Applied Environmental Microbiology
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Lecture - 09
Microbial Energetics III

Hello students. Welcome to the second lecture on Microbial Energetics. In the previous lecture I introduced you to the concept of Gibbs free energy and how we have arranged our reactions in increasing order of Gibbs free energy and we call it redox tower and how this helps us a ascertain Edouard in what sequence will the different kinds of electron acceptors be utilized.

Gibbs free energy plays another very important role in helping us determine whether a reaction is feasible in the first place or not. For example, if there is a reaction that has plus 20 kilojoules per electron equivalent of Gibbs free energy, then because it is greater than 0 this reaction is not feasible. In other words the lower Gibbs free energy change for any reaction the more feasible and profitable letters and it definitely has to be less than 0. So, it has to be negated for it to be feasible to begin with.

In context of microbes microbial activities require that the Gibbs free energy of any reaction or the change in Gibbs free energy of any reaction is always less than 30 kilojoules. And here I want to start with giving you an example of how we can use the data that we have in our textbooks to determine whether a particular substrate will be oxidized or reduced for microbes.

Now, in the previous class I also told you about how oxygen is the best electron acceptor because when oxygen is reduced to hydrogen it gives it has a it produces a tremendous change in Gibbs free energy, a tremendous reduction in Gibbs free energy, minus 78 kilojoules and so on. And this is the highest in terms of all the electron acceptors that we have that are available for life on earth and thus a oxygen or the aerobic forms of life that consume oxygen as electron acceptors are the most profitable forms of life.

Now, let us say there are 2 reactions or to make it simpler let us say there are 2 substrates food 1 and food 2. If microbes eat food 1 it could be glucose or lactose or anything food 1 they produce a Gibbs change in Gibbs free energy in terms of minus 40 kilojoules. Let us say when they consume same microbial community consumes food 2 they produce a change in Gibbs free energy of minus 60. So, it must be particularly to you by now that them it will be more profitable for microbial community to first degrade food 2, which produces a greater change or in a low a lower overall Gibbs free energy. In because the from thermodynamics perspective that will be more profitable for microbes and they will be able to produce more ATP more electron currency more energy currency for them to sustain and grow.

So, let us take an example here and I want to show you some standard charts that are of10 available in most microbiology books like Richmond and McCarty.

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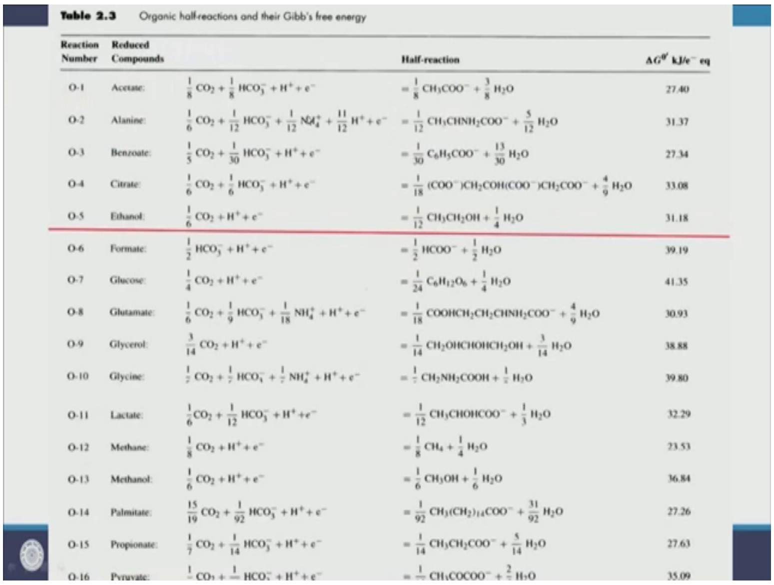

Table 2.3 Organic half-reactions and their Gibb's free energy

Reaction Number	Reduced Compounds	Half-reaction		$\Delta G^{0'}$ kJ/e⁻ eq
O-1	Acetate:	$\frac{1}{8} CO_2 + \frac{1}{8} HCO_3^- + H^+ + e^-$	$= \frac{1}{8} CH_3COO^- + \frac{3}{8} H_2O$	27.40
O-2	Alanine:	$\frac{1}{6} CO_2 + \frac{1}{12} HCO_3^- + \frac{1}{12} NH_4^+ + \frac{11}{12} H^+ + e^-$	$= \frac{1}{12} CH_3CHNH_2COO^- + \frac{5}{12} H_2O$	31.37
O-3	Benzoate:	$\frac{1}{5} CO_2 + \frac{1}{30} HCO_3^- + H^+ + e^-$	$= \frac{1}{30} C_6H_5COO^- + \frac{13}{30} H_2O$	27.34
O-4	Citrate:	$\frac{1}{6} CO_2 + \frac{1}{6} HCO_3^- + H^+ + e^-$	$= \frac{1}{18} (COO^-)CH_2COH(COO^-)CH_2COO^- + \frac{4}{9} H_2O$	33.08
O-5	Ethanol:	$\frac{1}{6} CO_2 + H^+ + e^-$	$= \frac{1}{12} CH_3CH_2OH + \frac{1}{4} H_2O$	31.18
O-6	Formate:	$\frac{1}{2} HCO_3^- + H^+ + e^-$	$= \frac{1}{2} HCOO^- + \frac{1}{2} H_2O$	39.19
O-7	Glucose:	$\frac{1}{4} CO_2 + H^+ + e^-$	$= \frac{1}{24} C_6H_{12}O_6 + \frac{1}{4} H_2O$	41.35
O-8	Glutamate:	$\frac{1}{6} CO_2 + \frac{1}{9} HCO_3^- + \frac{1}{18} NH_4^+ + H^+ + e^-$	$= \frac{1}{18} COOHCH_2CH_2CHNH_2COO^- + \frac{4}{9} H_2O$	30.93
O-9	Glycerol:	$\frac{3}{14} CO_2 + H^+ + e^-$	$= \frac{1}{14} CH_2OHCHOHCH_2OH + \frac{3}{14} H_2O$	38.88
O-10	Glycine:	$\frac{1}{6} CO_2 + \frac{1}{6} HCO_3^- + \frac{1}{6} NH_4^+ + H^+ + e^-$	$= \frac{1}{6} CH_2NH_2COOH + \frac{1}{2} H_2O$	39.80
O-11	Lactate:	$\frac{1}{6} CO_2 + \frac{1}{12} HCO_3^- + H^+ + e^-$	$= \frac{1}{12} CH_3CHOHCOO^- + \frac{1}{3} H_2O$	32.29
O-12	Methane:	$\frac{1}{8} CO_2 + H^+ + e^-$	$= \frac{1}{8} CH_4 + \frac{1}{4} H_2O$	23.53
O-13	Methanol:	$\frac{1}{6} CO_2 + H^+ + e^-$	$= \frac{1}{6} CH_3OH + \frac{1}{6} H_2O$	36.84
O-14	Palmitate:	$\frac{15}{19} CO_2 + \frac{1}{92} HCO_3^- + H^+ + e^-$	$= \frac{1}{92} CH_3(CH_2)_{14}COO^- + \frac{31}{92} H_2O$	27.26
O-15	Propionate:	$\frac{1}{7} CO_2 + \frac{1}{14} HCO_3^- + H^+ + e^-$	$= \frac{1}{14} CH_3CH_2COO^- + \frac{5}{14} H_2O$	27.63
O-16	Pyruvate:	$CO_2 + HCO_3^- + H^+ + e^-$ [illegible]	$= CH_3COCOO^- + H_2O$ [illegible]	35.09

In these charts, we have organic half reactions and there gives free energy. So, these are for example, I have shown you substrates that are organic in nature and when they are oxidized or reduced some change in Gibbs free energy is produced.

For example acetate when it is now here in left hand side we do not have acetate, but we have it on the right hand side. So, basically this notation is suggesting when carbon dioxide and bicarbonate are reduced to form acetate the overall change in Gibbs free energy is plus 27.4 o kilojoules per electron equivalent.

Now, this is positive. So, this reaction is not possible. So, if I ask you in your test a very simple question well there is this equation and it has this delta G will this reaction happen and the answer is of course, not because Gibbs free energy change is positive. Now on the other hand if we reverse the reaction. So, if instead of thinking about reducing carbon dioxide and bicarbonate and producing acetate we look at acetate being oxidized to carbon dioxide and bicarbonate, then they say the magnitude of the change in Gibbs free energy would be same, but it is sign would change. So, if we go from right side of the reaction to left side we will have a minus 27.4 o change in Gibbs free energy.

Notice here this these are only half the reaction, if you are interested in this way then carbon dioxide and bicarbonate are getting reduced, but we do not know what is getting oxidized. In biology, in chemistry, if one thing is being reduced the other has to be oxidized and that is the reason why we often refer to this as redox reaction reduction and oxidation something is gaining electron and something else is losing electron.

For example here carbon dioxide by a car made a gaining electron something else needs to be included that will be losing electron for this reaction to be complete without that this is half reaction. Similarly we have reaction for glucose formation has delta G of 41.35 which as you can notice in this particular table is the highest, there after converting carbon dioxide into reduced from glucose is going to be very energy consuming with delta G or 4 plus 41.35 and thereafter not feasible.

However if we think about the reverse reaction making carbon dioxide and proton from this glucose molecule it is going to be energetically most favorable compared to all other compounds in this table. And no wonder that glucose is the common essential food for microbes and if they give if we give them another food they need to first convert it into glucose most of them and then from glucose they make carbon dioxide or other products and they make energy out of it.

Now, here is another thing to note I mentioned here that carbon dioxide and proton plus electron converting them into glucose is energetically not feasible because they have a positive delta G; however, if we provided enough energy, if you provided at least this much energy and maybe some more then it is quite possible to convert carbon dioxide into glucose, which as you might remember and know is something that plants and trees do all the while. So, all phototrophic organisms they convert carbon dioxide into glucose by obtaining energy from sunlight and I want to mention here that not all organisms that convert carbon dioxide into glucose obtain this energy from sunlight there are other forms of life forms that I shared in the previous lecture autotrophs .

So, in fact, anything that converts carbon dioxide into glucose and does make their own food are called autotrophs, the autotrophs can be phototrophs that is when they used light for this energy for receiving this energy to make this reaction feasible and if they use other chemical sources then they have they are not phototrophs, but they are still autotrophs.

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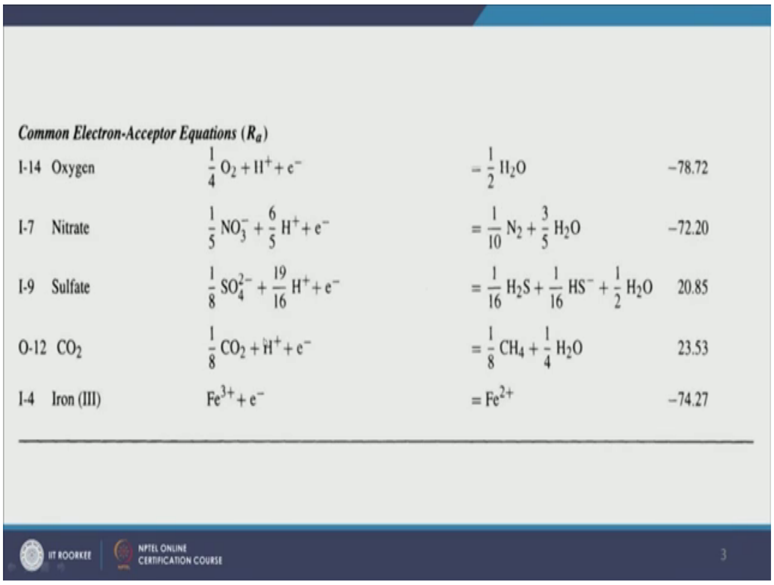

Now, here we have common electron acceptor equations. So, remember here we have common electron donors these electron donors, because when they accept electrons all of the delta G is positive not feasible. So, they want to give electrons and here we have common electron acceptors. So, oxygen nitrate sulfate carbon dioxide and ferric these are the common electron acceptors and you will know that they are delta G is negative xa for sulfate and carbon dioxide that is the reaction going from left side to right side is favorable.

So, to make oxygen from water we need to provide at least 78.7 2 kilojoules of energy per electron equivalent; however, from to reduce oxygen to water this much energy would be released and this energy can be used by microbes they can consume this energy. Now here I have highlighted in red a particular electron donor ethanol and I want you to notice that among oxygen nitrate sulfide carbon dioxide and methane the most energetically favorable electron acceptor is oxygen. So, if a simple question is put forth to you that which is the most suitable electron acceptor it is oxygen.

Now, let us say there are 2 microbial communities both are reoxidized in glucose. So, they both have same electron acceptor electron donor, but one of them is being is using oxygen. So, it is aerobic and the other is using nitrate. So, it is anoxic or anaerobic which of them will show a higher microbial growth.

Now, a question such as microbial growth can also be answered using Gibbs free energy in sense that microbes require energy to grow they require energy to sustain. So, whichever community gets more energy they will grow faster and we can be very sure that aerobic organisms grow fastest. So, aerobic degradation when possible will be faster than anaerobic degradation.

And note here that sulfur and carbon dioxide have delta G of thus this implies said reaction as such is not energetically favorable and yet we know that in environment methanogenesis of formation of methane and sulfate reduction happen under anaerobic conditions. And how do they happen well microbes use some very interesting enzymes that we talked about in one of the previous lectures to make this reaction favorable and reduce this energetic boundary.

Now, what I want to do right now is give you an example of using oxygen as electron acceptor and ethanol as an electron donor. So, let us say I want to find out what happens when microbes are fed and a diet of ethyl alcohol or ethanol and their aerobic microorganisms and thus they use oxygen. So, tell me what will be the net change in the Gibbs free energy or in other words how much free energy would be available for microbes to use it for growth or for sustenance.

So, what you can do is you can write these equations for oxygen and ethyl alcohol and I have written here it for you.

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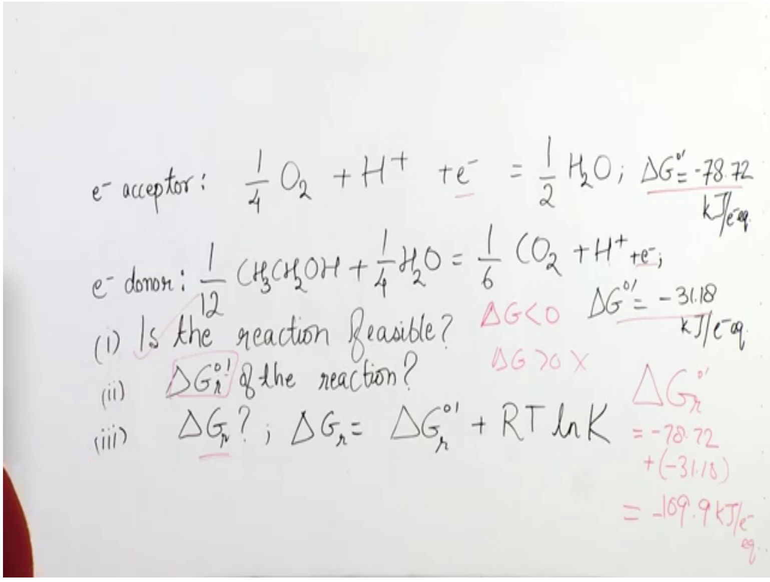

So, here we have equation for electron acceptor or oxygen which is accepting 1 electron and we a notice a delta G of minus 78.7 2 and then we have electron donor ethyl alcohol, which is donating an electron this is this has the stoichiometric coefficients have been adjusted to match electron. So, even if we add or subtract these equations we are dealing with only one electron remember for microbes this electron is the energy currency if they have electron they can convert they can use it as an energy currency.

So, we have normalized all these equations and the tables that I will provide you for your homework and the tables that you find mostly in the books are all normalized to have one electron. So, notice half oxygen this does not makes say one fourth of oxygen which is half of an oxygen atom does not make sense, but stoichiometrially it is important because we want to normalize it to one electron.

Now, we have delta G for electron acceptor equation we have delta G for electron donor equation and I have written delta G here and I require you to find out delta G r and why do you need to define delta G R, because the first question is a reaction feasible and you know that delta G r here delta implies change G Gibbs free energy and R reaction. So, when this reaction happens what is the change in Gibbs free energy and we are still dealing with prime naught which is understand it operating, temperature, and pressure, and PH and prime means everything is in 1 molarity because that is the standard notation for delta G here.

So, if I know what is the final delta G r prime naught I can tell straight away whether this reaction is going to be feasible or not. So, if delta G is less than 0 then the reaction is feasible and if delta G is greater than 0 reaction is not feasible and the more less it is compared to 0 the more negative delta G is the more energetically profitable this reaction would be for microbes.

So, now in order to find out delta G r from these 2 equations what we have to do is you have to balance the electron and thus our equ; what we need to do is we need to add these equations up and notice here we have one electron on this side and one electron on that side. So, if we add these equations up we will cancel the electrons and we will complete the equation. So, 2 half equations will come together to complete it.

Now, notice one thing in the table that I showed you on the slide and let us take a look ethanol is written like this carbon dioxide converting into ethyl alcohol with a delta G of minus 31.18; however, what I have written here is ethyn ethyl alcohol converting into carbon dioxide. So, have reversed the equation in the textbook or in the slide we have carbon dioxide turning into ethyl alcohol, but I have reversed it and therefore, I have also reversed the sign of delta G they display 31.18 here it is minus 31.18 and in this sense I will when we add these equations up now our reaction will be complete, we will have ethyl alcohol 1 12th 1 4th of oxygen plus 1 4th of water plus proton producing carbon dioxide water and the proton will cancel with the proton on the left side.

And now we can easily calculated delta G r which we can find by adding these 2 equations, these 2 delta G values. So, we have delta G r is equal to minus 78.72 plus minus 31.18 and you can be rest assured that delta G value here is less than 0 and thus this reaction is definitely feasible.

Now, if you add these 2 up you will get the delta G r of the equation and now you have calculated the delta G of the equation now the question is we have delta G r prime naught. So, these are under standard temperature and pressure PH and for everything we consider it is to be one molarity. So, we are assuming that at the end of reaction we have at the beginning and the end we still have ethyl alcohol oxygen water carbon dioxide everything is at one molarity which as we can see is not likely to be the case, we do not want one molarity of ethanol still lying around in our pool after microbes have eaten it.

So, we need to find out delta G r what if when things proceed towards forward direction then the chemical equation reaction moves towards forward reaction forward direction the delta G becomes positive and the reaction is no longer feasible. So, we need to figure that out and in order to find that out we use a simple formula that I shared last time delta gr is equal to delta G r prime 0 plus R T log K, where K is your equivalent constant.

So, if you are given the atmospheric pressure of oxygen and carbon dioxide you can find out their concentration and you will know if you know the starting in the ending point of methyl alcohol and water you can assume to be quite constant molarity, then you can find a value of K your R is 8.3 1 4 temperature has to be in kelvin and you can calculate the value of delta G.

Now, the next table here has information about cell synthesis. So, in the previous example that I showed you the general assumption was the microbes just required the energy. Now this energy that they will require in the previous example that we shared oxidation of ethanol we will have an energy of minus 109 kilojoules

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Table 2.4 Cell formation (R_c) and common electron acceptor half-reactions (R_a)

Reaction Number	Half-reaction	$\Delta G^{0'}$ kJ/e^- eq
Cell Synthesis Equations (R_c)		
Ammonium as Nitrogen Source		
C-1	$\frac{1}{5} CO_2 + \frac{1}{20} HCO_3^- + \frac{1}{20} NH_4^+ + H^+ + e^- = \frac{1}{20} C_5H_7O_2N + \frac{9}{20} H_2O$	
Nitrate as Nitrogen Source		
C-2	$\frac{1}{28} NO_3^- + \frac{5}{28} CO_2 + \frac{29}{28} H^+ + e^- = \frac{1}{28} C_5H_7O_2N + \frac{11}{28} H_2O$	
Nitrite as Nitrogen Source		
C-3	$\frac{5}{26} CO_2 + \frac{1}{26} NO_2^- + \frac{27}{26} H^+ + e^- = \frac{1}{26} C_5H_7O_2N + \frac{10}{26} H_2O$	
Dinitrogen as Nitrogen Source		
C-4	$\frac{5}{23} CO_2 + \frac{1}{46} N_2 + H^+ + e^- = \frac{1}{23} C_5H_7O_2N + \frac{8}{23} H_2O$	

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Now this energy can be used by microbes to eithers drive their day to day operation their sustenance or to form new cells to replicate.

Now, if microbes use different nitrogen and carbon sources we notice that they have different reactions that they undergo and each of these reaction has a different delta G value. Now if they are using ammonium as nitrogen sources then this is a very basic equation for cell formation now; obviously, we do not know the exact composition of cell and it varies, but in general we know the ratio of carbon hydrogen oxygen and nitrogen within any microbial cell and in this way a cell can be often summarized as C 5 at 7 O 2 N.

Now, please remember this that in no terms in no way is this suggesting that a microbial cell has merely 5 carbonate atoms, 7 hydrogen atoms, 2 oxygen and 1 nitrogen in 1 of the few lectures in 1 of the first lectures I shared how genetic material has millions of base pairs and each of them have plenty of Nitrogens in them and plenty of carbon hydrogen and oxygen in them therefore, this is definitely not true, but as a proportion it is most likely to be correct for any given microbial cell and what is important to note is that as a nitrogen sources change, because here we are assuming a carbon source is same carbon dioxide as a nitrogen sources change the stock a metric coefficient of the cell changes, but the composition of cell does not all righty .

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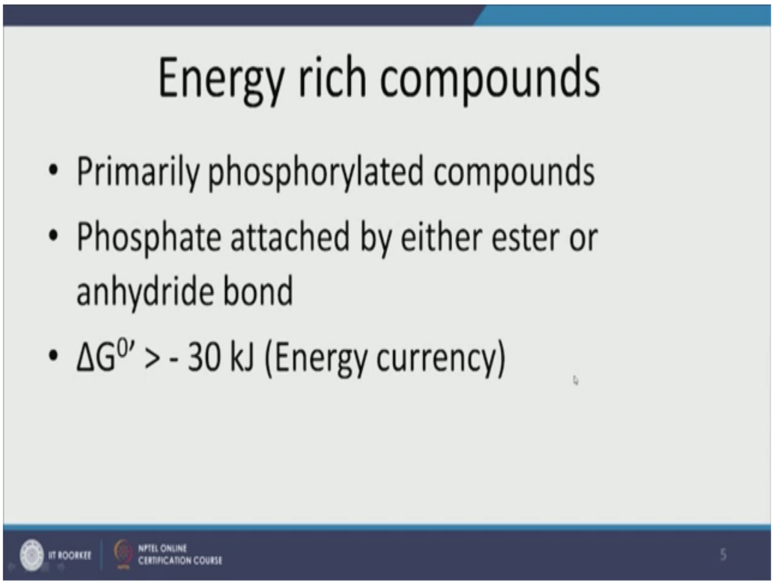

Now, it is important to know how this energy that will be released from electron acceptors and electron donors doing the redox reaction will be used by cells. Now what the microbes do is that they use compounds that are usually phosphorylated compounds and because this phosphorylated compounds usually are attached with very strong and hydride phosphate bonds they are very good for storing energy and these are for short term energy consumption like day to day liquid currency microbes love and hydride phosphate bonds compounds that are attached with it. And their other condition for microbes that is that the delta crime not for these Phos and hydride phosphate attached compounds should be less than minus thirty kilojoule for them to use as energy currency.

Now, when we speak of energy currency in terms of microbes this is there a currency for carrying energy from 1 point to another when electron has transferred then they need to tap this energy this energy that is released and they cannot tap it in terms of heat or light, but they have to have some compounds that undergo chemical modification using this energy that is released and when they undergo chemical modification they can be taken to other places. And they can reverse in to their original form while releasing this energy and thus they act like energy carriers.

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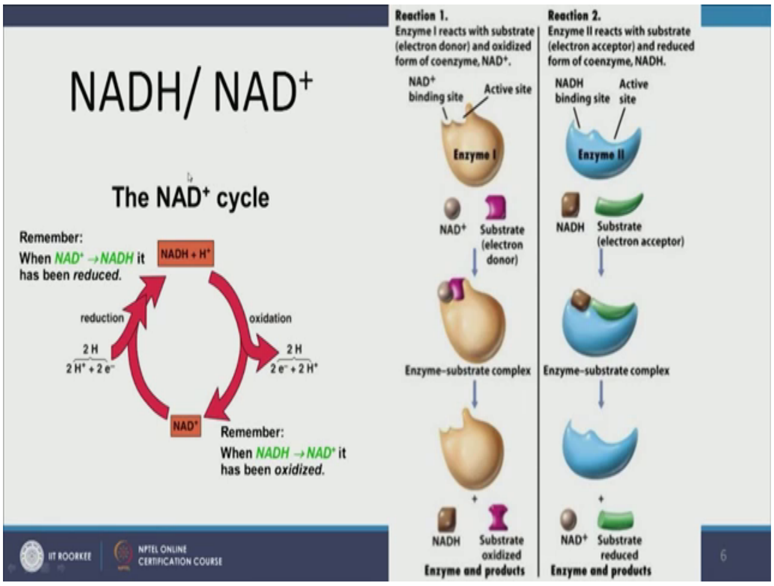

One of the first one that we mentioned yesterday was NADH and NAD plus and I explained to you how using 2 different enzymes NAD plus will reduce one particular substrate while oxidizing another and thus mediate the oxidation reduction reaction.

So, in this let us take this example of ethyl alcohol being oxidized by oxygen. So, in this enzyme what will happen NAD plus will attach here in this active site and in this active site will have ethyl alcohol attaching then due to it is catalytic activities NAD plus will become NADH enzyme will remain unaltered and ethyl alcohol would have been oxidized.

Now, NADH a has now additional electron in it. So, it will go to the next enzyme attached in it is position and electron acceptor will attach here and it gets reduced and NADH becomes NAD plus again therefore, if I ask you the question what mediates the redox reaction in microbial cell the answer is clearly NADH plus NADH and NAD plus all righty.

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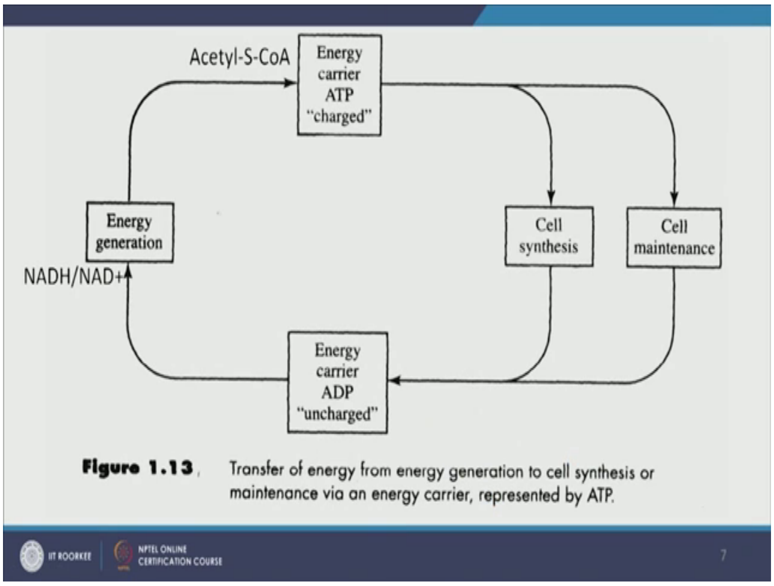

Now, where the energy generation is happening or where the redox reaction is happening we have NADH and NAD plus mediating the redox reaction. Now; how is this energy that has been created carried forth to the cell for cell synthesis and cell maintenance a here we have the role of ATP. Now when ATP is well when ATP is charged or it has an extra phosphate an hydrated attached phosphate bond then an it is an ATP form then it is charged it has extra energy and it can go get uncharged into ADP adenine dye phosphate and thus give energy for cell synthesis or some maintenance. So, this is the carrier of energy remember this is the mediator of the energy generation reaction and this is the carrier of energy.

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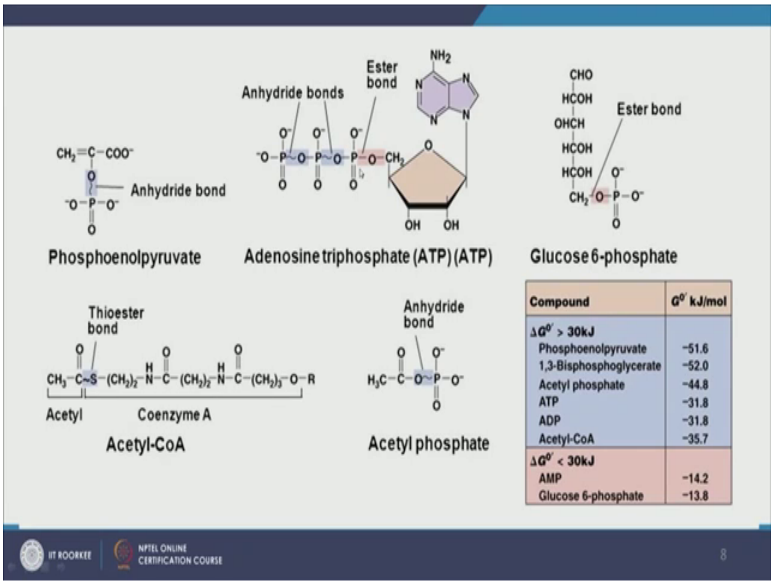

Now, these are some other energy rich compounds that are used by cell either as energy carriers or as energy mediators. Now adenosine triphosphate this is ATP. Now notice here it has 3 phosphate attached to adenosine now this must remind you of the adenosine we studied in genetic elements, when we were studying the 4 different kinds of nucleotides, adenosine, guanine, thymine, cytosine, and in case Ofrna uracil. So, this is the same adenosine.

Now, it is attached to 3 phosphate notice that the first one is ester bond. So, it does not have a lot of energy the other 2 anhydride bonds. So, they have plenty of energy. When ATP converts into ADP it loses this phosphate. So, it is not diphosphate not triphosphate and when it loses the energy it loses a lot of energy the energy is given out. So, this energy that has been given out can be consumed by itself for various activities and then when it gains back the phosphate it consumes energy. So, now, it has stored energy and you can understand that ester bonds with phosphate ester bonds are not very energy rich and therefore if you remove the 2 phosphate amp or adenosine monophosphate is not suitable for carrying energy.

Then we have acetyl COA acetyl CO COA or acetyl coenzyme a plays a very important role in catalyzing ATP.

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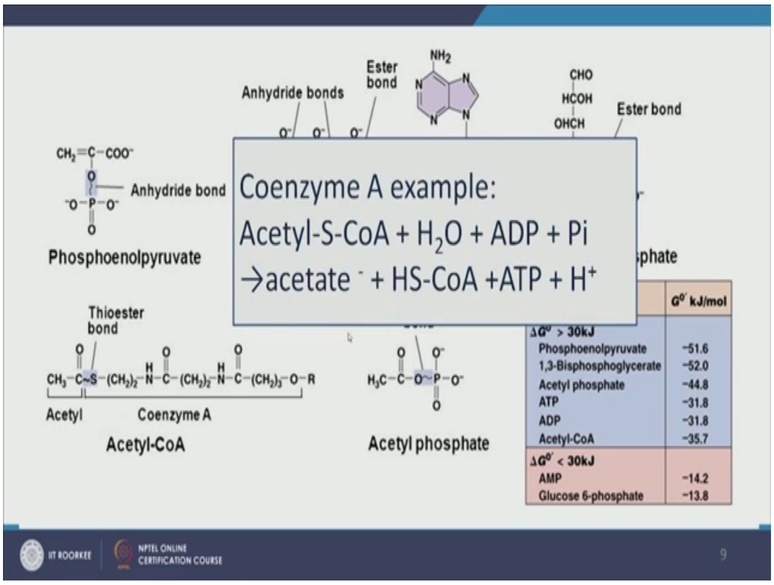

So, when ADP has to be converted into ATP it is acetyl S COA that actually catalyzes this reaction and therefore, they all interact with each other and help each other to carry energy .

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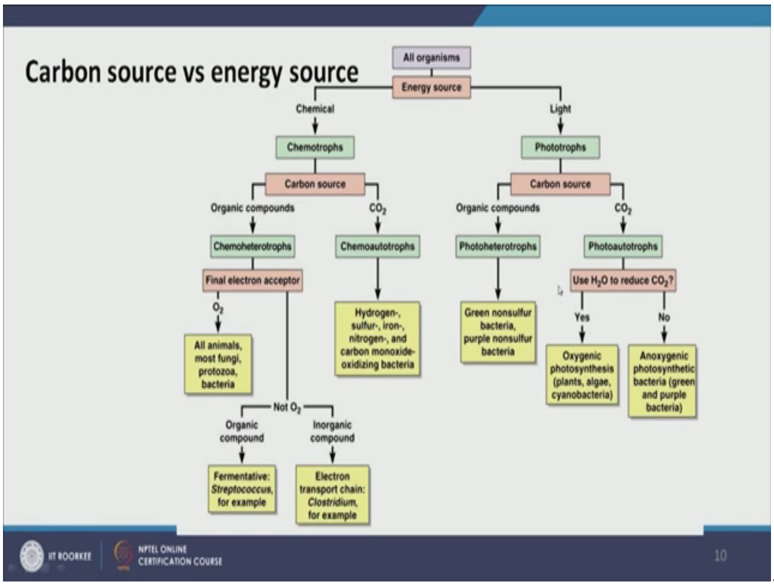

Now, in the previous class I also briefly mentioned about chemotrophs, phototrophs, heterotrophs, autotrophs, and I think it is a good idea. Now that we have studied about the basic of microbial energetics we know what delta G is why it is important, we know how microbes carry energy how they mediate the reactions the redox reaction and how acetyl COA helps ADP ADP convert into ATP it is a good time to revisit the general organization of microbial community in terms of their carbon source and energy source.

So, far we have been focusing on the energy source, but as we noticed just few slides earlier, when the energy has been obtained microbes have to decide whether they want to synthesize new cells or they want to use this energy for sustenance. If they want to synthesize new cells the definitely new need additional carbon sources.

Now; obviously, microbes that are eating; obviously, microbes that are eating carbon rich compounds or organic compounds such as a ethyl alcohol or glucose can also use it as carbon source, but things get a little tricky when your source for energy is non-carbon. For example, if you are an autotroph, but do not depend upon sunlight for producing your energy for strapping the energy and producing your food then where do you get your carbon for.

So, this table here it sort of summarizes different kinds of microbes and what their carbon sources and what the energy sources. So, look here on the top we have all organisms, everyone needs energy source to live the ones whose energy source is light they are called as phototrophs. Now photo means light trophs means food now trophs means how they get energy.

So, now these phototrophic organisms can either get their carbon source from organic compounds like glucose or lactose or other sugars and like ourselves we get our carbon sources from other things, but we are not phototrophic these are called as photo heterotrophs. So, they get the carbon from various sources, but they used light for energy and the examples would be green on sulfur bacteria and purple on surfer bacteria, if you remember in the very first lecture I talked about the green bacteria that was the first organism which started oxygenating our environment long before trees were formed and we owe a lot of vl vo our existence definitely to these microbes, these are photo heterotrophs because they use light for energy and for carrying out the redox reactions, but for they use multiple car organic compounds for their carbon source.

However there are some life forms that use light for their energy and use carbon dioxide as source of their carbon these are called as photoautotrophs and a pretty simple example would be our plants our trees, they use carbon dioxide in the air for making glucose and they used light for catalyzing this redox reaction and thus they are an example of photoautotrophs.

Now, when we talk about photoautotrophs we need to ask the question do they use water to reduce carbon dioxide or not. Now in terms of plants yes they need and you must have studied this in your science basic science the plants use carbon dioxide moisture and sunlight to produce food. So, they use water to reduce carbon dioxide into glucose, but if they do not use water then they are called as anoxygenic photosynthetic bacteria examples are green and purple bacteria.

Now, if the energy source is a chemical not light then they are called as chemotrophs. Now depending on the carbon source they can be called as chemoheterotroph or chemoautotrophs let us say they use some chemical for producing energy. So, they are chemotrophs, but they use carbon dioxide as carbon source an example would be sulfate reducing bacteria because they sorry sulfur oxidizing bacteria, because they use this reaction to produce the sorry they use this reaction chemical reaction to produce energy, but they use carbon dioxide to produce their cell matter and here are some examples for you hydrogen sulfur iron nitrogen carbon monoxide oxidizing bacteria.

Now, what if both the organic compound is source of carbon and some chemical organic or inorganic a source of their energy then we have chemoheterotroph. So, hetero here implies anything that uses some organic compound a source of carbon auto means they use carbon dioxide an inorganic compound a source of carbon.

Now, depending on what they finally, electron acceptor is if they are aerobic then they are most animals and higher orders of life and anaerobic microorganisms, but if it is anaerobic then the electron acceptor can be an organic compound such as when in case of fermentation, which we will talk in the next lecture or it could be an inorganic compound and for example, clostridium uses multiple inorganic compounds for the electron acceptor they can be sulfate reducing bacteria and nitrite itrucing nitrate reducing bacteria iron reducing bacteria all of these use inorganic compounds which are not oxygen for the electron as their electron acceptors.

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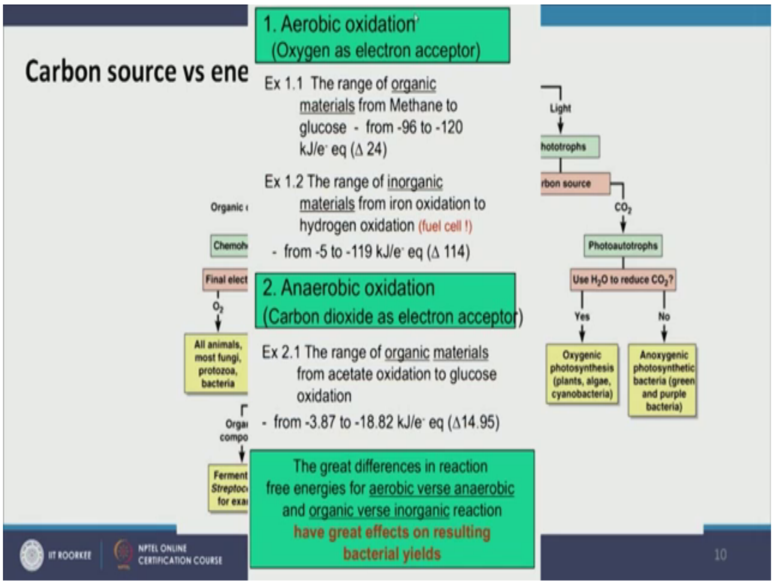

Now, this is very interesting thing and I have sort of mentioned this before the beginning of this lecture that if a microbe uses air or oxygen for oxidation or oxygen is electron acceptor then it will generate more energy right. So, up to 1 1 4 delta G kilojoules and thus they will have more energy available for growing faster more energy for replicating faster and evolving faster.

In case of anaerobic oxidation the maximum delta G that they can achieve is 14.9 5 it is much lesser than aerobic oxidation and thus we know that aerobic oxidation would be much more energetically profitable, than anaerobic oxidation and thus the great differences in reaction free energy for aerobic versus anaerobic and organic versus inorganic reaction have great effects on resulting bacterial yield.

So, if I ask you a very simple question well I have a microbe a which is aerobic and it is surviving on glucose, but and I have micro b which is anaerobic and it is still surviving on glucose, but it is using sulfate as an electron acceptor which will have a higher bacterial yield you should be very quickly able to point out that an aerobic bacteria is more likely to have a higher bacterial yield.

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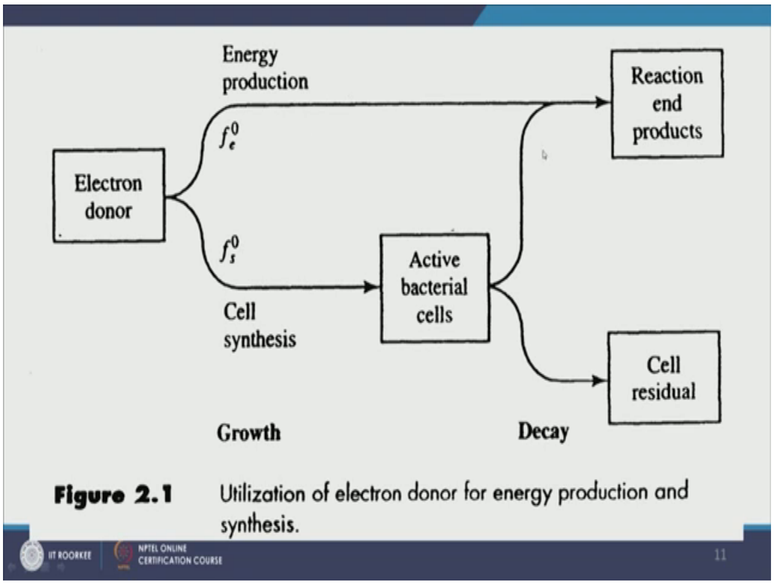

And this is a diagram representing what we have already talked about. So, far that we have electron donor and the electron donor gives electron and that is used for producing energy. This energy can be used for carrying out the reactions in the cell it can also be used for synthesizing new cell and once the new cell have been synthesized the active bacterial cell. Again need more energy to carry the end products and then the dead ones will produce cell residual and they will decay again notice here this cell residual can also be often recycled as electron donors if not by the same microbe than by other microbes.

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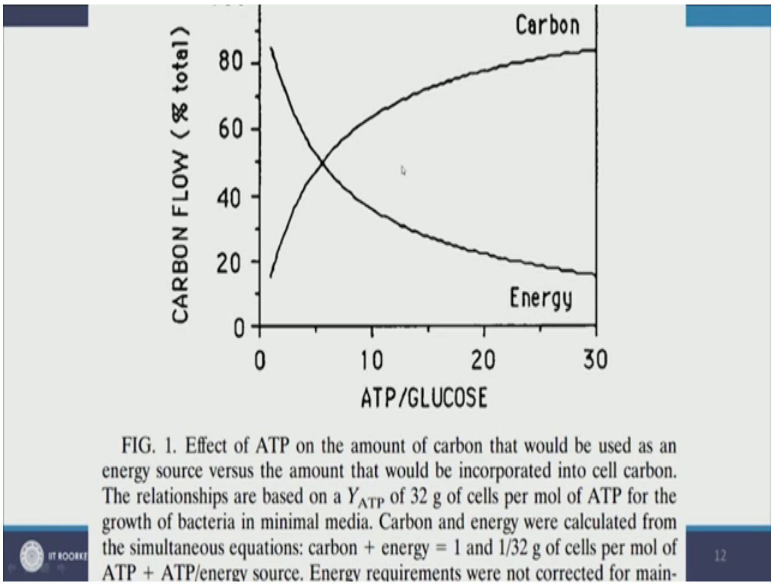

Now, this is a very neat diagram that I want to talk about this on x axis we have ATP per glucose and on the Y axis we have carbon flow. So, what happens when the ATP changes how where does the carbon flow there is a carbon flow towards making more biomass or does the carbon flow towards more consumption of energy, we notice that as ATP increases the cell yield increases that is the biomass the current portion of carbon that flows into biomass increases thus coming back to over this slide as the energy increases as we have more energy, more ATP, more carbon will be pushed to making more biomass than carrying on the reaction and this is again in line with what we studied just now that aerobic microorganisms will have higher bacterial yield because they have more ATP available for the cell.

So, now that the energy is available to cell and it can either use it for making biomass or it can use it for getting out energizing the reactions there is another option available to microbes.

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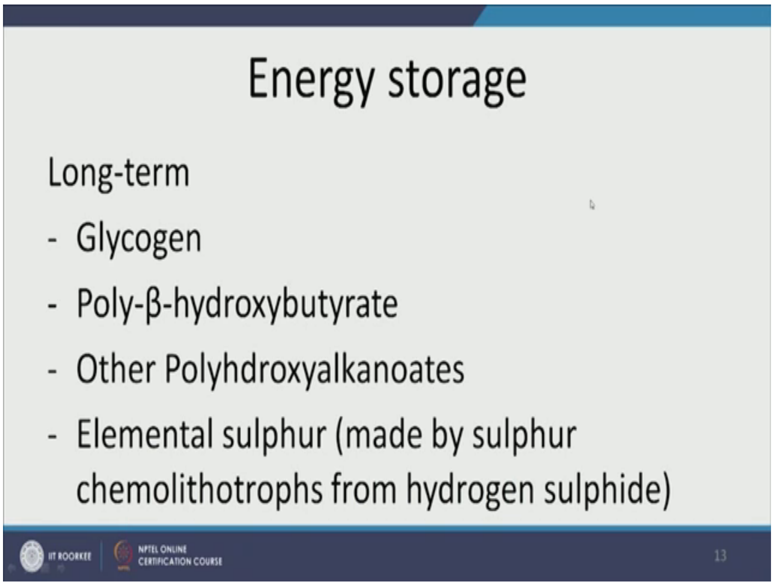

Which is to store the energy? So, microbes can actually they do not have to use the energy the instant it is produced and we can store it for longer term use. So, just like how we mammals do and for long term storage and usage of energy microbes have multiple options available they can create glycogen, which is what is done in our liver by the way our liver also produces glycogen or the glucose or we can use poly beta hydroxybutyrate a very energy rich compound.

So, they can make this compound and let it sit in the cell until they need more energy where they can oxidize, this compound we can make other similar polyhydroxyalkanoates and then elemental sulphur is also used by many chem chemolithotrophs they make it from hydrogen sulfide and they use it as their long term energy storage.

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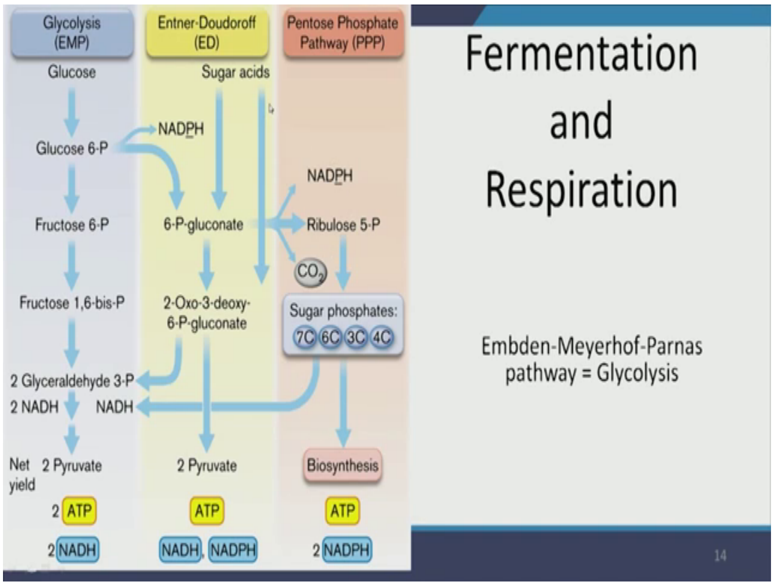

Now, dear students in the next lecture we will talk about fermentation and respiration which are the 2 mechanisms, 2 pathways through which microbes use their primary source of energy which is glucose they can either ferment it which usually happens under anaerobic condition all they can respire or breathe it which happens under aerobic condition.

So, in the next lecture I will talk about fermentation in respiration which is when microbes have their essential form of sugar glucose available to them for consumption, they can either ferment it or they can aerobically degrade it and that will conclude our microbial energetic.

Thank you very much.