Introduction to Biomolecules
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Lecture – 16
Bioenergetics (Part 1/2)

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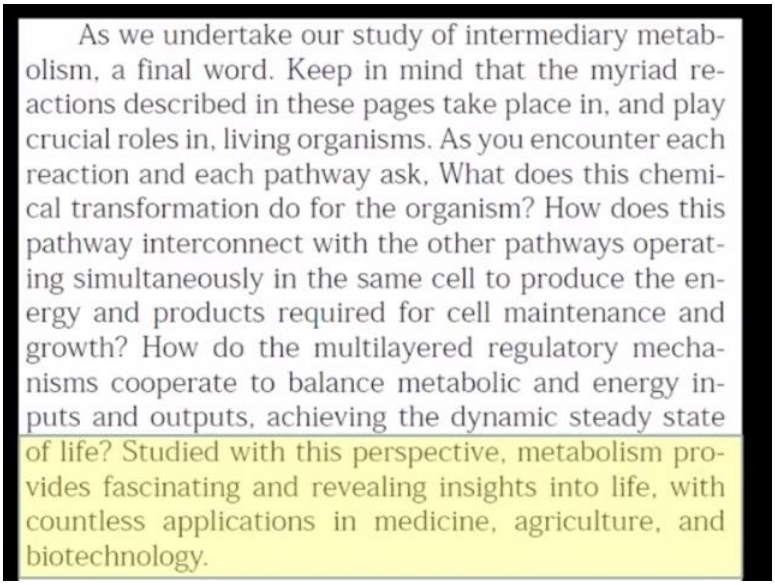

Before I begin, I will answer that question on the chat. The question is what is reciprocal regulation I guess, right. What was reciprocal regulation? So yesterday I was telling you about the general characteristics of metabolic pathways and one of them is so we were talking about a series of reactions leading to the biosynthesis of a molecule and that would be the synthetic reaction.

And breakdown of the same molecule I was telling you does not involve exact reversal of the biosynthetic pathway. Multiple steps may be the same but at least one step will be different that will be energetically favorable in one direction but not in the other direction. So that is where you have the reciprocal regulation. So when you have the biosynthetic pathway on, like for example if the end product is in short supply in the cell, then the degradation of that pathway would be the catabolic pathway, will be blocked.

Because it involves at least one enzymatic reaction that is different from the same step in the opposite direction that is in the biosynthetic direction. So, therefore while the synthetic direction of that particular step is allowed because it is catalyzed by a different enzyme which

is not inhibited, the opposite the breakdown direction of that step catalyzed by a different enzyme is subject to inhibition that kind of regulation is what we call as reciprocal regulation.

So is that clear?, great. So, let us move on. So yesterday I told you the metabolic pathways are a lot of them in our system. There are thousands of biochemical reactions that happen in a single cell. So when you look at them, they will be very intimidating and that is where we were looking for common features like we looked at the general characteristics for example the catabolic pathways or convergent, anabolic pathways or divergent.

And then we saw five major common type of chemical reactions. So we saw oxidation-reduction, carbon-carbon bond formation or breakdown like aldol condensation, then isomerization rearrangement internally and group transfer free radical and so on. So, our focus is going to remain like this common theme emerging main point and when we view from that angle it is actually quite fascinating.

And to make you stay grounded on this metabolism and not lose interest so here is a direct paragraph from the textbook. As we undertake, I am going to take the time to slowly read this because I feel it is important for us to remember this. As we undertake our study of intermediary metabolism, a final word. Keep in mind that the myriad reactions described in these pages take place in and play crucial roles in living organisms.

So, these are not isolated reactions, one factor making one product, another factor making another product and there is no connections and networking. So, as you encounter each reaction and each pathway ask what does this chemical transformation do for the organism, how does this pathway interconnect with the other pathways operating simultaneously in the same cell to produce the energy and products required for cell maintenance and growth.

For example, pyruvate being produced on the way from glucose to carbon dioxide for the purpose of obtaining energy is also an intermediate for the biosynthesis of amino acids, transamination of pyruvate will give you alanine. So, like that they are connected and that connection is critical. How do the multilayered regulatory mechanisms cooperate to balance metabolic and energy inputs and outputs achieving the dynamic steady state of life?

So, all of this is constantly happening without even your knowledge. You are not putting any conscious effort, but in your body all these fine balancing is always happening. Lot of reactions happen and all of them are happening in a cooperative manner and they are all balanced. So how do they achieve the dynamic steady state of life? Studied with this perspective, metabolism provides fascinating and revealing insights into life.

So that is the main point with countless applications in medicine, agriculture and biotechnology. So, whatever be your focus other than going and answering phone calls in a call center if you are going to follow any serious career in any of these aspects, a good understanding of the chemistry of life is critical as also the genetics, it is just that I am not teaching genetics right now as part of this course. So, remember this paragraph, make this sketched in your mind.

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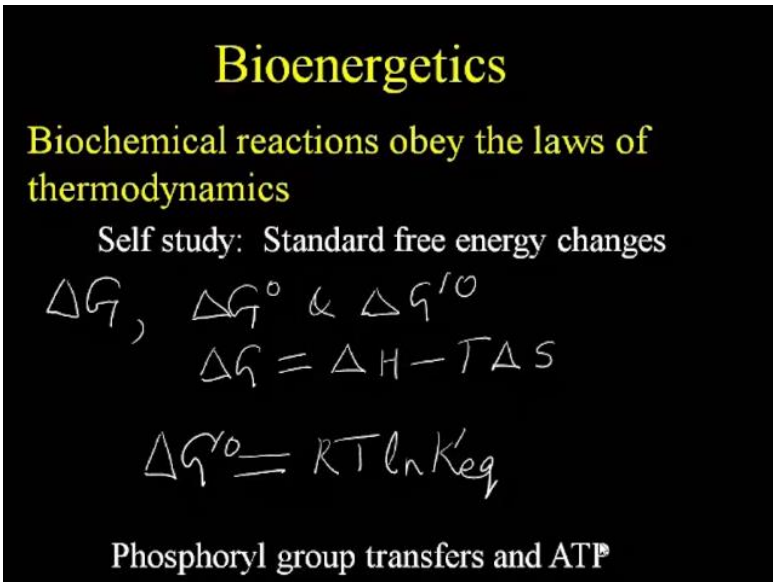

So, what we are going to do today is another preparation. So we first prepared in terms of the chemistry, so now we are going to prepare ourselves in terms of the energy. So the purpose of breaking down glucose is to make ATP which is the temporary storage of chemical energy which is usable for many synthetic reactions. For example, every time a ribosome is cruising along an mRNA making a protein it constantly keeps breaking GTP into GDP plus inorganic phosphate, so energy is being consumed.

So, every time a kinesin is zipping past on a microtubule in your cell energy is being consumed and so on every reaction physical, I chose a couple of examples that are sort of physical but then there are many types of activity that happens and all of them require energy

and the energy production is one of them. And also many of them consume the energy, so we have input output, like we generate energy as well as we use energy.

So, this gives you an idea where I am going, so we need to understand the laws of thermodynamics. So we are not going to go and learn thermodynamics as part of biochemistry, all we are going to understand is that the living system strictly obey with no room for any violation of the laws of thermodynamics. So that is the main point here and I will elaborate it as we go along.

And there is an important concept called standard free energy and standard free energy changes, so this I am going to leave it to you to do self-study, I am assuming you have already learned this enough in chemistry as part of electrochemistry I guess and therefore I am going to leave it to you to do on your own. So, when you are going to prepare, the main focus that I want you to have is make sure you understand what is Gibbs free energy and what is Gibbs free energy change.

This delta indicates the change in free energy and what is delta G0 and delta G prime 0. So, these three terms make sure you understand and if you have difficulty and if you are unable to understand then please bring it back to me and I will try to explain. Then, this all important equation delta G = delta H – T delta S. So, this is something you need to understand and how this free energy change is actually related to the chemistry that is equilibrium constant.

The equilibrium constant is going to relate the ratio of the products to the concentration of the products to the concentration of the reactants that is what the equilibrium constant tells and how that equilibrium constant is related to free energy change. So, this is another important equation. So, these are the three lines here that I want you to focus in learning when you are going to do this.

So here we are primarily going to focus on one aspect of group transfer that is important in bioenergetics topic, so this is what we are going to focus. But before I go into it, I do not want to totally leave it to you I want to just at least explain a little bit here because some of you may not be so much into mathematics and chemistry and you may understand better when it is explained in plain simple language.

And I belong to that category and therefore I want to make sure such students are not left behind. So, let us try to understand here what is this energy and energy change from a chemistry perspective. So, in our hands what do we have? We have macromolecular structures like cells or tissues and organs and we do not have problem going from there to molecules like carbohydrates, lipids and proteins and we are familiar.

So, let us go to a molecule. Let us take glucose. So why is glucose having energy and that can come out when it becomes carbon dioxide. So, why is free fatty acids or triacylglycerol having more energy than glucose per mole? One mole of glucose versus one mole of palmitic acid for example, palmitic acid has nearly double that of glucose, so why? So, we want to understand in data in that way like what is in it in the glucose that makes it to have energy?

And what is in it in carbon dioxide that it does not have that much energy related to glucose? So, this is what I want to make sure you understand. So, take for example you walk up the ladder in a swimming pool to the diving board, so you go and stand on top of the diving board, so that is one state of your existence. You have a certain energy at that state and that gets released when you jump into the pool.

And that is why in the pool you are able to plunge into the water, you are able to displace water and go inside and that is because of the energy released from the two state of you like one is standing on the diving board, another one being in the pool. So, I am going to argue here that the state of your existence itself has energy like when you stand yourself on the diving board you have a state where the energy content of the way you are is more than the energy content of you when you are in the pool.

So, there is a difference in the energy content between the two and the one when you are on the diving board is higher than the one when you are in the pool. So, therefore when you go from the diving board that is higher energy state to yourself in the pool lower energy state there is a difference between the two and that energy is what is delta G in the simplest way. And that is the energy we call free energy because that is the energy that is available for doing work.

Here the work is you plunging into the water and the water getting displaced and you go into the water. If you really want to understand that energy doing some work, do not practice this,

but try falling flat on the water and the impact on your chest you will know. So do not do this ever because depending on the height from which you are plunging it could be fatal, you will die if you are sufficiently falling from a height.

So, there is a work that is being done and for that work energy is required and that energy comes from the difference in the energy between the two states. So, this is with me physically at one place to another place I know you are talking about potential energy difference and my falling down is the potential energy change becoming kinetic energy doing mechanical well I know all of that, but talk about glucose versus carbon dioxide.

So, glucose or any molecule depending on the kind of atoms and bonds that are formed they are either like you standing on the diving board or you in the swimming pool. The kind of bonds carbon and oxygen have like two double bonds C double bond O and another C double bond O, CO 2 is like you perfectly at ground state in the water in the swimming pool. And the way the bonds are made in glucose is like you standing on a diving board but about 3 feet above the swimming pool level.

And triacylglycerol is like you are standing on the diving board at 6 feet high or the highest diving board available. So therefore, the energy content when we talk about molecules is actually the kind of atoms and bonds that are there. And this is to do with their affinity for electrons, so that concept we will go to after couple of slides. Now delta H is the one that you would have memorized somewhere as enthalpy.

So in chemistry, this H is the heat content or the energy content of a molecule and this reflects the atoms and the kind of bonds that are there. And when you go from glucose to carbon dioxide the difference in the energy content, the glucose has a certain enthalpy or H and carbon dioxide has certain other enthalpy or H energy content, the difference between the two is what is delta H.

And that difference is not going to be entirely available for you as free energy available to do work but that is because in the process of obeying second law of thermodynamics some energy goes into increasing disorder in the system in the open universe and that is what is delta S. This is not retrievable. It is a total loss to into the environment and that is a function

of the temperature as well. So, a product of these two need to be subtracted from this to get the usable energy.

And since energy change is always negative, so this delta G always goes with a negative sign. So now you go and figure out this 0 and prime 0 all those things. So, this is something you are going to learn on your own, these 3 terms, I think the first term I finished explaining, but these two as well as this equilibrium constant linking to delta G because this is the chemical reaction and from that we need to get the energy. So now let us go to this phosphoryl group transfer.

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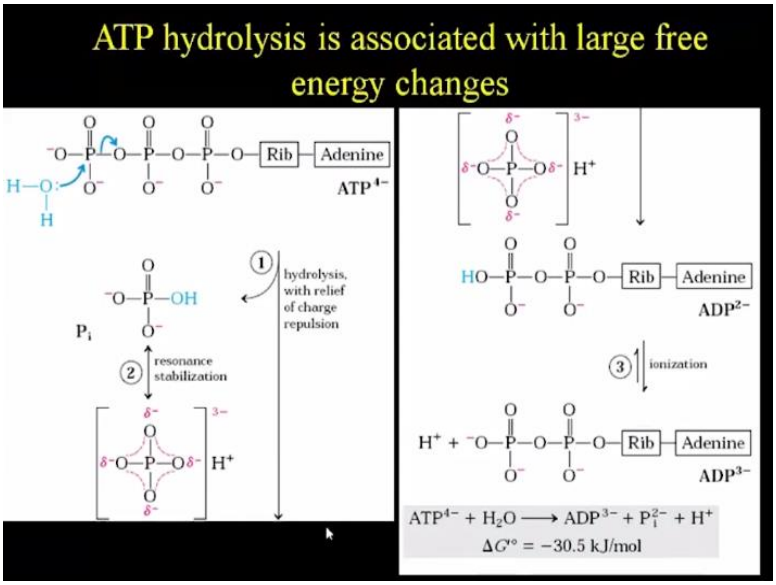

So before we get into phosphoryl group transfer, yesterday itself we talked about how the phosphate group is a good leaving group and therefore formation of mixed anhydride with carboxylic acid or ester with alcohols like for example glucose 6-phosphate these are activating those molecules or energizing those molecules for further reaction. So, this is what yesterday I told you.

So now what we are going to do is we are going to have a close look at ATP and try to understand what is special about ATP. So, ATP let us look at this structure, so we are not going to look at the nitrogenous base we already know that, ribose we know that and in the ribose we have the three phosphate groups here. So, this is adenosine triphosphate. So up to this is adenosine and this would be AMP, this is ADP and this is ATP adenosine triphosphate.

So, if you look at it so this is relatively a strong acid, it dissociates in water which has very little proton 10 power –7 molar proton only is there in water. So, it readily loses proton and becomes negatively charged and look at all the negative charges next to each other, so serious charge repulsion. So, they would like to break away by this sort of electron flow and that is standing on the diving board, topmost diving board.

Just you cannot stand there, if you fall asleep you are going to fall down, so you will constantly be at your edge to stay there. So, when you hydrolyze this charge repulsion is relieved, remember step one or reason one why ATP is a high energy molecule. So, I am slowly introducing the term that we need to remember. ATP is a high energy compound, so why is it high energy compound? One of them is this.

So, if you hydrolyze charge repulsion is relieved and secondly this phosphoric acid liberated can have resonance. So, it is not just this one the oxygen is double bonded, the double bond character is shared by all four, so this actually leads to a tetrahedral structure with the phosphate at one corner and that is acidic and these are negatively charged and this is positively charged.

So, this resonance stabilization makes it lot more stable in the free form, so flipping between these two structures. So, this is a lot more stable than being part of this molecule. Charge repulsion is one issue and second is lack of resonance stabilization here but that is provided here. So, the broken down product that is ADP and the inorganic phosphate are more stable than ATP itself.

This is you floating in water and this is you standing on top of the diving board, this is one and two. And the third this hydrolyzed ADP can readily deprotonate, for example this can really deprotonate because the surrounding medium water has very little proton, remember 10 power –7 at neutral pH, so it spontaneously loses this in a higher to lower situation. And that ionization is another reason why this hydrolyzed product is more stable.

Charge repulsion, resonance stabilization, then ionization. So, these are the three major reasons why the hydrolyzed products are more stable and therefore have a less enthalpy than the ATP molecule itself. So, this is what I meant by saying the energy content or enthalpy

alpha molecule is dependent on the kind of bonds that are there and the kind of atoms that are linked by those bonds. So here you get an idea of this.

So, this is the energy content of molecules. So that is one way of using ATP as an example to understand that concept that is one thing. Second main point here is, but the question when it comes you know why is ATP high energy molecule these are the reasons. So, this you need to remember it from that angle as well. And in living systems ATP is used as energy currency. So, I am sure you guys can understand the concept of currency.

Let us try assimilating as of we are physically here and it is a normal regular class because I was not sure whether that is possible and I never asked questions. So, I want to ask one question here. **"Professor – student conversation starts."** The question is what is the definition of a currency? Can someone shout it out? Mode of exchange. Sorry, mode of exchange. Try elaborate little bit more, like more elaborating I love words.

What do you mean by mode of exchange? Like for example I am a farmer growing tomato and you are a weaver and you make clothes and I give you tomato and buy clothes, so is the tomato currency and clothes currency. So, there was mode of exchange there. **"Professor – student professor conversation ends"**. So if you elaborate that you are in the right direction, if you elaborate or if someone else from there picks up and takes us forward it will be good.

So, I myself will answer. See currency means something that we assign a value and we decided to trust that as a mode of exchange. Someone here typing mode of exchange of a common substance, the window closed, just one second I will read that. Common substance assigned a value, yes that is a further improvement on the original thing. So, the main point is when you have the common thing that everyone trusts.

The farmer trusts, the weaver trusts, the driver of the taxi trusts and the banker trusts, lawyer, everyone accepts that as a unit of wealth or product of human labor and you are able to use it as a currency. So, all of us can use that like if I am a grocery store owner, I can use 100 rupees note to go and buy some supplies to my shop. And if you are a textile merchant and you want to sell your clothes and in return you want to go and buy food and if the guy who sells food to you accepts currency.

So therefore, you are able to even your customer gave a hundred rupee note and that you gladly took it because the food seller will accept that and give you food, so you have that confidence and that is sort of a common thing that we use for exchange is what is a currency. So that is the job ATP does in our body. So, ATP everyone meaning the biochemical pathway that makes triacylglycerol.

And tries to store in adipose tissue or the mitochondria in the liver trying to break up glucose to get some energy so that some mechanical work can be done or ribosome translating and making a protein or a biosynthetic main pathway producing amino acids for this translation by ribosome all of these different people they all can use ATP or the when the mitochondria and liver broke down glucose into carbon dioxide temporarily it makes ATP.

It is like the textile store owner selling the clothes and getting rupees. Rupees he cannot eat, he cannot consume it as medicine, but temporarily he gets the currency. Later he will go to the vegetable shop and buy vegetables using that that temporary storage ATP. So the glucose breakdown to carbon dioxide is not directly coupled that energy released there is not directly coupled to the ribosome translating an mRNA into protein.

Instead, the glucose breakdown to carbon dioxide ended up making ATP molecules and the ribosome translating mRNA into protein uses this ATP for its energy needs. So, this is the job ATP does. So, this is why ATP is considered as the energy currency in the system and the currency is really good currency for the reasons that we just discussed. I hope this is clear to you because these are all really the core of biochemistry.

And any person who is educated needs to know this regardless of whether you are going to answer phones in OMR or you are actually going to manufacture drugs or discover new drugs or solve a new biological problem. It does not matter, but I feel any educated person should know this much about life. So do not ignore them.

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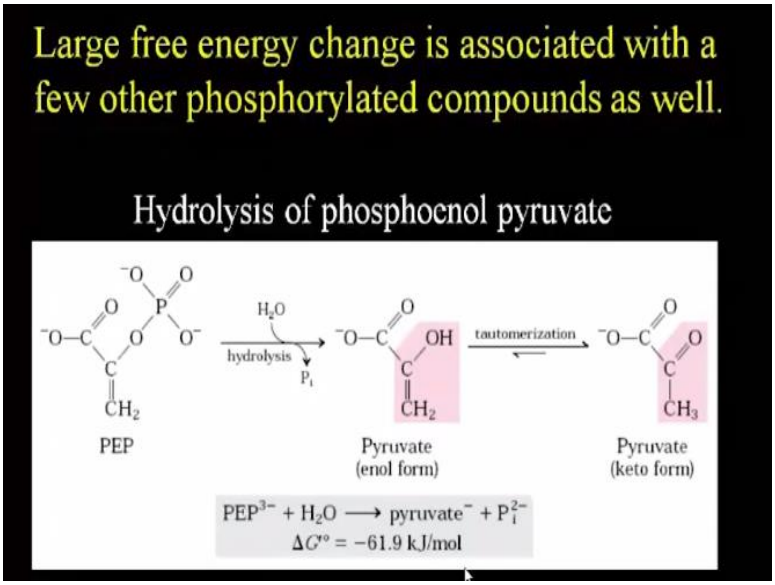

So, we continue with our phosphoryl group transfer theme here. There are other molecules as well, it is not just ATP alone that is a molecule standing on the top diving board. So, there are others also. One of them is phosphoenolpyruvate, you will learn this, do not worry. This structure will become very simple and easy for you to remember when we go to glycolysis. This is an intermediate in glycolytic pathway.

So, when this is hydrolyzed here what first of all we are going to get the inorganic phosphate, we know this inorganic phosphate will have this resonance stabilization. That is going to be there every time from any molecule this phosphate is hydrolyzed, so the product is more stable, at least one of the products is more stable. Here what we are going to do is we are going to focus attention on the other one.

The other one is going to have this keto-enol tautomerism. So, you can have this double bond flipping between these two and that is a more stable structure than being like this. So that is how PEP is a high energy compound. So, in all of these you see the negative sign and delta G as kilojoules per mole. So, you know how many molecules and therefore how many joules we get energy out of this, sometimes calorie is also used. So that is also acceptable, although standard is joules.

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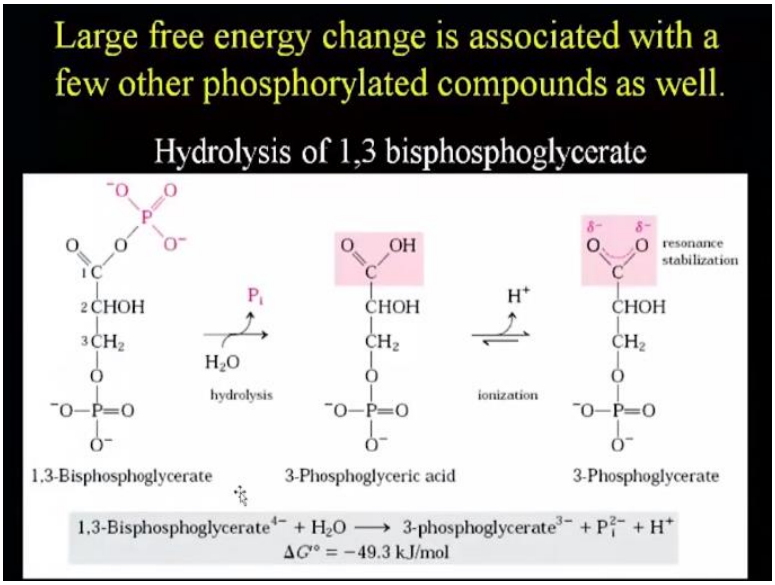

And another one. So this is also an intermediate of glycolysis, this is an early intermediate glucose, glucose 6-phosphate, fructose 6-phosphate, yesterday we saw glucose 6-phosphate becoming fructose 6-phosphate the bond rearrangement there and then it gets hydrolyzed to trioses the glyceraldehyde 3-phosphate and dihydroxyacetone phosphate and they later get phosphorylated again to make this 1, 3 bisphosphoglycerate.

So, every step of this I am just telling it to say that it is part of a sequence, but the actual sequence we will be learning, do not worry that from the little I said now you need to learn that. So, we will learn that in detail later. So, this 1, 3 bisphosphoglycerate if you look at it so this is again a high energy molecule. When you hydrolyze again resonance stabilization of the inorganic phosphate is one thing.

And second here you have the same resonance stabilization. So, therefore the products are more stable meaning less enthalpy or less heat content in their bonds than the substrate the starting reactant.

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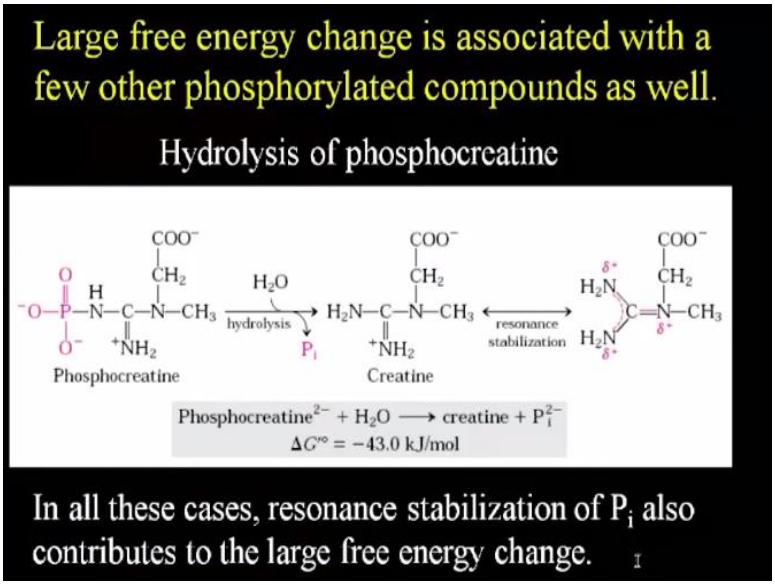

And one more example phosphocreatine. So, we will not be learning about creatine-creatine metabolism so often in an introductory class, but this is one of the well-known high-energy molecules especially plays an important role in our cardiac muscles, the heart cells. So here again this hydrolysis resonance stabilization of inorganic phosphate and then here again similar resonance stabilization. So, in all these cases this I was telling you every time that this is understood to be part of the thing.

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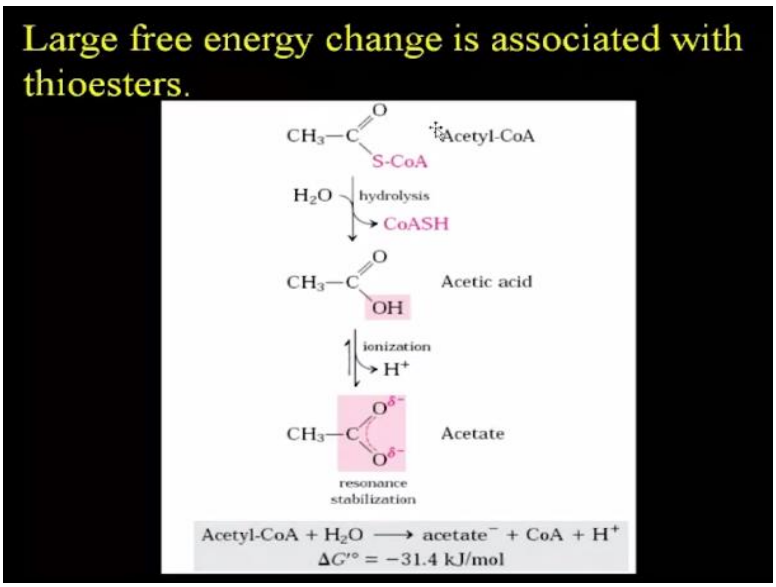

Now this is all about the phosphoric acid phosphor esters and did we have any anhydrate here? I do not think we saw any anhydrate, yeah this is anhydrate, glycerate this is carboxylic acid. So, we saw a mixed anhydride and then esters phosphor esters now here is an example of a non-phosphorous molecule, phosphate containing molecule.

This is a thioester SH in ester linkage with this carboxylic acid. And here again hydrolysis leads to stabilization by this resonance structure shown here and therefore the product is more stable than the reactant.

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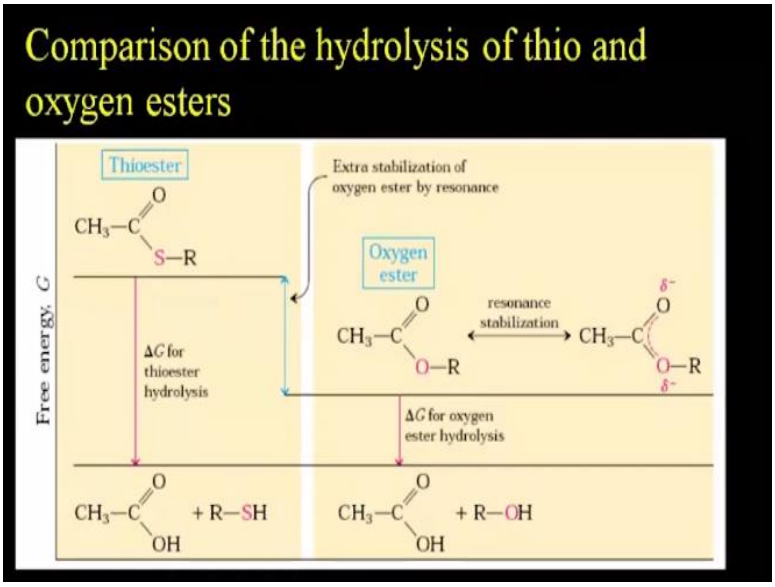

And in thioesters there is an interesting feature that we want to consider here. If you look at an oxygen ester, carboxylic acid with ROH, let us assume this is glucose and this is acetic acid. So here now when you hydrolyze you get ROH and this structure here can have a resonance stabilization in the reactant itself. So as a result, it is somebody standing on the 3 feet diving board.

So, this is somewhat stable compared to thioester where that kind of a resonance stabilization is not possible, therefore this is somebody standing on a 6 feet diving board. So therefore, thioesters have more energy, more enthalpy in them than the oxygen esters. So, when you hydrolyze the thioester you get a lot more delta G. So, I hope this is clear the importance of thioesters when compared to oxygen esters in terms of enthalpy.

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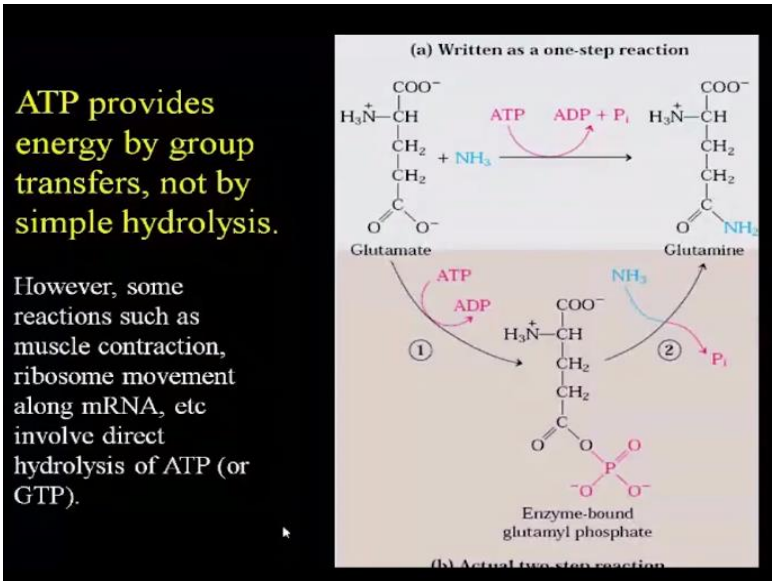

So now fine, we understand ATP is energy currency and this is the way reactions share the energy among themselves the producer and consumer they couple via ATP. And is it that I hydrolyze ATP and the energy is released into the environment and from the environment the molecules capture it? No that is not going to be that efficient. So, the way ATP participates and the way the energy from ATP is utilized is be coupling the reactions.

So, what do I mean by coupling that is shown here like for example glutamate forming glutamine. This is the first step in nitrogen fixation after the bacteria convert nitrogen into ammonia, I remember in the nitrogen cycle I told you about this. Nitrogen is inert triple bonded structure and our enzymes cannot use them to make the amino group of amino acids or incorporate the nitrogen in making the nuclear nitrogenous bases of nucleotides.

So, instead we need them already reduced and available in the biomolecules in terms of amino groups or nitrates or nitrites. And the first step is the plant cells do this the ammonia produced by bacteria is used to make this amide group, glutamate to glutamine and that requires energy. So, these are more stable than this. So, therefore here it is an endothermic reaction or endergonic reaction.

It consumes energy and that energy comes from the hydrolysis of ATP to ADP+ Pi. Here the products are more stable than the reactant. And if you look at the energy content, the final one is energetically favorable. This has gained energy and gone off the diving board, but then these are more at a ground state, and therefore overall these have less energy content than this and that is why this reaction can happen.

So, but anyway the main point here is I understand this hydrolysis releases the energy and the released amount of energy is more than the energy needed to synthesize this and therefore this is made possible thermodynamically favorable, fine. But how is this energy released here is used for making this amide bond? And that happens via this mechanism at the bottom.

So first the phosphate group is temporarily transferred to the enzyme-bound glutamine group, you have a glutamyl phosphate. When ATP is hydrolyzed the phosphate is attached only ADP is released. Then this amide bond formation releases the inorganic phosphate. So, this is how these are coupled. So ATP provides energy by group transfer, so here the phosphoryl group transfer, remember we learnt this as an important thing in the last class and not very simple hydrolysis.

So, there are exceptions some reactions such as muscle contraction, ribosome movement along mRNA involve direct hydrolysis of ATP. So, the ribosome example I kept telling there it is not ATP, these are one of the exceptions where instead of ATP it is GTP and GTP by similar reasons as what we saw in ATP structure is a high energy compound. So, this is an important point I want you to remember.

ATP provides energy by group transfer and not by simple hydrolysis. So, for example when we cook food you have the vessel on top of the cooker and then you turn on the stove and a whole lot of heat that is obtained by release by burning the gas is lost into heating the surrounding atmosphere. Instead, if the entire heat can be transferred directly into the water in the vessel, you would really more efficiently use it.

But the gas stove and the way you cook is a whole lot more efficient than burning charcoal or firewood or coal, so there you will release a lot more into the atmosphere. So just for that energy efficiency this group transfer based energy transfer is what happens here. So alright, we got some introduction into the bioenergetics, primarily right now focusing on the phosphoryl group transfer and then initial discussion on how molecules have energy in their structure. So, this is what we learned till now.

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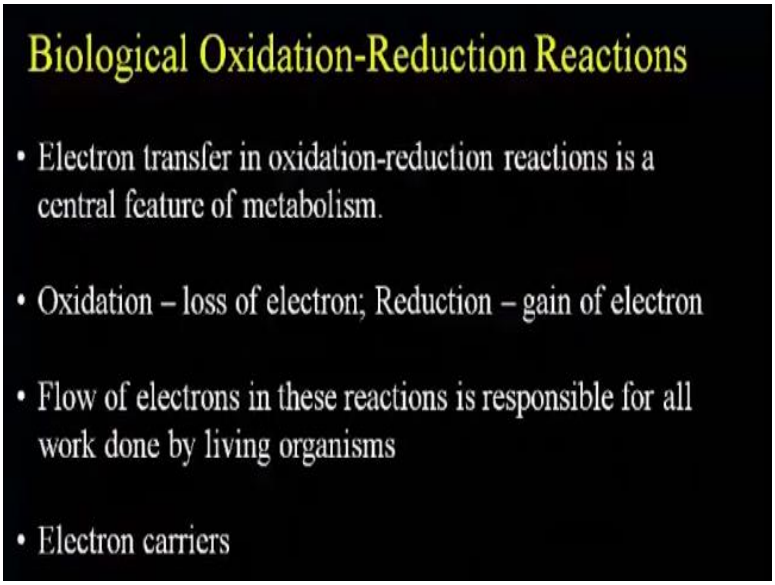

So now we need to get into another very important concept**.** I know we have only 10 minutes but we will at least begin the discussion and in the next class we will elaborate. Most of the biochemical reactions in our system actually involve electron transfers. It is actually electron flow from a molecule that does not like electrons so much therefore has low affinity for electrons to molecules having high affinity for electrons.

And this low affinity to high affinity means it is a spontaneous flow and because it is electron transfer and like it is electricity and you can think of electromotive force, we need to learn a little bit of electrochemistry. So, our energy difference in this discussion what we are looking at is we are getting little deeper into the bonds we talked about in the previous discussion.

When a bond is broken down like ATP is hydrolyzed to ADP and inorganic phosphate and there we talked about the energy content of ATP being higher than ADP plus Pi, so we sort of tried to understand it at a little macro level. Now what we are actually doing is we are getting into where is this energy content there? In ATP we kind of understood why is it high, but further details of what actually in that structure that makes it and it is primarily the affinity for electrons.

So, the energy that we tried to learn in terms of chemical reaction now we are going a little bit deeper where we are actually going to look at this as electron transfers. So therefore, we are going to look at some basic principles of electrochemistry because that directly applies in the biological systems. So, textbook has one nice example. So, you have a battery like car battery, any of those batteries that you can think of.

So, in the battery what you have? You have a positive electrode and you have a negative electrode. So, from the negative electrode electrons flow to the positive electrode simply because the chemical reactions that are taking place at one electrode is readily willing to lose electrons. They have low affinity for electrons and the chemical species that exist at the other electrode has high affinity for electrons and it is readily willing to take the electrons.

And if these two are connected by a conductor that can allow electron flow through like a wire a metal wire, then electrons will spontaneously flow from one electrode with lower electron affinity to the other electrode with the higher electron affinity, so it will readily flow. And when it flows, the force generated is equal to the difference between the two in terms of the electron affinity and that is what you call as electromotive force.

So that is the force that is directly determined by the difference between the electron affinity of the two electrodes here. And the difference between the two affinity for the electrons generates a force and that is what we call as electromotive force. So, if there is force then I can use it to make some work that is possible if you connect in the circuit. Instead of directly connecting the wire from one electrode to another electrode, let us say you connect to an electric motor.

And from the motor then you connect back to the other electrode. So, if it takes a detour by a motor then the motor rotates and the shaft in the motor rotates and then you can connect it to variety of things and get work done by that motor. So, the motor is basically energy transducer. So, from a waterfall to give you another example the potential energy change water at a higher altitude to water at a lower altitude freely falling has a force that is the potential energy difference.

There is kinetic energy available if you put a turbine below a water wheel, the water wheel will rotate by the force of the water that is falling. And the water wheel there or the turbine there is an energy transducer. This is exactly what happens in our cells. So electrons flow from molecules that have low affinity for electrons to molecules that have high affinity for electrons. Example glucose to oxygen, so oxygen at the end becomes carbon dioxide.

And when the electrons flow in this our body has a series of transducers, at each time the electron is allowed not to fall deep some 200 feet waterfall, instead it is allowed to fall 10 feet so that a certain water mill which will run a certain machine that you want to use mechanical work only that much energy is needed and therefore you do not want the water to crash down 200 feet. Instead of 10, 10 feet increments you allow it to fall down.

And you have 20 water mills on the way that is 20 transducers and 20 mechanical works you get done. Like for example if I only want to have one this compact fluorescence lamp in my office, I do not need to explore an atom bomb to get that energy, I will only need little bit and the rest of it will destroy everything around. And this incremental transduced steps and transducers is how our system works.

One glucose to one 6 carbon dioxide molecule is like exploding an atom bomb, instead when you go in increments and at every step you have a transducer you can get multiple things done and that is how our system works. So that is how the biological oxidation-reduction reactions happen. Here oxidation meaning you lose electrons and reduction you gain electrons, oxygen gets reduced to carbon dioxide, glucose gets oxidized to carbon dioxide.

So, these are therefore coupled. When one loses an electron, it is not an isolated losing electron, another one gains the electron, so these are coupled and that is where we are going to use the word redox in the next class. So, this is a central feature of metabolism electron transfer in oxidation reduction reactions. So, you already know this oxidation loss of electron, reduction gaining electron.

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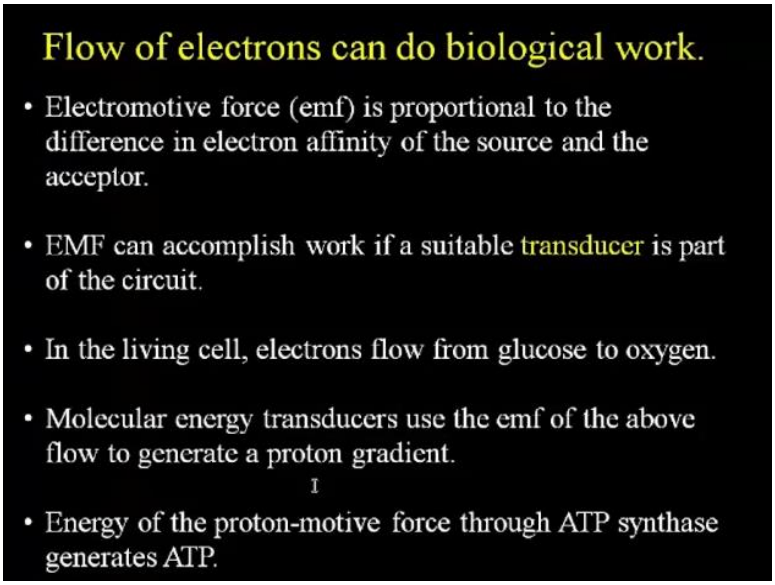

Then flow of electron in these is responsible for the work. And electron carriers, the temporary molecules that take up electrons, these are the ones that create those incremental steps making multiple transducers possible. So, we will have a good discussion to 4-5 slides discussion appreciating the beauty of the structures of this electron carriers later.