is phosphorylated it is going to be the less active, if the pyruvate kinase is dephosphorylated it is going to be more active. Dephosphorylated means pyruvate kinase is present in the native form. It is going to be more active. If it is going to be phosphorylated then it is going to be less active.

So, when it is going to be, when there will be change in the blood glucose level it is actually going to change the phosphorylated as well as the de phosphorylated developed pyruvate kinase into the cell. And that is how it is actually going to regulate the level of these phosphorylated pyruvate kinase versus the dephosphorylated or the native pyruvate kinase. And that is how it is actually going to regulate the glycolysis.

Apart from that, we can also have the allosteric regulations. So, allosteric regulation is a regulation where the molecule does not bind into the or does not modify the enzyme. It actually goes and binds to the allosteric sites, and that is how it actually modulates their activities. So, that is happening for the enzyme which is called as the phosphofructokinase. And the phosphofructokinase is going to the be allosterically been modified by the molecule which is called as the fructose 2, 6 bis phosphate, and it is going to allosterically regulate the activity of the phosphofructokinase. And that's how that is going to regulate the production of fructose 1, 6 bis phosphate. And you know that if there is an increase in the production fructose 1, 6 bis phosphate it is actually going to increase the glycolysis level.

So, this is all about the glycolysis. What we have discussed so far? We have discussed about the different steps of the metabolic reactions what is happening into the glycolysis, what is the energy production within the glycolysis, and under the different environmental conditions how the energy production is going to be modulated.

And in addition to that we have also discussed about the regulation of the glycolysis by the different means, either it will be by the entry of the glucose into the cell by the mean of the insulin hormone, or by the covalent as well as the allosteric regulations of the different enzyme what is present into the glycolysis. So, with this I would like to conclude my lecture here.

In our subsequent lecture we are going to discuss about some more biomolecules. Thank you.