Animal Physiology
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Lecture – 20

Welcome back to the NPTEL lecture series on Animal Physiology, so we finished with gastro intestinal physiology and now we will be moving onto metabolism and thermo regulations. So, this is section 13 and they are dedicated two lectures for that, so what will essentially do in this section. So as of now we studied when we take the food we chew it up, the first set of reactions start by the salivary gland, then the food passes through the ISO forages kind of a tunnel and goes to the stomach in an acidic environment.

There it is exposed to hydrochloric acid and from there it moves on to small intestine, that is significant amount of absorption take place and then to the large intestine, likewise gets rejected. During this process, we have appreciated how pancreases secretes, different exocrine secretion, and endocrine secretion, secretions of insulin ((Refer Time 01:25)), we talked about the secretion from the liver, the pile juices how they helped in a multiplication of the fats and everything.

So, as if you now we talked about in terms of the anatomical features and the movement of food, so this an anatomical structure. What we will essentially do now is, will give it biochemical flavor, so what does that mean is, so food basically consist of five different components. So, one of the major component is water, carbohydrates, lipids, proteins some minerals, which eventually from the electrolyte in our body and some vitamins and some hormones which are needed in very, very low concentration and a series of minerals.

So, these are absorbed, first of all these are degraded in through series of reaction, so what we will do, first of all we will talk about or we will classify the different enzymes, which are involved in breaking down of carbohydrates which is one of the major component of food, the lipids and the proteins. Once we talk about those, then we will talk about two or three different cycles by which these enzymes are involved in two distinct processes of metabolism.

So, metabolism this word could be, we divided into two parts or the addition of two words could be considered as metabolism, so one is catabolism and the other one is anabolism. Catabolism is a process, when there is a breakage of a bigger molecule into smaller pieces through enzymatic action, whereas the reverse process when the smaller molecules added up to make a bigger molecules.

Say for example, small peptides making a polypeptide chain or small single carbohydrate sugar molecules making a stars molecule or glycogen molecule, that is constructive process or where there that involves the integration of smaller molecule and that process is called anabolism. And both anabolism and catabolism are regulated by a series of enzymes, so say start up with I will enumerate the different enzyme, which plays significant role in our digestive, in the digestion of the three different chemical components, so coming back to the slides.

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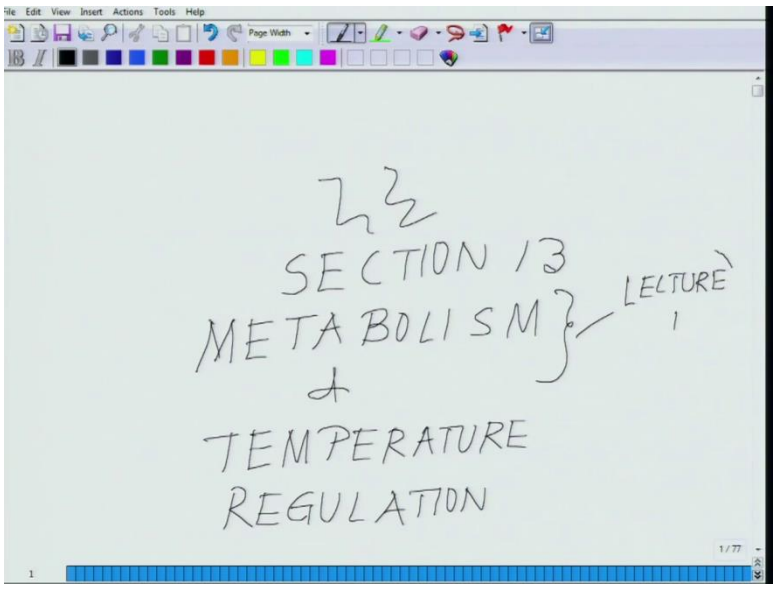

So, we are in essentially into section 13, metabolism and temperature regulation, this is a second part of this, so today will be dealing with metabolism which is our lecture 1, so coming to the different components of the food we talked about.

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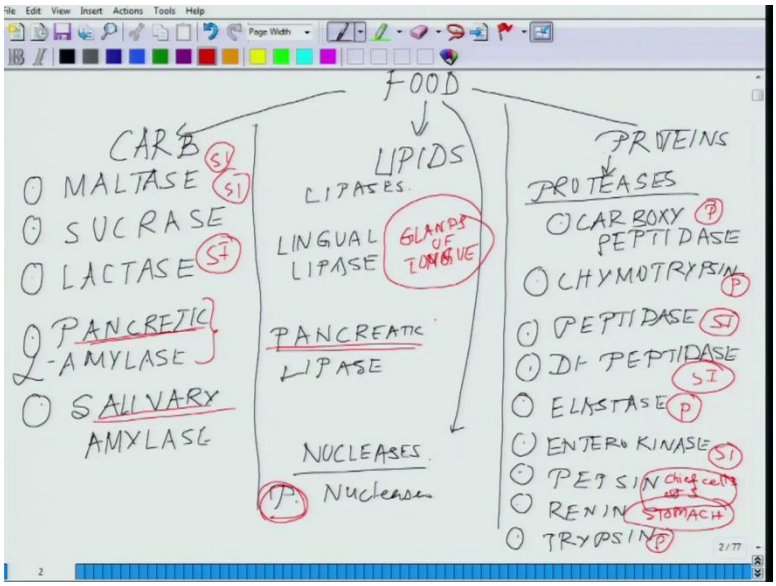

We have to divide food in terms of chemical origins, so then we carb, lipids and proteins and if I classify the different enzymes which are involved in it, for a carbohydrates you have maltase, taking care of maltose sugar, sucrase breaking down into sucrose sugar, lactase breaking the milk sugar or the lactose. Then you have secretion from pancreases, pancreatic amylase or alpha amylase, you have salivary amylase is taking place from the saliva.

Then from there, let us move on to the enzymes which are involved in breakage of proteins, some of them are called proteases, so proteases includes carboxypeptidase, you have chymotrypsin, you have dipeptidase, peptidase. So, breaking down the peptidase bond dipeptidase, you have entero kinase, elastase and then you have pepsin, then you have rennin, then you have trypsin, these are some of the major ones.

And then coming to lipids, they are mostly falling under the title of lipases which includes lingual lipase and you have pancreatic lipase. And then you have in that section, a smaller section you can add which are called nucleases, which includes mostly pancreatic nucleases. So, coming back, so I have enumerated the list of different lipases, different proteases, different carbohydrate breaking enzymes and many nucleases, so these are secreted by a different parts of a digestive system or different act part of the body.

So, what I will do now, I will highlight which part of the digestive systems, some of them are self explanatory is if pancreatic lipase means it secretary away the pancreases, but there are others which are secreted by multiple organs of the digestive crack. So, we will just enumerate them, so you put them different color, so that makes more sense, so coming to the maltases.

So, maltases are secreted by small intestine I am just putting as S I, means small intestine, sucrase small intestine again, lactase small intestine, pancreatic life is as its says that is by the pancreases, salivary amylase is it is by the saliva, the among the lipases, lingual lipase, so lingual lipase is basically the glands of tongue. So, basically all the way in the mouth, then you many have pancreatic lipases basically your pancreases, nucleases where the pancreatic, pancrease.

And among the proteases, so carboxypeptidase is by the pancreases, then you have chymotrypsin by the pancreases, then you have dipeptidases, that is by the small intestine, then have entero kinase by the brush border and the lumen of the small intestine. Then, you have elastases, elastases are secreted by the pancreases, dipeptidase by the small intestine, then you have the renin which is secreted by the stomach and you have trypsin which is again by the pancreases.

And then you have the pepsin, which secreted by the chief cells of the stomach, so coming back, so if you look at it, so all these different enzymes are secreted by the different parts of the digestive system. And in that whole process, there is division of labor, so once it goes to the mouth, it is chewed up by the teeth and these couple of enzymes are secreted either from the salivary gland or from along the mouth, during in the water cavity there are secretion. Then the food moves, then there are renin and few other stomach enzymes are secreted from their in the intestine.

But, if you see the huge chunk of these, concentration of these enzymes are concentrated along this, in the small intestine and around that pancreas, so this is the zone where most of them are concentrated, along this small intestine and the pancreas. So, from here what we will do, after giving this over view of these different enzymes which are getting secreted, we will move on to the different catabolism process and the anabolism process, which are involved in the whole process.

Before we do so I will just take one step back, so I talked about all this and all these different kind of enzymes in the slide, we will devote one more slide, talking about all the different products of carbohydrates, fats and proteins, how their smaller components are getting absorbed and which part of the digestive system are getting absorbed. Once will do that, then will move on to the catabolism and anabolism, the different cycles which are involved the grip cycles, cytolysis, gluconeogenesis. And all those process, which are regulating the different aspects of metabolism within our body, so coming back to the slide now, so what will do essentially at this point will talk about who is absorbed where, so we talked all the components.

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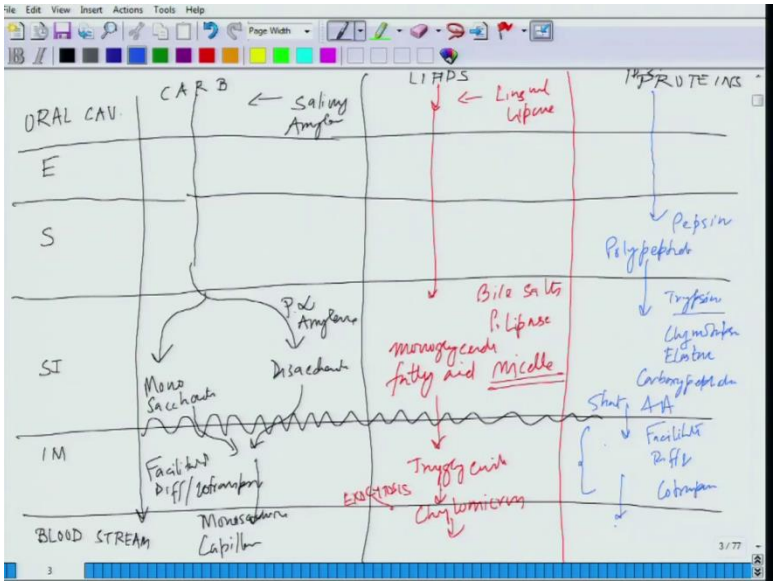

So carb, we have lipids and we have the proteins, so what is happening in the oral cavity, in oral cavity here you have the salivary amylase, so from here it is getting broken down then so let us try and do under the iso figures, then you have the stomach. I am just putting the initials, small intestine and then you have intestinal mucosa and then you have the blood stream, where the major absorption is taking place.

And during this course of movement of the food, what is getting effected where, so in the oral cavity, it is basically salivary amylase from here it moves all the way to the small intestine, in this small intestine, so basically 1 second, just I am putting it slightly wrong. Let me put some, let me put lines that way it will be easy to break it down what is

happening where fine now its fine, so the carbohydrates is moving all the way to small intestine after getting broken down into by the action of salivary amylase.

So, here you have the pancreatic amylase which comes into play, pancreatic alpha amylase and this pancreatic alpha amylase break down it into disaccharide and monosaccharides and from here, these are absorbed by the intestinal mucosa, so these are the intestinal mucosa where it is getting absorbed. So, basically these different component monosaccharides and disaccharides, through facilitate diffusion and co transport diffusion and co transport.

And to further diffusion moves into the capillaries, they are all in the form of monosaccharides, so this is how the carbohydrate is being absorbed, so initially it chews the food salivary amylase acts on it. Then the food is kind of partially broken down the carbohydrate part, then those partially broken down carbohydrates moves on to the small intestine, in the small intestine it receives secretion from the pancreases.

So, the pancreases take alpha amylase helps in breaking it down into the monosaccharides and a disaccharides and then these disaccharides and monosaccharides are absorbed by the diffusion of facilitate diffusion or cotransport into the mucosa, intestinal mucosa from intestinal mucosa they are transported to the blood stream. So, this is the fate of the carbohydrates, so let us talk about the fate of the lipids, what is happening to the lipids molecules.

So, lipid molecules out here are under the action of lingual lipase we talked about this, so from lingual lipase, then it moves into the small intestine where the bile salts play a key role. In animals you bile salts and pancreatic lipase, these two play very critical role forming monoglyceride fatty acids in micelles, so these micelles then diffuse inside the intestinal mucosa. And they formed triglyceride man they form, chylomicron in this chylomicrons are then moved via exocytose.

So, here basically a exocytose taking place and they move on to the a blood stream and the lacteal glades, so this is essentially is the fate of the lipids which is moving from the mouth all the way to the intestine. Where by the action of the bile acids are getting emulsified and broken down into them into the mono glyceride and then they it form triglyceride. And from the triglyceride it through the chylomicrons and all everything it

is getting exocytosed and then it moves into the blood vessels and travel through the specific order through wherever it has to do it is much.

So, from here we will talk about the fate of the proteins, so the proteins once their first action takes place in the stomach where basically your pepsin comes into play. So, protein become poly peptide next action, from here they move on to this polo intestine where there are series of enzymes which are involved trypsin, chymotrypsin, elastase, carboxypeptidase, elastase, carboxypeptidase. So, that form the short amino acids, from there it diffuses into the intestinal mucosa in the intestinal mucosa.

So, mostly this facilitate diffusion in cotransport just like the carbohydrates facilitate diffusion and cotransport. So, here there are two different enzymes comes into play exopeptidase and dipeptidase and from here it moves on to the blood vessels. So, essentially in that whole process, what is happening is a huge protein molecule is getting broken down into smaller amino acids, this amino acids through diffusion and co transport process are absorbed.

So, one absorption which I have not talked as if now while talking about carbohydrates lipids and fatty, how the different ions are getting absorbed, what are the different process. So, what we will do, I will talk about the different ionic electrolytes the, I will just give an enumeration, I will enumerate list of the different ions which are involved and how there transported across the body and from there we will move on to the catabolism and anabolism process, so let enumerate the different ions which are involved in our body.

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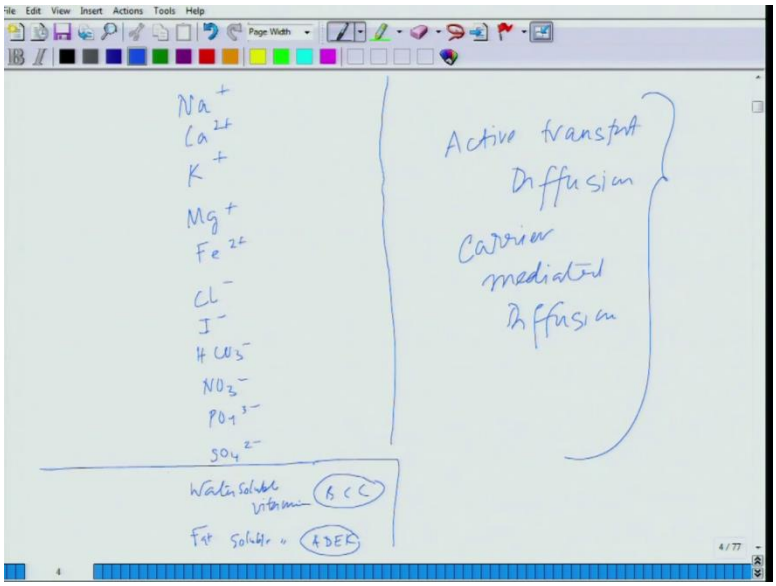

So, essentially we have sodium, calcium I am only talking about the major ones potassium, magnesium, iron, chloride, iodine, HCO 3 minus, NO 3 minus, PO 4 3 minus, SO 4 2 minus and they are certain after this list you have water soluble vitamins and fat soluble vitamins, so which includes A D E and K, B and C. So, most of these are absorbed through the intestinal mucosa while process of either active transport. So, mostly they will be either active transport or diffusion and sometime carrier mediated diffusion.

And they are also absorbed not only in the intestinal mucosa these are also absorbed along the kidney, as we have discussed in the kidney, they are along those the nephron, there are different zones where some of these are getting retain by the body and that what is help in the electrolyte regulation within our body. So, from here what we will do we will move on to the overall metabolic like overall layout of the catabolism and anabolism to give you an idea.

We have talked about the enzymes, we have talked about where these enzymes along the digestive track are involved in the breaking down of the food components, we talked about enumerated the different ions and vitamins, which are being used up by used by the body for different metabolic process, and how they are transported across the lumen into different parts of the body, where they will be needed for further anabolic action or catabolic action. So, now we will move on to the overall layout of the catabolism and

anabolism process. So, let us come back to the overall classification of anabolism and catabolism.

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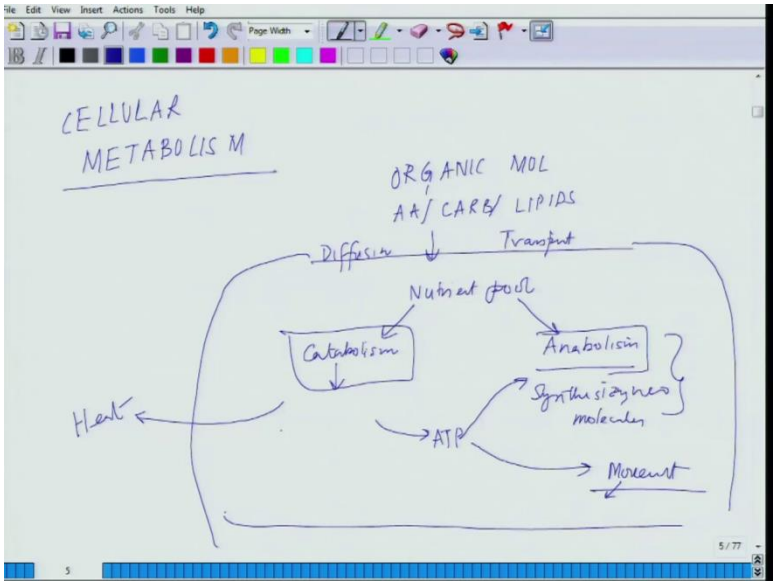

So, basically, this falls under the, a of cellular metabolism, so cellular metabolism could be divided like this, you have these organic molecules which includes your amino acids carb and lipids. These organic molecule either by a you have seen diffusion or transport, they are on these two major modes, they entered into the nutrient pool of the cell. Here, there are two possibilities involved in a anabolism, so where basically your synthesizing, so if this is the part of the cell synthesizing new molecules or they are involved in catabolism.

So, what is essentially happening in the catabolism, they are involved in different kind of breakage process and which generates heat and similarly during this catabolism process ATP is produced, this ATP helps in the synthesis of different kind of these anabolic process, as well as other aspects like you know movement, cellular movement in terms of mitosis, when there is a movement of the different kind of cell organelles and the chromosomes which are moving.

The transport, where the transport needs enormous amount of ATP molecules, co transport ATP dependent transport, movement of the muscle there are several zones where that ATP which is produced as a part of it is. Let us coming back to the slide, ATP which is produced at part of the metabolism process is being used. So, this is overall

geometry if I have to tell you, that how this all this things are happening, so this is how this whole process is running and talking about the metabolic turnover cellular ATP production.

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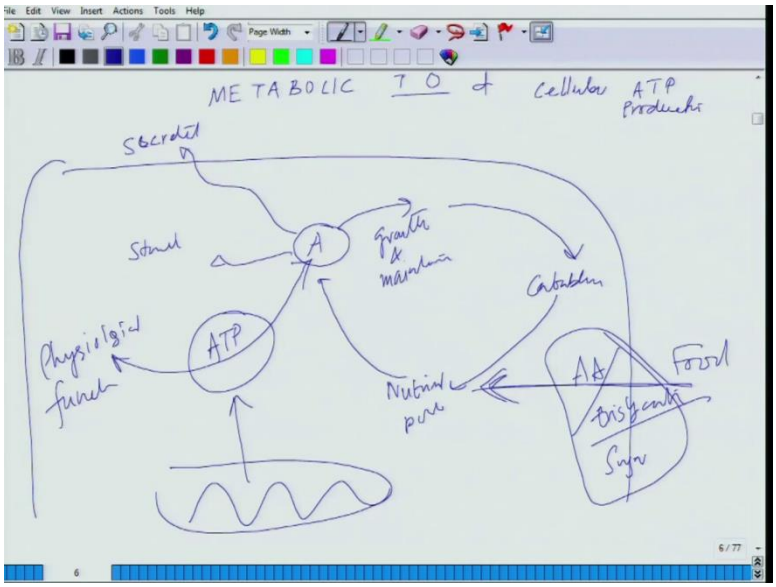

So, metabolic T O, I am just putting short form of the turnover and cellular ATP production of it. So, essentially what is happening is that during, so I am representing anabolism A, on this the anabolism there are two possibilities either these anabolic product secreted by the cells, if this is the cell or they are stored or these anabolic products have multiple roles.

So, these could be broken down and helps in the different physiological function, of course, for that you need the energy rich molecules ATPs which are of course produced by the mitochondria and this anabolic products are helping growth and maintenance, and these growth and maintenance eventually leads to a lot of catabolism process, which enhance the nutrient pool of the body and this nutrient pool is again used up by the growth and maintenance. And there is continues supplying the form of food and which is form of amino acids, triglycerides and sugar they are coming into play.

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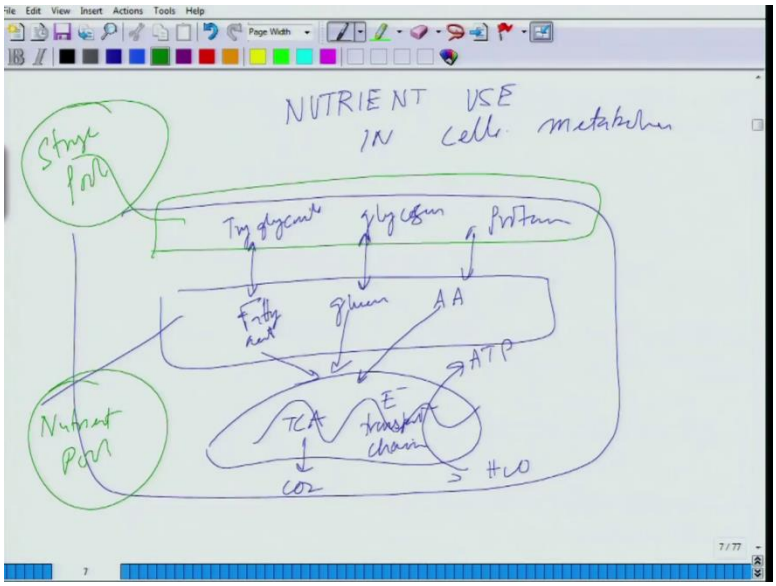

So, and if you look at the nutrient use in cellular metabolism, use in cellular metabolism, so it is something like this, so you have the mitochondria. So, where the TCA cycle is taking place and come to that, which is producing carbon dioxide and in that process out here you have the ATP production and using electron transport chain. And you have this small carbons like you know from glucose amino acids, which are all involved here fatty acids and you have this triglyceride glucose are coming from glycogen.

And then you have these amino acids coming from the proteins, so this is your essentially the nutrient pool of the cell and this is essentially the storage pool. So, whenever they a individual cell always have two faces of a story, one will be the nutrient pool which is readily available like they are broken down into small pieces the readily available for energy production and there is another pool which is the storage pool, where you have the bigger molecules which are setting there.

So, those bigger molecules when they are breaking down into a smaller nutrient pool they follow the catabolic route and then again those molecules are being utilized for energy production and simultaneously, in order to have those storage molecule you have to go through the whole anabolism process. So, this is the overall kind of layout of the metabolic events at the cellular level from here we will move on to the three specific zones. We just browse through it about carbohydrate metabolism, lipid metabolism and protein metabolism. So, let us moving on to the carbohydrate metabolism.

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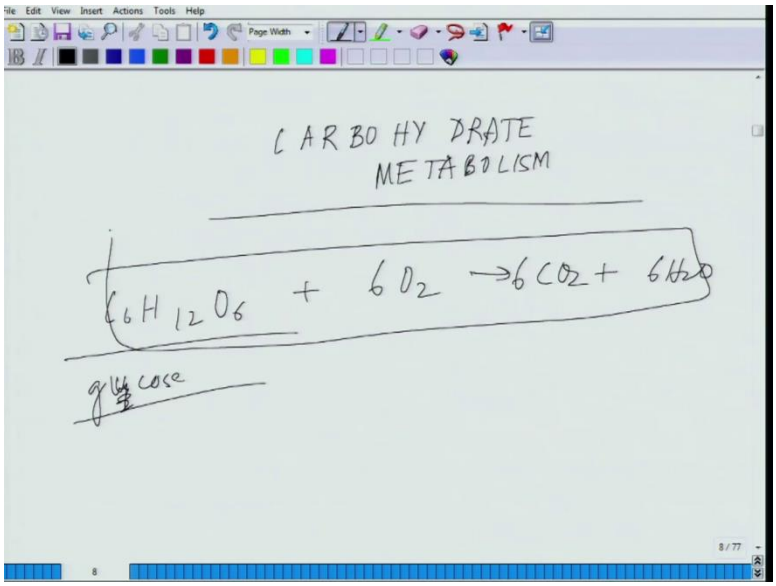

Now, Carbohydrate metabolism, so carbohydrate metabolism have to get the basic reaction is glucose plus oxygen leading to carbon dioxide and water formation, so this is here, glucose and here you have the water. So, this is the basic, basic most fundamental reaction of carbohydrate metabolism, so the carbohydrate metabolism is, are formation of glucose molecule in this whole process, utilization of glucose molecules. So these are the most should say most fundamental energetic bioenergetics process in our body.

So, in this section we will talk about the glycolysis, grip cycle and how all this process are inter twined in the gluon genius process and in the building of process. So, coming back to the glycolysis process, what is happening.

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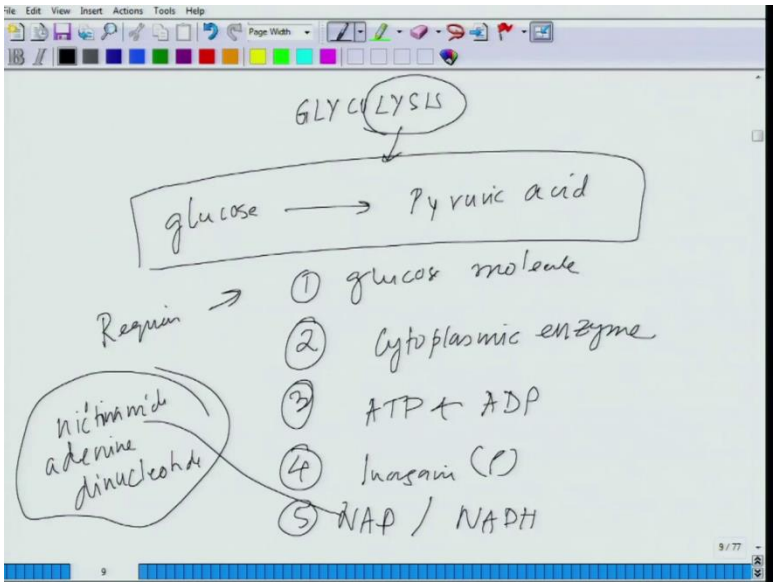

So, the first the word which comes here will be glycolysis, so whenever you see any word called lysis means broking down, breaking it down into. So, basically what is happening is that glucose is broken down into pyruvic acid, this is basically what you meant by glycolysis process and what it requires, there are some basic requirements, first one is glucose molecules, second one is cytoplasmic enzyme, third one is ATP and ADP, fourth one in a t in organic phosphate in organic phosphate and NAD and NADH, Nicotinamide adenine dinucleotide. So, NAD stands for Nicotinamide adenine dinucleotide, so these are the five major things, what is needed for the glycolysis process.

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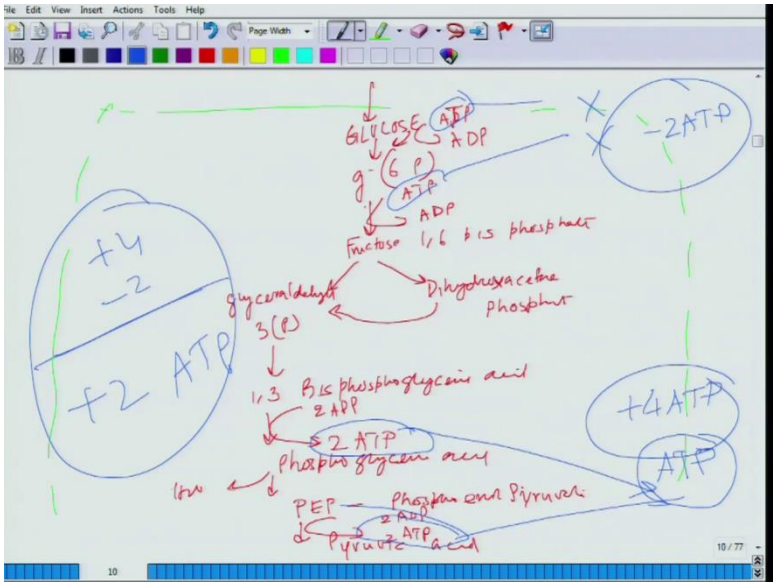

So, what are the steps in glycolysis, so as we already talked about, so this is happening inside the cell, so let me remarket it like this, so this is the green line what you see is inside the cell. So, the glucose is coming inside the cell, so here is you have the glucose from glucose is converted into glucose 6 phosphate and that in that process, there is an ATP to ADP conversion.

So, and there is a lot of energy, which is needed in that process from glucose 6 phosphate it forms fructose 1, 6 this phosphate, this step is also energy requirement processes ATP to ADP Andeno dypous((Refer Time: 34:40) andenous diphosphate to administrate di phosphate at this stage there are two fates, possibly two fates one is glyceraldehydes 3 phosphate or it could form dihydroxacetone phosphate.

So, dihydroxacetone phosphate can again transform into glycerol dehydrate 3 phosphate and from here glycerol had three phosphate forms 1, 3 bisphosphorglyceric acid and from there and this stage from 1,3 bisphosphorglyceric acid to phosphor glyceric acid there are 2 ADP molecules transform into 2 ATP molecule for the first time the reverse process is taking place in this cycle. And from here it get would have water molecules and then it form something called PEP Phospho enol pyruvate.

And Phophron pyruvate it forms Pyruvic acid during this formation again 2 ADP molecule is utilized to make 2 ATP molecules. So, if you look at this process at this two zones out here and out here, you have developed ATP molecules where has here you have consumed, this is basically a broken down ATP molecule and here you have need ATP molecule and if you look at the energy summary in terms of the ATP.

So, there are minus 2 ATP and here you have plus 4 ATP and essential game is plus 4 minus 2 is plus 2 ATP in this whole process and here it is, I will highlight one thing we saw this reaction I will do it so easily but think of it, anybody can draw that reaction, but how many enzymes are involved in. So, that every step of this reaction from glucose to glucose 6 phosphate, biss phosphate, phosphinal pydovate, pyruvic acid all these are regulated by enzymes.

So, as of, now we only talked about the enzymes which are involved in breaking down of the carbohydrate. Amylase, alpha amylase, pancreatic alpha amylase, salivary alpha amylase, lactase, cyalactase, so on and so forth. But they are just a big chunk of

carbohydrate, which are breaking down into twick it into small, small, small, pieces but then that individual glucose molecule is going through from glucose to pyruvic acid.

What, I just now drew for you, you must have observe that how like how many reactions are involved in that and each one of these reactions are regulated by a specific enzyme, without that this process would not have it. So, that is the reason, that the cellular metabolism needs all those different enzymes at one point of time other than enzymes what we have already enumerated and we have seen this whole glucose break down process to pyruvic acid finally, lead to the formation of two energy rich molecule.

So, every molecule of glucose at the end produce two energy rich ATP molecule, there is essentially is the take on message from this process what is happening in the breaking down process glucose, it is a catabolic process by the way and this catabolic process where glucose is further. So, first series of catabolic process is like this, if I had to put.

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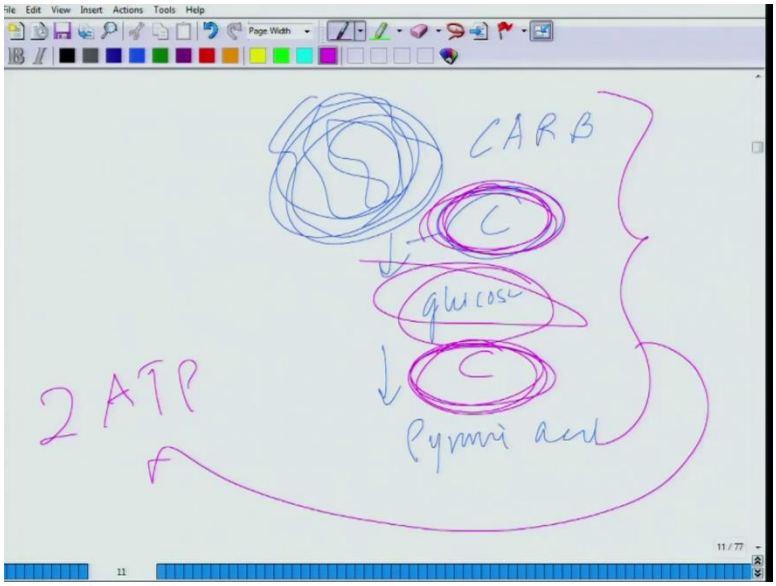

So, we have this huge carbohydrate molecule then this forms small say glucose, small molecule, so this is a catabolism I am just representing we think c the thing c. So, there is a catabolism process, from here it forms pyruvic acid, so this is another catabolising process and during this whole catabolism process, it leads to formation of 2 ATP. So, each one, each one of these molecule lead to formation of 2 ATP molecule.

So, this is very, very essential and just once they are forming pyruvic acid, it is not end of the story, that pyruvic acid went inside the mitochondria and leads to a cycle called TCA cycle, Tricarboxylic acid cycle that tricarboxylic acid is fit into the electron transport change of the mitochondria, and they replace another set of reaction for the anabolic and the catabolic process. So, what we will do today we will go through the tricarboxylic acid cycle of that pyruvic acid we just form, coming back to the one second let me just go through the this one, fine ((Refer Time: 40:34)).

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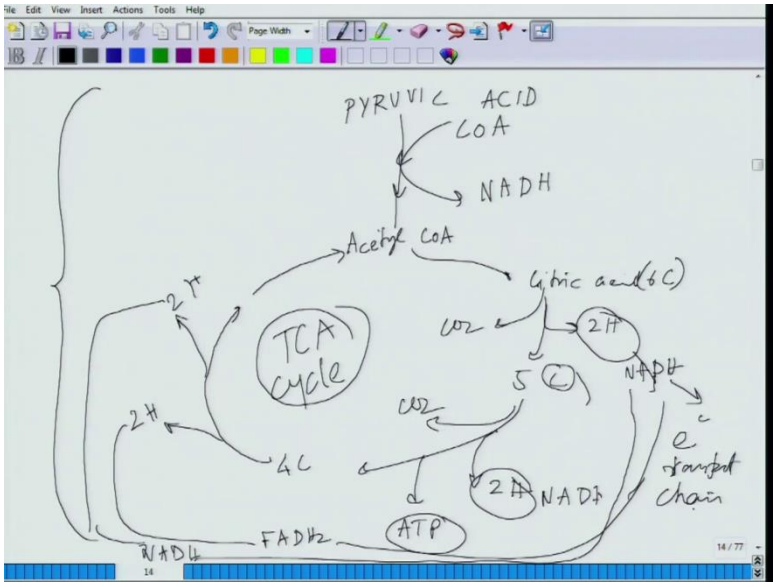

So, now you have the pyruvic acid out here, fine pyruvic acid this pyruvic acid through the enzyme A and process utilizing an NADH out here become acetyl CoA, acetyl CoA from citric acid and it form a 5 carbon structure and then it form a 4 carbon structure then that 4 carbon structure in that process eventually become acetyl enzyme and this is all happening, out here inside the mitochondria.

And out here what is essentially happening during this process is that, there are this keep on looking I am just. So, this is generating ATP out here there is always proton gradient which is getting created in this process and carboxyactric acid 6 carbons, so this is basically 6 carbon gives away CO 2 out here and 5 carbon it is giving out CO 2 out here and these proton gradients which are getting generated out here, 2 H, 2 H these are different proton gradients.

So, these all these proton gradients along here, along here are being picked up by this different FADH 2, NADH they are, so for here the other out here through NADH. So, 2 here also NADH and all these become part of the electron transport chain of the mitochondria. So, they are involved in the electron transport chain and this is one of the most key reaction TCA cycle which is called so this is one of the most key reaction of the body which is involved in feeding the electron transport chain and formation of the ATP molecule. So, what is happening, what is fate of these different NAD and NADH system is inside the mitochondria.

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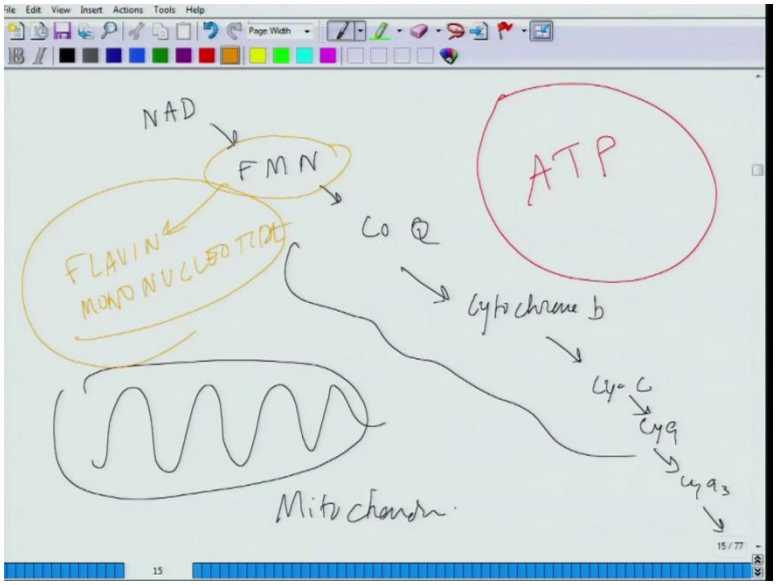

So, this NAD is through the series of reactions, so basically this whole electron transport chain is go at different gradient, going through CoQ, cytochromo oxidase, cyto chrome b, cytochromo c, cytochromo a, cytochromo a 3, likewise all these different reaction process and different donors of the electron along this whole process inside the mitochondria, is leading to the formation of final N product of this whole game is ATP production.

So, some of the things which I have already discussed, so this is FMN is basically Flavin mononucleotite and these are the co enzyme, a co enzyme, q co enzyme a and different other factors which are involved in this whole process, so if you look at it, so we started ins outside the cell when the glucose might is started coming in glucose mitosis they got transform and from that point onward through the formation of glucose to pyruvic acid

and then this pyruvic acid gets inside the mitochondria and through the acetyl co enzyme A formation and everything leads to up proton gradient and this proton gradient is eventually involved in the production of the ATP molecules out there.

And this proton gradient which is created along the mitochondrial membrane, is one of the critical aspect or bio energenetics, which is kind of the lifeline, this thing some of these reactions are the bio energetic bases of the life form on the floor of earth. So, in that process what we will do, now will summarize the whole process in terms of the ATP production before we move on to the lipid and the protein metabolism, so talking about the summarize in this whole process in terms of the lipid production in terms of the ATP production. So, this is what is essentially happening.

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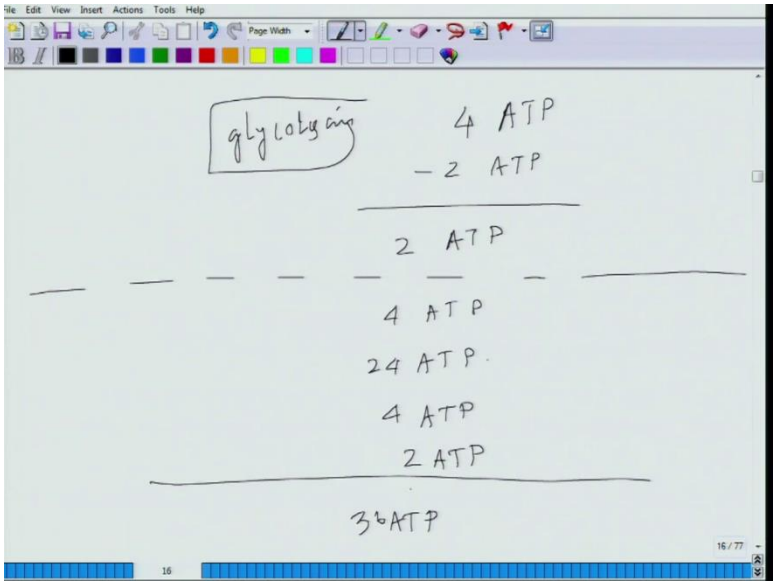

So, during glycolycies you have 4 ATP then minus 2 ATP is being used and what you get is 2 ATP, now at the electron transport chain, now we are entering into the electron transport chain. So, you have 4 ATP then you have 24 ATP in the TCA cycle and you have another 4 ATP which is formed different stages of the cycle another 2 ATP which is formed. And sum total of the cell during this net game of the cell from aerobic catabolism from 1 glucose molecule what we essentially get is 36 ATP molecule and how that happens we are going to come. Now, I will draw the chart to show you how this whole thing is happening.

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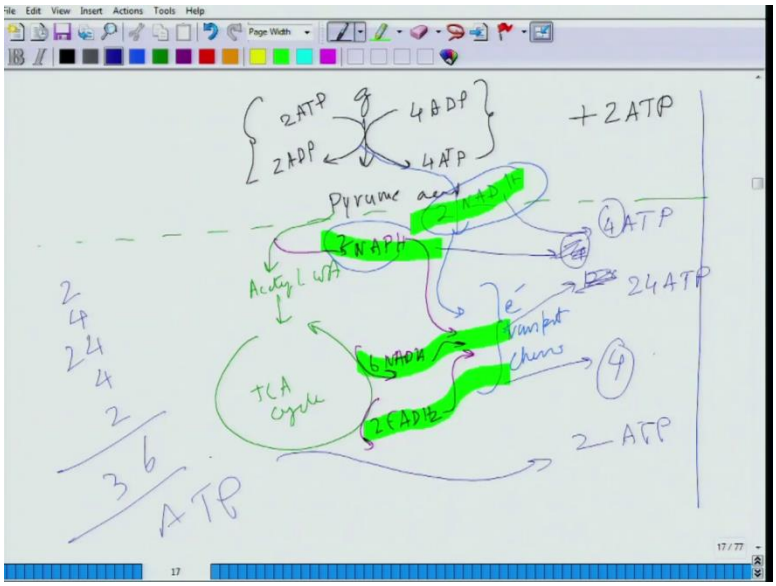

So, you have glucose and you have 2 ATP forming 2 ADP, so we are utilizing a ATPs now and you have 4 ADP forming 4 ATP. So, this is the first set of reaction which leads to plus two ATP formation, from glucose 6 carbon to pyruvic acid, now pyruvic acid is entering inside the mitochondria, inside the mitochondria pyruvic acid goes through to form acetyl CoA and acetyl CoA in enters inside the TCA cycle and during that process, it forms from pyruvic acid to acetyl co enzyme a it is forming NADH these NADH through the electron transport chain.

So, there are 2 NADH here and there are 6 NADH and there are 2 FADH 2 which of all out from of the tricarboxylic acid cycle. So, this an via an there are few there is one more source by which it comes, so the during formation of glucose to pyruvic acid there is another, I will just show it you in another color, so that there is an NAD molecule which is formed which is fit from here from outside this NAD molecules also be come apart of the electron transport chain.

So, if you look at it there are 2 NADH molecule which are coming in from here, there is another two which is coming from here, so let me highlight them, so 2 coming from here 2 coming from here, 2 plus 2, 4 and you have 6 NADH coming from fit from here 2 FADH, 2 fit from here and in that process what is happening out here. So, this is leading to the formation of 4 ATP out here 2 NAD is again leading to the formation of 4, 2, so two is leading to the 4 this 2 is leading to another 4 and this 6 is leading to 12 and you

have 2 FADH 2 molecule which is leading to formation of 4, so if you add up this 4,12 plus 4, 64, 48, 84, 12,12, 24 and you are making 26.

So, essentially what is happening is that, you have 2 NADH, 6 NADH, 2 FADH 2 and so 2 NADH and 6 NADH is leading to the formation of actually 8 multiplied by 2 basically out here just let me out here you are making 24 ATP molecules and there is 2 more which is coming from from A GTP and GTP. And this eventually leads to 4 ATP here, 24 ATP here, you have 4 ATP here and another two coming from the tricarboxylic acid cycle and what essentially get is that 2 plus 4 plus 24 plus 4 plus 2, 4 plus 2, 6 extend 10, 14, 16, 36.

So, this is basically what is happening in the process of ATP production there are 36 ATP molecules which are generated from a single glucose molecule when it goes through the whole process of pyruvic acid formation and tricarboxylic acid and through the tricarboxylic acid. So, what we will do next is that in the next class I will closing here in the next class, we will move on to in the glycogenic process, lipid metabolism and protein metabolism and thermo regulation.

Thanks a lot.