Biological Inorganic Chemistry
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Lecture 16
Metal ion assimilation

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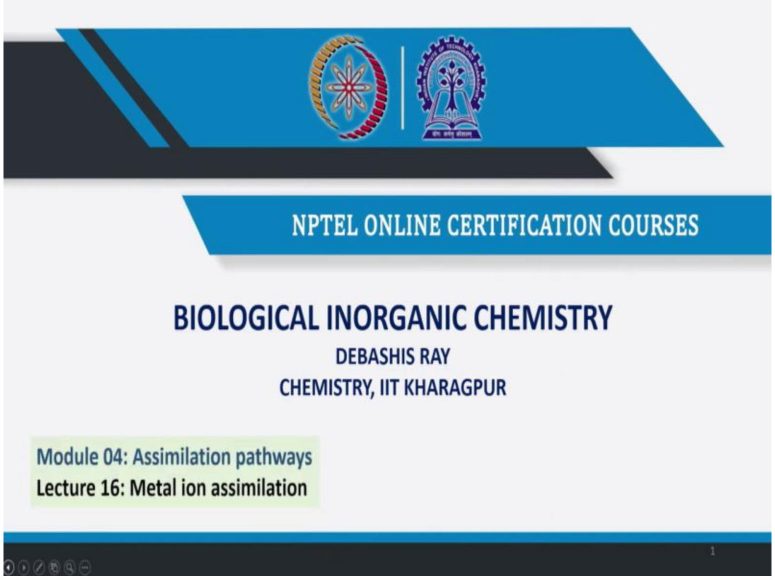

Hello. Good morning, everybody. So, from here, we will continue to module 4. So, in this module we will talk about the assimilation pathways, their metabolism and little bit some other applications regard to that. So, this lecture 16 is devoted to the metal ion assimilation, how we can consider, how we get the source of these metal ions in our system to the different plants also.

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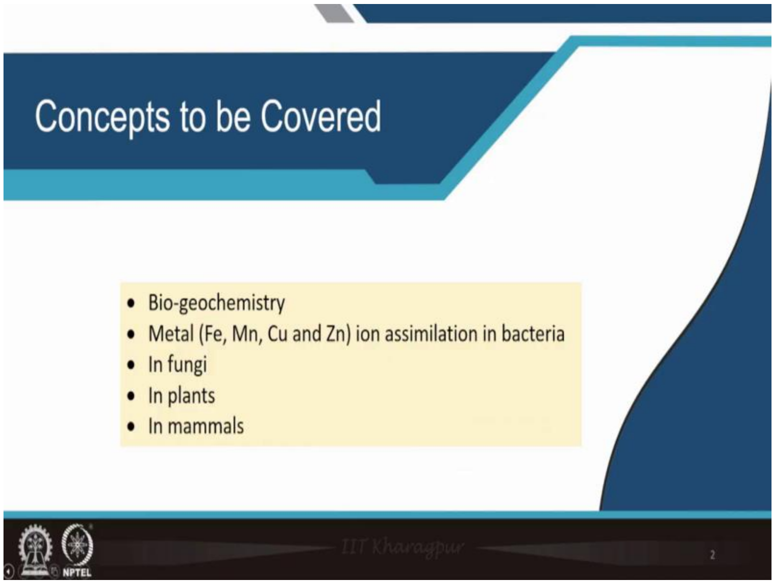

So, a little bit to talk about one or two slides on biogeochemistry, the environment, how we get. If we consider the metal ions, what is written over here in your second bulleted point that the metal ions like iron, manganese, copper and zinc, so what are the sources in the environment and how they can be taken up by starting from bacteria to the mammals. So, that particular process is a little bit complicated process, because we do not know much about all these things.

So, these are all recent observations and recent findings, because the genomics is also developing day by day, but whatever information we have gathered so far is very much interesting also, because the knowledge of the bacterial ion thing that means, that total ion chemistry in terms of is ion, presence of ion in biology, so fungus to plants to mammals we can consider.

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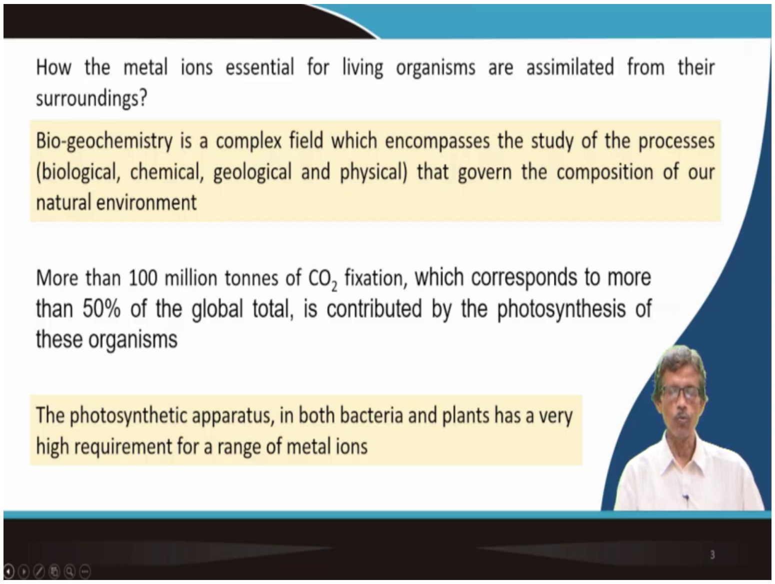

So, how the metal ions are essential for all the living organisms from plants to mammals and how these are assimilated from its biological or geological environment from the surroundings therefore. So, is a very complex field which encompasses the study of the processes. What are those processes? We are always interested only the chemical part, the chemical reactions, and what is happening for that, but the biology will also come there and the geological as well as the different physical prospects, what control the corresponding concentration of their availability. So, the composition of a natural environment, so what we get, we are getting from the nature.

And one simple example what we can have in our hand is that, around more than 100 million tonnes of CO2 fixation is taking place, which corresponds to more than 50 percent of the global total is contributed by the photosynthesis of these organisms. So, if we consider that this photosynthesis process is dependent on the metal ion, so cyanobacterias are there, oceanic life is also there. So, this particular CO2 fixation which is a global threat definitely, that how much CO2 can be fixed by the kingdom which is available on the sea.

So, that will be, therefore, dependent on the presence of the metal ions. So, what do you find then that the photosynthetic apparatus in both bacteria and plants also because we know the cyanobacteria and the oldest one, oldest known and oldest found also bacterium which is responsible for photosynthesis has a very high requirement for a range of different metal ions, not only a single metal ion, but a range of different metal ions. So, as we all know, for the typical thing the photosynthesis, typical photosynthesis is dependent on magnesium in chlorophyll we all know as well as manganese in PS2, the photosystem II for water oxidation.

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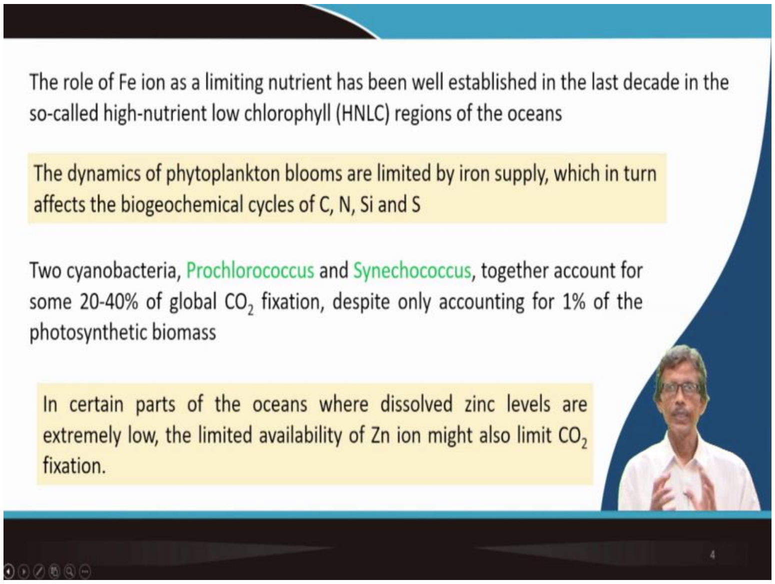

Then, we just again we will mainly focusing our attention on four metal ions, three to four metal ions only. We are not making our life complicated when we talk about other things also during applications also. So, four to six metal ions we try to know, try to understand nicely. So, what about the iron for all these categories of the living species? So, it is limiting nutrient has been well established in the last decade also in the so called high nutrient low chlorophyll regions of the ocean.

So, if you have highly nutrient species starting from your iron, but the chlorophyll concentration is less what is happening over there. So, the phytoplankton blooms are limited by iron supply. So, they are not getting that typical iron supply. So, that disturbing the cycles related to the corresponding relative concentrations of the availability of carbon, nitrogen, silicon and sulfur. So, we consider it as your corresponding biogeochemical cycles will also be hampered. So, iron will have some role to play over there.

So, two well-known cyanobacteria are we have, so prochlorococcus and synechococcus they are, they account 20 percent to 40 percent of global CO2 fixation. You see the oceanic thing is also because the ocean is largely responsible for the greenhouse emission, what we emit to the environment through our daily activities like the running of your cars and all these things. So, the only accounting for 1 percent of the photosynthetic biomass, but the photosynthetic biomass is not very much, but you can have the corresponding CO2 fixation efficacy is much more.

In certain parts of these oceans, therefore, we have the dissolved zinc levels. So, if we just moved from iron to the zinc so we can have certain amount of zinc levels if we take out that (()) (6:06) sample of seawater and we can analyze for zinc will find that particular concentration. So, where do we have the dissolved zinc concentration is very low, the limited availability of zinc ion might also limit the CO2 fixation, because we know that for CO2 fixation as the bicarbonate and the carbonic acid we require zinc, in our body also we take zinc based carbonic anhydrases. So, the requirement of zinc is also there. So, that also really point out the availability or the importance of zinc for the CO2 fixation.

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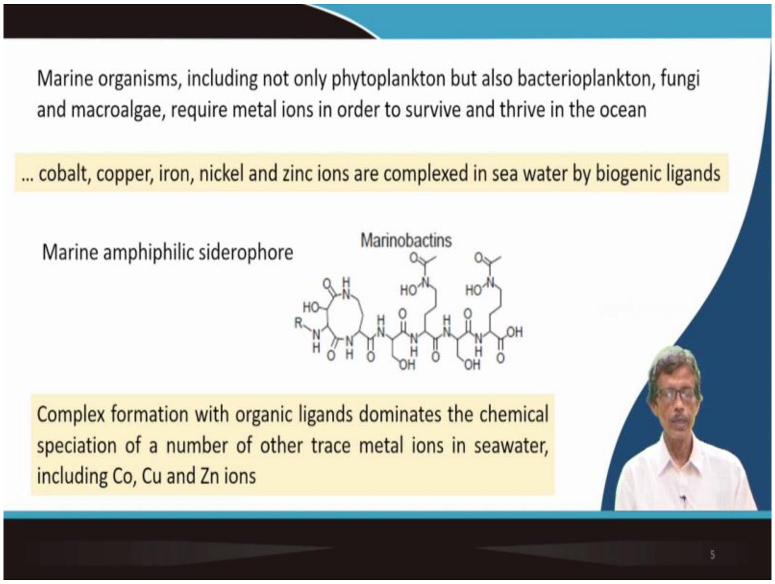

So, all these marine organisms including not only the phytoplankton, but also bacterioplankton, so phyto means the plant origin and the bacterial origin fungi and the macroalgae all require metal ions for their survival. So, if we consider say bring cobalt, we are bringing cobalt, we are bringing copper also and nickel also and zinc ions, so if these ions are they are available so you should always be master enough to know about the corresponding coordination chemistry of all these metal ions.

Your school days, from your school days, you are studying the corresponding coordination chemistry of all these metal ions. So, never forget that very basic coordination chemistry related to all these metal ions, otherwise, you cannot have any understanding of these things because your life will be much more complicated when you bring the biogenic ligands and those biogenic ligands are coming from say ocean water or sea water. So, your life will be a little bit complicated from there.

So, similarly, if you have the marine origin, marine amphiphilic siderophore, we have learned about the siderophore from the bacterial origin so that bacteria also infect us like the threat from virus, we had the threat for the bacteria also. So, that is why we consume large amount of antibiotics for our survival also. So, marine chemicals, because the marine chemistry is a very huge area, we do not study much. So, the marine chemistry is really rich when we talk about in terms of the living organisms like the siderophores which are amphiphilic in nature.

So, that amphiphilic siderophore how it looks like you see, so exciting molecule it is, which is known as marinobactin, like E. coli what do you know that from the E. coli we get enterobactin so which giving us the disease also, the enterobactin infection from that particular bacterium. So, the marine origin of these, the marinobactin, you see such a complicated molecule, but you see the backbone is all are made up of amide function CONH, CONH, CONH and all these things and at the end also you have the hydroxamate function and you have one part, we have the cyclic, macro cyclic ring like your tetrapyrrole porphyrin and you have that alcohol part also CH2OH part.

So, this siderophore can be used as a good ligand such that you can control the level of your available metal ions in the water, of the sea water. So, they are responsible for your chemical species and how they are selective for a particular metal ion. And they are also useful for other metal ions in seawater including cobalt, copper and zinc ions. So, these biologically originating ligands are very much useful to control the corresponding concentration, the concentration gradient to fix within the marine life.

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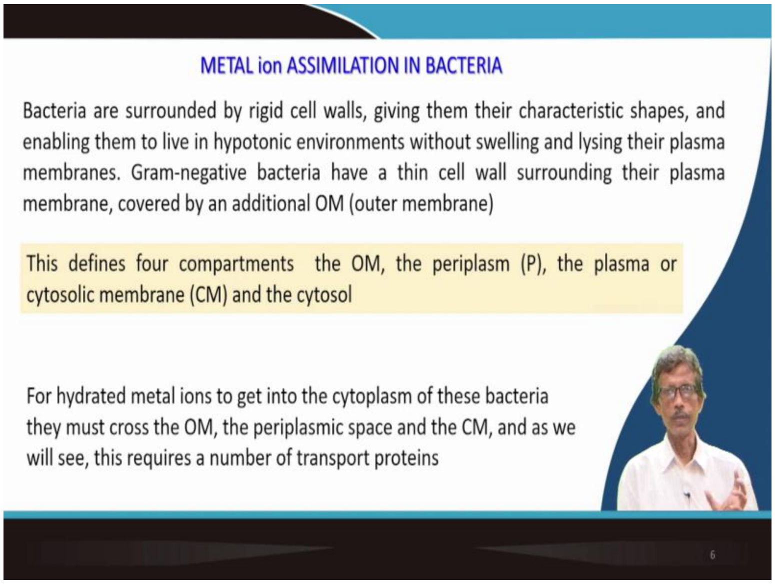

So, now quickly we will see from bacteria, fungus and the plant and the mammals, so metal ion assimilation in all these species, all these living organisms, metal then ion. So, is a deliberately written as small letter as ion. So, do not forget to write it as the metal assimilation in bacteria. It is not metal. It is the metal ion. So, everything we are talking about the metal ion.

So, when we have the bacteria which are surrounded by rigid cell walls, a little bit of these bacterial thing you will read again, you will recalculate it what do you have read in your school days, earlier school days in science books that they can have the characteristic steps and they live in hypotonic environment without swelling and lysing, lysing mean hydrolyzing the cell wall, their plasma membrane. The plasma is stored by the membrane, but you are not degrading the membrane if your environment is changing.

So, Gram, scientist, by the name of scientist Gram's name, so Gram-negative bacteria will have a thin wall surrounding their plasma membrane. So, you have two membrane; one is thin cell membrane and thin cell wall then you have the plasma membrane covered by, which is covered by additional outer membrane which we abbreviate as OM. So, apart from OM, you have the periplasm, the plasma for cytosolic membrane and the cytosol. Cytosol is the corresponding liquid environment within the cell.

So, if you now get a hydrated metal ion, say hexa eco Fe2 plus or Fe3 plus so what happens there then? So, for hydrated metal ions, it tried to get into the cytoplasm of these bacteria and they must cross the outer membrane OM, the periplasmic space and the CM, the cytosolic membrane, so outer membrane as well as cytosolic membrane so they have to pass. So, you see that the hydrophilicity is so important for this particular hexa eco species that it should be allowed to pass through these membranes.

And we will see that these requires number of transport proteins, without the help of these transport proteins, this transfer of these metal ions will not take place. So, these transport proteins will come, the metal ion is coordinating to some ligand and then sitting on that transport protein and transport proteins are taking all these things.

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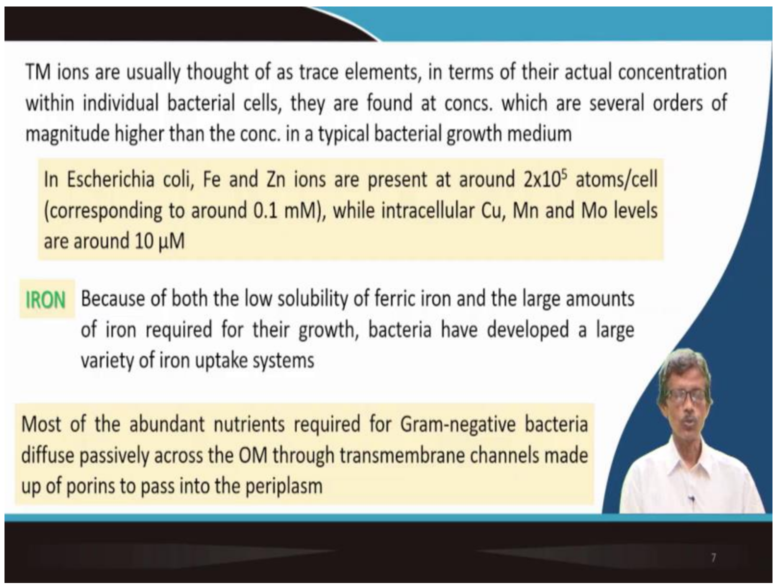

So, TM ions, the transition metal ions, which are we are considering as the trace elements and their actual concentration is also varying for the individual cells of the bacterium. So, they are several orders higher in the concentration of the typical bacterial growth medium. So, in the growth medium, you have a one particular concentration, but it is varying.

So, E. coli, in E. coli what we have the iron and zinc ions are present in around 2 into 10 to the power 5 atoms per cell concentration which is equivalent to that of your 0.1 millimolar concentration. So, that 1 millimolar concentration you can reach, you can achieve, while the intracellular copper, manganese and molybdenum levels are around 10 micromolar. So, these concentrations are very important.

You have a cell, you have cell wall, you have the cell membrane, and outside cell you have one particular concentration and inside cell you have one other particular concentration that we all know in our body also. In our human body, we all know that we only consume sodium chloride. We never consume potassium chloride, but we need potassium chloride also for our survival. Why? We get the potassium ions from the food materials only. But the concentration of the sodium ion as well as the potassium ions are different within the cell and outside the cell. So, that is why the mechanism for this transfer, mechanism for this particular storage and everything will be different.

So, if you now see the very two simple metal ions like sodium ion as well as the potassium ions, how we control the corresponding movement, its storage and some implication for our health and diseases, so that will be very much important. So, here also the corresponding concentrations, not only for your iron and zinc, but also for the copper, manganese and molybdenum, so these levels we can get it by only from E. coli.

So, for iron what happens then? Let us see. So, for iron, we have very low solubility of ferric iron. All the time we know how you prepare a solution of ferric chloride in a volumetric flask. In our college days question is a very, I am very much fond of asking everybody to that particular question that what will you do, what precautions will you take to make that particular iron in the solubilized form? Because these iron in the solubilized form as iron ion will only be assimilated for the growth of even for the bacteria. So, you must have an iron optic system in the solubilized form.

So, if we consider that these iron ions are your nutrients which are required by Gram-negative bacteria, but they diffuse across the OM through the transmembrane channels made the porins to pass into the periplasm. So, those mechanisms are there where it can be available for the transfer of all these groups from one side to the other.

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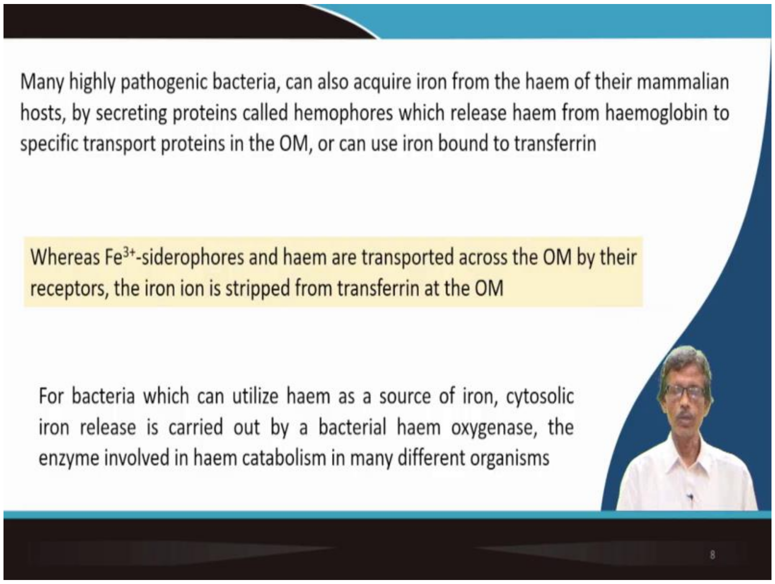

We all know that the disease causing bacteria known as the pathogenic bacteria can also require iron that is why the siderophores we all know, we study siderophore a lot, because the siderophore always go for the competition when we are looking for iron for our survival, for the synthesis of our myoglobin and hemoglobin. Bacteria is also struggling for that amount of iron for their survival. So, they secreting proteins which are known as hemophores and release haem into from hemoglobin to specific transport proteins in the OM, the outer membrane and can use iron bound to transferrin.

So, they are so much clever that they can use the iron present in hemoglobin, iron present in the transferrin molecules, the transferrin molecules in our system it is there which is required for transfer of iron from one side to the other. So, we find that the ferric iron binding siderophores, so these ferric iron binding siderophores and haem are transported across the outer membrane, where you have the receptors. The receptors are similar to that of your ligands. Ligands are there which are binding the metal ions, but receptors are taking care of the entire metal ion complex or entire entity, where your metal ion is bind to the protein or the small molecule protein system.

So, the iron ion is stripped from the transferrin at the outer membrane. So, the fighting is going on and it will try to take up that particular iron from there. So, for the bacteria, so large number of bacterias utilize the haem as a source of iron. So, they destroy the haem. The cytosolic iron is released and is carried out by bacterial haem oxygenase. So, bacterial haem oxygenase is there which can destroy the haem. That is the enzyme which involved in haem catabolism, the destruction of haem in many different organisms not only in human body, but also in other living system.

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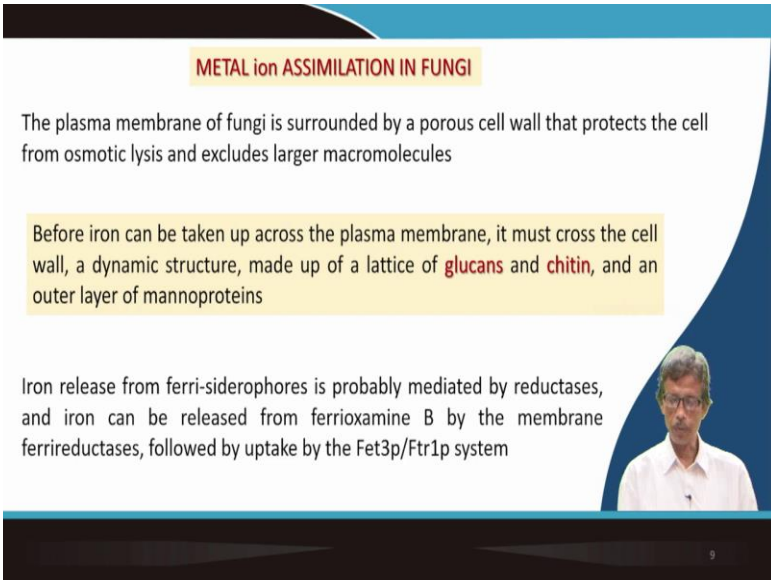

So, what about in fungi? Metal ion assimilation is taking place in fungi also apart from bacteria. So, the plasma membrane is also responsible again for the fungal assimilation of the metal ions. Then you can have the osmotic lysis that means the breakage which excludes larger macromolecules. So, larger macromolecules are involved there for this particular type of operation.

So, before iron can be taken up across the plasma membrane so it must cross the cell wall which is made up of glucans and chitin, we call is chitin, and an outer layer mannoproteins. So, these are the constituents of the cell wall or the cell membrane, but iron will pass through it. In that particular case, the fungal movement of iron release is taken place by ferri-siderophores. That means the ferric ion is bound to the siderophore and is mediated by several reductases. And in that particular process iron is released from ferrioxamine B.

So, if your ferrioxamine is a species siderophore molecule bound to iron by the membrane ferrireductase, you reduce the thing, so you reduce the ferric ions. Ferric ion is strongly bound to the siderophore. But if you reduce it, it will be released, because your corresponding binding constant is very less compared to your ferric ion. And then it is taken up by Fet3p and Ftr1p system. So, these are the other bigger molecules, other controlling molecules which can take up that ion for your assimilation.

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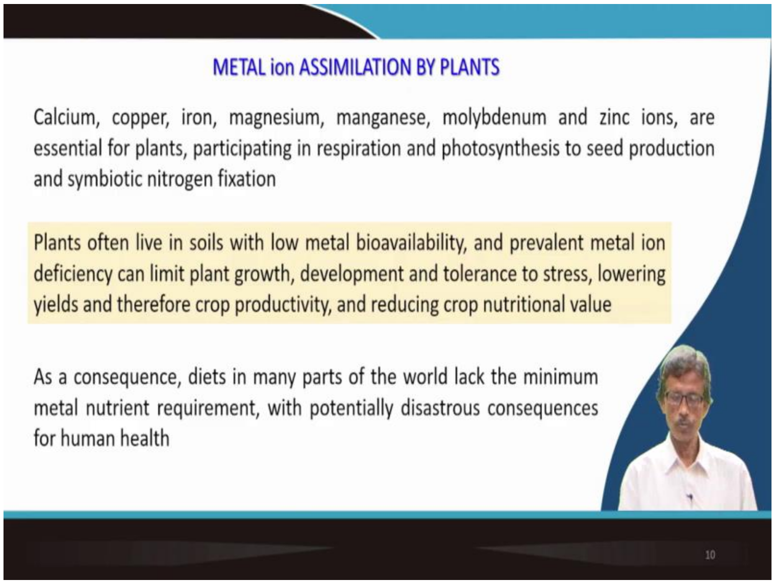

What about in plants? In plants also, not only iron, but calcium, copper to molybdenum to zinc also they are essential. But we do not care about all these things. When we grow plant, we only talk about the fertilizers, we talk about the nitrogen, we talk about the phosphorus and we talk about the potassium only. But these are there. They are micronutrients. Very small amount they need. So, where you have the bioavailability less, the prevalent metal ion deficiency we can see and can also limit the plant growth. So, definitely it will part off the plant growth.

So, not, we do not get the healthy plants, like healthy human being, so the development and tolerance to stress. So, the metal iron deficiency will lead to the stress, lowering the yields, the crop productivity and reducing the crop nutritional value, because whatever it is producing as a crop, the nutritional value will be less if they have the metal ion deficiency. So, this is also a very important part, particularly the botanists who are studying all these things, but they do not study much about the metal ion, involvement of the metal ion, because everybody thinks that metal ion is only by doing by the chemist, not the chemist, but only the inorganic chemist or the coordination chemists only. It is not like that.

The metal ions, we can learn it all these things. So, whatever diet then finally we get it in many parts of our world lack minimum metal ion nutrients requirement. So, those foods whatever we are getting throughout the world, whole world, some part we produce that particular wheat, some part we produce rice. If the soil is deficient in metal ions, so the micronutrients what should be there with your rice, what should be there with your wheat will be deficient in those particular metal ions. So, is a disastrous consequence for human health also for this type of deficiency.

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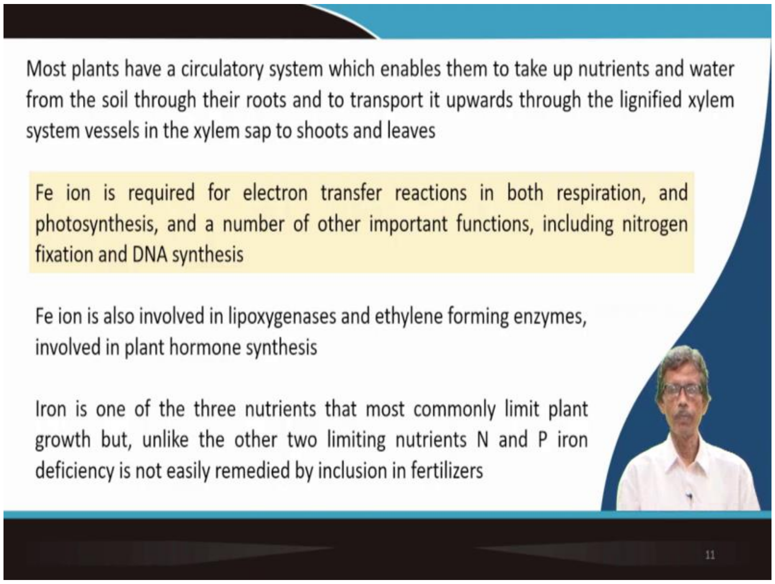

So, you have, in the plant also you have the circulatory system and that circulatory system is taking up all these nutrients and water from soil it take up from the roots and transport upwards through your xylem. We all know from our school days. Again I have the detailed language I have given to you. I am providing all this language from the books also is very important.

You read it several times such that you can again recapitulate all these things whatever you have learnt earlier. The roots and xylems and all these things now you will be studying roots and xylems in terms of the transfer and the passage of the metal ions because we never learnt in that fashion that your roots, plant roots and plant xylems is utilized for metal ion transfer.

So, if you have the iron ion which is required for electron transfer reaction, in our previous class we are talking so many things about the metal ion involved in electron transfer reactions starting from your iron to copper. So, these reactions are responsible and useful for your respiration and the photosynthesis and number of other important functions including nitrogen fixation and DNA synthesis. So, iron is so important for plants.

So, it is also involved in lipoxygenases that means the corresponding lipid oxidation. Lipoxygenases are responsible for lipid oxidation. So, any kind of lipid or plant origin or any other kind of lipid what we can have can also be responsible for the generation of these oxidized form of the lipid. Then ethylene formation of the corresponding fruit ripening, we all know the ethylenes are required that is why you keep carbide for fruit ripening. So, to produce these ethylenes we require some enzymes where iron is involved and involving in all the different other synthesis of the different essential hormones.

So, it is one of the three nutrients that mostly commonly limit the plant growth, unlike other two limiting nutrients as we are calling as the NPK, nitrogen and phosphorus always required. The iron deficiency is not easily remediated by inclusion in fertilizers, because we do not supply, we do not provide iron. We only take iron tablets, iron tonics for the human being. But we do not provide iron to the plants. We only think, we only talk about the nitrogen, phosphorus and potassium, the NPK fertilizers.

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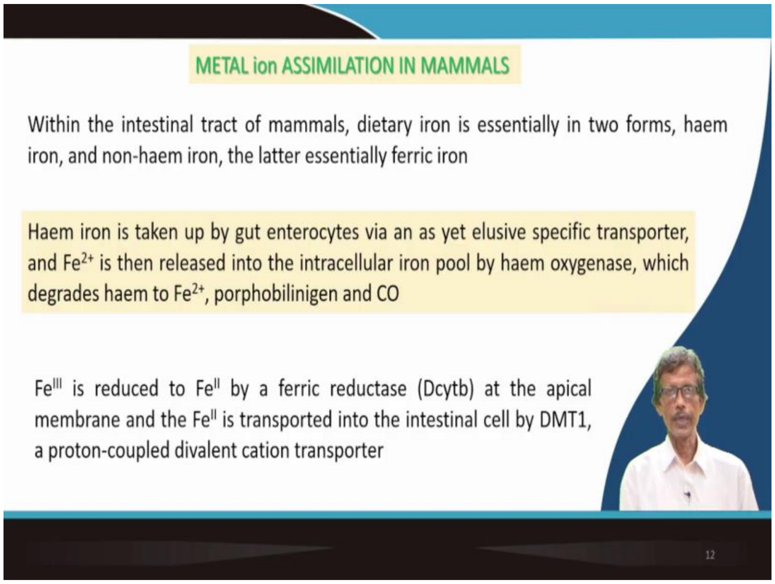

So, lastly, we have list here where we have the mammals, the metal ion assimilation in mammals, the human being what we can have. So, in the mammals what we see that in our GI tract, the intestinal tract, the gastrointestinal tract, what we have, the dietary iron is essentially coming from the food materials. So, either you have the haem iron and non-haem iron once during our introductory classes, I discussed it also that the haem iron is easy to assimilate.

But essentially what are these, essentially they are ferric iron, the oxidized form of iron, not the ferrous iron. So, the gut enterocytes will present in your GI tract. They are responsible for the different elusive specific transporters. And if your Fe2 is forming there, Fe2 is then released into the intracellular iron pool by haem oxygenase. The haem oxygenase you see the oxygenase reaction, the redox enzyme what is there for the oxygenase reason for the haem which degrades haem to, you just you break down. We know that the blood has certain lifetime in our body. We synthesize blood regular fashion, in a regular fashion in around 120 days or so. It has the lifetime.

After that what it happens? So, after that it breaking everything. You have to synthesize a new porphyrin. You have to synthesize the new haem system and all these things. But the role of these oxygenase is such that it can degrade the haem and is taking up the Fe2 plus. That Fe2 plus if it is not going away from your body, it will be there. It will be again can be recycled. It can be reused. And you have the porphobilinigen. Porphobilinigen is degraded product of your porphyrin.

So, one CH2 methylene bridge we will talk again about these, the methylene bridge is degrading and that is giving you the CO. So, one of these methylene bridge in the porphyrin ring, so porphyrin ring will open up with the removal of the CO. So, carbon monoxide will be removing from there and the degraded form of the porphyrin is there, but you have the ferrous ion and that ferrous ion you are storing in your system and it can be recycled back for your blood syntheses, for your iron sulfur protein synthesis, for your cytochrome synthesis.

So, these Fe3 when it is reduced to Fe2 and that system when we get by a ferric reductase. So, Fe3 can be reduced by a biologically available reducing agent, because these two things are important. So, we see we store that iron when we synthesize myoglobin and hemoglobin. It is there as Fe2 plus. Similarly, when it is oxidized in some form, the ferric ion is there in cytochromes and all. But if we want to reduce it, so you bring one reducing agent. So, biological reducing agent is your ferric reductase, D cytochrome b, Dcytb.

So, Dcytb which is related to your cytochromes also, Dcytb at the apical membrane and the Fe2 is then transported into the intestinal cell by DMTA divalent metal transporter proteins. DMT1 is nothing but divalent metal transporter protein. So, you see that if your iron is the trivalent state, it will not take care anything. If you go down to ferrous state by reduction, your divalent metal transporter will come into the picture and can trap that particular one and it is available in your intestine e.

So, intestinal cell is there, intestinal cell can take care of this DMT1 and you can have something which we call as a proton coupled divalent cation transfer, because when you have we always know that whenever you have electron transfer along with that we can have also the proton transfer. So, electron transfer coupled with proton transfer we can have. So, when you have the electron transfer, so electron is going which is negatively charged, but you can have the corresponding control of the proton.

So, in the oxidized form the system it has some part, it can have some part which can be deprotonated, we will try to deprotonate also. So, not only electron is going, but also your proton can be going there during abstraction of that electron also that means ferric is going to the ferrous state. You reduce the center from ferric to ferrous then your site can also be protonated. So, if you have the protonation then the proton coupled divalent cation transporter can come. So, divalent cation transfer, DMT type of thing which is proton coupled one also so you must have the corresponding supply of these protons.

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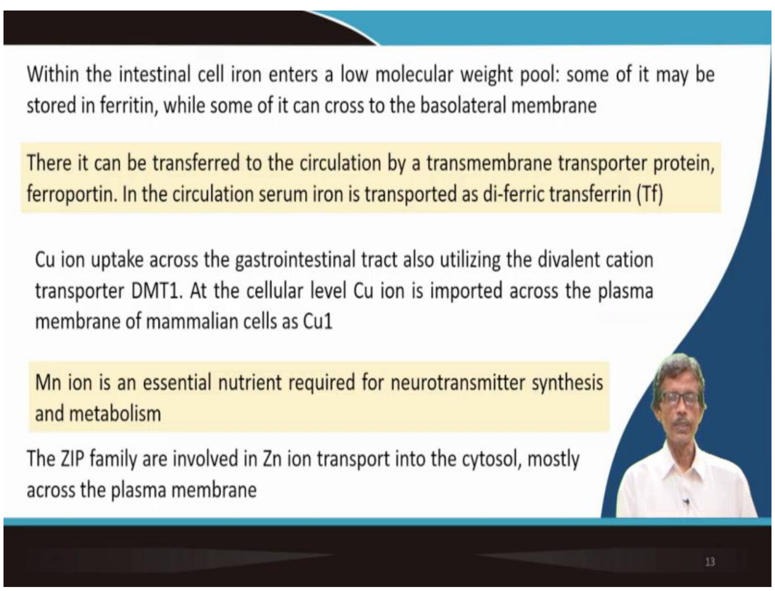

So, within this intestinal cell iron enters a low molecular weight pool, it gives you a low molecular weight pool and some of it may be stored in ferritin. Ferritin is our storehouse of iron, is a bank of iron ions or ferrous or ferric ions in our system. So, it is a protein for the storage.

When we talk about the metal ion storage proteins, we will discuss everything in detail once again.

So, there it can be transferred to the circulation of the transmembrane transporter proteins, the ferroportin, not protein, portin. In the circulation serum iron is transported as di-ferric transferrin. So, transferrin is the carrier molecule. So, the carrier molecules are there. So, these carrier molecules are taking that iron from one particular point to the other.

Similarly, for the copper assimilation, we have the copper ion uptake also, again from the gastrointestinal tract, but it is a little bit less known. We know much about iron only. We know less about copper. But the recent discovery or the recent findings tell that for the bivalent cation, because the copper can have the two oxidation state cuprous and cupric, so the cupric one is the more prevalent one. So, again DMT1 will come into the picture and can take care of that particular iron of different type.

So, at the cellular level, the copper ion is imported across the plasma membrane of mammalian cell as Cu1. So, you can have the corresponding transportation. It can go to the copper in the cuprous 1 form or it can go at one other form as the cupric state. And also the manganese also we have, so I am giving all these examples whatever you can have, is again an essential nutrient for us, for the neurotransmitters and there is where you require manganese ion. Why we require? Is for the neurotransmitter synthesis. Then the zinc ion, for the ZIP family involved in zinc ion transport into cytosol and across the plasma membrane is required for this transportation.

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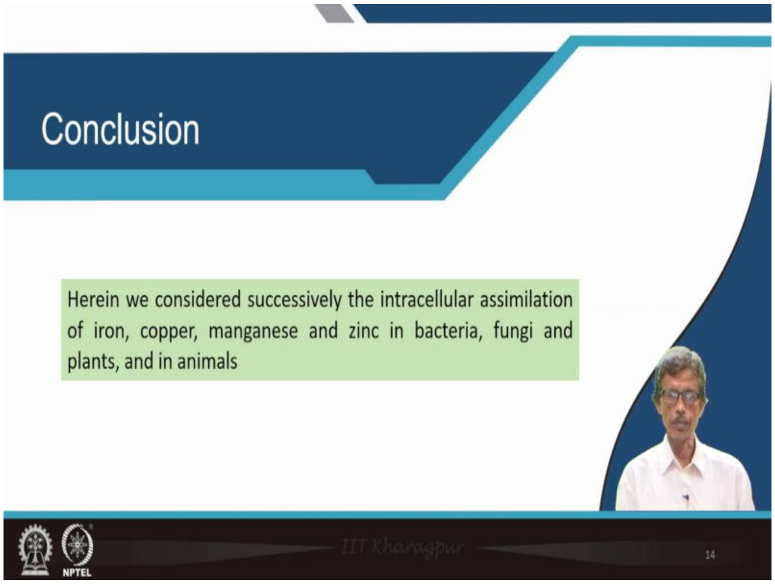

So, what do we have learned from this particular class. What we have seen that successively we have considered the intracellular assimilation, is not extracellular, it is the intracellular, within the cell, how we can assimilate the metal ions. Which are the, what are those metal ions. Metal ions are iron, metal ions are copper, metal ions are manganese and zinc. Not only for our system animals or the mammals or the human being, but also for bacteria, also for fungi and also for the plant, because we are all dependent on these materials that means we are dependent on plant. The bacteria can give you some disease condition. The fungal infection can also harm you. So, that is why we should know about the corresponding assimilation the simple metal ion iron for all these species, all these living species.

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So, the references like these, the Metal ions biology, you can access. You can use other keywords also for accessing Wikipedia and the book of Crichton. So, thank you very much. Thank you for your kind attention.