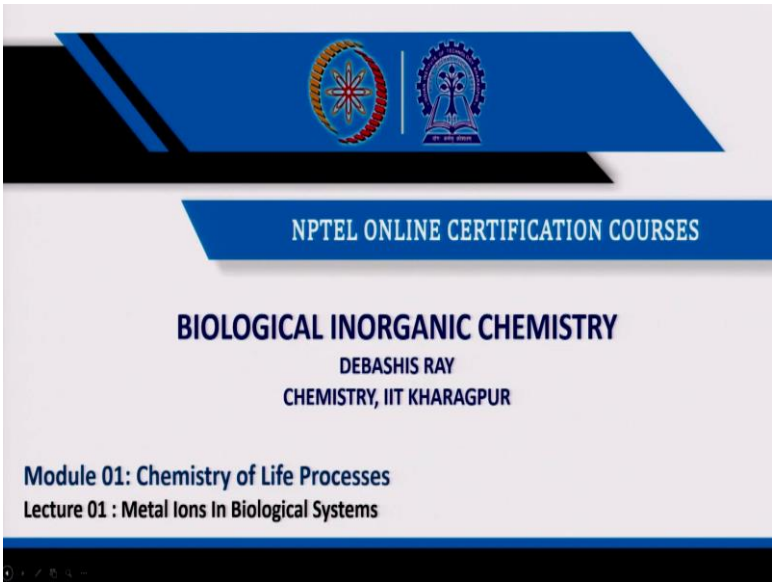
Biological Inorganic Chemistry
Professor Debashis Ray
Department of Chemistry
Indian Institute of Technology, Kharagpur
Lecture - 1
Metal Ions in Biological Systems

(Refer Slide Time: 00:33)



Hello, everybody, so good morning to all of you. So, we will be starting today a new course, which is your biological inorganic chemistry. In this particular course, what we will be trying to focus is basically how much chemistry particularly the inorganic chemistry or more precisely, if you consider at the coordination chemistry is important to know about the different life processes.

As we all know, when I am talking with you, in this particular class, that we are breathing, you are also when you are listening you are also breathing, but we do not know precisely how much oxygen we are inhaling and what chemistry is going on, your chemistry is the coordination chemistry, how much chemistry is going on during that particular process.

And we little bit we know from our school days also that we can have haemoglobin and myoglobin like of molecules available, which can interact with the auto molecule that means the oxygen. Why we require that oxygen? We require that particular oxygen for getting the energy in our system such that we can work, such that we can talk, such that we can write.

So, how that particular oxygen because we must have some mechanism where the oxygen will be attached to a biomolecule. And that particular biomolecule will be available to transfer that oxygen for some useful purposes, such that we can go for some energy currency preparation like that ATP synthesis.

So, slowly do not worry much, slowly we will be entering over there. And how we can consider this particular topic is well known, we can consider these as the by inorganic chemistry, or biological coordination chemistry or bio coordination chemistry. So, the module number one, we will be talking about the chemistry of life processes. And in this particular lecture, that means, in lecture one we will be talking on about the metal ions in biological systems.

So, first of all we should know what are those metal ions, the example just now I gave it to you is the haemoglobin and myoglobin that we all know that iron is present within the porphyrin pocket. So, that particular iron which is bound to the porphyrin pocket is your heme, heme system. And in that particular heme system, if you allow that particular Rn centred to interact with the auto molecule, we will get the corresponding oxymyoglobin system or oxyhaemoglobin system.

So, initially we will be talking about what are the metal ions available and how these metal ions can be useful to understand your this particular type of chemistry that means the biological inorganic chemistry.

(Refer Slide Time: 03:29)

So, what are those concepts basically, we will be trying to cover, basically always when we can have a lecture class, you try to understand that what are the concepts you can build over this particular class. So, what we get? What are essential elements, so right in that particular way that, what are elements you can have and if you have both these two that means, the metal ions as well as the non-metallic elements also, which are essential for our system, not

only our system, which can be available to the entire biological world, which can be available to the plant system as well. Why?

Because you know that we are getting this particular essential elements or the essential metal ions what we will be talking about if you take the typical example, what we are learning from our school days iron simple iron, how we get that particular iron in our system, in our body, we get it through our food materials. And we all know that once we are anaemic, we do not have the certain concentration or the prescribed concentration what doctors prescribe that amount of haemoglobin we do not have.

So, if you have less amount of haemoglobin in your body, or less amount of myoglobin you will be body, you will not get sufficient amount of oxygen for the burning of food elements, but the first thing is that like a geologist, how we get the metal ion in a rock, in a ore, or in a mineral, we know that there are certain food material say vegetables or the non-veg items also, they are rich in iron content, but the thing is, you have to consume that particular sample that means that particular food material and you have to go for the assimilation of those metal ions.

So, that again depends on your system, if your system is very good, it can rightly assimilate whatever amount of iron available in that food material to convert that particular iron in the available iron in your body. And something will happen there, some ligands, will consider as the ligands you know also the terminology.

The ligands will come and take up or abstract those metal ions to give that in system, which will be required for incorporation in a bigger protein molecule that means the globin chain and you get the myoglobin as well as the haemoglobin molecule. So, in this particular class basically, we will be considering quickly that what are the metal ions we can have.

And at the end of this particular class, towards the end of this particular class, we will be talking about some non-metallic elements, because we are not focusing everything on your coordinates in chemistry or the bio coordinates in chemistry, we have to talk about something related to the non-metallic elements, say iodine.

We know that every day when we open up your television set or radio you will know that the iodized sample of salt, the sodium chloride. Why do we need iodine in that particular sodium chloride the table salt what we are consuming every day in our food. So, in that particular

case is a typical example at one hand you have iron, the metal ion and the typical example for the non-metallic element is your iodine.

Now, if I ask you that if both these two are your essential elements, how can you define the essential metal ions for our system, for human body and the essential non-metallic element for our system also? So, we will just see that how one by one we can see, we can categorise it, because not that the corresponding concentration is there in our body. So, if you are deficient in iron, you are anaemic doctor will prescribe you for some iron tonic, iron tablet or something.

But the iodine deficiency can be inherent quantity, because how we get iodine that we should know, if we are not getting through sodium chloride table salt, we must have some other mechanism of getting iodine from other food material. And this iron, which is coming to your food material is coming via soil. So that is why I uttered one term that is the geological understanding or the philosophical part of the geology.

So, if the iron is present in the soil, the plant can pick up that particular iron for its assimilation, then if we consume that plant, that green leaves, we can have iron, but we do not know we have to know that because we know that the green leaves are containing magnesium due to the presence of chlorophyll.

So, is a huge area of understanding huge area of your study, but you have to love it in a way that it is directly related to your life process, it is directly related to your health, your well-being as well as we are trying to understand something which is in the domain of your nature. So, the mother nature is doing all these things for us.

And we are trying to understand a little bit of that already during the last say 50 or 75 years or so, we have learned a lot about these processes, the inherent chemistry, the inherent coordination chemistry and all these related to the presence of metal ions in our system, in our body. So, definitely we if we have the metal ions in you, in your system, we can have the magnitude, how much you have.

So, the bulk, the trace and ultra-trace metal ions. We all know the two examples only I have given you the sodium chloride I uttered, iron we have uttered and then iodine, then iodized salt in which form the iodine will come to your salt. Similarly, if you consider that we can have huge amount of this bulk metal ions in our system, which is present in maximum

concentration because the inorganic chemistry if it is dependent on the knowledge of coordination chemistry, in other hand it will definitely be dependent on analytical chemistry.

So, analysis of those protein molecules or the metal enzymes can tell us that how much iron you have, that means in terms of total iron content in your body, what doctor analyse basically when we go for the pathological centre to determine your right amount of haemoglobin concentration in your blood, we all know that in that particular case, the total amount of haemoglobin in some unit definitely, you should know the unit also is present.

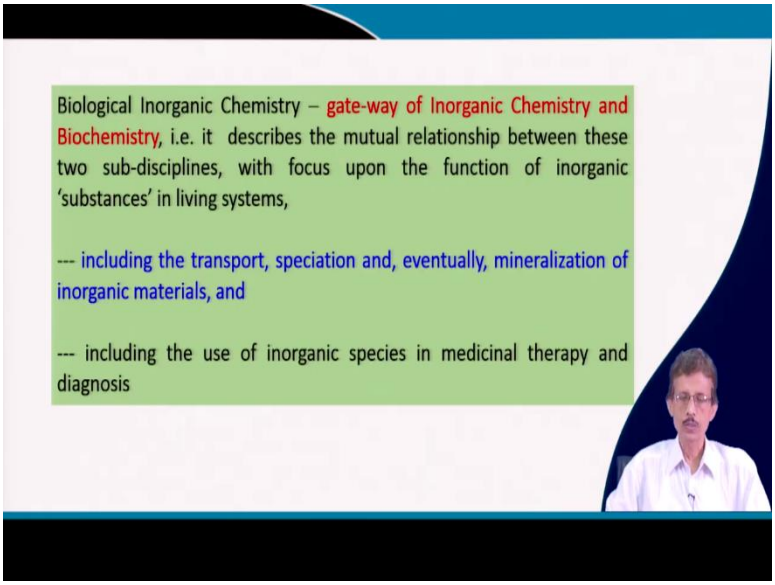
But if we consider that, if we convert it in terms of only the iron as the elemental composition, how much iron you can have. So, we will see that we can have three different types of metal ions you can have. So, one is in the higher amount, and one is the very less amount, but they can play some significant role in our well-being, then we will consider the family tree of metallobiomolecules.

So, we all know that chemists are always interested to know about the molecules, when we have a molecule like simple O2 molecule just now, I uttered, nature has given us we are very fortunate enough such that we can have huge amount of O2 around 20-21 percent of O2 in air, where we are taking our breathing.

So, then we can have the biomolecules not that simple molecule like O2 or H2O water, water is also a very simple molecule, molecule there, so we put it in some biomolecules. So, the biologically if the water is available, and if it is attached to some other interesting molecule, which is attached to the biological system, we consider those as the biomolecules.

Then we bring the metallic part or the metal ion part to it, the whole thing will be your metallobiomolecule system. So, what is that? The typical example of your myoglobin, the typical example of your haemoglobin is our your metallobiomolecules. So, will be considering those metallobiomolecules, how we can take up all these things.

(Refer Slide Time: 12:33)



So, while we can define now, we see that, that how a textbook can define the subject the biological inorganic chemistry. So is basically gateway, we are trying to enter in the domain of biochemistry with the help of a strong understanding of inorganic chemistry.

So, you must be very much expert in inorganic chemistry or to be specific in coordination chemistry, then only you can go and you can approach this particular domain or particular area in understanding from your eyes of inorganic chemistry to look at it something what is happening there in terms of your biochemistry.

Therefore, it will describe the dependence, it will describe the relationship of these subdivisions and focus upon the function of inorganic substances in living systems. It is not a very complicated terminology over here, I am giving you these things, you can open up any book you will find some these books, type of statements and all these things, because if you have these statements with you, you try to read it nicely and try to explain it and try to understand it.

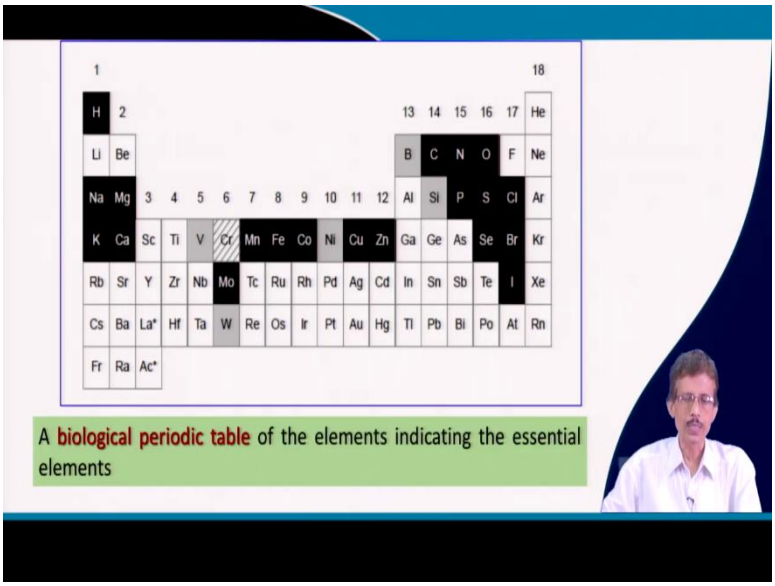
So, those substances can be your metal ions also. So, if you have a metal ions and if it gives some functions like the coordination to that of your O2 molecule, just now I told you that iron is present and iron will be responsible for the coordination of your O2 molecule. So, iron should be function as a essential metal ion and O2 will be functioning as a very good ligand.

And how we can categorise all these things, so including the transport, speciation and eventually mineralization of inorganic materials like mineralization of iron, from the geological point of view, we call it as the biomineralization process, where we consume iron

through food materials, the excess iron not all are utilised for your synthesis of haemoglobin and myoglobin, some will be reserved for your body, for your future use or as and when required.

So, this is important for your mineralization process. So, all of these and at the end also if our time permits, basically if we will be able to manage us that there are different inorganic species in medicinal therapy and diagnoses also, we all know the name of cisplatin, where the metal ion is your platinum. So, again the metal ion can serve as the purpose of a medicine or a drug or a important pharmacological constituent.

(Refer Slide Time: 15:16)



So, if we consider if we take the entire periodic table and that periodic table will tell us okay, we have these. So, these black marked thing that this the we can consider, and if we think of all these things as a biological periodic table of the elements, which will focus our attention on again those essential elements what we have defined just now.

So, if we consider these black marks like your carbon, nitrogen and oxygen, so what do you find over here that we all know that a biological molecule like amino acids, simple amino acids, we all know that corresponding acids, organic acids, the acetic acid, we know what do you have? You have carbon, you have the top one the hydrogen and you have the oxygen and when you go for the corresponding amino acid it will be the nitrogen.

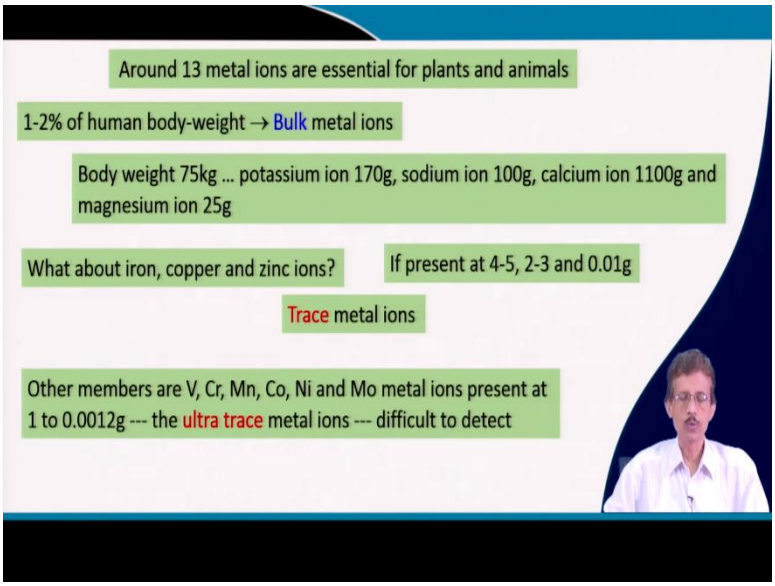
So, the amino acid can be your building block for dipeptide, tripeptide and then ultimately to the protein. So, definitely you can have C H N O all these there. And we all know that there are sulphur bearing amino acids, and we can have the phosphorus as phosphates. Similarly,

we can have huge amount of sodium and potassium in our system, in our fluid, in our biological fluid, we all know that the sodium potassium imbalance, some person is suffering from sodium potassium imbalance.

So, like iron we should all know also that how much sodium you can have in your system, and how much potassium you can have in your system, and how much, which is important and how much do you know in terms of if I ask you the corresponding coordination chemistry of sodium ion and the potassium ion, then we will stop and we will think something else.

So right now, we will be talking about the first tiny sensory element because these are the ubiquitous, these are the maximum amount of these samples are present starting from your manganese to zinc. And there are some examples where you can have the vanadium and you can have molybdenum and we can have tungsten. So, the black mark, the shaded marks and all these things will can consider in terms of your biologically important element from the entire periodic table. So, how many are they?

(Refer Slide Time: 17:23)



So, they are 13 only. So, if we can have these 13 metal ions, which are essential for not only us, the human being, it is essential for animals, and these are also essential for the plants also because we will be consuming plants, the different animals, the cows and goats, they are also consuming those plants. So, these are the sources of the metal ions for them also.

And if we have in our body, what is your average body weight, if we consider that our average body weight is 75 kg. So, 1 to 2 percent of the human body weight if it contains

there, then we consider as the bulk metal ions. What are those metal ions? The bulk metal ions, if you just simply think of it, you will be able to answer me. We all know that we can have bones, we can have teeth and all these things are there and only thing that you should understand because we I have shown you that the periodic table.

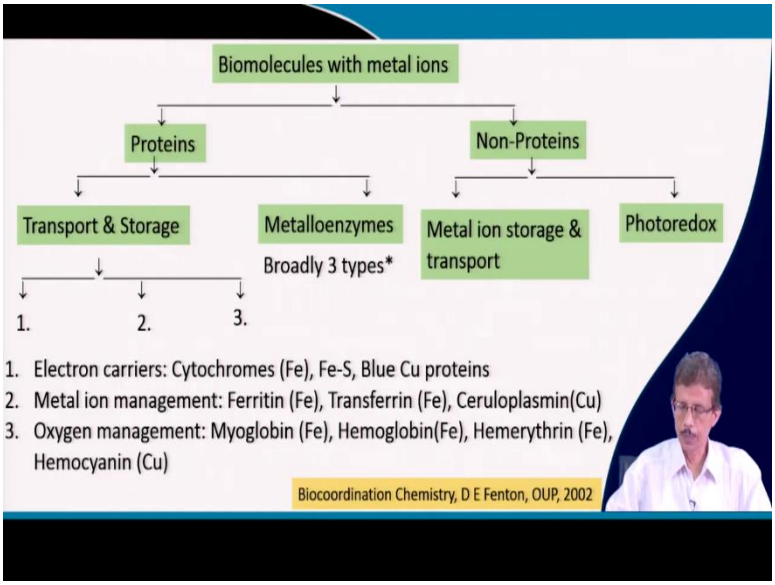
So, if you can have the sodium as well as the potassium is there in the fluid, but if you have the calcium, we all know that the in active ingredient in your calcium in your bones and your teeth. So, that is the huge mass we can have. So, those are definitely the bulk metal ions. So, for that particular body weight, we can have this much potassium, this much sodium, this much calcium and this much magnesium.

So, the average weight and the average amount of these are available to us, so you see starting from calcium which is the highest one, for your bones and teeth's, which is 1100 grams to that of your magnesium which is only 25 grams you can have. Then if we consider because we have started our discussion on iron, copper and zinc.

So, we will quickly, we will can go when we study also that we will finish iron fast when it come to the exact subject. Then we can go for the copper and then we can go for the zinc. And you see compared to the calcium and the amount of calcium present, which is 1100 gram these are present in several ranges like iron in the range of 4 to 5 grams, copper in the range of 2 to 3 grams and zinc in the range of 0.01 grams only, but those are very much essential for our survival.

So, what do you call them, so bulk is gone. Now, you can consider these three as your trace metal ions. Then other members in the series starting from vanadium to molybdenum what I showed in your periodic table, they are present at the level of 1 gram can be something it can be very higher also and 0.0012 gram. They are below to that of your trace amount. So, they are ultra-trace metal ions and they are very difficult to detect also, because the concentration is so less that we can have some several other mechanisms to find out the exact concentration.

(Refer Slide Time: 20:17)



Now, we will go for the biomolecules with metal ions, that means the family tree we will be talking about, and this biomolecules with metal ions, where we can have. So, certain part I have just coming along with that, how we can define a metalloenzyme and where we can have the metalloenzyme in our hand.

And how we can classify the metal ions storage and transport that I from the very beginning I was talking about that, that if you have iron, how you can store that iron and how you can transport that particular iron in your body for the synthesis of haemoglobin and myoglobin and also for the cytochromes, which are also very much useful for us.

And there are some other groups so, how to fill up if considered that this is a part of that particular family tree. So, you start from somewhere, then you go down, go down, go down, and ultimately, we will be reaching somewhere where you will be able to tell it. So initially if we consider that metallobiomolecules, you can have these are of two types, definitely, we are talking about proteins and we are talking about non-protein, so they are of two types.

Then, these proteins again are of three, one is the transport and storage type, forget about the other part that that is your metal ion storage and transport for non-protein part, now your levelling is the non-protein part. So, definitely your haemoglobin and myoglobin will not come here. So, they are protein part because already I told you that you have the globin chain, the globin protein part you have. So, that will go for your transport and storage part from your non-protein part and from your metallobiomolecule category.

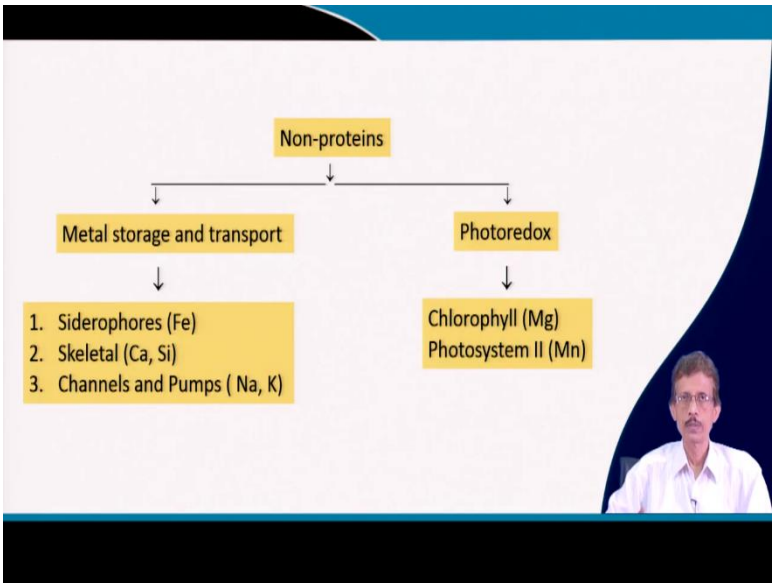
So, these are again of three types number one, number two, and number three. So, from the left basically we will be discussing everything. So, if you start from the top that you have the metallobiomolecule or protein category, then transport and storage type, what do you get, the number one category will be electron carriers, number two will be involved in the metal ion management and number three your oxygen management.

From the very beginning of our class, we are talking about haemoglobin and myoglobin. So, these are the oxygen management molecule, molecules responsible for O2 management only. So, they are what? They are myoglobin, they are haemoglobin, they are hemerythrin one other type of material, where the situation is different and hemocyanin which is present in with that of your copper.

For electron carriers which are cytochromes your content is iron content, then iron sulphur proteins are also responsible for electron carriers and then blue copper proteins are also there. Then for management, that means, the storage and the supply the ferritin that means you can have the ferritin molecules, which is the bio mineralized form of your iron what you have consumed.

Then transferrin which is responsible for transfer of iron from one side to the other, cellular plasmin in a similar way is your copper storing molecule, which is of that category that means the storage and transport type within the protein category. So, this is done from the left-hand side. So, what about the other part?

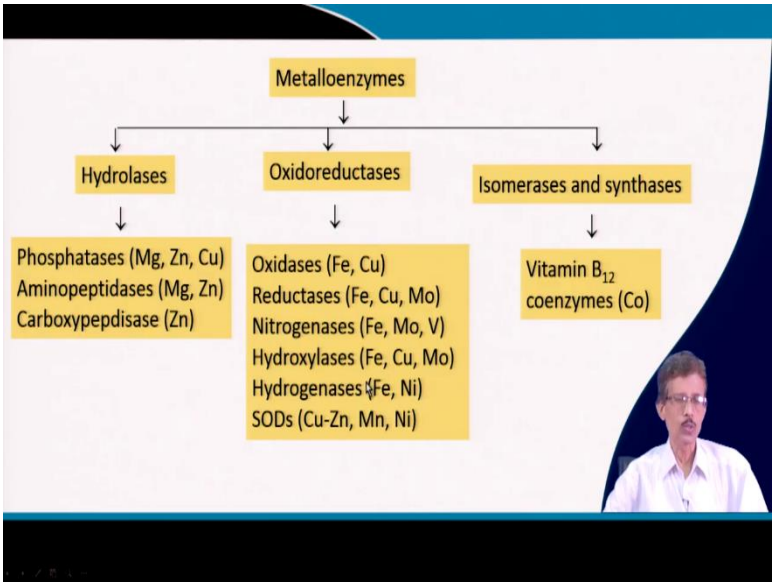
(Refer Slide Time: 23:35)



So, other part means your non-protein part and that non-protein part gives us something where you can have the metal storage and transport molecules, they are siderophores, they are skeletal calcium and silicon containing molecules that means our bones and all, bones and teeth's, and the channels and pumps what I told you that the sodium ion the potassium ions are there in the ion channels and ion pumps which are there in the fluids.

And the Photoredox which is a non-protein part. So, we are talking on the right-hand side also protein part and the non-protein part. The chlorophyll all we know the green colour of the leaves and in the photosystem II which is manganese. So, two M, you should be able to remember one is your manganese and another is your magnesium for this particular part.

(Refer Slide Time: 24:22)



Then the most interesting part is your metalloenzymes. We all know and we should not be confused that which one is your metalloenzyme and which is not. There are hydrolases, do not worry much about from this particular point, but is my primary duty to show the classifications first, otherwise we cannot proceed.

We all know the carboxypeptidases, probably you have heard the name. So, the carboxypeptidase which is a zinc bearing molecule which is hydrolysed type that means it gives hydrolysis, the biological hydrolysis, the chemical hydrolysis we all know that in a reaction vessel, in a test tube or in a reaction chamber you can go for the hydrolysis.

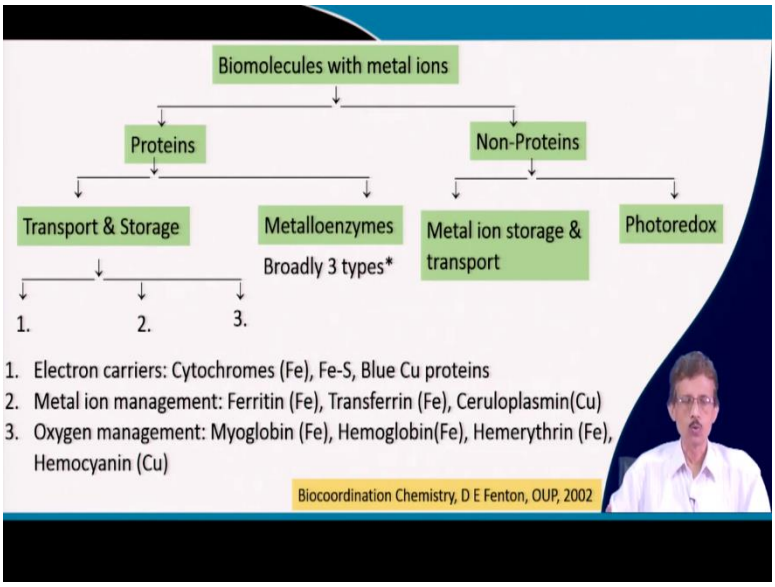
But what about these similarly, phosphatases, the phosphatases are hydrolysis molecule. Aminopeptidases, is also the peptidases, that means the peptide bond from the aminoin it can be used for the hydrolysis. Then you can have the oxidoreductases, there are a huge list, do

not worry about these, because we will come back again and again with these when we go for the exact examples.

So, starting from oxide oxidases bearing iron and copper, you can have that superoxide dismutase's, at the end. Then the third category not much only three types of metalloenzymes you can have, we will be talking about all these only. So, isomerases and synthases.

So, isomerases and synthases are having the vitamin B12 and this can go for your corresponding coenzymes. So, these coenzymes can give us these metalloenzymes. So, if we consider that, what are these things we can have. Therefore, if I ask you that, okay, we can go back a little bit, do not worry for that.

(Refer Slide Time: 26:10)



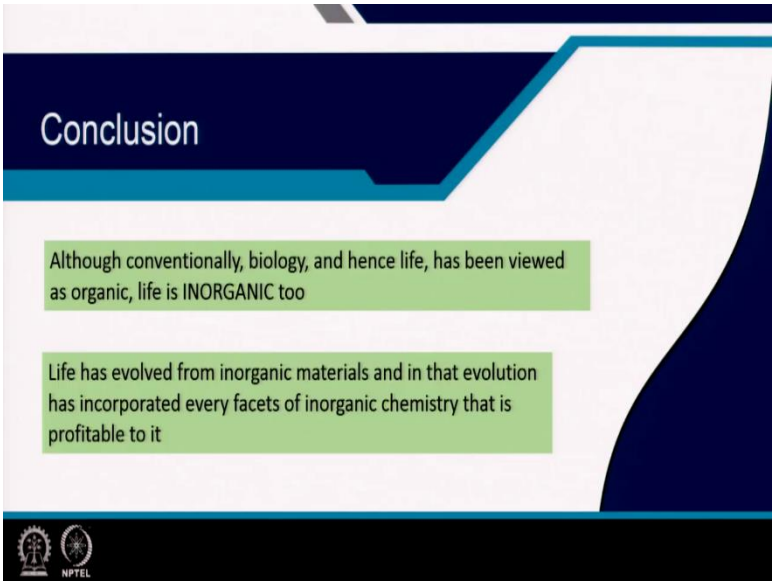
So, quickly we can summarise, we have to summarise this for this particular class because this time is short. So, we will be here if you see that, if I ask you that define myoglobin and define haemoglobin in the language of your biological inorganic chemistry class. What you are learning from here? How we can define a myoglobin and haemoglobin?

So, myoglobin molecule will be such a molecule, it can involve in oxygen management. So, it can be involved for oxygen either transport or storage, and it is a protein type. And that particular protein type of this particular system will tell us that one particular category which is your metallobiomolecules of protein type, and that those protein type molecules can be your either myoglobin or haemoglobin.

So, simply if you just only memorise what you have learned from your school days, what is haemoglobin? You know the structure little bit; you know everything and you know that it is

interacting with the O2 molecule. But if I put you with that bigger world of metallobiomolecules, it is definitely a very small category of molecules apart from your the entire biochemistry world, where large number of biomolecules are there.

(Refer Slide Time: 27:39)



So, you should be able to define from the this particular family tree also. So, many molecules I have given the examples, so, that will be useful for you for knowing that thing. So, what we have learned therefore, that convincingly what we can understand, what is your life. So, the biological word, you can consider that it is in the organic chemists, all will say no, no, no, it is typically without metal ions or without any inorganic species, we are only happy with that carbon, nitrogen, oxygen and sulphur and little bit of phosphorus and all these things, but it is not that because they are very much interlinked.

So, if we consider the nature has given us your life, and hence, the different processes of life, not the biological process, we are talking about the life processes, because our life processes are dependent on our health during this particular time also, during this pandemic time, during this COVID time also, you know, how much we are talking about every day almost we are talking about the oxygen, we are talking about the oximeters and we are talking about our oxygen in our system in our body, why that is important.

So, we should all know in that particular perspective, that is why doctors are also studying it, doctors know in from their point of view, what are myoglobin's and what are haemoglobins. Similarly, we can also know because we know as inorganic chemist, what is iron? What is the chemistry behind that particular iron?

So, we can view it as organic and life is also inorganic. So, when you bring that particular component that means the inorganic component, that inorganic component is just simply to be very simpler thing for your understanding, bring the metal ion, the very first example what you can give all the time, bring metal ion, sir I know that this is the example of that particular inorganic system which is your metal ion, and we all know that it is in our blood. So, iron from our childhood, we are learning it, but make your learning, make your knowledge complete.

So that is why the life has evolved from inorganic materials. So, if you have some storage molecules, so life has evolved from there, and in that evolution has incorporated many facets of inorganic chemistry that is profitable to you or profitable to the system. So, if it is profitable to the synthesis of myoglobin and haemoglobin, it will utilize that coordination chemistry, how iron will be inserted into that particular system.

(Refer Slide Time: 30:19)

So, the references we can have your Biocoordinates in Chemistry, by D F Fenton of Oxford University Press and the last published one we can, what we are considering as 2002. Thank you all.